Saint Catherines Press

Science, Technology and Society in Seventeenth Century England
Author(s): Robert K. Merton
Source: *Osiris*, Vol. 4 (1938), pp. 360-632
Published by: on behalf of
Stable URL: http://www.jstor.org/stable/301533
Accessed: 19/12/2010 18:35

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PREFACE

This study might be more exactly entitled " some sociologically relevant aspects of certain phases of the development of science in seventeenth century England." For it is not a history of science, technology and society during this period. It does not touch on all phases of the subject but deals only with the more elementary of them. Many of the historical details which it contains are indeed widely known, although their sociological implications are less widely recognized. To be sure, the view that the science of any period is not divorced from its social and cultural context has become, properly enough, a commonplace, but there are few empirical studies of the relations which do obtain. Many persons in our own day view the extended investigations of science as comprising an activity natural to man; hence, as neither requiring nor being susceptible to further analysis. This study is concerned above all with some of the cultural roots of the modern acclaim and patronage of science. In more general terms, it is an empirical examination of the genesis and development of some of the cultural values which underlie the large-scale pursuit of science.

Much has been omitted which would require inclusion in a more comprehensive study. Perhaps the most striking lacuna is the absence of any special treatment of the connections between science in England and on the Continent. Important as these undoubtedly were in many respects, they are not of immediate relevance for the central purpose of this study. Rather they introduce further complications which leave the picture materially unaltered. For a similar reason, little account has been taken of contemporary philosophical developments, which have only an oblique bearing on the subject in hand.

Acknowledgment is due the editors of *The Scientific Monthly*, *The Sociological Review* and *Scientia (Rivista di Scienza)* for permission to use sections of my articles which appeared in these journals. I am indebted to the Harvard University Committee on Research in the Social Sciences for its generous assistance.

In the following pages I have attempted to acknowledge my chief obligations to other writers, recognizing that their studies may have influenced this one in points of difference as well as agreement. There are less obvious forms of indebtedness for which specific acknowledgment is not as easily made—the guidance of teachers, the discernment of colleagues and the stimulation afforded by frequent discussions.

I am indebted to Professor Edwin F. Gay for the stimulus which initially led me to the study of science and technology. My thanks are likewise due to Professor Carle C. Zimmerman for his helpful suggestions and to Professor Talcott Parsons, whose incisive criticism rectified errors of emphasis and inference. Dr. Theodore Silverstein has generously given me the benefit of a perspective gained from his experience in a related sphere of study. I am grateful to Dr. George Sarton for his kindly encouragement and guidance in a field where my equipment is but that of the neophyte. I have a deep sense of obligation to Professor Pitirim A. Sorokin for his continued direction. My debt to him is undoubtedly greater than occasional citations may suggest.

Cambridge, Massachusetts Robert K. Merton.
4 *April* 1937.

CHAPTER I

INTRODUCTION

The various fields of culture do not develop at a constant rate. At intervals, attention is chiefly directed toward one or more of these areas, only to yield, in time, to other interests. To be sure, historical development is continuous in the sense that a sphere of culture is seldom, if ever, ignored completely, yet pronounced shifts in the foci of interest do serve to quicken or to retard its growth.

Thus, without reducing cultural eras to a ready formula, it may be ventured that in the Periclean Age, philosophy and art attracted most widespread attention. The primary focus of interest for the greater part of the Middle Ages was religious and theological. Marked attention to literature, ethics and art generally characterized the Renascence. Whereas in modern times, especially during the last three centuries, the center of interest seems to have shifted to science and technology.

But what are the reasons for such shifts of emphasis? Obviously the internal history of each of the fields of culture to some extent furnishes us with an explanation. Yet it is at least plausible that other social and cultural conditions have also played their part. And this raises at once a series of fundamental questions. Which social processes are involved in shifts of interest from one division of human activity to another? What, indeed, is the nature of the sociological conditions that are associated with pronounced activity in any of these domains? To plunge at once into such expansive questions would but sacrifice depth of inquiry to breadth, comprehension to comprehensiveness, but by limiting ourselves to a single cultural sphere the general problem may be illuminated by the specific case. For this reason, and also because it constitutes a subject still unduly neglected, this study will be concerned with the sociological factors involved in the rise of modern science and technology.

Within this broad context, however, there are several other pertinent considerations. Historians of science and students of cultural development assure us that, at varying intervals, there also occur shifts of interest from one science, or group of sciences, to another; from one field of technological application to another (1). Thus, Dr. SARTON points out that interruptions have occasionally occurred in the early development of a single branch of science (2). Nor is this foreign to later times. The period of HIPPARCHUS, the seventeenth century and the last quarter of the nineteenth century, says DE SITTER, stand out in bold relief as epochs of accelerated progress in the history of astronomy (3). The late eighteenth and early nineteenth century in France, as we learn from the historian of mathematics, KLEIN, constituted a period of notable interest in the physico-mathematical disciplines, followed by a comparative decline after 1830 (4). With the possible exception of BRADLEY's discovery of stellar aberration, which is more properly classified in the field of astronomy, the eighteenth century was singularly barren of optical discoveries, in deep contrast to the striking advances in electrical research (5). Sir EDWARD THORPE observes that chemical research ebbed conspicuously during the first three decades of the last century (6). The experience of the medical sciences is similar. As is shown by a statistical analysis of the European literature of comparative anatomy from 1543 to 1860, interest in this field as well varied considerably from period to period (7). The virtual cessation of interest in physiology during the middle of the nineteenth century in England stands

(1) P. A. SOROKIN, *Social and Cultural Dynamics*, 3 volumes (New York : American Book Company, 1937), Vol. II. *Cf.* GABRIEL TARDE, *La Logique sociale* (Paris : F. ALCAN, 1895), p. 185.

(2) GEORGE SARTON, *Introduction to the history of science* (Baltimore : The WILLIAMS & WILKINS Co., 1927-31), Vol. I, *passim*.

(3) W. DE SITTER, *Kosmos* (Cambridge : Harvard University Press, 1932), pp. 9-10.

(4) FELIX KLEIN, *Vorlesungen über die Entwicklung der Mathematik im 19. Jahrhundert* (Berlin : JULIUS SPRINGER, 1926-27), Vol. I, p. 63; pp. 87-88.

(5) E. T. WHITTAKER, *A History of the Theories of Aether and Electricity* (London : LONGMANS, GREEN & Co., 1910), p. 100 f.

(6) "Progress of Chemistry," *Nature*, CIV (1919), 217-219.

(7) F. J. COLE and N. B. EALES, "The History of Comparative Anatomy," *Science Progress*, XI (1917), 578-96.

in sharp contrast to its industrious cultivation both prior and subsequent to this period (8). And to note but one more instance of such fluctuations in attention, the contemporary concentration of interest upon the physical sciences and the comparative neglect of biology differs markedly from the situation which obtained during the latter nineteenth century (9).

The occurrence of such fluctuations furnishes the basis for the second fundamental problem with which we must deal : what sociological factors, if any, influence the shifts of interest from one science to another, from one technologic field to another?

The Carlylean " heroic " explanation purports to find the origin of periods of intellectual efflorescence in the simultaneous appearance of geniuses. But, as has frequently been observed, n considering the periods in which an unusual number of intellectual giants appear, the phenomenon to be explained " is perhaps not the multiplication of superior natural endowments but the *concentration* of superior endowments upon the several occupations concerned." (10) The coincidence of such distinguished men of religion as ZWINGLI, LUTHER, CALVIN, KNOX, MELANCHTHON and BEZA; of such dramatic and lyric poets as SPENSER, MARLOWE, SHAKSPERE and JONSON ; of such scientists as BOYLE, WREN, WALLIS, HOOKE, NEWTON, HALLEY and FLAMSTEED cannot readily be attributed to the chance concurrence of individuals biologically endowed with predispositions toward special fields of activity. The more plausible explanation is to be found in the combination of sociological circumstances, of moral, religious, aesthetic, economic and political conditions, which tended to focus the attention of the geniuses of the age upon specific spheres of endeavor. A special talent can rarely find expression when the world will have none of it. " The social

(8) Sir EDWARD S. SCHAFER, " Developments of Physiology," *Nature*, CIV (1919), 207-8.

(9) H. H. DALE, " Biology and Civilization," *Discovery*, XIII (1932), 27-30.

(10) THEODORE DE LAGUNA, *The Factors of Social Evolution* (New York : F. S. CROFTS & Co., 1926), pp. 131-32. Even GALTON acknowledged that " these sudden eras of great intellectual progress cannot be due to any alteration in the natural faculties of the race, because there has not been time for that, but to their being directed in new productive channels." Quoted by R. H. LOWIE, *Are We Civilized?* (New York : HARCOURT, BRACE & Co., 1929), pp. 286-87.

explanation is conceivable. The biological is no explanation at all."

The civilization of seventeenth century England provides peculiarly rich material for such a study of shifts and foci of interest in science and technology. We have only to remember, for example, that the last year of the sixteenth century witnessed the publication of the first great work of modern science in England, GILBERT's *De magnete*, a contribution which heralded the modern instauration of science. It was this same age which built the foundations for much of succeeding scientific advance. *Systematic* experiment was introduced into science (11); through the achievements of NAPIER, BRIGGS, BARROW, WALLIS, WREN and NEWTON, mathematics was transformed; the fundamental instruments of the modern physical laboratory, such as the telescope machinery for grinding lenses, the pendulum timepiece, the thermometer, the barometer, and the air pump were either first produced or materially improved (12); in physiology occurred the supreme achievements of HARVEY, MALPIGHI and WILLIS; fundamental theories of dynamics, pneumatics and hydrostatics were introduced; with BOYLE, chemistry was largely divorced from alchemy and medicine (13); while with GREW, LEEUWENHOEK, WILLUGHBY and RAY, botany was brought to a new and hitherto unequalled level. Small wonder that this century of genius affords an abundant basis for a study of those sociological factors which in large measure account for the marked development of science and for the direction of interest into specific departments of inquiry.

But before we can treat of the conditions and factors of rapid advance in science, it is necessary to establish the fact that development was " rapid " in relation to some standard. Accordingly, our first step is to determine the shifting degrees of interest in science generally during this period. Likewise, we must ascertain the various foci of scientific interest at this time. Which

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(11) FERDINAND ROSENBERGER, *Die Geschichte der Physik* (Braunschweig, 1882-90), Vol. II, pp. 3 ff.

(12) MARTHA ORNSTEIN, *The Rôle of Scientific Societies in the Seventeenth Century* (University of Chicago Press, 1928), Chapter I.

(13) HERMANN KOPP, *Geschichte der Chemie* (Leipzig : A. LORENTZ, 1931), Vol. I, pp. 163-72.

of the sciences were most assiduously cultivated? And further, within these disciplines, which problems were accorded the greatest measure of attention? Although it is not possible to answer these questions with a fine precision, approximate indications, adequate for our immediate purposes, are not wanting.

Once these basic developments have been systematically determined, it becomes possible to ascertain the sociological elements which, at least in part, account for them. The body of this study is devoted to the (largely concrete) description of the complex inter-relationships which existed between these and the associated social and cultural developments. In the concluding section, additional elements—demographic and ideological—are briefly treated.

CHAPTER II

Social Background : Shifts in Vocational Interests

The shifting scene of man's occupational interests varies from age to age. Pursuits which in one society constitute the pivotal point of interest for the intellectual elite are in another accorded a bare modicum of attention. Since these shifting foci of interest are all part of the same social and cultural complex, changes in some generally entail changes in their correlates. New activities, with their associated cluster of attitudes and values, may spread and prosper at the expense of other vocations by diverting attention from closely related and apparently incompatible pursuits. If, then, we are to appreciate more fully the growth of interest in science and technology, the distribution of vocational interests in general can scarcely be ignored. What was the cost of the increasing proportion of occupational interest devoted to science in the course of the seventeenth century? Which pursuits suffered the losses which were the gain of the new natural philosophy? To what extent? Answers to these questions, thrown against the background of the shifting values of the time, point the way to a further understanding of the problems which are our basic concern.

Source of Materials

The *Dictionary of National Biography (D. N. B.)* has been adopted as the least objectionable source for what may be called a " select occupational census." This compilation of 29 120 biographical notices p obably includes some mention of practically all individuals who achieved a measurable degree of distinction in British history. The wide scope of the compilation is illust ated by the fact that approximately one in every 6,000 individuals in seventeenth century England who reached adult life (*i.e.*, their twenty-fourth year) receives mention of some sort (1).

The data for this study were assembled in the following fashion. A separate card was filed for each individual who, living in the course of the seventeenth century, was of sufficient importance to be mentioned in the *D. N. B.* A more p ecise definition of the persons included in the tabulations may be briefly s ated.

1. All individuals listed in the *D. N. B.* whose dates *both* of birth and death occurred within the compass of the seventeenth century, *except* : *a*) those who left England *before* they had manifestly selected their subsequent field(s) of vocational interest; *b*) those foreigners who settled in England *after* their subsequent field(s) of interest had been selected.

2. Those individuals who were *born* in the *sixteenth* century but who had manifestly selected their field(s) of interest in the *seventeenth* century.

3. Those individuals who *died* in the *eighteenth* century but who had manifestly selected their field(s) of interest in the seventeenth century.

Since the major purpose of this tabulation is to enable us to determine the fluctuations in the interests of the period, it is likewise necessary to determine the approximate time at which each individual first evidenced interest in his chosen field or fields. Information concerning this point is available about as often as the date of birth, and since the primary sociological concern is the adoption of a sphere of endeavor rather than birth-dates as such, this constitutes the basis of the temporal classification. In all but 152 of 6,034 instances, the required evidence was available.

No hard and fast mechanical rule was applied in fixing the approximate time of initial interest. Many biographical details were used to obtain as accurate an estimate as possible of the time at which the individual first evidenced interest in his field of endeavor. In many doubtful instances, biographical accounts other than those in the *D. N. B.* were consulted. This procedure frequently brought to light the desired information.

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(1) *Cf. D. N. B.*, Vol. I (1917), p. lxix. About one in every 5,000 English adults through the historic ages is mentioned in this biographical dictionary.

Moreover, since the various initial interests are grouped by quinquennia, there was no necessity for an extremely precise dating of these interests. There was usually but little difficulty experienced in determining within five years the time at which any individual first became interested in his occupation. Each person was assigned to a given quinquennium but was not carried through his active life. In other words, the figures are distributive, rather than accumulative.

If no indication of the date of initial interest is available, he individual is classified in the quinquennium in which his twenty-second birthday falls. This procedure is not so arbitrary as may appear at first thought, for when an individual evidences his initial interest at a very early or very late age (2), this fact is sufficiently unusual to be noted in the *D. N. B.* memoir. Moreover, the median age at which 200 individuals, chosen at random from the *D. N. B.* compilation of those concerning whom the specific information is available, evidenced initial interest in given occupations was 21.85 years (3). This would seem to justify our assumption. In those instances, however, where data concerning both date of birth and of initial interest are lacking, the given individuals were not included in the tabulations. Of these, as previously mentioned, there were 152. So much for the method used in the temporal classification.

A more difficult problem was involved in the classification of individuals according to field(s) of interest. For those who were interested in but one field throughout their lives, the basis for classification was clear. But for those whose interests extended to broader horizons, the most advisable procedure was not so obvious. The final decision, made on the basis of expediency, held that polymaths and others interested in several spheres of application would be classified in each field in which they worked. In this way, appropriate distinctions were made between the varied interests of a JOSEPH MEAD and the single-minded architectural interest of a JOHN WEBB.

A word about the categories in the classification. The category,

(2) For example, special mention is accorded the fact that RICHARD BAXTER "turned to a religious life" when he was 15. Likewise, ROBERT BOYLE manifested a marked interest in natural philosophy at the tender age of 13.

(3) The coefficient of dispersion was .08.

musicians, refers not only to instrumental and vocal performers but also to musical composers. Likewise, drama includes both actors and playwrights (dramatists). Prose writers include satirists, essayists, biographers and " character writers." The category of historians includes antiquarians and students of heraldry. Scholars include lexicographers, philologists and translators. There is no effort made to draw tenuous distinctions between politicians of varying degrees, statesmen and ambassadors to foreign countries. Those of the nobility who by virtue of birthright alone became members of Parliament were not included among politicians. The clergy category includes divines of all faiths and all ranks as well as theologians. Scientists include individuals devoted to mechanical invention, mathematics and the various sciences, except economics, which is classified separately.

These, then, constituted the various criteria governing the tabulations of initial interests. While it is possible that occasional inaccuracies may have occurred despite the utmost care which was exercised, there is no reason to suspect any systematic error, so that the general picture obtained from the presentation of these data is probably not gravely affected. This statement is partially substantiated by the statistics concerning entrance into the Army and Navy. In this instance, we have good reason to expect that the peaks of interest or the chance of military fame (4) would be in the forties and eighties of the seventeenth century —the two periods when war and revolution were most rife in England, the periods of the Civil War, the Great Rebellion, and Glorious Revolution. This is precisely what one finds (5). Such " verification " for one category of the classification suggests the probable validity of the statistics for the other categories; a probability which is increased by further materials.

Questioning of Assumptions

But what of the basic assumptions underlying the tabulation of these data? Are we warranted in supposing that there is

(4) A marked increase of those achieving fame in a given sphere is itself an indirect indication that interest in this field had probably increased. Degree of interest and acclaim are likely to be positively associated, as we shall see.

(5) See Table 1.

any approximate correspondence between the fluctuations in the number of individuals mentioned in the *D. N. B.* in any one occupational field and the fluctuations of seventeenth-century interest in that field? This question is exceedingly complex, but a probably valid answer may be suggested. The selection of individuals worthy of mention in the *D. N. B.*, as well as the amount of space devoted to their memoirs, is a function of :

1. The prominence (or notoriety) of an individual as judged by his contemporaries, which is in turn a derivative of (*a*) the contemporary evaluation of the field of endeavor and (*b*) the contemporary evaluation of the importance of the given individual in that field.

2. The opinions of the compilers of the *D. N. B.* as to which individuals and occupations are important in British history.

At first blush, this last consideration would seem to destroy the utility of these tabulations as appropriate indices of fluctuations of seventeenth century occupational interests, for it is evident that any bias on the part of the *D. N. B.* compilers would affect the number of individuals in any one field who are deemed worthy of mention. Thus, there may be a marked tendency to devote greater consideration to politicians, statesmen, and military leaders than to scientists. Admittedly, then, such a bias vitiates the possibility of ***comparing the relative importance of different fields*** during the seventeenth century. But, it in no way affects the possibility of comparing ***fluctuations within the same field*** in the course of that century, for in this case, the bias of the compilers is " cancelled," *i.e.* remains approximately constant (6). To assure the constancy, and to obviate any vitiating influence of this factor, the total number of individuals in any one field is equated to a hundred per cent., and the frequency in any given quinquennium is accorded a corresponding percentage of the total.

To put it more precisely, it is true that if at any given time the proportion of statesmen to scientists mentioned in the *D. N. B.* is 15 : 1, it does not follow that this ratio represents the approximate

(6) This is to say that there is no reason to suspect any appreciable change in the attitudes of the editors of the *D. N. B.* toward the comparative importance of the different fields of occupational endeavor.

difference of interest manifested in those fields during the seventeenth century. This ratio is probably, in large part, an outcome of the emphasis of the compilers on one field as compared to the other. But, if there are, say, threefold as many scientists mentioned at one time than at another, then it is likely that this does reflect a variation of interest in science during that period since the emphasis of the compilers on the *field itself* remains relatively constant. Thus, if one restricts comparisons to fluctuations *within* fields, and makes no attempt to compare the relative importance of *different* fields, this approach would seem to be approximately indicative of such fluctuations,—" approximately " indicative, because it would be too much to imagine a perfect one-to-one correspondence between the indices (*D. N. B.* statistics) and the actual fluctuations. Of course, this assumption is checked, wherever possible, by appropriate means of verification from other sources.

The Army and Navy

The charts (7) indicating the fluctuations in occupational interests throughout the seventeenth century are almost self-explanatory, but a brief consideration of each of them will serve to uncover the workings of those subtle changes of value and belief which underlie them all.

A brief allusion has already been made to the major fluctuations in occupational interest in the Army and Navy. The first marked increase is noted in the quinquennium, 1636-40, especially in the last two years of this period, reaching its peak in the next quinquennium (8), and then declining. Allied with this great

(7) These charts, as well as the statistics upon which they are based, will be found in the appendix to this chapter.

(8) This tremendous increase in military interest has been aptly, if rhetorically, noted by JOHN W. FORTESCUE, *A History of the British Army* (London : 1899), Vol. I, p. 279. " It is hardly too much to say that for, at any rate, the four years from 1642 to 1646 the English went mad about military matters. Military figures and metaphors abounded in the language and literature of the day, and were used by none more effectively than by JOHN MILTON. Divines took words of command and the phrases of the parade ground as titles for their discourses." The significance of this continual warfare for scientific and technologic development will be noted subsequently.

increase, attendant upon the Scotch Rebellion and the Civil Wars, was the establishment of an English standing army. The next outstanding peak occurs in the latter eighties with the campaign of WILLIAM OF ORANGE (9). The concurrence of the fluctuations of this compilation based upon the *D. N. B.* memoirs, with expectations based upon a review of the military history of the period, suggests that these tabulations probably present, in general, an adequate summary of the oscillation of interests during the century.

The Fine Arts

Turning now briefly to consideration of the variations of interests in the arts, one notes similarly understandable movements. In painting and sculpture, for example, there is something of a decline after the Elizabethan period, and for the greater part of JAMES' reign, until the arrival of VAN DYCK in the early twenties (10). The influence of VAN DYCK, and to a less degree, that of RUBENS and GERARD HONTHURST, who arrived a few years later, was evidenced in the enhanced interest manifested in this field of artistic effort. The slackened rate of increasing interest in these arts, evident as it is during the time of the Commonwealth,

(9) These periods of major interest in military careers are the most striking but, of course, throughout the century, the many conflicts occasioned similarly appreciable interest, though not to the same extent. A brief memorandum of the more important military events of the time may serve to indicate the continual unrest.

1600-04. England, ally of the Netherlands against Spain.
1604 ff. Following treaty of JAMES I with Spain, many contingents of English troops continued to enter service of the Netherlands.
1619-37. Contingents of English troops in Thirty Years War.
1639-41. Scotch Rebellion.
1642 ff. Civil War.
1646-51. Great Rebellion (Scotch and Irish Campaigns).
1652. Dutch War.
1654. Scotch Campaign.
1657. Conflict with Spain.
1672-74. France and England versus Holland.
1688. Glorious Revolution.
1689-97. With Allies versus France; Scotch and Irish Campaigns.

(10) See Figure 1. *Cf.* also ANDRÉ MICHEL (ed.), *Histoire de l'Art* (Paris : A. COLIN, 1922), Vol. VI, pp. 788 ff.

is not as marked as one might expect from the traditional accounts of the Puritan suppression of artistic activities. However, this suppression, as we are assured by more recent studies, and as we may deduce from the interests of such eminent Puritans as CROMWELL and MILTON, was by no means as complete as is too readily supposed.

Throughout the century there was continued interaction between foreign painters and sculptors and the native contingent. DOBSON may be thought of as a disciple of VAN DYCK, and the influence of LELY may be seen in WISSING, MARY BEALE, JOHN RILEY and many others. GODFREY KELLER, LARGILLIÈRE and DAHL were some of the foreign artists who brought increasing attention to art during the days of CHARLES II and JAMES II. Thus, although England produced no native sculptors or artists of the first rank—EDWARD PIERCE and JONATHAN RICHARDSON not excepted—many of less ability were found in varying numbers. It is of interest to note the coincidence of increased interest in these fields and the arrival of the foreign masters who spent some time in England (12). With the Restoration, foreign artists were " imported " to satisfy the tastes of the Court. The enhanced prestige attached to these fields served to attract an appreciably greater number of individuals. The importance of such interaction between foreign and native talent was not confined to art—it was similarly significant as providing an impetus to scientific development.

As for interest in music, there is the same correlation between the descriptions of competent historians and the curves derived from the *D. N. B.* tabulations. The Elizabethan age saw one peak of English music : madrigals, ayres, instrumental and the contrapuntal Anglican sacred music drew many to musical study. But, despite ORLANDO GIBBONS and the older WILLIAM BYRD, the beginning of the seventeenth century was marked by slackened interest in this field (12*a*). Though the Puritan suppression

(11) EDWARD DOWDEN, *Puritan and Anglican* (New York : HENRY HOLT and Co., 1910), pp. 24 ff.

(12) *Cf.* MICHEL, *op. cit.*, Vol. I, p. 796.

(12*a*) See Figure 1. Compare HENRY DAVEY, *History of English Music* (London : J. CURWEN, 1895), pp. 169 ff.; p. 244; H. ORSMOND ANDERTON, *Early English Music* (London : Musical Opinion, 1920), pp. 30 ff.

of music has been characteristically exaggerated by those musical historians, such as BURNEY, CHAPPELL, OUSELEY, HULLAH, who were misled by caricatures of the Puritan, it is true that ecclesiastical, though not secular, music was almost completely suppressed during the Commonwealth (13). This would partly account for the lessened interest in music during this period which is reflected in the *D. N. B.* statistics. With the advent of England's greatest musical genius, HENRY PURCELL, was attained in the seventies the crest of the second wave of church music, and with it an enhanced interest in music as a career. In this respect, one need but recall PURCELL's disciples, such as WILLIAM CRAFT, WILLIAM HINE, VAUGHAN RICHARDSON, and WILLIAM NORRIS.

Profound changes in literary interests occurred in the course of the seventeenth century. The two forms of literature which had attained the highest development by 1600—drama and lyric poetry—both evidenced a trend of declining interest despite occasional brief periods of efflorescence (14). The Elizabethan dramatists had reached the peak of English accomplishment in this field—an achievement associated with intense interest in the drama (15). But, says WENDELL, " by 1612... the drama was already disintegrant " (16). If MARLOWE, DEKKER, HEYWOOD, JONSON, SHAKSPERE, CHAPMAN, BEAUMONT, FLETCHER and MIDDLETON could still claim many adherents in the early seventeenth century, there was none the less a significant decline of interest early apparent. The decline of interest in the drama evidenced by our statistics was observed by the eminent biographer and historian of literature, DAVID MASSON.

Forms of literature, like forms of life and society, have their periods, and much of the talent, and also of the leisure and the capital, that had for forty

(13) See DAVEY, *op. cit.*, pp. 265 ff. See especially PERCY A. SCHOLES, *The Puritans and Music in England and New England* (Oxford University Press, 1935), who has most fully demonstrated the falsity of the older view. The first opera which appeared in England was produced under the aegis of the Puritans. *Cf.* also ERNEST WALKER, *A History of Music in England* (Oxford University Press, 1924), pp. 122 ff.

(14) *Cf.* BARRETT WENDELL, *The Temper of the Seventeenth Century in English Literature* (New York : CHARLES SCRIBNER's Sons, 1904), pp. 47 ff.; DOWDEN. *op. cit.*, pp. 2 ff.

(15) See Figure 1.

(16) *Op. cit.*, p. 73; also, W. V. MOODY and R. M. LOVETT, *A History of English Literature* (New York : CHARLES SCRIBNER's Sons, 1926), p. 143.

years attended to the sustenance of the drama, was now [*c.* 1630] drawn away in other directions (17).

The closing of the theatre by the Puritans in 1642 is reflected in the depressed number of those who turned to drama during this period. The Restoration, in gay reaction to the Puritan regime, saw a revival of interest, which, however, thereafter declined.

Poetry, under the influence of SPENSER, HALL, MARSTON and JONSON continued to excite considerable, though declining, interest in the first part of the century (18). There is a marked, and rather inexplicable, decline in the twenties of this century which, significantly enough, has also been noted by EDMUND GOSSE :

For some reason or other the publication of verse in the third decade of the seventeenth century was extremely slack, though preceded and followed by periods of great publishing activity (19).

HENRY PEACHAM, one of the astute contemporary intellectuals, also noted this relative decline in the prestige of poetry. " Poets now adaies are of no such esteeme, as they have been in former times." (20)

After a brief advance in poetic interest, the decline continued —partly, no doubt, due to Puritan influence, partly to the intensified realistic temper of the scientific movement—even after the casual spurt of the Restoration. On the basis of a critical survey, both WENDELL and DOWDEN observe that there was a definite decline in poetry during this period (21).

The sources to which this decline has been variously ascribed —Puritanism, the new philosophy and science—bear in common

(17) DAVID MASSON, *The Life of* JOHN MILTON, 3 volumes (London : 1875), Vol. I, p. 339.

(18) See Figure 1.

(19) *From* SHAKESPEARE *to* POPE : *An Inquiry into the Causes and Phenomena of the Rise of Classical Poetry in England* (New York, 1885), p. 19. The *D. N. B.* tabulations indicate a similarly marked decline during this decade, as may be seen in the appropriate table and chart. Thus, on the basis of an entirely different body of data—the Stationers' Register—than that used in our tabulations, similar results are obtained. Such unlooked for confirmation lends additional credibility to the indices here employed.

(20) HENRY PEACHAM, *The Compleat Gentleman* (London, 1662), p. 82.

(21) WENDELL, *op. cit.*, pp. 128 ff; DOWDEN, *op. cit.*, pp. 320-21.

an increasing utilitarianism and realism. SPRAT rejects poetry as involving undesirable ornaments of speech, as elevating the specious at the cost of the real and speaks of poets as a " pleasant but unprofitable sort of men." (22) JOHN SMITH, the Platonist, resurrects his PLUTARCH and warns that " God hath now taken away from his Oracles Poetrie, and the variety of dialect, and circumlocution, and obscuritie; and hath... ordered them to speak... in the most intelligible and persuasive language." (23) HOBBES would tolerate the innocent pleasure of poetry, but urges that " this isn't the serious employment of words which are properly signs for real things and their connections." (24) LOCKE, on much the same grounds, is less indulgent, and declares that if a child has a poetic vein, the parents, rather than cherish it, " should labor to have it stifled and suppressed as much as may be." This utilitarian critic likewise reminds that " the air of Parnassus may be pleasant, but its soil is barren." (25) It was this very same seriousness of temper which led men both to decry the charms of poetry and to bespeak the virtues of science. The " immoderate hydroptic thirst of learning " of which DONNE speaks could scarcely be quenched by imaginative poesy (26).

The trend of varying interest in prose is entirely different. In WENDELL's word, " ... as poetry disintegrated and declined, prose, under the same influences tended to develop more power." (27) Associated with this development was an enhanced

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(22) THOMAS SPRAT, *History of the Royal-Society of London* (London, 1667), p. 419, *passim*.

(23) See BASIL WILLEY, *The Seventeenth Century Background* (London : CHATTO & WINDUS, 1934), p. 153 *et passim*. For the references to SMITH, HOBBES, and LOCKE, I am indebted to this excellent study which shows " how inevitably the whole philosophic movement of the century told against poetry."

(24) THOMAS HOBBES, *Leviathan*, Chap. IV.

(25) JOHN LOCKE, *Works* (London : 1794), Vol. VIII, p. 167.

(26) The Scottish minister, JOHN BROWN, warns that " few plays or romances are safely read, as they tickle the imagination and are apt to infect with their defilement." *Cf.* HERBERT SCHÖFFLER, *Protestantismus und Literatur* (Leipzig, B. TAUCHNITZ, 1922), p. 9, and chap. I generally. On the basis of a close examination, SCHÖFFLER concludes that " Bis 1700 kann, soviel ich nach jahrelangem systematischen Suchen sehe, kein weltlich-schöngeistiges Buch nachgewiesen werden, das von einem Verfechter dissentierender Kirchenanschauungen oder auch nur eines innerkirchlichen Puritanismus geschrieben wäre."

(27) *Op. cit.*, p. 162; also p. 203.

interest in prose as a medium of expression (28). With occasional fluctuations, there is a tendency toward increasing interest in prose during the course of the century. This trend is not totally unrelated, as we shall see, with the similar development of interest in science : both fields were concerned with the exposition and description of empirical phenomena. The emphasis of the period was on the descriptive and " true " rather than on the imaginative and fictitious. Even the novel, with its avowed fictional basis, was not yet " invented." It is not at all surprising, in view of the social norms which, as we shall see, were dominant at this time, that the various modes of literary expression other than prose declined in prestige.

This increased interest in prose and declining interest in poetry and drama is correlated with a manifest change in the temper of the age. Throughout this period there occurred an increasing emphasis upon " classic realism," upon working realistically with the " actual conditions of life " rather than escaping in flights of romantic imagination (29). The objection to rhetorical fancies on the ground that these corresponded to no concrete reality, that, just as the stigmatized traditional philosophy, they represented only figments of the imagination rather than " things," implicitly destroyed the very basis of poetry (30). The emphasis was upon a simple unadorned style, devoid of tropes, figures and similitudes, which would be direct, economical and concrete. The scientific standard of impersonal denotation was applied to all forms of literature, which traditionally is personal and connotative.

The mark of these scientific criteria is found in the drama and poetry of the latter part of the century. Restoration drama was chiefly a Comedy of Manners, the satirical depiction of real life. The changes from SHAKSPERE's comedies through those of JONSON, MIDDLETON and SHIRLEY to those of the Restoration

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(28) See Figure 1.

(29) WENDELL, *op. cit.*, pp. 345 ff; EMILE LEGOUIS and LOUIS CAZAMIAN, *A History of English Literature*, 2 volumes (London : J. M. DENT, 1927), Vol. II, pp. 2 ff.

(30) RICHARD F. JONES, " Science and Prose Style in the Third Quarter of the Seventeenth Century," *Publications of the Modern Language Association*, XLV (1930), p. 985.

dramatists were chiefly toward an increase of the realistic (*i. e.*, concretely descriptive) element. At the same time, even poetry was approximating " the virtues of prose rather than those of poetry, the utilitarian qualities, neatness, clearness, energy, rather than imaginative suggestion." (31) Perhaps the best indication of this attempt to achieve the efficiency of prose, is found in DRYDEN's justification of the heroic couplet in his *Religio Laici* (32) :

> And this unpolished rugged verse I chose
> As fittest for discourse, and nearest prose.

Clearly the literary norms of the second half of the century were those of the scientists, who sought careful observation and accurate recording of varied phenomena. In this connection, it may be observed that PEPY's *Diary* " in its detail reflects the patient, industrious habits by which business and science were to thrive." (33) As literary expression becomes valued for its utilitarian role of sheer exposition and communication of fact rather than for its aesthetic qualities, interest in prose tends to flourish as that in poetry declines. Rhetoric by calling up emotional responses can serve only to distort not to describe fact; it is persuasive, not informative; it invites obscurity rather than lucidity. The regard for science, as then generally conceived, created a distrust of the unbridled imagination (34). DRYDEN's couplet almost echoes the decision of the Royal Society

> ... to reject all the amplifications, digressions, and swellings of style : to return back to the primitive purity, and shortness, when men deliver'd so many things,

(31) MOODY and LOVETT, *op. cit.*, p. 206.

(32) In the light of DRYDEN's attitude, it is significant that he was a member of the Royal Society as well as of its committee to improve literary style. It seems certain that he was not unresponsive to the intellectual impulses aroused by the new scientific movement. *Cf.* LOUIS I. BREDVOLD, " DRYDEN, HOBBES, and the Royal Society," *Modern Philology*, XXV (1927), 417-438; for a revised estimation of DRYDEN's connection with the Society, see CLAUDE LLOYD, " JOHN DRYDEN and the Royal Society," *Pub. of the Modern Language Association*, XLV (1930), 967-76.

(33) MOODY and LOVETT, *op. cit.*, p. 209.

(34) RICHARD F. JONES, " Science and Language in England of the Mid-Seventeenth Century," *Journal of English and Germanic Philology*, XXXI (1932), 315-331. In an earlier paper Professor JONES traces the religious sources of the new stylistic norms. See " The Attack on Pulpit Eloquence in the Restoration," *Journal of English and Germanic Philology*, XXX (1931), 188-217.

almost in an equal number of words. They have exacted from all their members, a close, naked, natural way of speaking; positive expressions; clear senses; a native easiness : bringing all things as near the Mathematical plainness, as they can (35).

This allusion to " Mathematical plainness " may possibly represent a reflection of the rapid development of mathematics and the increased prestige of this discipline at the time (36). Moreover, as Professor JONES has shown, throughout the latter half of the century there were repeated efforts to establish a language which would be as concise and exact as mathematical symbols. SETH WARD, CAVE BECK, DALGARNO (assisted by BOYLE, WILKINS, WARD, BATHURST, PETTY and WALLIS), SAMUEL PARKER and JOHN WILKINS all attempted to formulate languages which would approach the vaunted mathematical plainness (37). Language was to become an instrument of precision, rather than a blunted and inexact tool. The attitudes which were basic to these attempts at linguistic invention permeated the field of literature proper (38), so that the decline of poetry and the ascent of prose becomes quite comprehensible. These implicit norms of utilitarianism (literature as a means of concrete description and exposition) (39) and instrumentalism will take

(35) THOMAS SPRAT, *The History of the Royal-Society of London*, p. 113.

(36) JONES, *op. cit.*, pp. 199 ff; *cf.* FLORIAN CAJORI, *A History of Mathematics* (New York : The MACMILLAN Company, 1909), p. 158.

(37) JONES, *op. cit.*, pp. 322 ff. cites the following works : WARD's *Vindiciae Academiarum* (London, 1654); BECK's *The Universal Character* (London, 1657); DALGARNO's *Ars Signorum* (London, 1661); PARKER's *A Free and Impartial Censure of the Platonic Philosophy* (London, 1666) and WILKIN's *Essay toward a Real Character and a Philosophical Language* (London, 1668), which was sponsored by the Royal Society. Impressed by the demonstrated utility of mathematical symbols, WARD hoped " that the same course might be taken in other things... My first proposal was to find whether other things might not as well be designed by symbols, and herein I was presently resolved that Symbols might be formed for every thing and notion."

(38) *Cf.* CARSON B. DUNCAN, *The New Science and English Literature in the Classical Period* (Menasha : Banta Pub. Co., 1913), pp. 26 ff; G. N. CLARK, *The Seventeenth Century* (Oxford : Clarendon Press, 1929), p. 232. " This was not only one of the greatest periods of progress in mathematics, but it was the period in which mathematical knowledge had the greatest influence on knowledge in other spheres, and consequently we may say, on life in general. "

(39) Though MILTON did not necessarily follow the implications of his statement, none the less he could observe that " language is but the instrument conveying to us things useful to be known." *Of Education* (London : 1644), p. 4.

on added significance in the light of our later discussion. Suffice it to say at this point, subject to later qualifications, that they constituted the values about which the culture of that period was integrated.

The New Education and Historiography

The views of the " progressive educators " of the period were likewise permeated by practical empiricism. Surprisingly enough, there does not appear to be any marked increase of interest in the art of education (40), insofar as we may rely upon the data pertaining to the number of educators. There was, however, a significant and decided change in the goals of education (41). Educational reformers followed the lead of COMENIUS and condemned the excessive study of words to the neglect of the study of things. As with literature, empiricism and utilitarianism constituted the keynote of educational theory.

WILLIAM PETTY, sanguine of technological progress, proposed a " College of Trade," at which the mechanical arts would be taught so that new inventions would be " more frequent then new fashions of clothes and household stuff." (42) MILTON, in like fashion, condemns beginning a formal education with the " most intellective abstractions of Logick and Metaphysics " rather than with those subjects which " appeal directly to the senses." (43) JOHN WEBSTER, Puritan and Baconian, boldly and explicitly advocated the substitution of experimental science for the classical studies in the universities (44). Similar attitudes

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(40) See Figures 1, 2.

(41) FOSTER WATSON, *The Beginning of the Teaching of Modern Subjects in England* (London : PITMAN & Sons, 1909), pp. 220 ff.

(42) WILLIAM PETTY, *Advice to* S. HARTLEIB *for the Advancement of Some Particular Parts of Learning* (London, 1648), p. 2.

(43) *Of Education* (London, 1644).

(44) JOHN WEBSTER, *Academiarum Examen* (London, 1653). See especially chapter 3 where WEBSTER emphasizes the utilitarian aims of education. Note the similar attitude expressed by JOHN HALL in his *Humble Motion to the Parliament of England concerning the Advancement of Learning* (London, 1649). The same norms which led Puritans largely to eschew the drama and poetry invited an attendance to science. Thus as the one-time Master of Gonvil and

were expressed in the Utopias which pictured desirable educational changes (45). Perhaps the epitome of this attitude is to be found among the maxims drawn up for his son by " an eminent lawyer " in 1682, who advises : " do not study anything unless there is profit to be had by it." (46)

The number of historians in the course of the century fluctuates, with a slight upward trend toward the end of this period (47). The increased interest in history at this time has likewise been noticed by a modern historian (48). It may not be too far amiss to suggest that this increase presages that beginning of enhanced interest in man and his activities which became marked at the beginning of the next century. The same elements found in the physical science of the period were observable in the " new history."

> The same union of empiricism with rationalism which recreated physics and astronomy was at work among the historians, and it is not a mere compliment but a sober statement of fact to say that the seventeenth century has to its credit the creation of the modern scientific study of history (49).

Medicine, Religion and Science

Interest in medicine and surgery becomes conspicuously accentuated in the middle of the century (50) remaining more or less constant after that time. A historian of medicine observes

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Caius College would have it : " ... the mathematics especially are to be had in good esteem in universities; as arithmetic, geometry, geography, and the like : which, as they carry no wickedness in them, so are they besides very useful to human society, and the affairs of this present life." *Select Works of* WILLIAM DELL (London, 1773), p. 580.

(45) J. HARRINGTON, *The Common-wealth of Oceana* (London, 1656); SAMUEL HARTLIB, *A Description of the Famous Kingdom of Macaria* (London, 1641). In all of these Utopias, science and invention which contributes so much to national " health and wealth " is to be the focus of the new education.

(46) Quoted by DAVID OGG, *England in the Reign of* CHARLES II, 2 volumes (Oxford : Clarendon Press, 1934), Vol. II, p. 705.

(47) See Figures 1, 2.

(48) OGG, *op. cit.*, Vol. II, pp. 714-15.

(49) G. N. CLARK, *The Seventeenth Century*, p. 274.

(50) See Figures 1, 2. Note the correlation between foci of interest in medicine and in science which suggest that these fields were subject to much the same social forces.

that this century may be called the century of aggrandizement of physicians, being characterized by a marked improvement of their position in the eyes of the public (51). The general picture derived from the *D. N. B.* statistics may be held to reflect this progressively favorable attitude toward " physick " and its practitioners. In any event, it accords with our basic assumption that the increased cultivation of those fields of vocational endeavor which receive attention in such compilations as the *D. N. B.* is associated with the growing prestige of these vocations. The striking peak in the forties may possibly be due to the demands for surgical and medical attention raised by the bloody Civil Wars (52), which would accentuate the secular trend. Both THOMAS SYDENHAM, possibly the greatest physician of his day, and RICHARD WISEMAN, who so signally advanced surgery, saw considerable military service. In any event, the enhanced interest in this field was very likely an aspect of growing interest in science. Although the physician *qua* physician was much more divorced from the biological sciences than he is today, concretely the physician and scientist were frequently one and the same individual (53). It has been said that a special characteristic of the seventeenth century physician was his marked preoccupation with chemistry, mathematics and natural philosophy (54). Such eminent scientists as GILBERT, HARVEY, BROUNCKER, LISTER, MORISON and WOODWARD were likewise physicians (55). Of all professions, medicine was most akin to science and hence it is

(51) JOHANN H. BAAS, *Outlines of the History of Medicine and the Medical Profession*, trans. by H. E. HENDERSON (New York, 1889), p. 564. *Cf.*, also ARTURO CASTIGLIONI, *Histoire de la Médecine* (Paris : PAYOT, 1931), p. 463; " Au cours du XVII[e] siècle, nous constatons une grande amélioration dans la situation des médecins. Ils commencent à jouir de plus de considération et à occuper un rang social qui leur vaut du respect."

(52) Compare GEORGE SARTON, *Introduction to the History of Science*, Vol. II, p. 519, who observes : " War is the mothei of surgery."

(53) A. WOLF, *A History of Science, Technology and Philosophy in the 16th and 17th Centuries* (London : ALLEN & UNWIN, 1935), Chapter XIX.

(54) BAAS, *op. cit.*, p. 552.

(55) Some other scientists of less imposing eminence who were also physicians were : JOHN BAINBRIDGE, JOHN BEAUMONT, JOHN CASE, GEORGE CHEYNE, JOHN CRAIG, ARTHUR DACRES, WILLIAM DAVIDSON, FRANCIS GLISSON, EDWARD JORDAN, RICHARD LOWER, JOHN MAYOW, Sir THOMAS MILLINGTON, WILLIAM PETTY, LEONARD PLUKENET, HENRY POWER, Sir ROBERT SIBBALD, FREDERICK SLARE, JOSEPH WARDER and ROBERT WOODS.

not surprising to find a very high correlation between the shifts of initial interest in these two fields.

Two important fields of interest remain to be discussed (56); each of which shows a noteworthy, though contrasting, secular trend during this period. Although religion remained one of the dominant social forces throughout this period, it may fairly be said that the social prestige of the clergy lessened with time (57). MACAULAY, in a famous passage, has described the increasingly menial position of the clergy, especially in the rural districts (58). This decreasing prestige of the clergy was no doubt due in part to the Reformation doctrine that the burden of salvation rests upon the individual rather than upon the Church. The *D. N. B.* data indicate an almost continuous and unbroken decline of interest in the ministry as an occupation (59) : a trend which has been noted by contemporary and later investigators (60).

Moreover, as we shall indicate in some detail, the clergy were promulgating the same utilitarian doctrines which we have found so notable in the other fields of culture. Preachers saw no harm in indicating to their congregations that they might make the most of both worlds, and that they should " learn the *plainest and most useful* before the deepest and most subtle " of truths (61).

In contrast to the distribution of clergy and theologians in

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(56) The data for the fields of scholarship, law and politics which are not directly related to our major problems are summarized in the appendix. The number of travelers, merchants, engineers, architects, craftsmen, economists and philosophers mentioned in the *D. N. B.* is too small to justify drawing any inferences regarding foci and shifts of interest in these fields.

(57) See EDWARD CHAMBERLAYNE, *Angliae Notitia* (London, 1672. 6th ed.), Vol. I, p. 263; R. H. GRETTON, *The English Middle Class* (London : G. BELL & Sons, 1917), pp. 151 ff.

(58) THOMAS MACAULAY, *The History of England* (New York : 1852), Vol. I, pp. 243-251.

(59) See Figures 1, 2.

(60) JOHN EACHARD, *The Grounds and Occasions of the Contempt of the Clergy* (London, 1670); CAROLINE F. RICHARDSON, *English Preachers and Preaching*, 1640-70 (New York : The MACMILLAN Co., 1928), pp. 254 ff; W. C. SYDNEY, *Social Life in England*, 1660-1690 (London, 1892), p. 164; " It is incontestable... that of their [*i.e.*, the clergy's] condition and character throughout the whole of the second half of the seventeenth century a very low opinion was held."

(61) THOMAS SPRAT, *Sermons on Several Occasions* (London, 1722), p. 13.

this century is that of scientists. There is a consistently increasing interest in science in the first half of the century, reaching its peak in the quinquennium, 1646-50 (62). Since we may expect a lag of ten or twenty years between the time of initial interest and significant scientific productivity,—an hypothesis which will be checked in the next chapter—one would look for the peak of scientific discoveries and inventions in the decade, 1661-70. After the middle of the century, initial interests decline somewhat, but remain at a significantly higher level than during the first part of the century.

Data concerning the changing attitudes toward science reinforce the impression derived from these statistics. Relatively speaking, at the beginning of the century, theology and the humanities were commonly held in much higher regard than was science. Literature was a vocation to which one could devote himself entirely, while science was at best a hobby to which one could occasionally turn (63). Mathematics was not considered to form any significant part of a liberal education (64). Of some interest is the fact that JOHN EARLE's *Microcosmographie* (1628), in which fifty-four " characters " or " types " were described, did not include a scientist. WILLIAM ROBINSON, writing to OUGHTRED, observed that science is definitely slighted and is regarded with little esteem (65). WALLIS, who was at Emmanuel College in 1635, noted that " mathematics were scarce looked upon as academical studies," and that few students would study a discipline held to be of such little importance (66). When Sir KENELM DIGBY became interested in science (in the '30s) it was a new thing for a " man of quality " to attend to such

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(62) See Figures 1, 2.

(63) KATHARINE MAYNARD, " Science in Early Fnglish Literatuie, (1550-1650)," *Isis*, XVII (1932), 96-97.

(64) W. W. R. BALL, *A History of the Study of Mathematics at Cambridge* (Cambridge University Press : 1889), p. 32.

(65) See STEPHEN J. RIGAUD, *Correspondence of Scientific Men of the Seventeenth Century*, 2 volumes (Oxford University Press : 1841), in which is published ROBINSON's letter dated June 11, 1633.

(66) Quoted by C. WORDSWORTH, *Scholae Academicae* (London, 1877), p. 65. *Cf.* ROBERT T. GUNTHER, *Early Science in Oxford*, 9 volumes (London : WATSON & VINEY, 1920-32), Vol. I, pp. 116-117.

matters (67), but his interest was itself a reflection of the gradually changing attitude of the time (68).

Toward the middle of the century, science, as a social value, rose conspicuously in the scale of estimation. Lord HERBERT OF CHERBURY encouraged the study of anatomy (69). Moreover, he thought it expedient to study arithmetic and geometry " as being most useful for keeping accounts and enabling a gentleman to understand fortifications." On similarly utilitarian grounds, he advises gentlemen to study botany and medicine. WALLIS observed that " the practise of chymistry is a piece of knowledge not misbecoming a gentleman." (70) JOHN WILKINS likewise recommended to gentlemen the study of " mechanical Geometry." (71) The well-known book-seller, WILLIAM LONDON, notes that " mathematics is a study of late much engrossed by many of these parts... " (72)

Science became fashionable, which is to say : it became highly approved. CHARLES II himself, with his interest in chemistry and navigation, set the example. PRINCE RUPERT commended the pursuit of natural philosophy and also participated in such activity. Sir MATTHEW HALE and Lord Keeper GUILFORD attended to problems in hydrostatics. It began to be considered almost abnormal for a " gentleman of culture " to overlook the " charms " of science (73). Though the interest of these worthies contributed little directly to scientific development, it was highly

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(67) PARK BENJAMIN, *The Intellectual Rise in Electricity* (New York, 1895), p. 379.

(68) It would of course be absurd to maintain that the change toward a positive evaluation of science occurred within the compass of a few years. It is not at all implied that there was *no* interest in science at the beginning of the century; but rather, that this interest was considerably enhanced in the course of the century, and that the *comparative* increase of positive estimation accounts largely for the significantly heightened attention devoted to science toward the latter part of this period.

(69) SIDNEY L. LEE (ed.), *The Autobiography of* EDWARD, *Lord* HERBERT OF CHERBURY (London, 1886), p. 59.

(70) Quoted by GUNTHER, *op. cit.*, Vol. I, p. 15.

(71) JOHN WILKINS, *Mathematical Magick* (London, 1646), " To the Reader."

(72) WILLIAM LONDON, *Catalogue of the Most Vendible Books* (London : 1658). *Cf.* W. W. R. BALL, *op. cit.*, p. 33. " The middle of the seventeenth century in England marks the beginning of a new era in mathematics."

(73) LEGOUIS and CAZAMIAN, *op. cit.*, Vol. II, p. 53.

important as a symbolic representation of the social esteem and enhanced value attributed to scientific inquiry.

The increased estimation in which science was coming to be held is evidenced by several other developments. As previously remarked, the social ranking of physicians—who were closely allied with the contemporary scientific activity—became perceptibly higher. By virtue of its new found prestige, scientific prowess even afforded a channel for social advancement. For example, when the Royal Society demurred at admitting JOHN GRAUNT (74), simply because he was a tradesman, it was severely reproved by KING CHARLES who announced "that if they found any more such tradesmen, they should be sure to admit them all without any more ado." The bourgeoisie for whom science and its practical technical offshoots were to become increasingly valuable, was beginning to find scientific activity as well as business a most satisfactory means of social ascent (75).

Littérateurs of the period, such as COWLEY and DRYDEN, eulogized both the outstanding scientists and science in general. The Royal Society was one of the hobbies of the king. Distinguished personages patronized science often making available considerable sums of money for research purposes, increasing the social reputation of science (76). Science had definitely been elevated to a place of high regard in the social system of values; and it was this positive estimation of the value of science —an estimation which had been gradually becoming increasingly favorable—which led ever more individuals to scientific pursuits. This increased attention to science—which is reflected in the data concerning shifts of vocational interests—was a necessary condition, if not a sufficient cause, of the accelerated rate of advance in the latter part of the century (77).

Although the universities remained largely outside the stream

(74) GRAUNT was the author of one of the first important works in political arithmetic : *Natural and Political Observations upon the Bills of Mortality.*

(75) The life of HUMPHREY DAVY, in the nineteenth century, provides a most instructive case-study of this process. Cf. J. G. CROWTHER, *British Scientists of the Nineteenth Century*, (London : K. PAUL, TRENCH, TRUBNER & Co., 1935).

(76) ERIK NORDENSKIÖLD, *The History of Biology*, trans. by L. B. EYRE (New York : A. A. KNOPF, 1928), p. 142.

(77) See the subsequent discussion of factors in the rate of scientific and technologic development.

of scientific development during this period, they none the less evidence to some extent the gradually increasing importance attributed to scientific disciplines. The shift in emphasis which occurred even within the universities is illustrated by a synopsis of some of the new chairs established therein.

1546.—Five Regius Professorships established at Oxford and Cambridge by HENRY VIII.
1. Divinity.
2. Hebrew.
3. Greek.
4. Civil Law.
5. Medicine [only point of contact with science].

1575.—Gresham College founded—included Professorships in
1. Mathematics.
2. Astronomy.

1583.—Edinburgh University—Professorships in
1. Mathematics.
2. Natural Philosophy [science].

1619.—Oxford University.
1. Savilian Professorship of Geometry.

1621.—Oxford University.
1. Sedleian Professorship of Natural Philosophy.
2. Savilian Professorship of Astronomy.

1663.—Cambridge University.
1. Lucasian Professorship of Mathematics.

1669.—Oxford University.
1. Professorship of Botany.

1702.—Cambridge University.
1. Professorship of Chemistry.

1704.—Cambridge University.
1. Professorship of Astronomy.

The contrast between the earlier and later periods is clear In the middle of the sixteenth century the emphasis was definitely placed upon the humanities. The " medical course " at Cambridge in HARVEY's time, was principally devoted to logic and divinity, rather than physic (78). The study of mathematics and astronomy instituted at the newly-founded Gresham College was definitely due to " the practical demands of navigation." (79) Increasingly, thereafter, occurs a definite tendency to introduce chairs in the various sciences. Thus, the leading studies in Cambridge at the

(78) *Cf.* ROBERT WILLIS, WILLIAM HARVEY (London, 1878), p. 157.

(79) ARTHUR SCHUSTER and ARTHUR E. SHIPLEY, *Britain's Heritage of Science* (London : CONSTABLE & Co., 1917), pp. 46-47.

beginning of the seventeenth century were definitely the classics, rhetoric and divinity. Mathematics was slighted and the various sciences were practically ignored. It was not till about the middle of the century that the study of mathematics assumed any prominence as an academic influence. ISAAC BARROW's introductory lecture as Lucasian professor of mathematics reflects the shifting emphasis. BARROW justified his retirement from the chair of Greek saying that he had exchanged grinding at the mill o grammar for the palestra of mathematics; at the same time, he takes care to emphasize the practical benefits of science (81). The shift is further illustrated by JOHN EACHARD's observations :

> ... we are now in an Age of great Philosophers and Men of Reason, ... And *Greek* and *Latin* which heretofore, though never so impertinently fetch'd in, was counted admirable, because it had a learned Twang, yet now, such Stuff being out of fashion, is esteemed but very bad Company." (82)

This completes our brief résumé of fluctuations of initial interests in seventeenth century England. It serves not only to describe these changes but to set certain problems which demand further attention. Which factors were predominantly involved in the various shifts of interest which have been uncovered? A considerable part of our later discussion will be concerned with this problem. Another leading impression derived from this survey is the fact that the fluctuations which occurred are related to the application of canons of utilitarianism and practicality. Those pursuits which are most obviously linked to the furtherance of man's " conveniences of life " gain most in prestige and popularity. Even such vocations which are deemed ordinarily self-sufficient, demanding no further justification than their productions as " ends-in-themselves,"—literature, for example—change their character to become instruments for further goals. As Professor CLARK has observed : " Philosophy, science, and literature followed a well-marked path toward

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(80) JAMES B. MULLINGER, *Cambridge Characteristics in the Seventeenth Century* (London, 1867), pp. 46, 63.

(81) ISAAC BARROW, " Opuscula," *Works* (London, 1683-87), Vol. IV, p. 88.

(82) JOHN EACHARD, *op. cit.*, pp. 30-31.

utilitarian ethics and a ' natural religion ' which contained nothing of the miraculous or of revelation." (83)

Realism, in the sense of concrete empiricism, permeated all fields. The realistic genre and landscape painting predominated; in music, the realistic opera was introduced; in literature, the realistic drama and concretely descriptive essay.

Some ardent spirits were not content with the slow development of the sciences in the universities and one of the more articulate of them, JOHN WEBSTER, published a treatise on this subject which met with considerable popular success (84). He would change the entire system of English university studies, proposing to reform them on thoroughly utilitarian principles. He would have " more mathematics, physics and the sublime and never-sufficiently praised science of Pyrotechny or Chymistry." MILTON's third oratorical exercise at Cambridge was based upon a similar attitude. Poetry, oratory and history, said the young MILTON, are all delightful, each in its own way, but they are not *useful.* It is much more desirable to study instead the natural sciences, especially geography, astronomy, and natural history (85).

It is unlikely that these tendencies have evolved through sheer chance, inasmuch as they comprise a clearly integrated development. In later chapters, we shall have occasion to consider, in some detail, some of the social and cultural elements involved in these movements, particularly those connected with the rise of interest in science.

(83) *The Seventeenth Century*, pp. 317-18.

(84) JOHN WEBSTER, *Academiarum Examen* (London, 1653).

(85) DAVID MASSON, *The Life of* JOHN MILTON, Vol. I, pp. 211-212.

TABLE I.

Shifts of Initial Interests among English Elite, 1601-1700.

Years	Army and Navy		Painting, Sculpture		Music		Drama		Poetry		Prose		Education		Historiography		Medicine & Surgery		Religion*		Science		Scholarship		Law		Politics	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1601-05	9	1.5	5	2.4	12	9.7	15	11.0	28	12.8	10	3.3	3	1.2	18	7.1	9	2.8	102	7.0	6	1.7	6	3.1	22	5.8	46	5.4
1606-10	6	1.0	3	1.5	15	12.1	13	9.5	18	8.2	14	4.6	10	5.6	11	4.5	10	3.1	98	6.8	9	2.6	10	5.1	22	5.8	38	4.5
1611-15	6	1.0	4	2.0	4	3.2	7	5.1	19	8.7	11	3.6	12	6.7	7	2.8	9	2.8	106	7.3	8	2.3	8	4.1	17	4.5	43	5.1
1616-20	10	1.7	9	4.4	4	3.2	6	4.4	15	6.9	12	4.0	9	5.1	13	5.1	7	2.2	118	8.2	10	2.9	11	5.6	13	3.4	46	5.4
1621-25	21	3.6	6	2.9	1	0.8	4	2.8	9	4.1	13	4.3	3	1.7	9	3.5	7	2.2	114	7.9	11	3.2	10	5.1	22	5.8	53	6.2
1626-30	15	2.5	6	3.0	5	4.0	5	3.6	8	3.6	12	4.0	11	6.2	9	3.5	12	3.7	105	7.3	12	3.5	12	6.1	21	5.5	47	5.5
1631-35	14	2.3	8	3.9	6	4.9	4	2.8	13	5.9	11	3.6	12	6.7	15	5.9	13	4.0	91	6.3	16	4.6	16	8.2	25	6.6	49	5.8
1636-40	78	13.2	10	4.9	8	6.5	5	3.6	15	6.9	13	4.3	16	9.0	8	3.2	17	5.2	86	5.9	23	6.7	10	5.1	20	5.2	57	6.7
1641-45	104	17.6	7	3.4	3	2.4	1	0.7	12	5.5	12	4.0	5	2.8	8	3.2	19	5.9	80	5.5	20	3.8	7	3.6	14	3.7	51	6.0
1646-50	65	11.0	8	3.9	4	3.2	1	0.7	11	5.0	18	5.9	8	4.5	16	6.3	28	8.6	74	5.1	26	7.6	10	5.1	18	4.7	43	5.1
1651-55	43	7.3	10	4.9	4	3.2	2	1.5	9	4.1	19	6.3	7	3.9	17	6.7	23	7.1	78	5.4	24	7.0	8	4.1	22	5.8	32	3.8
1656-60	20	3.4	10	4.9	4	3.2	7	5.1	11	5.2	24	7.9	14	7.9	11	4.3	18	5.6	71	4.9	22	6.4	9	4.6	20	5.3	46	5.4
1661-65	15	2.5	13	6.4	3	2.4	12	8.8	5	2.3	16	5.3	8	4.5	9	3.5	21	6.5	52	3.6	22	6.4	10	5.1	24	6.3	43	5.1
1666-70	15	2.5	18	8.8	5	4.0	10	7.4	6	2.7	15	4.9	10	5.6	9	3.5	20	6.2	47	3.2	19	5.5	9	4.6	19	5.0	41	4.8
1671-75	18	3.1	21	10.3	9	7.3	10	7.4	8	3.6	14	4.6	9	5.1	19	7.5	20	6.2	35	2.4	21	6.1	7	3.6	21	5.5	31	3.6
1676-80	20	3.4	18	8.8	9	7.3	9	6.6	5	2.3	17	5.6	11	6.2	14	5.5	22	6.8	48	3.3	22	6.4	7	3.6	20	5.3	34	4.0
1681-85	22	3.7	14	6.9	10	8.1	7	5.1	5	2.3	21	6.9	6	3.4	12	4.7	18	5.6	35	2.4	23	6.7	11	5.6	13	3.4	40	4.7
1686-90	70	11.8	16	7.9	8	6.4	6	4.4	6	2.7	16	5.3	12	6.7	11	4.3	15	4.6	46	3.2	15	4.4	9	4.6	17	4.5	46	5.4
1691-95	24	4.1	9	4.4	6	4.8	7	5.1	7	3.2	20	6.6	6	3.4	18	7.1	16	4.9	34	2.4	17	4.9	12	6.1	16	4.2	33	3.9
1696-00	16	2.7	9	4.4	4	3.2	6	4.4	9	4.1	15	4.9	6	3.4	20	7.9	20	6.2	28	1.9	18	5.2	14	7.1	14	3.7	30	3.5

*I.e., Clerics and Theologians.

TABLE 2

*Shifts of Initial Interest among English Elite in Miscellaneous Fields, 1601-1700**

Years	Travellers	Merchants and Bankers	Engineers and Architects	Craftsmen and Farmers	Econom-ists	Philoso-phers
1601-05	12	6	2	5	1	3
1606-10	7	7	—	3	1	5
1611-15	1	2	1	2	2	1
1616-20	2	4	1	5	—	4
1621-25	4	4	1	4	2	1
1626-30	6	5	2	1	1	—
1631-35	2	6	1	1	2	1
1636-40	2	6	2	3	—	2
1641-45	1	4	1	5	1	2
1646-50	—	6	4	6	3	2
1651-55	1	4	4	2	1	2
1656-60	—	3	1	5	4	1
1661-65	2	5	2	4	—	—
1666-70	2	1	1	1	3	2
1671-75	2	6	1	3	1	1
1676-80	1	7	1	4	—	4
1681-85	3	4	1	5	2	3
1686-90	1	9	1	1	2	1
1691-95	2	5	1	3	2	3
1696-00	4	5	2	6	—	4

* The number of cases in any one category is too small to warrant drawing any conclusions regarding shifts of interest.

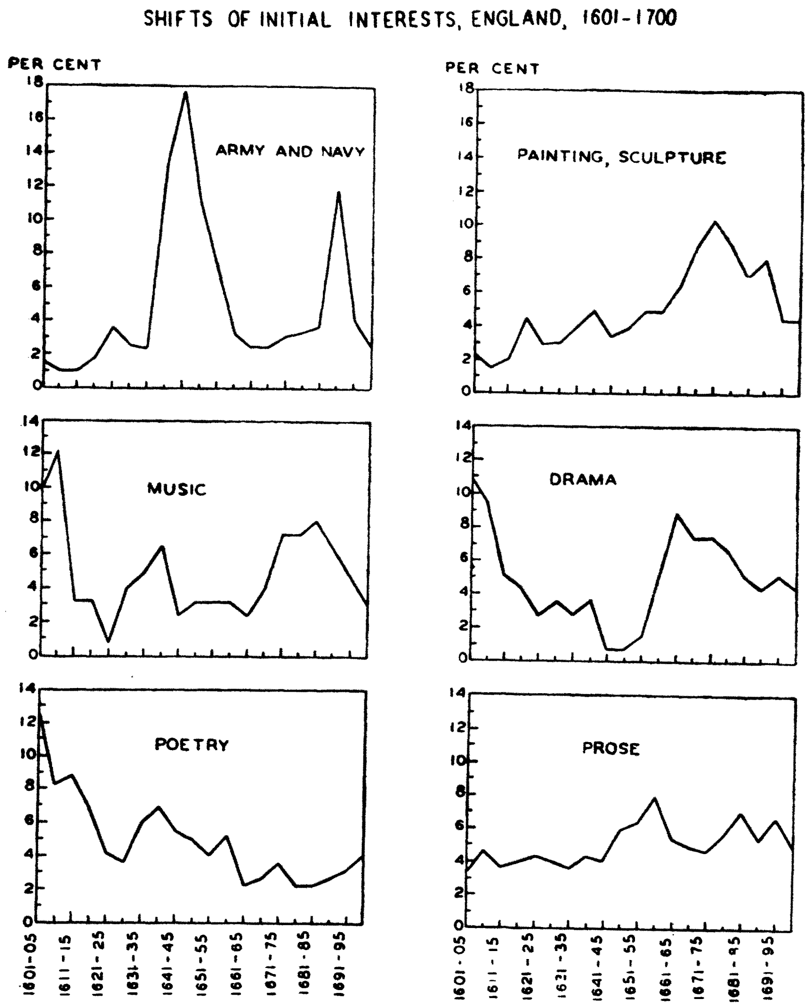
SHIFTS OF INITIAL INTERESTS, ENGLAND, 1601-1700
PER CENT
ARMY AND NAVY
PAINTING, SCULPTURE
MUSIC
DRAMA
POETRY
PROSE
0 2 4 6 8 10 12 14 16 18
1601-05
1611-15
1621-25
1631-35
1641-45
1651-55
1661-65
1671-75
1681-85
1691-95

Fig. 1.

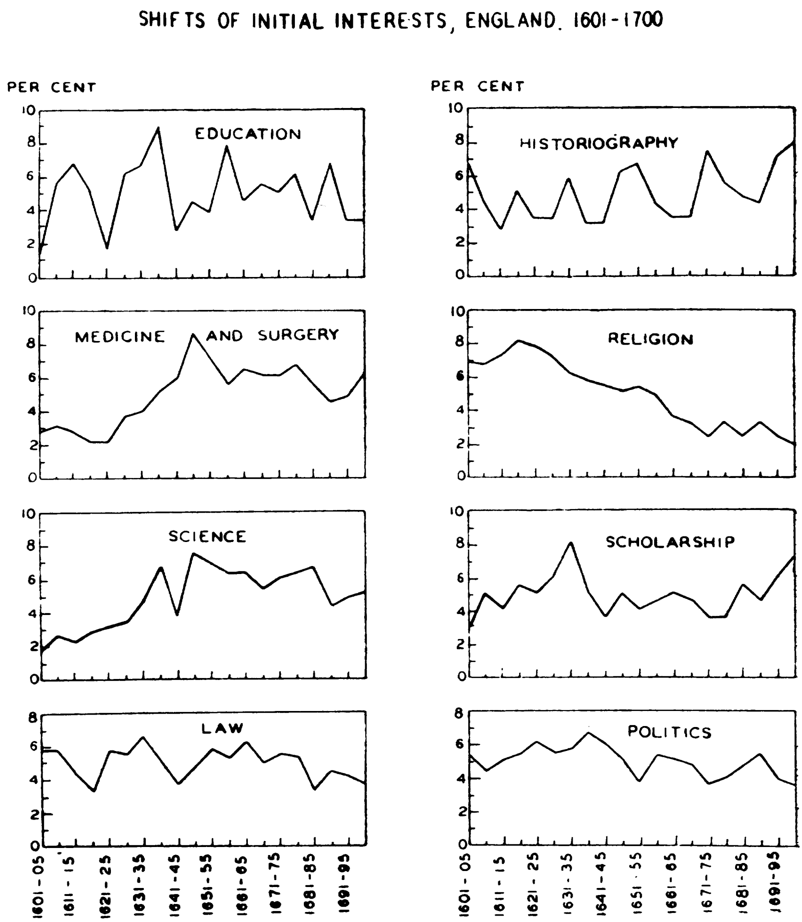

FIG. 1. (continued)

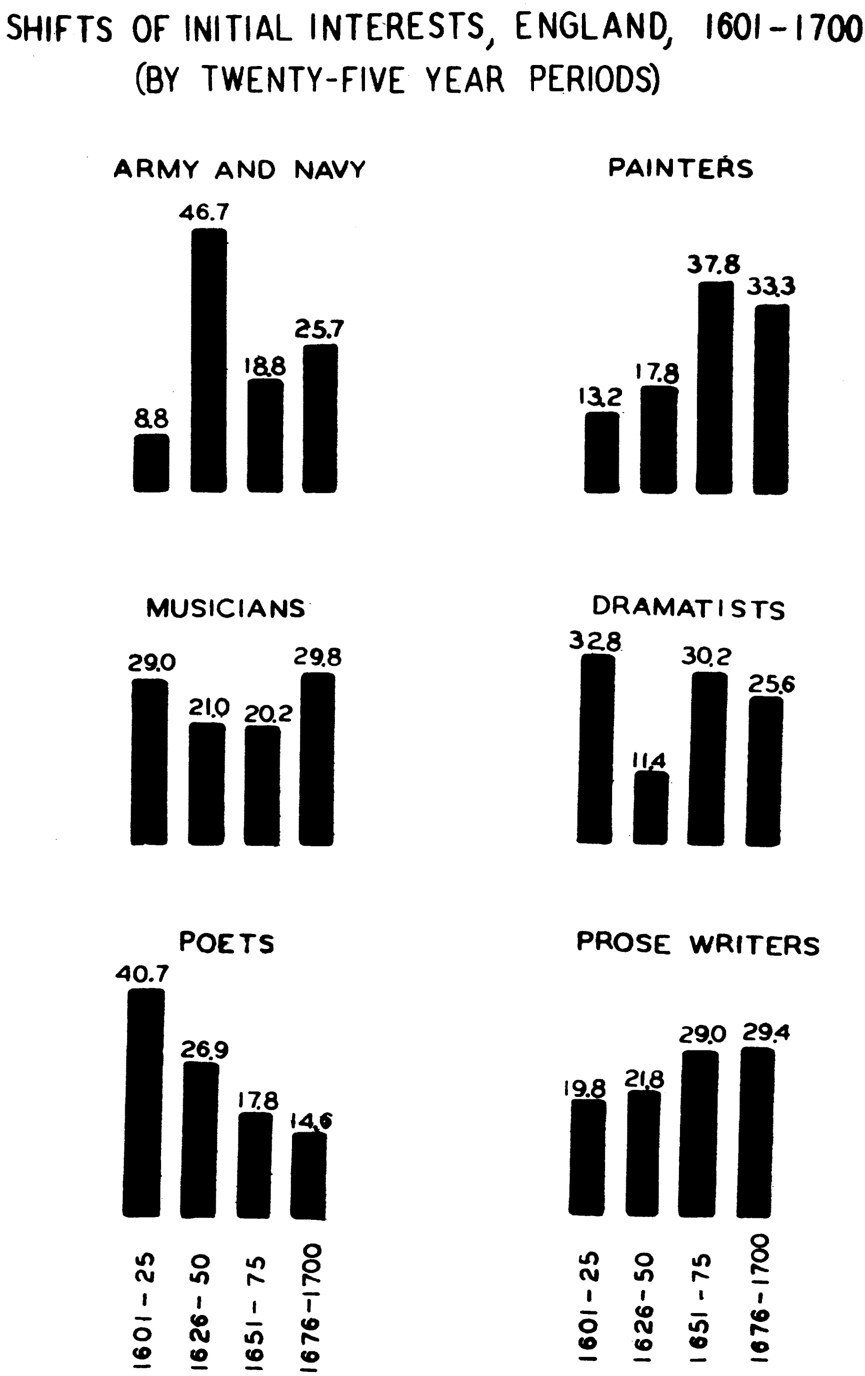
SHIFTS OF INITIAL INTERESTS, ENGLAND, 1601-1700
(BY TWENTY-FIVE YEAR PERIODS)
ARMY AND NAVY
8.8
46.7
18.8
25.7
PAINTERS
13.2
17.8
37.8
33.3
MUSICIANS
29.0
21.0
20.2
29.8
DRAMATISTS
32.8
11.4
30.2
25.6
POETS
40.7
26.9
17.8
14.6
PROSE WRITERS
19.8
21.8
29.0
29.4
1601-25
1626-50
1651-75
1676-1700
1601-25
1626-50
1651-75
1676-1700

FIG. 2.

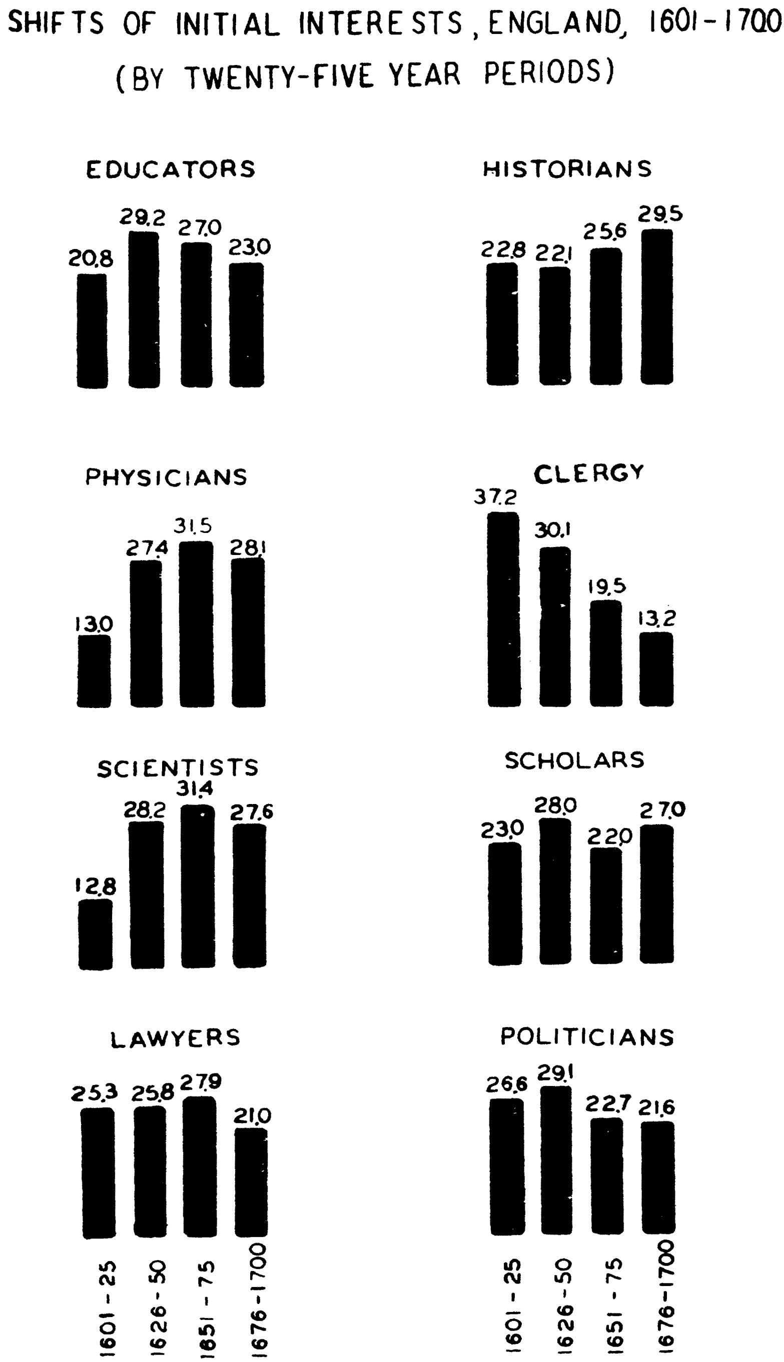

FIG. 2. (continued)

CHAPTER III

FOCI AND SHIFTS OF INTEREST IN THE SCIENCES AND TECHNOLOGY

We have seen that an unusually large number of persons who later made their mark in these fields first turned to science and technology during the fifth and sixth decades of the seventeenth century. Before exploring the causes of this apparent expansion of interest in science, it would seem wise to determine whether the fact itself is securely established. Does additional evidence sustain the impression derived from the *Dictionary of National Biography* memoirs? And, furthermore, which of the sciences were accorded the greatest measure of attention? Did any of these disciplines maintain an unchallenged primacy throughout this period, or were there, on the contrary, shifting foci of scientific interest?

Method of Study

An independent source of data which may afford a basis for answering the first of these questions is the compilation by LUDWIG DARMSTÄDTER and twenty-six associated scholars: *Handbuch zur Geschichte der Naturwissenschaften und der Technik* (1). This is a chronological list of important scientific and technologic discoveries and inventions which, although not exhaustive, very closely approximates completeness. This work contains occasional errors in the attribution and dating of discoveries (2), but these shortcomings do not vitiate our use of this material, since in this instance we are not concerned with the attribution

(1) Berlin: J. SPRINGER, 1908.

(2) *Cf.* GEORGE SARTON, *Introduction to the History of Science*, Vol. I, p. 144; BORIS WEINBERG, " Les lois d'évolution des découvertes de l'humanité," *Revue générale des sciences*, XXXVII (1926), 43-44.

of discoveries to particular individuals. Furthermore, since the entries pertaining to seventeenth century England have been verified, there is little reason to suspect the subsistence of any significant residual error.

The difficulties inherent in the statistical use of lists of discoveries have not been completely obviated in this study, but they have been sharply modified by the nature of the inquiry in hand, since the primary objective is not so much the measurement of rates of scientific advance, as of the relative degrees of scientific interest reflected in output. Hence there is no need for establishing a precise one-to-one correspondence between individual discoveries and the ' units ' of the tabulation. Each scientific increment, irrespective of its significance for scientific development, is an index of interest in that field, and thus, certain strictures concerning the comparability and additiveness of somewhat heterogeneous units are precluded by the purpose of these tabulations (3). It is true that each increment recorded by DARMSTÄDTER may not reflect an equal amount of interest in the corresponding science, but in the absence of any contrary evidence, it seems admissible to assume that such variations are not cumulative, that they do not, in short, lead to biassed results.

The procedure involved in such tabulation depends upon certain assumptions which should be made explicit. It is assumed that the number of scientific discoveries mentioned in DARMSTÄDTER's *Handbuch* is a function of the degree of contemporary interest in science. Manifestly, this situation does not always obtain; possibly not in the century of scientific genius here under consideration. A few brilliant scientists —NEWTON, BOYLE, HALLEY—may produce more noteworthy

(3) For a critical discussion of the difficulties involved in statistical analysis of lists of inventions, see FLOYD H. ALLPORT and DALE A. HARTMANN, " The Prediction of Cultural Change," in *Methods in Social Science* (ed. by S. A. RICE) (University of Chicago Press, 1931), pp. 307-352. But contrast T. J. RAINOFF, " Wave-like Fluctuations of Creative Productivity in the Development of West-European Physics," *Isis*, (1929) XII, p. 287-88; P. A. SOROKIN and R. K. MERTON, " The Course of Arabian Intellectual Development : A Study in Method," *Isis*, XXII (1935), p. 516-524; ROBERT K. MERTON, " Fluctuations in the Rate of Industrial Invention," *The Quarterly Journal of Economics*, XLIV (1935), p. 454-74.

discoveries than say a hundred times as many pedestrian researchers (4). As an approximate index of interest in science this list taken alone will not suffice, but taken in conjunction with the foregoing collection of data, as well as with additional material garnered from independent sources, its reliability may be checked at every point.

Scientific Productivity

The tabulation derived from the *Handbuch*—by counting each discovery or invention as one " unit "—is presented in the following table. No effort was made to classify these discoveries according to the scientific fields to which they pertain since the number of items for any one field during a decade is too small to permit of acceptable interpretation.

TABLE 3

Number of Important Discoveries and Inventions (5)
England, 1601-1700

Years	Number	Years	Number
1601-10	10	1651-60	13
1611-20	13	1661-70	44
1621-30	7	1671-80	29
1631-40	12	1681-90	32
1641-50	3	1691-00	17

The contrast between the productivity of the two halves of the century is marked : there are three times as many discoveries

(4) However, broadly speaking, there seems to be an appreciable correlation between the *number* of workers and discoveries in any given field and the *importance* of both the scientists and discoveries. *Cf.* SOROKIN and MERTON, *op. cit.*, pp. 522-24; also Professor SOROKIN's recently published *Social and Cultural Dynamics* (New York : American Book Co., 1937), esp. Vol. II, chaps. I-IV, which seem to establish this point. The correlation is probably due to the fact that outstanding scientists frequently attract a cluster of less talented followers, so that periods with an unusually large number of brilliant scientists are also periods of great interest in science. Moreover, conspicuous success in any given field, as we shall see, is apt to attract the attention of a number of mediocre as well as able investigators.

(5) Compiled from DARMSTÄDTER, *op. cit.*

in the second half as in the first. This coincides with the frequent observation of historians of science that the advance of science became especially notable in England during the latter half of the century. After an initial period of trendless fluctuation in the number of important discoveries, there is a pronounced increase in the decade 1661-70, after which productivity slackens considerably. The low point in scientific output is reached during the period when the Civil Wars were rife. It is hardly to be expected that at a time of such intense social disturbance as this, scientists would be able to work very effectively. WALLIS, BOYLE, and others of their company frequently remarked the distracting influences of the wars. The same reaction occurred during the internal disturbances engendered by WILLIAM's entry into England in 1688, as was observed by the editor of the *Philosophical Transactions* upon the resumption of publication of this journal.

> The Publication of these Transactions [has] for some time past been suspended, chiefly by reason that the unsettled posture of Publick Affairs did divert the thoughts of the curious towards Matters of more immediate Concern than are Physical and Mathematical Enquiries (6).

Thus, internal disturbances undoubtedly retarded the acceleration of scientific research during the two middle decades of the century. The following decade, marked by the undisturbed and enhanced interaction of scientists attendant upon the official inauguration of the Royal Society, was one of great scientific activity. In fact, it was probably the very cessation of the civil disturbances as well as the great increase of interest in science during the decades immediately preceding (7) which account for the marked and " sudden " appearance of so many fundamental discoveries in the sixties. The scientific movement had been gathering momentum for some time previous, but had been repressed by the uncertainties and disorders of the two decades of strife (8).

(6) *Philosophical Transactions*, XVII (1693), p. 452.

(7) See Figure 1 and Table 1 in the preceding chapter.

(8) Professor G. N. CLARK adopts this same explanation for the " burgeoning " of science from 1660 on. See his excellent work, *The Later Stuarts* (Oxford : Clarendon Press, 1934), pp. 28-29.

The reliability of this tabulation may be determined by comparing it with independently derived data concerning much the same point. Thus, re-computing by decennia the statistics concerning scientific interests derived from the *D. N. B.* memoirs, the following results are obtained.

TABLE 4

Number of Initial Interests in Science and Technology, England, 1601-1700

Years	Number	Years	Number
1601-10	17	1651-60	46
1611-20	18	1661-70	41
1621-30	23	1671-80	43
1631-40	39	1681-90	38
1641-50	46	1691-00	35

It will be noted that with a lag of about a decade there is some correlation between indices of initial scientific interests and of scientific productivity. The discrepancies in the first part of the century are probably due to a variety of concrete disturbing circumstances. Though interest in science was consistently increasing during this time, it was, as far as productivity is concerned, a "period of incubation." Interaction between scientists was slight as compared with the intensive contact and discussion which attended the institution of the "Invisible College" and the outgrowing Royal Society. Another of the discrepancies may be accounted for, as previously suggested, by the disturbing effect of the Civil Wars (9). Furthermore, the interaction between the degree of interest manifested in science

(9) Professor SOROKIN has indicated that "an increase of men of genius [including scientists and inventors] during and after revolutions and wars has been manifested many times." *Cf.* his *Social Mobility* (New York and London : HARPER & BROTHERS, 1927), p. 513. This was true during the disturbances of 1642-60, at which time, according to our *D. N. B.* data, the peak of notable seventeenth century scientists in England was reached. This correlation has been likewise noted by R. T. GUNTHER, *Early Science in Oxford*, Vol. III, p. 380; and by the distinguished mathematician, S. BRODETSKY, *Sir Isaac Newton* (London : METHUEN & Co., 1927), p. 13. But despite the actual increase of interest in science a period of great social disorder can scarcely yield conditions favorable to scientific investigation.

and the rate of scientific output is complex and far from uniform. Enhanced interest in a particular field may lead to greater productivity, due allowance being made for a lag, and this increase in the number of discoveries may in turn arouse even heightened interest. But this process occurs only when there are no shifts of interest from science to other fields of endeavor, as will be indicated presently.

Upon the basis of the foregoing data, it seems justifiable to conclude that scientific development in England became especially marked about the middle of the seventeenth century. As the late MARTHA ORNSTEIN indicated in her exemplary study (10), a dividing line may be drawn at this point, for the forces in Western Europe which produced the scientific achievements of the first half of the century were different from those which produced the science of the second half. This is true, *a fortiori*, for England. The first half included GILBERT and HARVEY, as well as that peer of scientific propagandists, FRANCIS BACON, but science as embodied in a well defined social movement became clearly prominent in the latter period. Added to the coterie of great names at this time was the *popularity* of science. The new experimental philosophy became worthy of note; it became fashionable to dabble in nature's arcana (11). If this new-found popularity did not in itself result in notable achievements, it none the less facilitated the focussing of intellectual attention upon a realm which was previously most esoteric.

Indices of Interest in the Sciences

It is of further interest to ascertain in some detail the shifts of attention which occurred within the context of this enhanced interest in science; that is, to determine the relative variations of interest manifested in the several sciences and technology. The most readily accessible index of such shifts and variations

(10) *The Rôle of Scientific Societies in the Seventeenth Century*, Chap. II.

(11) THOMAS SPRAT described the fad in these words : " It [science] has begun to keep the best company, refine its fashion and appearance and become the employment of the rich and great, instead of being the subject of men's scorn." *The History of the Royal-Society of London*, p. 149.

is the only scientific journal published in seventeenth century England—*The Philosophical Transactions of the Royal Society of London*. Unfortunately, the *Transactions* were initially published not until 1665, three years after the official inauguration of the Royal Society, and hence, this source does not furnish indices of scientific interests during the first part of the century. This journal may be said to represent the current scientific interests as adequately as any other source. As a test of the reliability of this source, the results obtained from a classification of the items listed in DARMSTÄDTER's *Handbuch* will be compared with those garnered from the *Transactions*. If the results obtained from such independent sources show a significant correspondence, the requirement of establishing the essential reliability of these various data would seem to be largely fulfilled.

The classification of sciences has been adapted from the " Systematic Classification " used by the editors of *Isis* (12). Each article in the *Transactions* was classified in the field to which it pertained in the main. Reviews of books, which usually contained discussions of some length, were likewise considered as units in the tabulation. In order to reduce absolute figures to a comparable basis, the number of articles in each field for a given year was divided by the total number of articles in all fields for the corresponding period (13). In this way, " indices of interest " in the various sciences are readily obtainable. Of course, these indices are significant only within certain limits. In some cases there are no articles pertaining to a given field —for example, that of mathematics for the year 1677—for a varying period of time. This obviously does not denote a complete cessation of interest in that field, but rather a comparative

(12) *Cf. Isis : International Review devoted to the History of Science and Civilization, passim* (e.g. XIX [1933], pp. 431 ff.).

(13) Compare the methods used in similar studies by HORNELL HART, " Changing Social Attitudes and Interests," *Recent Social Trends* (New York : MCGRAW-HILL Book Co., 1933), Vol. I, p. 384 ff; HOWARD BECKER, " Distribution of Space in the American Journal of Sociology," *American Journal of Sociology*, XXXVI (1930), pp. 461-66; XXXVIII (1932), pp. 71-78. Since it is true, as my colleague Dr. E. P. HUTCHINSON has suggested, that with a relative base an increase in one category produces an apparent decrease in all the others, it is necessary to control interpretations based on the relative figures by reference to the absolute figures.

decline and possibly also, a relative shift of predominant interest to some other field or fields. Moreover, the essential significance of these indices is the basis they afford for an establishment of trends in scientific interests. Fluctuations from year to year are apt to be casual and accidental, *i.e.*, influenced by factors outside the cultural system which is our primary concern, but trends or lack of trends of these indices over a period of some thirty-five years may be assumed approximately indicative of actual developments.

Shifts of Interest between the Sciences

A summary of the complete results arranged by triennia for the period, 1665-1702, is presented in the following tables (14). The number of articles and indices of attention are grouped by three-year periods since, as previously suggested, our primary concern is the determination of trends, rather than random year-to-year oscillations.

These indices reveal several well defined movements. In the formal sciences—logic, epistemology, and chiefly mathematics—there appear three clearly marked " cycles." The first reaches its peak in the years 1668-70, when especially NEWTON, WALLIS, and JAMES GREGORY, and to a lesser degree, JOHN COLLINS, CHRISTOPHER WREN, J. J. FERGUSON, and VISCOUNT BROUNCKER were furthering interest in mathematics. Also, the *Logarithmotechnia* of NICOLAUS MERCATOR was published in 1668, providing fruit for consideration. It was at this time (in 1669), moreover, that NEWTON communicated to BARROW his conception of the method of fluxions and quadrature of curves. This tract, *De*

(14) It will be noted that there were two lapses in the publication of the *Transactions*, the first beginning in 1678 and lasting three years. In 1681, ROBERT HOOKE began to publish the *Philosophical Collections*, which have always been considered as constituting a part of the *Transactions*. (*Cf.* THOMAS THOMSON, *History of the Royal Society* (London, 1812), p. 7 ff.) *The Collections* were published until 1683, when the secretary of the Royal Society, ROBERT PLOT, revived the original publication, which continued until 1687, when another three-year intermission occurred. In 1691, RICHARD WALLER and more especially EDMOND HALLEY, edited the *Transactions* once again, and since that time the publication of this journal has continued unbroken.

TABLE 5

Classification of Articles in Philosophical Transactions, 1665-1702

Fields of Interest	1665-67	1668-70	1671-73	1674-76	1677-78	1681-83	1684-87	1691-93	1694-96	1697-99	1700-1702	Total
A. Philosophy	2	4	6	3	1	—	1	—	—	—	—	17
B. Formal Sciences	4	20	22	8	1	7	9	2	11	13	4	101
1. Logic and Epistemology	—	1	—	1	—	—	—	—	—	—	—	
2. Mathematics	4	19	22	7	1	7	9	2	11	13	4	
C. Physical Sciences	87	79	102	94	39	50	110	29	16	59	22	686
3. Astronomy	36	20	29	39	11	27	29	6	3	15	4	
4. Physics	22	32	39	22	5	7	34	7	6	23	5	
5. Chemistry	6	14	13	16	5	10	16	7	2	12	7	
6. Technology	23	13	21	17	17	6	31	9	5	9	6	
D. Biological Sciences	34	39	53	42	17	20	26	29	17	55	34	366
7. Biology	17	14	10	24	6	4	7	8	7	16	11	
8. Botany	7	15	24	13	7	8	5	14	5	20	16	
9. Zoology	10	10	19	5	4	8	14	7	5	19	7	
E. Sciences of the earth	24	22	20	14	5	9	21	15	14	34	8	186
10. Geodesy	5	2	1	4	—	1	3	—	—	2	1	
11. Geography and Oceanography	7	3	5	4	1	2	3	2	4	8	3	
12. Geology, Mineralogy, Paleontology	11	14	10	2	3	6	10	11	6	9	1	
13. Meteorology, Climatology	1	3	4	4	1	—	5	2	4	15	3	
F. Anthropological Sciences (physical)	26	24	23	18	11	22	33	7	14	28	20	226
14. Anatomy	13	17	16	9	8	14	24	5	8	19	9	
15. Physiology	13	7	7	9	3	8	9	2	6	9	11	
G. Anthropological Sciences (cultural)	—	3	2	11	3	6	19	8	7	12	13	84
16. History and Archaeology	—	1	1	4	2	6	15	3	7	7	5	
17. Economics	—	—	—	7	—	—	—	—	—	—	—	
18. Philology	—	2	1	—	1	—	4	2	—	4	2	
19. Political Arithmetic	—	—	—	—	—	—	—	3	—	1	6	
H. Medical Sciences	22	28	33	16	8	11	30	12	23	43	31	257
20. Pharmacy, Pharmacology	—	1	8	2	3	—	—	2	—	6	4	
21. Medicine	22	27	25	14	5	11	30	10	23	37	27	
I. Alia	14	12	12	8	3	3	7	5	12	16	15	107

TABLE 6

Indices of Interest in the Several Sciences, Philosophical Transactions, 1665-1702

Fields of Interest	1665-67	1668-70	1671-73	1674-76	1677-78	1681-83	1684-87	1691-93	1694-96	1697-99	1700-1702	Arithmetic Mean
A. Philosophy	.9	1.7	2.2	1.4	1.1	—	.4	—	—	—	—	.9
B. Formal Sciences	1.9	8.6	8.0	3.7	1.1	5.5	3.5	1.9	9.7	5.0	2.7	5.0
1. Logic and Epistemology	—	.4	—	.5	—	—	—	—	—	—	—	—
2. Mathematics	1.9	8.2	8.0	3.3	1.1	5.5	3.5	1.9	9.7	5.0	2.7	
C. Physical Sciences	40.8	34.1	37.4	43.9	43.5	39.1	42.8	27.0	14.1	22.7	15.0	33.8
3. Astronomy	16.9	8.6	10.6	18.2	12.6	21.1	11.3	5.6	2.6	5.8	2.7	
4. Physics	10.3	13.8	14.3	10.3	5.7	5.5	13.2	6.5	5.3	8.8	3.4	
5. Chemistry	2.8	6.1	4.8	7.5	5.7	7.8	6.2	6.5	1.8	4.6	4.8	
6. Technology	10.8	5.6	7.7	7.9	19.5	4.7	12.1	8.4	4.4	3.5	4.1	
D. Biological Sciences	16.0	16.9	19.5	20.0	19.5	15.7	10.1	31.1	14.9	21.2	23.2	18.0
7. Biology	8.0	6.1	3.7	11.2	6.9	3.1	2.7	7.5	6.1	6.2	7.5	
8. Botany	3.3	6.5	8.8	6.5	8.0	6.3	1.9	17.1	4.4	7.7	10.9	
9. Zoology	4.7	4.3	7.0	2.3	4.6	6.3	5.5	6.5	4.4	7.3	4.8	
E. Sciences of the earth	11.3	9.6	7.4	6.6	5.6	7.1	8.2	14.1	12.3	13.2	5.4	9.2
10. Geodesy	2.3	.9	.4	1.9	—	.8	1.2	—	—	.8	.7	
11. Geography and Oceanography	3.3	1.3	1.8	1.9	1.1	1.6	1.2	1.9	3.5	3.1	2.0	
12. Geology, Mineralogy, Paleontology	5.2	6.1	3.7	.9	3.4	4.7	3.9	10.3	5.3	3.5	.7	
13. Meteorology, Climatology	.5	1.3	1.5	1.9	1.1	—	1.9	1.9	3.5	5.8	2.0	
F. Anthropological Sciences (physical)	12.2	10.4	8.5	8.4	12.6	17.2	12.9	6.6	12.3	10.8	13.6	11.1
14. Anatomy	6.1	7.4	5.9	4.2	9.2	10.9	9.4	4.7	7.0	7.3	6.1	
15. Physiology	6.1	3.0	2.6	4.2	3.4	6.3	3.5	1.9	5.3	3.5	7.5	
G. Anthropological Sciences (cultural)	—	1.3	.8	5.2	3.4	4.7	7.5	7.5	6.1	4.6	8.9	4.1
16. History and Archaeology	—	.4	.4	1.9	2.3	4.7	5.9	2.8	6.1	2.7	3.4	
17. Economics	—	—	—	3.3	—	—	—	—	—	—	—	
18. Philology	—	.9	.4	—	1.1	—	1.6	1.9	—	1.5	1.4	
19. Political Arithmetic	—	—	—	—	—	—	—	2.8	—	.4	4.1	
H. Medical Sciences	10.3	11.7	12.1	7.4	9.1	8.6	11.7	11.2	20.2	16.5	21.1	12.6
20. Pharmacy, Pharmacology	—	.4	2.9	.9	3.4	—	—	1.9	—	2.3	2.7	
21. Medicine	10.3	11.3	9.2	6.5	5.7	8.6	11.7	9.3	20.2	14.2	18.4	
I. Alia	6.6	5.2	4.4	3.7	3.4	2.3	2.7	4.7	10.5	6.2	10.2	5.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Analysi per Aequationes Numero Terminorum Infinitas, in turn sent to COLLINS, was the occasion of sufficient admiration to stimulate additional interest in this field. A decline from that point continues until the second cycle, of lesser proportions, reaches its peak in 1681-83. It was at this point that interest had been revived in JOHN PELL's *Idea of Mathematics* written for HARTLIB in 1639. The previous comments on this *Idea* by DESCARTES and MERSENNE were again brought to light as interest grew. Again, there is something of a declining interest in mathematics until the third cycle, finding its peak in 1694-96. This notable manifestation of interest was coincident with the publication of the complete mathematical works of JOHN WALLIS, one of the most original mathematicians of his day. The interest centered about the problems with which WALLIS was primarily concerned—the method of finding the areas of curves by the use of the infinite series (which constituted an appreciable approach to the calculus) and the fluxionary calculus. Though NEWTON had generally employed the principles of the calculus in the *Principia* (1687), its peculiar English notation did not appear until the publication of WALLIS' *Algebra* in 1693 (15). These events apparently evoked considerable interest as is manifested by the articles not only of WALLIS himself but those of CASWELL, HALLEY, ABRAHAM DEMOIVRE, and others, on quadrature problems and the like.

It would seem, then, that the short-time fluctuations of interest in mathematics are largely explicable in terms of the appearance of important contributions by individual mathematicians. That is, upon the publication of a work recognized as highly significant, not only is mathematical interest stimulated in general, but the foci of interest within the general field are partially determined by the nature of the problems which have been explained or brought to light.

The conclusion that the minor, short-time fluctuations in scientific interest are primarily determined by the internal history of the science in question is borne out by other facts. Thus, as we know from the explicit statement of the authors, a considerable number of works resulted from GILBERT's researches on

(15) *Cf.* FLORIAN CAJORI, *A History of Mathematics*, p. 208 ff.

magnetism (16). Likewise, HARVEY's achievements especially stimulated English scientists to engage in research in both anatomy and physiology (17). English anatomists, such as GLISSON and WHARTON, turned their attention to those organs concerned with the preparation and movement of the blood : the liver and the heart (18). The attention paid to these fields deflected interest from adjacent subjects. The shift of interest to physiology and microscopic anatomy led to a decline of interest in surgery (19). However, the contributions of a scientific genius may also have a contrary effect. The prestige accorded the work of NEWTON, for example, prevented most of his immediate successors from daring any advance upon his discoveries. Thus, in the field of hydrodynamics (even though, as LAGRANGE said, NEWTON's work was least satisfactory in this subject) no significant advance was made in England until the time of THOMAS YOUNG (20).

Though the *general types of problems* which confront the scientist and which in turn suggest a host of derivative problems may be suggested by extra-scientific factors—as we shall see later—it is the development of these derivative problems uncovered through continuous scientific study which for the most part accounts for the foci and shifts of attention in given sciences over

(16) *E.g.*, works by EDWARD WRIGHT, THOMAS BLUNDEVILLE, MARKE RIDLEY, WILLIAM BARLOWE, NATHANIEL CARPENTER, GEORGE HAKEWELL, HENRY GELLIBRAND, HENRY BOND, Sir KENELM DIGBY, and Sir THOMAS BROWNE. *Cf.* P. F. MOTTELAY, *Bibliographical History of Electricity and Magnetism* (London : CHARLES GRIFFIN & Co., 1922), *passim.*

(17) ERIK NORDENSKIÖLD, *The History of Biology*, p. 147; *cf.* J. L. PAGEL who observes : " Unmittelbar nach dieser Publikation [HARVEY's *De motu cordis*] und in direkter Folge derselben wurde nun die Lösung einer ganzen Reihe wichtiger physiologischer Fragen angebahnt, und die grossen Physiologen schossen wie Pilzen aus der Erde hervor, lediglich angeregt durch Harveys Entdeckung." *Einführung in die Geschichte der Medizin*, revised and adapted by KARL SUDHOFF (Berlin : S. KARGER, 1915), pp. 262-3.

(18) HEINRICH HAESER, *Lehrbuch der Geschichte der Medizin und der epidemischen Krankheiten*, 2 volumes (Jena, 1881), Vol. II, pp. 287-8.

(19) HAESER, *op. cit.*, Vol. II, p. 430; PAGEL, *op. cit.*, p. 289; EDWARD WITHINGTON, *Medical History* (London, 1894), p. 329; " The surgery of the seventeenth century is much less important than that which came before or after it, for the wonderful progress of physiology seems to have attracted the ablest minds to the study of medical problems..."

(20) CHRISTOPHER WORDSWORTH, *Scholae Academicae*, p. 66 ff.; WILLIAM WHEWELL, *History of the Inductive Sciences*, 2 volumes (New York, 1858), Vol. I, pp. 349-50.

relatively short periods of time. In a sense, then, the study of these short-time fluctuations would seem the province of the historian of science rather than that of the sociologist or student of culture.

This conclusion seems again warranted if we turn to the trends of interest in the physical sciences—astronomy, physics and chemistry—during the latter seventeenth century. There occurs a rather definite trend toward declining interest in this field from approximately 1684-87. Up to this turning point the physical sciences claim by far the greater part of scientific attention but the approach of the " Age of Enlightenment " with its predominant interest in man rather than matter seems heralded by the gradual decline of interest in this field. This decline seems even more marked if one contrasts it with the notable increase of interest in the cultural sciences—history, archaeology, economics, philology and political arithmetic—revealed by our indices of attention (21).

Though these general trends may in part be accounted for by social, non-scientific factors, the short-time fluctuations seem explicable primarily by reference to the internal history of each discipline. Thus, the work of BOYLE on hydrostatics; of HOOKE and more notably, of NEWTON, HUYGHENS, WREN, and HALLEY in virtually every field of physics, sustained continued interest in physics. But it is outside the province of this study to attempt any systematic presentation of the history of the various sciences during this period.

Setting of a Problem

The data here presented purport to indicate the various trends in scientific interests during this period, to provide a factual background for subsequent discussion. Since this is the major purpose of this chapter, it might be well to summarize these movements briefly. In mathematics, as we have seen, there are three short-time cycles. In the physical sciences there is a more

(21) Partial corroboration of this trend is furnished by DAVID OGG who notes the increased popular interest in history beginning with the late seventies. *Cf.* his *England in the Reign of Charles II*, Vol. II, pp. 714-15.

or less continuously sustained high degree of interest until 1684-87, when a decline sets in. IRVINE MASSON, the historian of chemistry, notes a relapse in chemical investigation after BOYLE's death (22); a trend which is likewise reflected in our data. The biological sciences—natural history, botany and zoology—maintain an approximately constant share of scientific attention save for a small increase in 1691-93.

The sciences of the earth—geodesy, geography, and oceanography, geology, mineralogy, paleontology, meteorology, and climatology, to use the modern terminology—show no marked changes. In view of the approximative nature of the indices of attention here presented, the slight changes in these indicia do not warrant postulating any marked shifts in interest. The physical anthropological sciences—anatomy and physiology—show a very slight decrease from 1665 to 1676, followed by a more marked increase to 1683, followed by another small cycle. The cultural anthropological sciences—history, archaeology, economics, philology and political arithmetic—show an almost continuous increase, from 1668 to 1702. Finally the medical sciences —pharmacy, pharmacology and medicine—also show an increase during the period from 1665 to 1702.

It must be considered that the trends of the sciences grouped under each of these seven headings do not show a perfect correlation. This may be seen by a study of the tables which include the figures for these separate sciences. However, the trends are sufficiently alike for our purposes which do not demand an intensive study of minor fluctuations. A most suggestive summary of the trends is afforded by grouping the sciences into two general categories : those dealing with inorganic nature, and those dealing with organic nature. In the first group fall the formal and physical sciences; in the latter, the biological, the physical anthropological and medical sciences. Sciences of the earth are omitted since they imply a knowledge of both organic and inorganic nature. Likewise the cultural sciences are not included. The following table clearly indicates the changing emphasis on the two types of sciences : interest in the inorganic

(22) IRVINE MASSON, *Three Centuries of Chemistry* (London : E. BENN, 1925), p. 100.

remains consistently higher than in the organic until the late eighties, when there is an increasingly pronounced shift to interest in the latter group of sciences.

TABLE 7

Shifts of Attention Between Groups of Sciences (23)

Years	Physical and Formal Sciences (B + C) Index of Attention	Sciences of Organic Life (D + F + H) Index of Attention
1665-67	42.7	38.5
1668-70	42.7	39.0
1671-73	45.4	40.1
1674-76	47.6	35.8
1677-78	44.6	41.2
1681-83	44.6	41.5
1684-87	46.3	34.7
1691-93	28.9	48.9
1694-96	23.8	47.4
1697-99	27.7	48.5
1700-02	17.7	57.9

It may be suggested that these trends represent only a changing policy of the editors of the *Transactions* rather than any actual changes in the foci of scientific interests. This is of course possible but several considerations lead us to doubt it. First, the editors of the *Transactions* were prominent members of the Royal Society who were in constant direct contact with the immediate scientific interests of the leading scientists. Hence they would be inclined to publish articles corresponding to the interests of the readers. Secondly, the articles were contributed by the leading investigators of the time and hence, in the very nature of the case, would reflect their interests. And finally, the reliability of the data is attested by the almost identical picture derived from independent sources.

(23) The letters B, C, etc. refer to the categories in the preceding tables. The figures are percentages of the total number of articles published in the *Transactions*. The necessity for exercising care in the interpretation of these figures because of the relative base is apparent.

The significance of these trends will be discussed in some detail subsequently. To complete the presentation of these data of shifts of interest, it is necessary to introduce further evidence concerning the reliability of these data. This is afforded by a comparison of the material derived from DARMSTÄDTER's *Handbuch* and from the *Philosophical Transactions*.

This comparison must be restricted to the rank order of the various groups of sciences since the DARMSTÄDTER material does not include a sufficient number of English discoveries for this period to warrant either comparison by specific sciences or by yearly periods. However, since it is the reliability of the generalized picture of shifts of scientific interests which is in question, these restrictions are not of particular consequence. The tabular comparison follows (24) :

TABLE 8

Relative Interest in the Various Sciences, England, 1665-1702

	Darmstädter			Philosophical Transactions		
	Absolute Number	Per Cent	Rank Order	Absolute Number	Per Cent	Rank Order
Formal Sciences....	5	5.2	6	101	5.4	6
Physical Sciences ...	54	55.6	1	686	37.6	1
Biologic Sciences ...	13	13.4	2	366	20.0	2
Sciences of Earth...	6	6.2	5	186	10.2	5
Anthropological Sciences.........	10	10.3	3	226	12.4	4
Medical Sciences ...	9	9.3	4	257	14.4	3
Total	97	100.0		1822	100.0	

The marked agreement between indices derived from two

(24) In the tabulation of the *Philosophical Transactions*, the philosophy category (17 items), the cultural anthropological category (84 items) and the *alia* category (107 items) are omitted, since there are no comparable items in the DARMSTÄDTER compilation. This reduces the *Transactions* total from 2030 to 1822 items. The items mentioned in DARMSTÄDTER's compilation refer, of course, only to the period 1665-1702, in order that an adequate comparison may be effected.

totally independent sources argues well for the essential reliability of these data. The correlation in rank order is very high, virtually perfect. The one instance where there is some variation represents but a slight difference in percentage. Moreover, a competent observer of scientific development during this period ranks the sciences in approximately the same order. " The greatest progress was evinced in physics, astronomy, medicine and mathematics...; considerable progress was shown in botany, zoölogy, and chemistry; least in geology and paleontology." (25)

To be sure the DARMSTÄDTER data, since they include so few cases, cannot be used to verify the *trends* obtained from the *Transactions* compilation. But with the establishment of the reliability of the rank order of the sciences, it seems a reasonable assumption that the trend data are not misleading. These trends are ascertainable only through such indirect means as have been here employed and in view of the substantiation afforded by a variety of sources it seems justifiable to conclude that the indices are approximately accurate.

It is misleading to assume that these foci of scientific interest are exclusively due to the intrinsic developments within the various sciences. It was RICKERT and MAX WEBER who most forcefully indicated the phenomenon of *Wertbeziehung* in scientific activity, the fact that scientists commonly select for treatment problems which are vitally linked with the dominant values and interests of the day (26). Much of our study will, in fact, be devoted to the isolation of some of the extra-scientific elements which strongly influenced, if they did not determine, the centering of scientific attention upon certain fields of investigation.

(25) MARTHA ORNSTEIN, *The Rôle of Scientific Societies*, p. 19.

(26) *Cf.* the discussion by ALEXANDER VON SCHELTING, *Max Webers Wissenschaftslehre* (Tübingen : J. C. B. Mohr, 1934), esp. pp. 235 ff.

CHAPTER IV

PURITANISM AND CULTURAL VALUES

From the middle of the seventeenth century, science and technology claimed an increasing meed of attention. No longer an errant movement finding faltering expression in occasional discoveries, science had become accredited and organized. To this, the establishment of the Royal Society bears some witness. But all this was no spontaneous generation. It had its antecedents rooted deep in the culture which fathered it and assured its further growth; it was the child of a long period of cultural incubation. And if we are to find the specific sources of this newly expressed vitality of science, of this new-won prestige, they must be sought among these cultural values. If it be true that science, just as any other activity, attracts followers to its ranks to the extent that it is regarded with favor by society, then the marked increase in the number of scientists which occurred during the seventeenth century is a symptom of the changing temper of the time.

The Sociological Approach

Religion is one expression of cultural values—and in the seventeenth century a clearly dominating expression. In view of this, the commonly accepted and even more widely discussed thesis that science and religion have always been at odds is not unrelated to our inquiry. In the nineteenth century, bold intellectuals berated religious opposition and saw in the outcome of this conflict the triumph of reason over superstition, whereas pacific mediators sought to establish an essential harmony between science and religion. Neither of these was a properly sociological point of view. The sociologist is not a Defender of the Faith, religious or scientific. When he has uncovered the sentiments crystallized in religious values and the cultural orientation which governs their expression, when he has determined the extent to which this led men toward or away from scientific pursuits or perhaps influenced them not at all, then his task is, in its initial outlines, complete.

Puritanism, evoking and shaping the sentiments which pervaded every phase of human action in this period, was the religious movement which notably incorporated dominant cultural values. As such, it provided a measuring rod for the worth of various social activities. What, then, were its relations to science? Did Puritanism, as so often we are told, involve that sort of fervid fanaticism which brooks nothing but its own religious goals? And, if so, what of the cultural implications of such an attitude? What were the consequences for the new science of the powerful motivations which derived from Puritanism? In short, we are concerned with the complex modes of interaction between a religious ethic and science, not as these appear to apologists of the two camps, but as they occurred in the course of actual social development.

To this end, we must probe under the surface of theological contentions to the sentiments which give them meaning. The religious component of thought, belief and action becomes effective only when it is reinforced by strong sentiments which lend meaning to certain forms of conduct. These sentiments find expression in word and deed alike. Words are full of equivocation and doubtless we shall find many pious utterances which are more significant for what they leave unsaid than for what they say. We are concerned with verbal responses, religious exhortations and appeals, in so far as they enable us to arrive at the motivating sentiments which give rise to these ideas and the behavior associated with them. And, as we shall see, behavior in its turn reacts upon the sentiments, re-enforcing, moulding, at times altering them so that the whole process is one of incessant interaction.

The Protestant Ethic

Though the diversity of theological doctrines among the Protestant groups of seventeenth century England is evident

—in 1650, THOMAS EDWARDS enumerated 180 sects—there was a core of common values which was accepted by all (1). Sectarian differences were largely confined to matters of church ceremony and ecclesiastical organization as well as to esoteric theology (2); but all this did not materially influence the religious ethos. Anglicans, Calvinists, Presbyterians, Independents, Anabaptists, Quakers, and Millenarians—bickering and quarreling amongst themselves as they did—nevertheless subscribed to a substantially identical nucleus of religious and ethical convictions. This common attitude of mind and mode of life may be denominated by that " word of many shades," Puritanism. Nor need we be alarmed because this usage does not coincide with the original sense of the term as referring to the reform of the Church of England in a Presbyterian manner since our interest is primarily directed toward the social and not the ecclesiastic implications of Protestantism.

Calvinism spread its roots in all the Protestant sects of the time. Though Mr. TAWNEY notes that " Calvinist theology was accepted where Calvinist discipline was repudiated," (3) the converse may likewise be maintained. It is precisely Calvinism which constitutes the " ideal type " of that Puritanism which was confined to no single sect and which was represented in the Anglican Church almost as fully as in those groups which later broke away from it. (4) Differences in theological minutiae were brought to convergence in the actual social ethic. If later Presbyterianism differed from Calvinist Precisianism by declaring that man is justified by good works as well as by faith, it none the less led to a sanction of persistent, hard labor as a means of salvation, while the latter exacted the same sort of behavior as establishing the *conviction* of a state of grace.

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(1) G. N. CLARK, *The Seventeenth Century*, p. 317.

(2) JOHN TULLOCH, *English Puritanism and Its Leaders* (Edinburgh and London : WILLIAM BLACKWOOD, 1861), pp. 4 ff. This had been long since noted by GEORGE BERKELEY in his brochure, *Historical Applications and Occasional Meditations upon Several Subjects* (London, 1670, 2d ed.), pp. 101-2.

(3) R. H. TAWNEY, *Religion and the Rise of Capitalism* (New York : HARCOURT, BRACE & Co., 1926), p. 112.

(4) *Ibid.*, p. 198. *Cf.* H.H. HENSON, *Studies in English Religion in the Seventeenth Century* (London : J. MURRAY, 1903), p. 188. " It is very noteworthy that there is no essential divergence either of principle or method between Puritans and Anglicans on the subject of *moral* theology." [italics present writer's.]

The conception of "meritory works" was of course also current in the Middle Ages, but—especially in the early part of that epoch—its meaning was radically different from that of the Protestant precept (5). Monastic limitations and an other-worldly orientation (in a quite different sense from that of the Calvinists) were insuperable barriers to the utilization of the concept in active, worldly service. For both medieval Catholicism and Calvinism, this world was evil, but, whereas the prescribed solution for the one was retirement from the world into the spiritual calm of the monastery, it was incumbent on the other to conquer the temptations of this world by *remaking it* through ceaseless, unflinching toil. The sentiments with which the various Puritan sects were imbued, despite different rationalizations and theological views, led to approximately identical implications for social conduct.

Perhaps the one major Protestant variation from the Puritan ethos is afforded by Lutheranism, with its precepts of justification by faith only and its emphasis on penitent grief, but since this sect had no appreciable influence on English life, this divergence is of no importance. Again, there must be no confusion between CALVIN's own teachings and those of the subsequent Calvinist-Puritan movement (6), particularly in England, for the latter

(5) The importance of primarily considering the social meaning (*i.e.* definition) and correlated sentiments rather than the rationalized version of religious precepts is deftly summarized by FRIEDELL. "Protestantism denies justification by works and puts repentance in the heart, in mere faith, and yet at the same time it demands a practical, active Christianity and thus again comes back to a sort of sanctity of works, ... it sanctifies even *profane* works, thus achieving the last degree of sanctimoniousness. Catholicism accepts justification by works, but means by the latter only performances of a minor sort, and thus it arrives at apotheosizing the unworldly and other-worldly life, which is concentrated on inner penitence and meditation, and which knows nothing of profane works in the ordinary sense. Thus, starting from opposite standpoints, each ends in the contrary view from that with which it began : Protestantism, opposed to works, ends in a glorification of the most worldly tasks, the state, the magistrates, the family, manual work, *science*, even war; the more worldly Catholicism rises to complete contempt for all these things..." EGON FRIEDELL, *A Cultural History of the Modern Age* (New York : A. A. KNOPF, 1930-31), Vol. I, p. 259.

(6) One of the basic results of this study is the fact that the most significant influence of Puritanism upon science was largely *unintended* by the Puritan leaders. That CALVIN himself deprecated science only enhances the paradox that from him stemmed a vigorous movement which furthered interest in this very field.

represents a marked development of the Great Reformer's conceptions, rather than a rigid maintenance of them. As we shall see, the mode of life which bore the imprint of Calvinism was not so much adherence to the logical implications of a system of theology as domination by a particular group of sentiments. The values implicit in these doctrines which struck the deepest roots in English life were those congenial to tendencies developing independently in other compartments of culture, and, in this way, Puritanism was integrated with many cultural trends which were in their incipiency. A number of studies have shown that the Protestant ethos exerted a stimulative effect upon capitalism (7). Since science and technology play such dominant rôles in modern capitalistic culture, it is possible that tangible relationship likewise exist between the development of science and Puritanism (8). Indeed MAX WEBER incidentally notes the possibility of such a connection (9).

The dominant Puritan teachings of the time may best be culled, not from esoteric theological treatises which had no direct

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(7) MAX WEBER, *The Protestant Ethic and the Spirit of Capitalism*, trans. by T. PARSONS, (New York : CHARLES SCRIBNER'S Sons, 1930); ERNST TROELTSCH, *The Social Teachings of the Christian Churches*, trans. by OLIVE WYON (New York : MACMILLAN, 1931), 2 volumes; W. CUNNINGHAM, *Christianity and Economic Science* (London : J. MURRAY, 1911); TAWNEY, *op. cit.;* H. LEVY, *Die Grundlagen des ökonomischen Liberalismus in der Geschichte der englischen Volkwirtschaft* (Jena, 1912). A striking adumbration of the theories presented in these works appears in a book by JOHN WILKINS, one of the virtuosi of the seventeenth century, who was also a leading spirit in the group which formed the Royal Society. In his work, *On the Principles and Duties of Natural Religion*, interrupted by his death in 1672, he asserts that " Religion is a *natural* Cause of Riches," and proceeds to demonstrate this fact by isolating those Protestant teachings which sanction behavior inevitably conducing to the accumulation of capital. It should be noted that his explanation is a " naturalistic " one and not the familiar argument that the hand of Providence aids the virtuous, simply because of their religiosity.

(8) Since the completion of this study have appeared several papers and books by DEAN DOROTHY STIMSON, OLIVE GRIFFITHS and R. F. JONES which trace, with varying degrees of detail, a positive connection between Puritanism and science. These mateiials will be considered in a later chapter. See also ROBERT K. MERTON, " Puritanism, Pietism and Science," *The Sociological Review*. Vol. XXVIII (1936), pp. 1-30.

(9) *Op. cit.*, p. 249. But WEBER goes onto say : " Auf die Bedeutung [des Puritanismus] für die Entwicklung der Technik und der empirischen Wissenschaften kommen wir nicht zu sprechen." *Cf.* his *Religionssoziologie* (Tübingen : J. C. B. MOHR, 1920), Vol. I, p. 188 n.

influence upon the social life of the period, but from the compilations of *casus conscientiae*, sermons, and similar exhortations directed primarily toward the actual behavior of individuals. This procedure is based upon the assumption that these are expressions of the sentiments and values which permeated the thought and action of believers. Moreover, it is probable that sermons not only reflected but also reinforced the dominant sentiments of the day (10). If, as has been repeatedly noted, "RICHARD BAXTER is the most representative Puritan in history," (11) we may expect to find in his *Christian Directory* (12), that popular " Body of Practical Divinity and Cases of Conscience," a typical presentation of the leading elements in the Puritan ethos. In this way it is possible to arrive at an understanding of the values and sentiments which lent meaning to certain of the activities, among them science and technology, of seventeenth century man. Recourse to the writings of other spiritual leaders of that day will help us to determine the extent to which this compendium of Protestant ethics and convictions is typical.

" *Glorification of God* "

One formula which, largely meaningless though it be to the emancipated individual of today, became the focus of strong sentiments among Puritans is " the glorification of God " as the end and all of existence (13). Familiar to Christian ears

(10) Analogous assumptions are involved in the works of such anthropologists as RADCLIFFE-BROWN and MALINOWSKI and the sociological writings of DURKHEIM and PARETO, among others.

(11) JOHN S. FLYNN, *The Influence of Puritanism on the Political and Religious Thought of the English* (New York : DUTTON, 1920), p. 138. *Cf.* TULLOCH, *op. cit.*, p. 377, who writes : " Certainly, of all the men who express and represent the spiritual thought of the Puritan age, none does so more completely... than RICHARD BAXTER." *Cf.* also WEBER, *op. cit.*, p. 156.

(12) The edition used here was published in five volumes, London, 1825. The compendium was written in 1664-65. This work will be cited as *C. D.*

(13) " God must be the ultimate end of your religion : it must be intended to please and glorify him. God must be the continual motive and reason of your religion; and of all you do..." *C. D.*, Vol. I, pp. 165-6; *cf.* also, Vol. II, pp. 181, 239 ff. *Cf.* commentary of TROELTSCH, *op. cit.*, Vol. II, p. 588. Foremost in the Westminster Catechism (1648) was the query : " What is the chief and

as this was—medieval Catholicism knew the phrase well—it was now clothed with new meanings and a new emphasis. God must be glorified but institutional controls canalized this glorification in particular directions, with a variety of social effects. Since a wide variety of behavior, all of which is not equally desirable, may presumably be oriented toward the attainment of this goal, BAXTER proceeds upon a further definition of the most appropriate means. It is in the definition of these and other leading tenets of Protestantism rather than in the sheer phraseology (which resembles Catholicism in many respects) that the real significance of these teachings is found.

One of these directions was eminently practical. For those whom the new faith provided strong motivations was urged the subordinate, though highly important, aim of usefulness to one's fellow-men, of utility to society; for " Though God need none of our good works, yet that which is good materially pleaseth Him, as it tendeth to His glory, and to our own and others' benefit, which He delighteth in." (14) Nor need we halt here. The idea is carried to its extreme and we are told that " public service is God's greatest service." (15) Thus, a social utilitarianism, having been established as one of the leading criteria of acceptable, even praiseworthy, behavior inasmuch as it is a most effective means of glorifying God—the basic and ultimate end—is imbued with a power of its own. Various activities were built up around this and other tenets of a religious system which, at the time, carried with it all the force of deep-rooted, hardly questioned convictions. In fact, since the utilitarian principle lent itself to a ready concrete application, it came to be the guiding tenet in actual practice. It is this *definition* (16) of the precept

highest end of man?—To glorify God, and fully to enjoy him for ever." This is a concrete example of the exhortation of what WEBER has called " wertrational " action, i.e., " durch bewussten Glauben an den—ethischen, ästhetischen, religiösen oder wie immer zu deutenden—unbedingten Eigenwert eines bestimmten Sichverhaltens rein als solchen und unabhängig von Erfolg." *Wirtschaft und Gesellschaft* (Tübingen : MOHR, 1922), pp. 12 ff.

(14) *C. D.*, Vol. I, p. 322.

(15) *C. D.*, Vol. I, p. 456.

(16) The motivation for this " definition " will become more apparent as other features of this religious system are considered.

in basically *utilitarian* terms which allied Protestantism with the rest of the associated culture.

A further fundamental doctrine, peculiar, however, to the Calvinist sects, is that of predestination : God grants salvation to some purely of His own free will, irrespective of the faults or virtues of the elect. We need only realize the Puritan's profound anxiety concerning his spiritual grace to appreciate the desperate insistence with which he propounded the immediate question : how am I to know that I am among the elect? The Church could provide no assurance. Yet an answer was psychologically imperative; to continue the routine of daily life in the face of such uncertainty was simply unthinkable. An answer was demanded and soon came forth. Since the time of BEZA, it held that election is proved by " good works " which are outward signs of an inward state of grace (17). Here again, the essential difference between Catholicism and Puritanism is in the definition of a nominally similar conception. " Good works " in the Protestantism of this time is basically a term to refer to achievements which are useful and profitable in a worldly sense; at first blush, it would appear to be sheer utilitarianism. Good works now demanded participation in mundane affairs, not withdrawal from them through flight to the monastery.

Thus, by satisfying the drive for the conviction of one's election, *certitudo salutis*, the Calvinist doctrine of predestination escapes any drift toward an apathetic pessimism (18). Those sects which did not accept the notion of predestination, arrived at a conclusion which in its practical consequences is identical with those of the Calvinists, since for them " good works," still understood in

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(17) TROELTSCH, *op. cit.*, Vol. II, p. 590.

(18) ROLAND G. USHER, in his generally excellent study, *The Reconstruction of the English Church* (New York and London : APPLETON, 1910), 2 volumes, provides a careful summary of Puritan theology, but errs in his analysis of the *practical consequences* of Puritan beliefs, as is evidenced by the following " ... for his future bliss, the Puritan needed but faith in Christ : he could by his human ' works ' accomplish nothing : and he felt that such attempts were an insult to God and to His eternal grace." " Such a theology made man despondent morbid, morose, introspective." Vol. I, 78-79. As a matter of fact, as we shall have occasion to see, the doctrine of predestination with its Puritan corrollary of conviction of grace through successful labor obviated the feeling of individual helplessness and afforded a sense of transcendent power to the individual who felt that he was one of the elect.

the sense of worldly accomplishment, are equally necessary, but in this instance to *reach* a state of grace. Thus, we find abundant confirmation of MAX WEBER's dictum that " similar ethical maxims may be correlated with very different dogmatic foundations." (19) This likewise corroborates the contention that there is substantial uniformity in the *social* implications of the various Protestant dogmas.

Diligence and Industry

On these diverse theological bases—predestination and justification through good works—is erected the structure of an additional doctrine governing behavior : diligence in one's calling becomes a necessity (20). This principle merges into its consequences, for since systematic, methodic, and constant labor enables the attainment of success in one's profession—which is the hallmark of salvation—such achievement itself becomes a worthwhile goal.

The demand for constancy in labor is justified by all the fundamental Puritan doctrines which carry with them the absolute character of a closed system of integrated sentiments and beliefs. In the first place, it is a means of glorifying God (21), for " it is God that calleth thee to labour." Again, it is a means of aiding the public weal (22). Thirdly, diligence in our labors necessarily entails less leisure and liberty for succumbing to the multifarious temptations, odious to the sight of God, which beset us. Time must be spent solely in the way of duty and not an hour must

(19) *Protestant Ethic*, p. 97.

(20) " Be diligent in your callings, and spend no time in idleness, and perform your labours with holy minds, to the glory of God..." *C. D.*, Vol. II, pp. 196-97.

(21) *C. D.*, Vol. II, pp. 122-24. *Cf.* TAWNEY, *op. cit.*, p. 240.

(22) " The public welfare, or the good of the many, is to be valued above your own. Every man therefore is bound to do all the good he can to others, especially for the church and commonwealth. And this is not done by idleness, but by labour ! As the bees labour to replenish their hive, so man being a sociable creature, must labour for the good of the society which he belongs to, in which his own is contained as a part." *C. D.*, Vol. II, p. 580. Here is to be noted again the shift from a dominant emphasis on the glorification of God to a stress on utilitarianism.

be misspent (23), in excess of sleep or of play, for this is the sign of the fleshpleaser. Not stinting variations in the bases of appeal, the Puritan emphasis upon reason as a praiseworthy faculty is called into play. Labour is necessary for the preservation of the faculties of the mind (24).

These attitudes obviously do not at all imply monastic asceticism, *ausserweltliche Askese*, " far from the madding crowd's ignoble strife," but rather an intramundane asceticism, *innerweltliche Askese* (25). The Puritan ethic, couched in vivid, insistent terms which brooked no dispute, demanded participation in the affairs of this world. Thus, BAXTER raises the hypothetical question : " Must every man do his best to cast off all worldly and external labours, and to retire himself to a contemplative life as the most excellent ? " His answer is categorical :

> No : no man should do so without a special necessity or call : for there are general precepts on all that are able, that we live to the benefit of others, and prefer the common good, and as we have opportunity do good to all men... (26)

Once again there is the tendency to have the utilitarian criterion supersede that of the glorification of God, a transition which is even more marked in subsequent passages from BAXTER (27).

(23) *C. D.*, Vol. I, p. 334; Vol. II, Chap. IV.

(24) *C. D.*, Vol. II, p. 581. This rationalization possibly reflects the increasing esteem in which certain intellectual pursuits were coming to be held.

(25) The most lucid exposition of this point is by MAX WEBER, *op. cit.*, especially chapter IV. *Cf.* also TROELTSCH, *op. cit.*, Vol. II, p. 604 ff; TAWNEY, *op. cit.*, p. 240 *et passim*; MARGARET JAMES, *Social Problems and Social Policy during the Puritan Revolution* (London : ROUTLEDGE & Sons, 1930), p. 17, which is an excellently detailed study. *Cf.* CHRISTOPHER LOVE, *The Combat between Flesh and Spirit* (London, 1654), p. 52. " God never did so order Religion that it should be a disadvantage to our particular callings in the world."

(26) *C. D.*, Vol. II, p. 212. The extreme statement of this Puritan rationalization of secular and utilitarian activity is found in SPRAT's *Sermons*. He states : " ... so far is the True Religion from obliging all its Professors, either to withdraw wholly out of the World, or in Conscience to avoid all the usual Observances, and Manners, or even the innocent Delights of it, whilst they are in the World; that perhaps none are more capable of bringing more *Benefit to Mankind*, so of doing more Service to God, or exercising more Evangelical Graces, than those Men, that are of the most practical Lives, and engag'd in most secular Business." THOMAS SPRAT, *Sermons on Several Occasions*, pp. 18-19.

(27) *E. g.*, *C. D.*, Vol. II, pp. 244-5. " The work of a magistrate, a lawyer, a physician, and such like, is principally in doing good in their several callings which must not be neglected for contemplation. Some persons in the same

Choice of Vocation

Since the necessity for zeal in a calling has been admirably justified by reference to unquestionable fundamental Puritan dogmas, BAXTER goes on to rank the occupations in order of desirability. They are not equally efficient means of attaining the prescribed goals nor is every individual capable of pursuing those vocations which are most desirable. The general principles to be followed in the selection of a calling of course revert to the original premises : choose that employment in which you may be most serviceable to God (28) and that which most contributes to the common weal (29); " and, (' *caeteris paribus* ') that calling which most conduceth to the public good is to be preferred." (30) The callings, in order of desirability, are the learned professions —though only those who have had a " special call " should enter the ministry—agriculture, trade and the crafts (31). The pre-eminence of the learned vocation is congruent with the high esteem in which education is held by the Puritan.

These, then, constitute the fundamental elements of the Puritan ethos which together defined the acceptable " way of life." It is vital to an understanding of this world-view that we do not under-estimate the tremendous control that was then exercised

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calling, whose callings are not so urgent upon them, by any necessities of themselves or others, and who may have more vacant time, must gladly take it for the good of their souls, in the use of contemplation and other holy duties. And others that under greater necessities, urgencies, obligations, cannot be spared from the service of others, (as physicians, lawyers, etc.) must be less in contemplation and prefer the greatest good." This dictum quite clearly illustrates the transition; utilitarianism is not to be sacrificed to religious contemplation in any concrete case. The significance of this for the contemporary evaluation of science will be indicated later.

(28) *C. D.*, Vol. I, p. 332.

(29) *C. D.*, Vol. III, p. 186.

(30) *C. D.*, Vol. II, p. 584. This virtually completes the shift to a dominant emphasis on utilitarianism.

(31) *C. D.*, Vol. II, p. 584. This conception provides a definite basis for individuals to turn to the learned professions, other than the ministry, even though this latter is the most desirable calling. That this precept exercised some influence will be seen very definitely in at least two outstanding instances, those of ROBERT BOYLE and of Sir SAMUEL MORLAND. It is doctrines of this sort which much later emerge as definitely subversive of formal religion and which make for secularization.

by religion over the Puritan mind. We would certainly be led to profound error were we to assume that religious beliefs played the perfunctory rôle which is generally their lot today. No doubt, then as now, particular individuals had broken away from the strong hold of religious authority, but in the main, Puritanism was a powerful social force which was not readily gainsaid.

Blessed Reason

Closely related to the foregoing doctrines was another class of beliefs which pertains more directly to the social evaluation of science and technology. First among these is the tendency to laud the faculty of reason (32). The nominal basis for this attitude is manifold. Reason is praiseworthy because man, chosen of God, alone possesses it; it serves to differentiate him from the beasts of the field (33). Further, it is an admirable function since it serves to curb and restrain the appetite which provokes the " master sin," sensuality, fleshpleasing or voluptuousness (34); it limits any pernicious tendency toward idolatry.

The rôle of reason as a device for controlling idolatry of the flesh is sufficient to endear it to the Puritan heart, but it possesses still another exemplary characteristic; it enables man more fully to glorify God by aiding him to appreciate His works (35). Through the previously noted tendency toward relating the various elements of this religious system by a series of judgments and endowing each of these elements with the sentiments centered about the system as a whole, Reason takes on an exacting authority. Hence

(32) Thus, even ROBERT BARCLAY, the leading apologist of the Quakers, the most mystical of the major seventeenth century Protestant sects, exclaims : " [I do not] at all despise reason, that noble and excellent faculty of the mind, because wicked men have abused the name of [it] ..." *An Apology for the True Christian Divinity* (Philadelphia, 1805), p. 76; also p. 159. [This work was originally written in 1675.] The preponderant place of rationalism in the more orthodox Puritan sects has been established by WEBER, *Protestant Ethic*, p. 224, *et passim*.

(33) *C. D.*, Vol. II, p. 109. It is significant that this idea was specifically used as a basis for the justification of scientific study. *Viz. infra*.

(34) *C. D.*, Vol. II, p. 95 ff.

(35) For a detailed discussion of this point, *viz. infra*.

it becomes imperative for them who would rationalize these doctrines to " prove " that *reason* and *faith*—two such highly exalted virtues of the Puritan—are not inconsistent. It is in this vein that BAXTER maintains :

Though some deluded men may tell you, that faith and reason are such enemies, that they exclude each other as to the same object, and that the less reason you have to prove the truth of the things believed, the stronger and more laudable is your faith; yet, when it cometh to the trial, you will find, that faith is no unreasonable thing; and that God requireth you to believe no more, than is your perception of the reasons why you should believe : that God doth suppose reason, when he infused faith, and useth reason in the use of faith. They that believe, and know not why, or know no sufficient reason to warrant their faith, do take a fancy, or opinion, or a dream for faith (36).

This exaltation of reason and derogation of " enthusiasm " —in the original etymological sense of the term—is characteristic of the rationalistic aspect of the Puritan teachings (37). The Scriptures were not intended instead of reason or any of the sciences (38), since these latter may be independent, efficacious means for glorifying God. Anticipating, we may say that the elevation of an empirico-rationalism to such a lofty plane that it is admitted—at times by theologians themselves !—to be a

(36) *C. D.*, Vol. I, p. 171.

(37) Rationalism is here not used in its customary philosophical sense as the theory that reason is a source of knowledge in itself, superior to and independent of sense perceptions, *i.e.*, as opposed to empiricism; nor entirely in the theological sense as the doctrine which holds that religious opinions should be based on reason rather than on revelation, though it does include this latter meaning as a specific case. (Thus, BAXTER holds : " The Holy Spirit, by immediate inspiration, revealed to the apostles the doctrines of Christ, and caused them infallibly to indite the Scriptures. *But this is not the way of ordinary illumination now.*" *C. D.*, Vol. I, p. 104. And again : " Though your religion must not be taken upon trust, there are many controverted smaller opinions that you must take on trust, until you are capable of discerning them in their proper evidence." *C. D.*, Vol. I, p. 100). It means rather reasonableness, conformity to *reason and experience ;* it is a combination of rationalism and empiricism, as is quite evident from Puritan writings. This attitude of empirico-rationalism is of moment, as shall be indicated, for the relation between Protestantism and science.

(38) *C. D.*, Vol. I, p. 11. Reason is accorded a carefully circumscribed place. God is " irrational " in the sense that He cannot be measured by human reason. Rather, reason is one of the tools to be used in our tasks in this world. The intellect is to be used to aid action, the ultimate purpose of which is beyond our grasp. *Cf.* TROELTSCH, *Social Teachings*, Vol. I, p. 585.

justifiable criterion of the validity of various religious beliefs introduced the opening wedge for later processes of secularization (39). It may also be suggested that the emphasis upon reason—in the sense in which the term is used here—is no less related to the beginnings of biblical criticism (40) than to rationalization in industry and in science. Had the seventeenth century Puritan foreseen some of the consequences of his espousal of reason, he would have punctuated his repudiation of it with pious shudders.

Profitable Education

Allied with this emphasis on rationalism is the widely recognized interest of the Puritan in education. " Education and converse [conversation] have so great a power on the mind that they come next to grace, and are often the means of it." (41) But this education must be directed in specific channels; certainly not in literature or art or other similar " unprofitable studies " which are simply time-wasting self-indulgences (42).

(39) HENRY MORE, in his *Brief Discourse of the True Grounds of the Certainty of Faith in Point of Religion* (London, 1688), pp. 578-80, reflects this tendency. " ... to take away all the certainty of sense rightly circumstantiated, is to take away all the certainty of belief in the main points of our religion." " ... no revelation is from God that is repugnant to sense rightly circumstantiated."

(40) Cf. ÉMILE BRÉHIER, " The Formation of our History of Philosophy," pp. 159 ff. in *Philosophy and History*, ed. by R. KLIBANSKY and J. H. PATON, (Oxford : Clarendon Press, 1936).

(41) *C. D.*, Vol. I, p. 86. The attitude of the Quakers is quite the same as remarked by J. S. FLYNN, *op. cit.*, p. 159. " ... the whole Society [of Friends] placed the cultivation of the intellect next to the knowledge of God." See also BARCLAY, *op. cit.*, p. 323. BAXTER amiably announces that " it is a very good work to set up free-schools in populous and in ignorant places, especially in Wales [!]; that all may be taught to read, and some may be prepared for the Universities." *C. D.*, Vol. V, p. 481.

(42) *C. D.*, Vol. I, p. 150 ff; Vol. II, p. 167; Vol. III, p. 202; Vol. IV, p. 484. *Cf.* BAXTER's *Book of Self-Denial*, *passim*. This hostile attitude toward certain types of literature did actually result in Puritans largely eschewing this field save as it was related to expressions of Puritan sentiments. *Cf.* FRANS DIRK DE SOET, *Puritan and Royalist Literature in the Seventeenth Century* (Delft : J. WALTMAN, 1933), Introduction. HERBERT SCHÖFFLER remarks, in connection with this antipathy, that there was not a single Quaker poet of significance until ate in the Enlightenment. *Cf.* his *Protestantismus und Literatur*.

Flights of fancy could scarcely be condoned unless they carried moral implications. The cleric ALEXANDER HOME warned youth against the reading of " profane sonnets and vain ballads of love, the fabulous feats of PALMERINE and such like reveries." This attitude is correlated with the decline of interest in certain of the arts which was noted in Chapter II.

Nor is the pursuit of the scholastic philosophy approvable, for it is full of false teachings which seem to lead away from God rather than toward Him (43). Especially pernicious is this pseudo-Aristotelian philosophy because it induces error and confusion which is verisimilar by virtue of the rigorous syllogistic reasoning employed. But starting frequently from false premises it must needs come to false conclusions. Hence, in outlining a course of study for one who intends the ministry, BAXTER deliberately refrains from including any such philosophy (44). This careful direction of intellectual interests into definite fields and away from others is of moment when one considers the contemporary power of such religiously-founded attitudes. Having eliminated certain studies as inappropriate, BAXTER continues by designating those which are to be preferred.

The primary emphasis in education should be, of course, religious; but since all who seek instruction are not equally suited for the clergy one can best serve the public good by following one's individual inclination in the choice of other lawful, desirable callings (45). As already indicated, the other learned professions are next in point of desirability. In the educational curriculum, Mathematics, a part of " organical knowledge " since its uses are so fundamental and diverse, takes a prominent place. Physics, understood always as the study of God in his works, is the favorite Puritan scientific discipline (46). This selection illustrates the correlated aspects of Puritan thought: mathematics representing the rationalistic aspect and physics the empirical (47). The

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(43) *Cf.* observation of MAX WEBER, *Protestant Ethic*, p. 249.

(44) *C. D.*, Vol. IV, pp. 577-8. *Cf.* WEBER, *Religionssoziologie*, Vol. I, p. 564. " Nicht selten betrachtete daher die Religiosität die rein empirische, auch naturwissenschaftliche Forschung als besser mit ihren Interessen vereinbar als die Philosophie. So vor allem der asketische Protestantismus."

(45) *C. D.*, Vol. II, p. 212 ff.

(46) *C. D.*, Vol. IV, p. 577.

(47) It is this same convergence which characterizes the growth of modern

emphasis upon these studies is significant when one remembers that the advance in these fields was more pronounced than in any other.

A knowledge of many languages is also desirable since it facilitates the acquisition of further learning—it is esteemed not as an attainment desirable in itself, but as a means for attaining a further knowledge of *things*. The pure linguist, who did not apply his faculties to increasing man's knowledge, was too close to the inadmissible status of the contemplative monk. This attitude was also repeatedly maintained by the scientists of the period.

In his " directions for young Students, for the most profitable ordering of their studying Thoughts," the Reverend Mr. BAXTER skillfully steers a safe course, twixt the Scylla of utter conformity to intellectual tradition and the Charybdis of radical divergence from antecedent scientific conceptions (48). The test for the acceptance or rejection of theories is to be empirical : submission of the theses to the relevant sensory experience, " for it is not science, but human belief, else, whoever you take it from." (49) BAXTER would not dismiss rationalism beyond recall, but he would subordinate it; it is not to be preferable, but rather ancillary, to the study of irreducible and stubborn facts. Here is evidenced the revolt against scholasticism, against rationalism (in the philosophical sense) which is so characteristic of two of the major movements of the century : the Protestant-Reformist and the scientific.

science. The unrelieved rationalism of the Scholastics was insufficient; the unimaginative and incomplete empiricism of FRANCIS BACON could prove no better. But the interaction of abstract reasoning with experiment and observation, typified by the conjunction of mathematics and physics, was the fruitful key to the problem. Now while this development may have been largely an intra-scientific one, it was not wholly unrelated to the society in which it occurred. The coincidence of these converging movements in the realms of both religion and science was not fortuitous, as we shall see.

(48) The following quotation differs significantly from the rigidity of traditionalism manifest in the writings of medieval theologians and, in great part of CALVIN himself. " Avoid both extremes, of them that study no more, but to know what others have written and held before them; and of them that little regard the discoveries of others : learn all of your teachers and authors that they can teach you; but make all your own, and see things in their proper evidence..." *C. D.*, Vol. II, p. 246-7. The context emphasizes the empiricist bent.

(49) *C. D.*, Vol. IV, p. 579.

At this point a distinction must be drawn between medieval and seventeenth century rationalism. The impress of rationalism was marked throughout the latter Middle Ages; it was an essential of scholasticism. As Professor WHITEHEAD has shown (50), this engendered a habit of orderly thought which remained long after the scholastic philosophy had been repudiated. HOOKER, in his *Ecclesiastical Polity*, however, criticised the Puritans for their failure to subordinate themselves completely to such rationalism. With the Puritans, who so fully exemplify a mercantile and scientific age, the term reason takes on a new connotation : the rational consideration of empirical data. Logic is reduced to a subsidiary rôle. It is occasionally a useful element in thought, but the test of reality comes not from scholastic logic, which adds nothing to knowledge and may perpetuate falsehood, but from the observation of facts. It was this accent, coupled with an " irrational " faith in the efficacy and utility of science, which characterizes both Puritanism and modern science (51).

Physics : God in His Works

Education in general having been deemed a good work, the logically-minded BAXTER goes on to provide a rationale for the emphasis on scientific and empirical studies. Again, there is the reversion to the fundamental aim of all life as the basis for sanction : the study of natural phenomena is an effective means for promoting the glory of God (52). The study of Nature in a

(50) A. N. WHITEHEAD, *Science and the Modern World* (New York : MACMILLAN Co., 1931), pp. 17 ff.

(51) *Cf.* WALTER PAGEL, " Religious Motives in the Medical Biology of the XVIIth Century," *Bulletin of the Institute of the History of Medicine*, Vol. III (1935), pp. 97-128, who contrasts the preponderance of rationalism in medieval science with the " empirical implications " of seventeenth century science and religion.

(52) " The great means of promoting love to God is duly to behold Him in His appearances to man, in the ways of Nature, Grace and Glory. First, therefore, learn to understand and improve his appearances in Nature, and to see the Creator in all His works, and by the knowledge and love of them to be raised to the knowledge and love of Him." *C. D.*, Vol. I, p. 375. This argument for the justification of science is characteristic of all the Protestant sects. Thus GILBERT, Lord Bishop of Sarum [GILBERT BURNET] in *A Sermon Preached at*

" convincing, scientifical way " furthers a full appreciation of the Creator's power, so that the natural scientist must needs be better equipped than the casual observer to glorify Him. In this direct fashion, religion sanctioned science and raised the social estimation of those who pursued scientific investigation, with the associated intensification and spread of interest in such pursuits.

A further basis for the sanctification of science was found in the second major tenet of the Puritan ethos : *the utilitarian principle*. The linkage is apparent. " Knowledge is to be valued according to its usefulness," (53) since anything which tends " to sweeten the lives of mortals," to facilitate their material well-being, is good in the sight of God (54). The religiously-assigned value of science is hence immeasurably increased in view of the fact that the scientific study of nature tends to enlarge

the Funeral of the Honorable ROBERT BOYLE (London : 1692), p. 14, repeats : " ... the viewing of the works of God even in a general survey, gives insensibly a greatness to the Soul. But the more extended and exact, the more minute and severe, the Enquiry be, the Soul grows to be thereby the more inlarged by the variety of Observation that is made, either on the great Orbs and Wheels that have their first motion, as well as their Law of Moving, from the Author of all; or on the Composition of Bodies, ..." It is of course true that this same view—that the study of natural phenomena discovers the glory of God revealed in His handiwork—became fairly common toward the latter part of the Middle Ages. In Islam, the same notion was also widespread. AVERRÖES held that the noblest worship which can be paid to God lies in the knowledge of His works. But the experimental method, while faintly present, was not sufficiently cultivated to make for what is called modern science. In medieval Europe this neo-Platonic conception of God revealed in Nature was coupled with the doctrine of the complete subservience of these studies to the infallible teachings of the Bible (which were not interpreted by the individual in the light of his reason and experience but by the Church). Moreover, since this idea was then not allied with a similarly sanctioned emphasis on observation and experiment, it could at best lead to fruitless rationalistic discussions, largely divorced from empirical study. Seldom did religious leaders carry this point further and suggest that the scientist was better able to glorify God than were others; and hence the complete sanction of scientific work was in no wise comparable to that of the later Puritan teachings. It was the conjunction of these prerequisite factors, empiricism, rationalism and positive evaluation of science, in the post-Reformist teachings which was associated with the spread, and indirectly, with the advance of science.

(53) *C. D.*, Vol. I, p. 13.

(54) GILBERT BURNET, *op. cit.*, pp. 15-18.

man's dominion over it. Science is thought of as a powerful technologic tool and as such deserves to be highly esteemed.

Now, as has been indicated, there was a constant tendency for the to-the-greater-glory-of-God principle to recede as a guiding tenet of actual behavior and for utilitarian considerations to become ever more prominent. Or, to put it in another way, activity which was clearly useful in a practical sense, was increasingly held to glorify God most effectively. In view of this process, it may readily be seen that the social utility of both science and technology proved to be one of the most effective arguments for the positive estimation of such pursuits, an argument which was irrelevant to the medieval religious leaders who felt the futility of worldly interests of this sort. Indeed, considerations of mundane utility were simply foreign to medieval teachings. In contrast, Puritanism tends ever more and more to emphasize the value of reshaping this world. Consequently, science, as at least in part the handmaid of socio-economic utility, is positively sanctioned (55).

The Medieval Contrast

The monastic asceticism and the feeling of the impermanence and relative worthlessness of matter which was characteristic of the Middle Ages could obviously not lead to an interest in disciplines which were primarily concerned with this world of sense. The early Church Fathers, such as EUSEBIOS, ST. AMBROSE and LACTANTIUS, consistently proposed the chiliastic doctrine of the New Testament that this earth was soon to be destroyed, that there were to be new heavens and a new earth, and treated the physical sciences with contumely and contempt (56). The

(55) *Cf.* A. C. MCGIFFERT, *The Rise of Modern Religious Ideas* (New York : The MACMILLAN Company, 1922), Chapter 3.

(56) A. D. WHITE, *A History of the Warfare of Science with Theology*, 2 volumes (New York : APPLETON, 1901), Vol. I, pp. 375 ff. This attitude exemplifies what H. O. TAYLOR called the basic principle of patristic faith : that the will of God is the one cause of all things and *that this will is unsearchable*, is " secret." *Cf. The Medieval Mind*, Vol. I, p. 74. See also F. W. BUSSELL, *Religious Thought and Heresy in the Middle Ages* (London : ROBERT SCOTT, 1918), pp. 715-17. CALVIN's point of view, which closely resembled this, was submerged by the implications of his other tenets, which led to directly opposed developments.

investigation of natural phenomena seemed purposeless. As AMBROSE held in his *Hexaëmeron* [Vol. I, p. 6], " To discuss the nature and position of the earth does not help us in our hope of life to come. It is enough to know what Scripture says, that ' He hung up the earth upon nothing.' "

When this belief had lost something of its force, when the conviction of the imminent end of the earth was not so intense, science came to be regarded with dread since it was " black magic," representing an unlawful alliance with Satan (57). Writing in the late twelfth century, RICHARD OF ST. VICTOR, asks rhetorically : " What is all science but a picture without life, a phantom without movement or feeling ? " And BONAVENTURA in the following century, warns that " the tree of science cheats many of the tree of life or exposes them to the severest pains of purgatory." It is quite true that some of the great Reformers, in particular, LUTHER, were similarly antagonistic to natural science and humanist art, but the religious movements which stemmed from these charismatic leaders, grew away from this antagonism and vigorously espoused a favorable attitude (58).

One essential difference between the medieval and post-Reformation type of personality in which religion was the focal element, is clearly brought out by SPRANGER's ideal-types of the " transcendental mystic " and the " immanent mystic." The first finds rest only in a super-sensuous world. For such a being science is without value since it does not answer the ultimate questions; all his energies are concentrated on preparing his soul for inner vision. The immanent mystic, on the other hand, applies his religious beliefs in a totally different fashion. Life and action become positively valued precisely because they are indications of God. This type of individual possesses a sort of cosmic enthusiasm, for since God is present in every

(57) WHITE, *op. cit.*, Vol. I, p. 383.

(58) For this reason, it is necessary to insist upon the distinction between the teachings of the Reformers themselves and their subsequent *development* in the Puritan and similar movements. Of course, this does not deny that occasionally principles were adopted without any pronounced change. *Cf.* F. VON BEZOLD, " Staat und Gesellschaft des Reformations-Zeitalters " in *Staat und Gesellschaft der neueren Zeit* (Berlin : B. G. TEUBNER, 1908), p. 81, *et passim.*

aspect of life, none should be slighted. Science as the study of His works thus becomes highly regarded (59).

This type of attitude so characteristic of Post-Reformation religious leaders during a period when religion was still a singularly powerful social force may well have been congenial to the development of science. This is not to imply that the discoveries of NEWTON, BOYLE or other scientists can be directly attributed to the sanction of science by religion. Specific discoveries and inventions belong to the internal history of science and are largely independent of factors other than the purely scientific. But the fact that science became socially acceptable, in short, that it became a laudable rather than an unsavory occupation, could not but help direct talents into scientific pursuits which at other times would have found expression in other fields.

Nor is there any implication that religion was the primary factor, the independent variable, so to speak, and science the dependent. Religious conceptions were, as we shall see more clearly, definitely integrated with sentiments basic to the contemporary science and philosophy : there was throughout a reciprocal interaction. But the fact is that religion still constituted a most effective social force and as such it exerted a considerable influence upon contemporary action and the allocation of contemporary interests. In the values of that society, the ideals and goals of religion loomed large and science was regarded as an efficient means for the attainment of these aims.

As SPRANGER has indicated, values from other zones—in this instance, the realm of science—become religious when they are related to the final meaning of life, and consequently they embody a religious emphasis over and above their original value accent (60). This statement, however, should not be generalized for it applies only when religion is clearly a preëminent social value. The realization of the fact provides definite limits on the generalizability of the processes noted in this study, for obviously the influence of religion upon science necessarily varies with the degree of social control which religion manifests in a

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(59) EDUARD SPRANGER, *Types of Men*, trans. by P. J. W. PIGORS, (Halle : M. NIEMEYER, 1928), pp. 213-16.

(60) *Ibid.*, p. 285.

given society. The picture which our study has thus far afforded is characteristic of an historical epoch; it cannot be extended, without appropriate modifications, to a period such as the present where religious ideals are in a sense subordinated to others, particularly those of science and the industrial world. But all these are considerations which may best be dealt with in other connections.

Science : Handmaid of Utility

Social utility, an aim prescribed by religion, has been used to sanction science, viewed, in this case, as a handmaid of technology (61). BAXTER points out, further, that scientific and technologic discoveries and inventions increase man's felicity signally, for they enable their originators to arrive at an abundant conviction of their state of grace.

> Grace will become more notable and discernible [if you persevere and succeed in your labours] ... For the very exercise of love to God and man, and of a heavenly mind and holy life, hath a sensible pleasure in itself, and delighteth the person who is so employed : as if a man were to take the comfort of his learning and wisdom, one way is by the discerning his learning and wisdom which he hath, in reading and meditating on some excellent books, and making discoveries of some mysterious excellencies in arts and sciences, which delight him more by the very acting, than a bare conclusion of his own learning in the general, would do. What delight had the inventors of the sea-chart and magnetic attraction, and of printing, and of guns, in their inventions ! What pleasure had GALILEO in his telescopes, in finding out the inequalities and shady parts of the moon, the Medicean planets, the 62 adjuncts of Saturn, the changes of Venus, the stars of the Milky Way, etc...

The sentiments basic to these views would have been simply unthinkable in the medieval period, save as referring, at best, to the intellectual amalgam of science and theology presented by an AQUINAS. To regard with high esteem scientific discoveries attained empirically and without reference to Scriptural or other

(61) We do not wish to confuse the development of science and of technology —they are not identical though they coincided at many points. But the fact is that the religious evaluations were generally concerned with both, and in much the same fashion. At this point, then, they may be considered jointly.

(62) *C. D.*, Vol. V, p. 535.

sacred authority would have been almost as heretical as making the discoveries themselves (63). As Professor HASKINS has observed, the scientific spirit of Christian Europe in the Middle Ages was not liberated from the respect for authority which was characteristic of that epoch (64), whereas Puritan authority was enunciating the very doctrines which furthered interest in science and, ultimately, lack of concern with religion itself.

The contrast between BAXTER's statement and, say, that of PETER DAMIAN, the noted chancellor of POPE GREGORY VII, who declared that all worldly sciences are absurdities and fooleries is perhaps sufficient to account significantly for the social interest in science in the seventeenth century and, relatively speaking, its almost complete absence in the eleventh. This does not imply a complete cessation of interest in science during the eleventh or any other century of the period so popularly and erroneously called the Dark Ages.

The continuity of scientific development was unbroken, but it was a most tenuous thread in Western Europe until at least the twelfth century. Thereafter, science, as a phase of social activity, became increasingly significant, but it could not bloom and prosper for two reasons : the first, intrinsic to the nature of science, and the other, social in character. To a certain degree, a fixed order must prevail in the appearance of scientific discoveries; each discovery must await certain prerequisite developments (65).

(63) Contrast the attitude of Pope ALEXANDER III, who in 1163, in connection with the Council of Tours, forbade the study of physics to all ecclesiastics, which in that age meant the prohibition of scientific studies to the only persons who were even moderately equipped to pursue them. " What the Pope expressly forbade was, in the words of the papal bull, ' the study of physics or the laws of the world ' ..." WHITE, *op. cit.*, Vol. I, p. 386. The condemnation of ROGER BACON who dared suggest a scientific explanation of natural phenomena may have been simply an application of Franciscan discipline, but it seems also to have been animated by a dislike of his originality of theory. In 1278, the Franciscans condemned BACON's teachings as containing " suspected novelties." Likewise, the Dominicans interdicted the study of medicine, natural philosophy and chemistry. Such attitudes of religious authorities could scarce have provided a fruitful social soil for the development of science. *Cf.* LECKY, *History of... Rationalism*, Vol. I, p. 301.

(64) CHARLES H. HASKINS, *The Renaissance of the Twelfth Century* (Cambridge : Harvard University Press, 1928), pp. 336-37.

(65) *Cf.* W. F. OGBURN, *Social Change* (New York : Viking Press, 1932); S. C. GILFILLAN, *Sociology of Invention* (Chicago : FOLLETT Pub. Co., 1935

(The converse of this does not follow with the ineluctability which some cultural sociologists would have us believe—a discovery does not necessarily follow upon the existence of its " constituent elements " as is well attested by the history of science.) In this sense, we may talk of the time not being ripe for a far-reaching, swift-moving, wide-sweeping development until the seventeenth century (66).

The other factor was the absence of the requisite cultural animus of regarding scientific activity as highly desirable. Occasional " great intellectual sky-rockets " there were to light the world of science, but little in the way of concerted scientific effort viewed with favor by the chief agents of social control; the tendency was, rather, to look benevolently at theological activity and to turn one's back to scientific endeavors. Of course, this statement is but approximate. The tenets of medieval Europe were never as consistently applied and unchallenged as one is at times prone to believe. There were divergences from the dominant tendencies, but those few of the intellectual élite who ran counter to the trend were too much the exception to direct social attention into scientific channels.

The seventeenth century brought the prerequisite factors to convergence : an adequate accumulation of scientific knowledge to cope with the initial problems at hand, the maturation of the experimental method, a consistent provision of " intellectual genius adequate for the greatness of its occasions " and a complex of social attitudes which, for varying reasons, religious, economically utilitarian and idealistic, was favorable to scientific interests.

The specific developments, it should again be emphasized, were not directly dependent upon this social evaluation of science as a focus of social interest, but it is manifest that any field of activity which is regarded with favor will, particularly if like science, it possesses an ongoing dynamic of its own, advance more rapidly than when derogated (67). These social attitudes, positive or negative, are a function of a complex of social trends, which are more or less interdependent : economic, political,

(66) ALFRED VIERKANDT, *Die Stetigkeit im Kulturwandel* (Leipzig : DUNCKER & HUMBLOT, 1908), pp. 123-4 *et passim*.

(67) As BACON observed, " it is nothing strange if a thing [science] not held in honour does not prosper." *Novum Organum*, Vol. I, Aph. XCI.

religious, philosophic, scientific and the like. At various times, the dominant ideals and sentiments of a society are chiefly expressed in one or another of these fields, and it is they which largely determine the social attitudes toward other spheres (68). When, as was apparently the case during the seventeenth century, utilitarian norms are dominant, other activities are evaluated in respect of their apparent accordance with these ideals and, in this sense, may be said to be dependent upon them. Generalizations concerning these social processes are, then, relative to the specific social context; they are not timeless, universal, irrespective of social values and social structure.

The social values inherent in the Puritan ethos were such as to lead to an approbation of science because of a basically utilitarian orientation, couched in religious terms and furthered by religious authority. Scientific investigation, viewed from the rationalized Puritan system of ethics, seemed to possess those qualities characteristic of activities which are effective means for the attainment of the accepted goals. The possibility that science, as a means toward a religious end, would later break away from such religious supports and in a measure tend to delimit the realm of theologic control, was seemingly unrealized (69). The apparent conflicts between theology and science which arose when scientific findings seemed to disprove various contentions of orthodox theologians occurred later with each extension of scientific inquiry to realms which were hitherto regarded as "sacred." But this is simply another example of the frequently observed fact that the Reformers did not anticipate the full actual consequences of their teachings, consequences which did not coincide with their expectations (70).

(68) *Cf.* MAX SCHELER, *Versuche zu einer Soziologie des Wissens* (München und Leipzig : DUNCKER & HUMBLOT, 1924), pp. 31 ff.

(69) There were a few far-sighted exceptions, foremost among whom was JOSEPH GLANVILL.

(70) *Cf.* R. K. MERTON, "The Unanticipated Consequences of Purposive Social Action," *American Sociological Review*, Vol. I (1936), 894-904.

CHAPTER V

Motive Forces of the New Science

What we call the Protestant ethic was at once a direct expression of dominant values and an independent source of new motivation. It not only led men into particular paths of activity; it exerted a constant pressure for unswerving devotion to this activity. Its ascetic imperatives established a broad base for scientific inquiry, dignifying, exalting, consecrating such inquiry. If the scientist had hitherto found the search for truth its own reward, he now had further grounds for disinterested zeal in this pursuit. And society, once dubious of the merits of those who devoted themselves to the " petty, insignificant details of a boundless Nature," largely relinquished its doubts.

The Puritan Spur to Science

As we have seen, the capital elements of the Puritan ethic were related to the general climate of sentiment and belief. In a sense, these tenets and convictions have been accentuated through a biassed selection, but this sort of bias is common to all positive inquiries. Theories which attempt to account for certain phenomena require facts, but not all facts are equally pertinent to the problem in hand. " Selection," determined by the limits of the problem, is necessary. Among the cultural variables which invariably influence the development of science are the dominant values and sentiments. At least, this is our working hypothesis. In this particular period, religion in large part made articulate much of the prevailing value-complex. For this reason, we must consider the scope and bearing of the contemporary religious convictions, since these may have been related, in one way or another, to the upsurge of science. But not all of these convictions were relevant. A certain degree of selection is therefore necessary for the purpose of abstracting those elements which had such a perceivable relation.

Puritanism attests to the theorem that non-logical notions with a transcendental reference may nevertheless exercise a considerable influence upon practical behavior. If the fancies of an inscrutable deity do not lend themselves to scientific investigation, human action predicated upon a particular conception of this deity does. It was precisely Puritanism which built a new bridge between the transcendental and human action, thus supplying a motive force for the new science. To be sure, Puritan doctrines rested ultimately upon an esoteric theological base but these were translated into the familiar and cogent language of the laity.

Puritan principles undoubtedly represent to some extent an accommodation to the current scientific and intellectual advance. Puritans had to find some meaningful place for these activities within their view of life. But to dismiss the relationship between Puritanism and science with this formula would indeed be superficial. Clearly, the psychological implications of the Puritan system of values independently conduced to an espousal of science, and we would grossly simplify the facts to accord with a pre-established thesis if we failed to note the convergence of these two movements. Moreover, the changing class structure of the time reinforced the Puritan sentiments favoring science since a large proportion of Puritans came from the rising class of bourgeoisie, of merchants (1). They manifested their increasing power in at least three ways. First, in their positive regard for both science and technology which reflected and promised to enhance this power. Equally notable was their increasingly fervent belief in progress, a profession of faith which stemmed from their growing social and economic importance. A third manifestation was their hostility toward the existing class structure which limited and hampered their participation in political control; an antagonism which found its climax in the Revolution.

Yet we cannot readily assume that the bourgeoisie were Puritans solely because the Puritan ethic appealed to bourgeois sentiments.

(1) *Cf.* TROELTSCH, *Social Teachings*, Vol. II, p. 681; ROLAND USHER, *The Reconstruction of the English Church*, especially Vol. II which contains a statistical study of the social origins of Puritan ministers.

The converse was perhaps even more important, as WEBER has shown. Puritan sentiments and beliefs prompting rational, tireless industry were such as to aid economic success. The same considerations apply equally to the close connection between Puritanism and science : the religious movement partly " adapted " itself to the growing prestige of science but it initially involved deep-seated sentiments which inspired its followers to a profound and consistent interest in the pursuit of science.

The Puritan doctrines were nothing if not lucid. If they provided motivation for the contemporary scientists, this should be evident from their words and deeds. Not that scientists, any more than other mortals, are necessarily aware of the sentiments which invest with meaning their way of life. None the less, the observer may often, though not too readily perhaps, uncover these tacit valuations and bring them to light. Such a procedure should enable us to determine whether the putative consequences of the Puritan ethic truly proved effective. Moreover, it will disclose the extent to which all this was perceived by the very persons whom it most concerned. Accordingly, we shall examine the works of the natural philosopher who " undoubtedly did more than any one of his time to make Science a part of the intellectual equipment of educated men," ROBERT BOYLE (2). His investigations in physics, chemistry and physiology, to mention only the chief fields of achievement of this omnifarious experimentalist, were epochal. Add to this the fact that he was one of the individuals who attempted explicitly to establish the place of science in the scale of cultural values and his importance for our particular problem becomes manifest. But BOYLE was not alone. Equally significant were JOHN RAY, whom HALLER termed, a bit effusively, the greatest botanist in the history of man; FRANCIS WILLUGHBY, who was perhaps as eminent in zoölogy as was RAY in botany; JOHN WILKINS, one of the leading spirits in the " invisible college " which developed into the Royal Society; OUGHTRED, BARROW, GREW, WALLIS, NEWTON;—but a complete list would comprise a Scientific Register of the time. Further materials for our purpose are provided by the Royal Society which, arising about

(2) J. F. FULTON, " ROBERT BOYLE and his Influence on Thought in the Seventeenth Century," *Isis*, XVIII (1932), pp. 77-102. The range of BOYLE's prolific writings is shown in Professor FULTON's exemplary bibliography.

the middle of the century, provoked and stimulated scientific advance more than any other immediate factor. In this instance we are particularly fortunate in possessing a contemporary account, written under the constant supervision of the members of the Society in order that it might be representative of the motives and aims of that group. This is THOMAS SPRAT's widely-read *History of the Royal-Society of London*, published in 1667, after it had been examined by WILKINS and other representatives of the Society (3). From these works, then, and from the writings of other scientists of the period, we may glean the chief motive forces of the new science.

To the " Glory of the Great Author of Nature "

Once science has become firmly institutionalized, its attractions, quite apart from any economic benefits it may bestow, are those of all elaborated and established social activities. These attractions are essentially twofold : generally prized opportunities of engaging in socially approved patterns of association with one's fellows and the consequent creation of cultural products which are esteemed by the group. Such group-sanctioned conduct usually continues unchallenged, with little questioning of its reason for being. Institutionalized values are conceived as self evident and require no vindication.

But all this is changed in periods of sharp transition. New patterns of conducts must be justified if they are to take hold and become the foci of social sentiments. A new social order presupposes a new scheme of values. And so it was with the new science. Unaided by forces which had already gripped man's will, science could claim only a bare modicum of attention and loyalty. But in partnership with a powerful social movement

(3) *Cf.* CHARLES L. SONNICHSEN, *The Life and Works of Thomas Sprat* (Harvard University unpublished doctoral dissertation, 1931), p. 131 ff., where substantial evidence of the fact that the *History* was representative of the views of the Society is presented. As we shall see, the statements in SPRAT's book concerning the aims of the Society bear distinct similarity on every score to BOYLE's characterizations of the motives and aims of scientists in general. *Ibid.*, p. 167. This similarity is evidence of the dominance of the ethos which included these attitudes.

which induced an intense devotion to the active exercise of designated functions, science was launched in full career.

A clear manifestation of this process is not wanting. The Protestant ethic had pervaded the realm of science and had left its indelible stamp upon the attitude of scientists toward their work. Expressing his motives, anticipating possible objections, facing actual censure, the scientist found motive, sanction and authority alike in the Puritan teachings. Such a dominant force as religion in those days was not, and perhaps could not be compartmentalized and delimited. Thus in BOYLE's highly-commended apologia of science, we read :

> ... it will be no venture to suppose that at least in the Creating of the Sublunary World, and the more conspicuous Stars, two of God's principal ends were, the Manifestation of His own Glory, and the Good of Men (4).

> ... it will not be perhaps difficult for you [PYROPHILUS] : to discern, that those who labour to deter men from sedulous Enquiries into Nature, do (though I grant, designlessly) take a Course which tends to defeat God of both those mention'd Ends (5).

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(4) ROBERT BOYLE, *Some Considerations Touching the Usefulness of Experimental Natural Philosophy* (Oxford, 1664, 2nd ed.), p. 22.

(5) *Ibid.*, p. 27. This allusion to contemporary opposition to science refers to that of some zealous divines. Generally speaking, strictures on science arose from four primary sources. First, there were disgruntled individuals such as ROBERT CROSSE, an upholder of pseudo-Aristotelianism, who held that the Royal Society was a Jesuitical conspiracy against society and religion, and HENRY STUBBE, a professional literary bravo and Galenical physician who entered the fray for reasons of personal and professional aggrandizement. These exaggerated gestures of antagonism had little influence and are not at all indicative of the place held by science and men of science in the latter part of the century. See A. E. SHIPLEY, " The Revival of Science in the Seventeenth Century " in *Vanuxem Lectures* (Princeton University Press : 1914); F. GREENSLET, *Joseph Glanvill* (Columbia University Press : 1900), p. 78. The second source of opposition was literary. For example, SHADWELL in his Comedy, " The Virtuoso " (1676) and BUTLER, in his " Elephant in the Moon " and " Hudibras " ridiculed the pursuits of certain " scientists," but these literary satires were criticism of exaggerated scientism and dilletantism, rather than of the significant scientific works of the day. *Cf. The Record of the Royal Society* (Oxford University Press, 1912), pp. 45 ff. A third source of opposition, and by far the most important, was found among those churchmen who felt that the theologic foundations of their beliefs were being undermined by scientific investigations. But theology and religion must not be confused. Orthodox, dogmatic theologians then, as ever, opposed any activity which might lead to the contravention of their dogmas. But the implications of religion, particularly of the religious ethic, were quite contrariwise. It is this ethic, following with equal ineluctability from diverse theologic bases, which in its consequences was of far greater social

This is the motif which recurs in constant measure in the very writings which often contain considerable scientific contributions : these worldly activities and scientific achievements manifest the Glory of God and enhance the Good of Man. The juxtaposition of the spiritual and the material is characteristic and significant. This culture rested securely on a substratum of utilitarian norms which identified the useful and the true. Puritanism itself had imputed a threefold utility to science. Natural philosophy was instrumental first, in establishing practical proofs of the scientist's state of grace; second, in enlarging control of nature and third, in glorifying God. Science was enlisted in the service of individual, society and deity. That these were adequate grounds could not be denied. They comprised not merely a claim to legitimacy, they afforded incentives which cannot be readily overestimated. One need but look through the personal correspondence of seventeenth century scientists to realize this (6).

JOHN WILKINS proclaimed the experimental study of Nature to be a most effective means of begetting in men a veneration for God (7). FRANCIS WILLUGHBY, probably the most eminent zoologist of the time, was prevailed upon to publish his works —which, his excessive modesty led him to deem unworthy of publication—only when RAY insisted that it was a means of glorifying God (8). And RAY's panegyric of those who honor Him by studying His works was so well received that five large editions were issued in some twenty years (9).

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significance than the abstruse theologic doctrines which rarely penetrated to the life of the people. Professor R. F. JONES suggests a fourth source. After the restoration, ardent royalists impugned science, and particularly the Royal Society, because of the close connection between these, Baconianism and Puritanism. This suggests that contemporaries recognized the strong Puritan espousal of the new experimental science, as indeed they did. See JONES' excellent study, *Ancients and Moderns* (St. Louis : Washington University Studies, 1936), pp. 191-92, 224.

(6) See, for example, the letters of WILLIAM OUGHTRED in *Correspondence of Scientific Men of the Seventeenth Century*, S. J. RIGAUD, ed., pp. XXXIV, *et passim.* Or see the letters of JOHN RAY in the *Correspondence of John Ray*, EDWIN LANKESTER, ed. (London, 1848), pp. 389, 395, 402, *et passim.*

(7) *Principles and Duties of Natural Religion* (London, 1710, 6th ed.), pp. 236 ff.

(8) See EDWIN LANKESTER, (ed.) *Memorials of John Ray* (London, 1846), p. 14 n.

(9) JOHN RAY, *Wisdom of God* (London : 1691), pp. 126-29, *et passim.* Striking

Many " emancipated souls " of the present day, accustomed to a radical cleavage between religion and science and largely convinced of the relative social unimportance of religion for the modern Western world, are apt to generalize this state of affairs. To them, these recurrent pious phrases signify Machiavellian tactics or calculating hypocrisy or at best merely customary usage, but nothing of deep-rooted motivating convictions. This evidence of extreme piety leads to the charge that *qui nimium probat nihil probat*. But such an interpretation is possible only upon the basis of an unwarranted extension of twentieth century beliefs and attitudes to seventeenth century society. Though it always serves to inflate the ego of the iconoclast and sometimes to extol the social images of his own day, " debunking " may often supplant truth with error. As a case in point, it is difficult to believe that BOYLE who manifested his piety by expending considerable sums to have the Bible translated into foreign tongues as well as in less material ways, was simply rendering lip service to Protestant beliefs. As Professor G. N. CLARK properly notes in this connection :

> There is... always a difficulty in estimating the degree to which what we call religion enters into anything which was said in the seventeenth century in religious language. It is not solved by discounting all theological terms and treating them merely as common form. On the contrary, it is more often necessary to remind ourselves that these words were then seldom used without their accompaniment of meaning, and that their use did generally imply a heightened intensity of feeling. This sense of the closeness of God and the Devil to every act and fact of daily life is an integral part of the character of the century (10).

In various ways, then, general religious ideas were translated into concrete policy. This was no mere intellectual exercise. Puritanism transfused ascetic vigor into activities which, in their own right, could not as yet achieve self-sufficiency. It so redefined

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illustrations of the extent to which RAY had assimilated the Puritan sentiments are to be found throughout his correspondence. For example, he writes in a letter to JAMES PETIVER (April 4, 1701) : " I am glad your business increases so as to require more attendance, and take up more of your time, which cannot be better employed than in the works of your proper callings. What time you have to spare you will do well to spend, as you are doing, in the inquisition and contemplation of the works of God and nature." *The Correspondence of John Ray*, p. 390.

(10) *The Seventeenth Century*, p. 323.

the relations between the divine and the mundane as to move science to the front rank of social values. As it happened, this was at the immediate expense of literary, and ultimately, of religious pursuits. For if the Calvinist God is irrational in the sense that he cannot be directly grasped by the cultivated intellect, He can yet be glorified by a clear-sighted, meticulous study of His natural works (11). Nor was this simply a compromise with science. Puritanism differed from Catholicism which had gradually come to tolerate science, in demanding, not merely condoning, its pursuit. An " elastic concept," (12) the Catholic and Protestant definitions of which differed so fundamentally as to produce entirely opposed consequences, the " glorification of God " thus came to be, in Puritan hands, the " fructification of science."

" *Comfort of Mankind* "

But Protestantism had afforded further grounds for the cultivation of science. The second dominant tenet in the Puritan ethos, it will be remembered, designated social welfare, the good of the many, as a goal ever to be held in mind. Here again, the contemporary scientists adopted an objective which carried with it, in addition to its own obvious merits, a cluster of religious sentiments. Science was to be fostered and nurtured as leading to the improvement of man's lot on earth by facilitating technologic invention. The Royal Society, we are told by its worthy historian, " does not intend to stop at some particular benefit, but goes to the root of all noble inventions." (13) Further, those experiments which do not bring with them immediate gain are not to be contemned, for as the noble BACON had declared, experiments of Light ultimately conduce to a whole troop of nventions useful to the life and state of man (14). This power

(11) *Cf.* TROELTSCH, *Social Teachings*, Vol. II, p. 585.

(12) The changing definitions of nominally identical concepts comprise a fruitful field for sociological research. Such students of the sociology of knowledge as MANNHEIM and historians of ideas (LOVEJOY, BOAS, CRANE) have contributed significant studies of such developments.

(13) THOMAS SPRAT, *The History of the Royal-Society of London*, pp. 78-79.

(14) *Ibid.*, pp. 245, 351 ff.

of science to better the material condition of man, he continues, is, apart from its purely mundane value, a good in the light of the Evangelical Doctrine of Salvation by Jesus Christ.

Boyle, in his last will and testament, echoes the same attitude, petitioning the Fellows of the Society in this wise : " Wishing them also a happy success in their laudable Attempts, to discover the true Nature of the Works of God; and praying that they and all other Searchers into Physical Truths, may Cordially refer their Attainments to the Glory of the Great Author of Nature, and to the Comfort of Mankind." (15) " Experimental science was to BOYLE, as to BACON, itself a religious task." (16)

Earlier in the century, this keynote had been sounded in the resonant eloquence of that " veritable apostle of the learned societies," FRANCIS BACON. Himself the initiator of no scientific discoveries; unable to appreciate the importance of his great contemporaries, GILBERT, KEPLER and GALILEO; naively believing in the possibility of a scientific method that " places all wits and understandings nearly on a level "; a radical empiricist holding mathematics to be of no use in science; he was, nevertheless, highly successful in being one of the principal propagandists in favor of positive social evaluation of science and of the disclaim of sterile scholasticism. As one would expect from the son of a " learned, eloquent and religious woman, full of puritanic fervor " who was admittedly influenced by his mother's attitudes (17), he speaks in the *Advancement of Learning* of the true end of scientific activity as the " glory of the Creator and the relief of man's estate." (18) Since, as is quite clear from many official and private documents, the Baconian

(15) Quoted by BURNET, *A Funeral Sermon...*, p. 25.

(16) E. A. BURTT, *The Metaphysical Foundations of Modern Physical Science* (New York : HARCOURT, BRACE & Co., 1927), p. 188.

(17) *Cf.* MARY STURT, *Francis Bacon* (London : K. PAUL, TRENCH, TRUBNER & Co., 1932), pp. 6 ff. It is true, as Professor M. M. KNAPPEN has pointed out to the writer, that BACON supplied JAMES with his legal arguments against the Puritans. But this should not be confused with BACON's tacit acceptance of many of the *non-political* phases of Puritanism. For the congeniality of BACON's philosophy, see R. F. JONES' *Ancients and Moderns : A Study of the Background of the Battle of the Books*, p. 92 ff.

(18) In the *Novum Organum*, Book I, LXXXIX, science is characterized as the handmaid of religion since it serves to display God's power. This is not, of course, a novel contention.

teachings constituted the basic principles on which the Royal Society was patterned, it is not strange that in the charter of the Society, the same sentiment is expressed (19). THOMAS SYDENHAM, the zealous Puritan (20), likewise had a profound admiration for BACON. And, like BACON, he was prone to exaggerate the importance of empiricism to the very point of excluding theoretical interpretation entirely. " Pure intellectual curiosity... seemed to him, perhaps partly owing to the Puritan strain in his character, of little importance. He valued knowledge only either for its ethical value, as showing forth the glory of the Creator or for its practical value, as promoting the welfare of man." (21) Empiricism characteristically dominated SYDENHAM's approach to medicine which set above all the value of clinical observation, the " repeated, constant observation of particulars." It is of some interest that the greatest clinical observers of this century, MAYERNE and SYDENHAM, were of Puritan stock.

Throughout there was the same point to point correlation between the principles of Puritanism, and the avowed attributes, goals and results of scientific investigation. Such was the contention of the protagonists of science at that time. If Puritanism demands systematic, methodic labor, constant diligence in one's calling, what, asks SPRAT, more active and industrious and systematic than the Art of Experiment, which " can never be finish'd by the perpetual labours of any one man, nay, scarce by the successive force of the greatest Assembly? " (22) Here is employment enough for the most indefatigable industry since

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(19) In the second Charter, which passed the Great Seal on April 22, 1663, and by which the Society is governed to this day, we read that the studies of its Fellows " are to be applied to further promoting by the authority of experiments the sciences of natural things and of useful arts, to the glory of God the Creator, and the advantage of the human race." *The Record of the Royal Society*, p. 15. Note the increased emphasis upon utilitarianism.

(20) See JOSEPH F. PAYNE, *Thomas Sydenham* (New York: LONGMANS, GREEN & Co., 1900), pp. 7-8, *passim*, where abundant evidence of SYDENHAM's sternly Puritan background is presented. " We cannot appreciate his whole character and career without remembering that he was imbued with the intense earnestness of the Puritans, and was quite prepared, in opposition to authority of any kind, to be called, if necessary, a rebel."

(21) *Ibid.*, p. 234.

(22) *Ibid.*, pp. 341-42.

even those hidden treasures of Nature which are farthest from view may be uncovered by pains and patience (23).

Does the Puritan eschew idleness because it conduces to sinful thoughts (or interferes with the pursuit of one's vocation)? " What room can there be for low, and little things in a mind so *usefully* and successfully employ'd [as in natural philosophy] ? " (24) Are plays and playbooks pernicious and flesh-pleasing (and subversive of more serious pursuits)? (25) Then it is the " fittest season for Experiments to arise, to teach us a Wisdom, which springs from the depths of Knowledge, to shake off the shadows, and to scatter the mists [of the spiritual distractions brought on by the Theatre]." (26) And finally, is a life of earnest activity within the world to be preferred to monastic asceticism? Then recognize the fact that the study of natural philosophy " fits us not so well for the secrecy of a Closet : It makes us serviceable to the World." (27) In short, science embodies patterns of behavior which are congenial to Puritan tastes. Above all, it embraces two highly prized values : utilitarianism and empiricism (28).

In a sense this explicit coincidence between Puritan tenets and the eminently desirable qualities of science as a calling which was suggested by the historian of the Royal Society is casuistry. No doubt it is partly an express attempt to fit the scientist *qua* pious layman into the framework of the prevailing moral and social values. Since both the constitutional position and the personal authority of the clergy were much more important then

(23) RAY, *Wisdom of God*, p. 125.

(24) SPRAT, *op. cit.*, pp. 344-45.

(25) *Cf.* BAXTER, *C. D.*, Vol. I, p. 152; Vol. II, p. 167. *Cf.* BARCLAY, the Quaker apologist, who specifically suggests " geometrical and mathematical experiments " as innocent divertissements to be sought instead of pernicious plays. *An Apology...*, pp. 554-55.

(26) SPRAT, *op. cit.*, p. 362.

(27) *Ibid.*, pp. 365-66.

(28) SPRAT perspicaciously suggests that monastic ascetism induced by religious scruples was partially responsible for the lack of empiricism of the Schoolmen. " But what sorry kinds of Philosophy must they [the Schoolmen] needs produce, when it was a part of their Religion, to separate themselves, as much as they could, from the converse of mankind? when they were so farr from being able to discover the secrets of Nature, that they scarce had opportunity, to behold enough of its common works" *Ibid.*, p. 19.

than now, it probably constituted a bid for religious and social sanction. Science, no less than literature and politics, was still, to some extent, subject to approval by the clergy (29).

But this is not the entire explanation. Present-day discussions of " rationalization " and " derivations " have been wont to becloud certain fundamental issues. It is true that the " reasons " adduced to justify one's actions often do not account satisfactorily for this behavior. It is also an acceptable hypothesis that ideologies seldom *give rise* to action and that both the ideology and action are rather the product of common sentiments and values upon which they in turn react. But these ideas can not be ignored for two reasons. They provide clues for detecting the basic values which motivate conduct. Such sign posts can not be profitably neglected. Of even greater importance is the rôle of ideas in directing action into *particular* channels. *It is the dominating system of ideas which determines the choice between alternative modes of action which are equally compatible with the underlying sentiments.* Without such guidance and direction, non-logical action would become, within the limits of the value-system, random (30).

In the seventeenth century, the frequent recourse of scientists to religious vindication suggests first of all that religion was a sufficiently powerful social force to be invoked in support of an activity which was intrinsically less acceptable at the time. It also leads the observer to the peculiarly effective religious orientation which could invest scientific pursuits with all manner of values and could thus serve to direct the interests of believers into the channels of science.

The efforts of SPRAT, WILKINS, BOYLE or RAY to justify their interest in science do not represent simply opportunistic obsequiousness, but rather an earnest attempt to justify the ways

(29) HENSON, *op. cit.*, p. 209.

(30) Operationally, there is often a thin, uncertain line between " derivations " and " residues " (PARETO). Constant elements in the speech reactions associated with action manifest deep-rooted, effective sentiments. Speaking elliptically, these constant elements may be held to provide motivations for behavior, whereas the variable elements are simply *post facto* justifications. But, in practice, it is at times exceedingly difficult to discriminate between the two. Once aware of the strong emotional charge which certain religious convictions carried at the time, we may find it justifiable to treat these as residues rather than derivations.

of science to God. The Reformation had transferred the burden of individual salvation from the Church to the individual, and it is this " overwhelming and crushing sense of the responsibility for his own soul " which accounts in part for both the acute longing for religious justification (31) and the intense pursuit of one's calling. If science were not demonstrably a " lawful " and desirable calling, it dare not claim the attention of those who felt themselves " ever in the Great Taskmaster's eye." It it to this intensity of feeling that such apologias were due.

Rationalism and Empiricism

The exaltation of the faculty of reason in the Puritan ethos —based partly on the conception of rationality as a curbing device of the passions—inevitably led to a sympathetic attitude toward those activities which demand the constant application of rigorous reasoning (32). But again, in contrast to medieval rationalism, reason is deemed subservient and auxiliary to empiricism. SPRAT is quick to indicate the preëminent adequacy of science in this respect (33). It is on this point probably that Puritanism and the scientific temper are in most salient agreement, for the combination of rationalism and empiricism which is so pronounced in the Puritan ethic forms the essence of the spirit of modern science. Puritanism was suffused with the rationalism of neo-

(31) USHER, *op. cit.*, Vol. I, p. 15.

(32) It must be remembered that the use of reason was lauded by the Puritans partly because it served to differentiate man from beast. The extent to which this idea seeped into the thought of contemporary scientists may be indicated by a statement made by BOYLE. " So much admirable workmanship as God hath displayed in the universe, was never meant for eyes that wilfully close themselves, and affront it with the not judging it with the speculating, *Beasts inhabit and enjoy the world, man, if he will do more, must study & spiritualize it.*" BOYLE, *Works* (BIRCH ed.), Vol. III, p. 62.

(33) " Who ought to be esteem'd the most carnally minded? The Enthusiast, that pollutes his Religion, with his Passions? or the Experimenter, that will not use it [reason] to flatter and obey his own desires, but to subdue them." SPRAT, *op. cit.*, p. 361. BAXTER, it will be remembered, in a fashion representative of the Puritans, had decried the invasion of " enthusiasm " into religion. Reason " must maintain its authority in the command and government of your thoughts." *C. D.*, Vol. II, p. 199 *et passim*. In like spirit, those who, at WILKINS' lodgings, laid the foundations of the Royal Society " were invincibly arm'd against all the inchantments of Enthusiasm." SPRAT, p. 53.

Platonism, derived largely through an appropriate modification of AUGUSTINE's teachings. But it did not stop there. Associated with the designated necessity of dealing successfully with the practical affairs of life within this world—a derivation from the peculiar twist afforded largely by the Calvinist doctrine of predestination and *certitudo salutis* through successful worldly activity— was an emphasis upon empiricism. These two currents brought to converge through the ineluctable logic of an internally consistent system of theology were so associated with the other attitudes of the time as to prepare the way for the acceptance of a similar coalescence in natural science.

The Puritan insistence upon empiricism, upon the experimental approach, was intimately connected with the identification of contemplation with idleness, of the expenditure of physical energy and the handling of material objects with industry (34). Experiment was the scientific expression of the practical, active and methodical bents of the Puritan. This is not to say, of course, that experiment was derived in any sense from Puritanism. But it serves to account for the ardent support of the new experimental science by those who had their eyes turned toward the other world and their feet firmly planted on this. Moreover, as TROELTSCH has suggested, Calvinism which abolished the absolute goodness of the Godhead tended to an emphasis on the individual and the empirical, the practically untrammelled and utilitarian judgment of all things. He finds in the influence of this spirit a most important factor of the empirical and positivist tendencies of Anglo-Saxon thought (35).

A blunt Puritan, NOAH BIGGS, evidences this attitude in his sharp attack on the universities of his day.

> ... wherein do they [universities] contribute to the promotion or discovery of truth?... Where have we any thing to do with Mechanicall Chymistrie the hand maid of Nature, that hath outstript the other Sects of Philosophy, by her multiplied real experiences? Where is there an examination and consecution

(34) This observation constitutes one of the many contributions of Professor JONES' valuable book, *Ancients and Moderns*. *Cf.* chap. 5, esp. pp. 112-13. The derivation of this emphasis upon empiricism was not sufficently clarified in my paper on "Puritanism, Pietism and Science," *The* [*English*] *Sociological Review*, Vol. XXVIII (1936), pp. 1-30.

(35) ERNST TROELTSCH, *Die Bedeutung des Protestantismus für die Entstehung der modernen Welt* (München : R. OLDENBOURG, 1911), pp. 80-81.

of Experiments? encouragements to a new world of Knowledge, promoting, completing, and actuating some new Inventions? where have we constant reading upon either quick or dead Anatomies, or an ocular demonstration of Herbs? Where a Review of the old Experiments and Traditions, and casting out the rubbish that has pestered the Temple of Knowledge? (36)

It was a common practice for Puritans to couple their intense scorn for a "jejeune Peripatetick Philosophy" with extravagant admiration for "mechanicall knowledge," which substituted fact for fantasy. From every direction, elements of the Puritan ethic converged to reinforce this set of attitudes. Active experimentation embodied all the select virtues and precluded all the baneful vices. It represented a revolt against that Aristotelianism which was traditionally bound up with Catholicism; it supplanted passive contemplation with active manipulation; it promised practical utilities instead of sterile figments; it established in indubitable fashion the glories of His creation. Small wonder that the Puritan transvaluation of values carried with it the consistent endorsement of experimentalism (37).

Empiricism and rationalism were canonized, beatified, so to speak. It may very well be that the Puritan ethos did not directly influence the method of science and that this was simply a parallel development in the internal history of science, but it becomes evident that, through the psychological sanction of certain modes of thought and conduct, this complex of attitudes made an empirically founded science commendable rather than, as in the mediaeval period, reprehensible or at best acceptable on sufferance. In short, Puritanism altered social orientations. It led to the setting up of a new vocational hierarchy, based on criteria which inevitably bestowed prestige upon the natural philosopher. As

(36) I am again indebted to Professor JONES (*ibid.*, p. 104) for this quotation from BIGG's *Mataeotechnia Medicinae Praxeos* (London, 1651), dedicated to the Reformist Parliament of the time.

(37) DURY, in a *Lettre du sieur Jean Dury touchant l'état présent de la religion en Angleterre* (London, 1658), writes of the Independents, "Ils ne croient que ce qu'ils voient." Quoted by GEORGES ASCOLI, *La Grande-Bretagne devant l'opinion française au XVII*[e] *siècle* (Paris : Librairie Universitaire J. GAMBER, 1930), Vol. I, p. 407; "I am an enemy of their philosophy that vilify sense!" wrote BAXTER. And, on the practical side, JOHN WILKINS affirms that "our best and most Divine Knowledge is intended for Action; and those may justly be counted barren studies, which do not conduce to Practice as their proper End." *Mathematical Magick*, p. 2.

Professor SPEIER has well said, " There are no activities which are honorable in themselves and are held excellent in all social structures." (38) And one of the consequences of Puritanism was the reshaping of the social structure in such fashion as to bring esteem to science. This could not but have influenced the direction of some talents into scientific fields which otherwise would have devoted to callings which were, in another social context, more highly honored.

The Shift to Science

As the full import of the Puritan ethic manifested itself—even after the political failure of the Revolution which should not be erroneously identified with the collapse of Puritan influence upon social attitudes—the sciences became foci of social interest. Their new fashionableness contrasts with their previous state of comparative obscurity (39). This was not without its effects. Many, who hitherto might have turned to theology or rhetoric or philology, were directed, through the subtle, largely unperceived and newly-arisen predisposition of society, into scientific channels. Thus, THOMAS WILLIS, whose *Cerebri Anatome* was probably the most complete and accurate account of the nervous system up to that time and whose name is immortalized in the " circle of WILLIS," " was originally destined to theology, but in consequence of the unfavorable conditions of that age for theological science, he turned his attention to medicine." (40)

No less indicative of a shift of interest is the lament of ISAAC BARROW, when he was Professor of Greek at Cambridge : " I sit lonesome as an Attic owl, who has been thrust out of the companionship of all other birds; while classes in Natural Philosophy are full." (41) Evidently, BARROW's loneliness proved too much for him, for, as is well known, in 1663, he left this chair to accept

(38) HANS SPEIER, " Honor and Social Structure," *Social Research*, Vol. II (1935), p. 79.

(39) *Cf.* SPRAT, *History...*, p. 403.

(40) BAAS, *Outlines of the History of Medicine*, p. 492.

(41) Quoted by HERMANN HETTNER, *Geschichte der englischen Literatur* (Braunschweig, 1894), 16-17.

the newly-established Lucasian Professorship of Mathematics, in which he was NEWTON's predecessor.

The science-loving amateur, so prominent a feature of the latter part of the century, is another evidence of the effect of this new attitude. Nobles and wealthy commoners turned to science, not as a means of livelihood, but as an object of devoted interest. Particularly for these individuals were direct utilitarian benefits of an economic nature a wholly negligible consideration. Science afforded them an opportunity of devoting their energies to a highly honored task; an imperative duty as the comforts of unrelieved idleness vanished from the new scale of values (42).

In the history of science the most famous of these amateurs is of course ROBERT BOYLE, but perhaps the best index of their importance is to be found in their rôle in the formation of the Royal Society (43). Of those who, in that " wonderful pacifick year," 1660, constituted themselves into a definite association, a considerable number—among them LORD BROUNCKER, BOYLE, LORD BRUCE, SIR ROBERT MORAY, Dr. WILKINS, Dr. PETTY and ABRAHAM HILL—were amateurs of this type. Hardly less assiduous were the efforts of such virtuosi as LORD WILLUGHBY, JOHN EVELYN, SAMUEL HARTLIB, FRANCIS POTTER and WILLIAM MOLINEUX.

This social emphasis on science had a peculiarly fruitful effect, probably because of the general state of scientific development. The methods and objects of investigation were frequently not at many removes from daily experience, and could hence be understood not only by the especially equipped but by a large number of persons with comparatively little technical education (44). To be sure, dillettantish interest in science seldom enriched its

(42) This is clearly brought out by WILLIAM DERHAM's estimate of the virtuoso and zoologist, WILLUGHBY. " ... he prosecuted his design with as great application as if he had to get his bread thereby; all of which I mention... for an example to persons of great estate and quality that they may be excited to answer the ends for which God gives them estates, leisure, parts and gifts, or a good genius; which was not to exercise themselves in vain or sinful follies, but to be employed for the glory and in the service of the infinite Creator, and in doing good offices in the world." *Memorials of John Ray, consisting of his Life by Dr.* DERHAM, EDWIN LANKESTER (ed.) (London, 1846), pp. 34-35.

(43) MARTHA ORNSTEIN, *The Rôle of the Scientific Societies in the Seventeenth Century*, p. 91 ff.

(44) *Ibid.*, p. 53.

fruits directly, but it did serve to establish it more firmly as a socially estimable pursuit. And this same function was performed no less ably by Puritanism. The fact that science today is largely and probably completely divorced from religious sanctions is itself of interest as an example of the process of secularization. Having grown away from its religious moorings, science has in turn become a dominant social value to which other values are subordinated. Today it is much more common to subject the most diverse beliefs to the sanctions presumably afforded by science than to those yielded by religion; the increasing reference to scientific authority in contemporary advertisements and the eulogistic connotation of the very world " scientific " are perhaps not too far-fetched illustrations of the enhanced prestige of science (45).

The Process of Secularization

The beginnings of such secularization, faintly perceptible in the latter Middle Ages (46), were, in one sense, emerging more fully

(45) As Professor C. Bouglé remarks, " Science has decidedly advanced to the first rank in the table of values." *The Evolution of Values* (New York : Henry Holt & Co., 1926), p. 201.

(46) G. R. Owst, in his exemplary study based upon new documentary evidence, *Literature and Pulpit in Medieval England* (Cambridge University Press, 1933), pp. 188-89 ff; pp. 554-57, *et passim*, presents a painstaking analysis of medieval homilies, then so effective for the determination of the outlook of the folk, and notes this adumbrated tendency. As we have indicated it was the spokesmen of the medieval Church themselves who bade men to consider the work of God's hand in the multifarious appearances of Nature, and this was indeed a powerful justificatory principle for scientific pursuits. Associated with this, however, was the *odium theologicum* of secularized knowledge, but it was too much to expect the permanent abeyance of concerted efforts because of the peremptory prohibitions of the theologians. It was in part to combat this threatened secularization of knowledge, which became alarmingly noticeable with the great University movement of the twelfth century, that the Mendicant Orders were established. But " the very Mendicant preaching originally designed to steer a safe middle course in the moral and mental instruction of lay-folk was itself helping unconsciously to create a fresh crisis, in which such secularization would become at last inevitable." Owst, p. 189. It was with the advent of the post-Reformation religious ethic, which burst the last bonds of inhibitive control of natural philosophy and which created for it a rôle, then acceptable to scientists and religionists alike, of subserviency to ultimate religious goals and of autonomy within the scope of its investigations, that secularization

in the Puritan ethos. But the Puritan was not simply the last of the medievalists or the first of the moderns. He was both. It was in the system of Puritan values, as we have seen, that reason and experience began to be considered as independent means of ascertaining even religious truth. Faith which is unquestioning and not "rationally weighed," proclaimed BAXTER, is not faith, but a dream or fancy or opinion. In effect this grants to science a power which may ultimately limit that of religion. This unhesitant assignment of a virtual hegemony to science is based on the explicit assumption of the unity of knowledge, experiential and supersensuous, so that the testimony of science must perforce corroborate religious convictions (47).

This conviction of the mutually confirmatory nature of reason and revelation afforded a further basis for the favorable attitude toward experimental studies, which, it is assumed, will simply reinforce basic theological dogmas. The active pursuit of science, thus freely sanctioned by unsuspecting religionists, however, created a new tone and habit of thought—to use LECKY's phrase—which is the " supreme arbiter of the opinions of successive periods." (48) As a consequence of this change, ecclesiastics, no longer able to appeal to commonly accepted teachings of science which seem rather to contravene various theological doctrines,

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became as explicit and pronounced as it had hitherto been implicit and subdued. The Reformist tenets did not arise full-blown; they did not in their implications represent a radical break with the past, but, through a shift and intensification of emphasis, helped effect a change which, though prepared by a long history of antecedent tendencies, seemed saltatory. As OWST suggests, the Lollard teachings remind us " of the honoured place which Work has continued to hold in Protestant faith and practice. Its subsequent achievements, alike in science and industry, ... when ' meritory works ' are finally discountenanced, prove once again our kinship with the past. The gulf of the Reformation is thus bridged once more and the spiritual continuity of our history maintained in the face of all such inevitable changes." *Ibid.*, p. 557.

(47) There is so admirable an accord and correspondency between the findings of natural science and supernatural divinity, says BAXTER, that the former " greatly advantageth us " in the belief of the latter. *C. D.*, Vol. I, pp. 172-74. This illustrates the incipient tendency of theology to become in a sense the handmaid of science since religious concepts become dependent upon the type of universe which man can know. *Cf.* PAUL R. ANDERSON, *Science in Defense of Liberal Religion* (New York : PUTNAM, 1933), p. 191 ff.

(48) LECKY, *op. cit.*, Vol. I, p. 7. See also, A. C. MCGIFFERT, *The Rise of Modern Religious Ideas*, p. 18 *et passim.*

are likely once again to substitute authority for reason in an effort to emerge victorious from the conflict.

In one direction, then, Puritanism led inevitably to the elimination of religious restriction on scientific work. This was the distinctly modern element of Puritan beliefs. But this did *not* involve the relaxation of religious discipline over conduct; quite the converse. Compromise with the world was intolerable. It must be conquered and controlled through direct action and this ascetic compulsion was exercised in every area of life. It is, therefore, a grievous error to portray the Puritan espousal of science as simply an "accommodation" to the intellectual environment of the age (49). Such secularized elements there were, especially with the passage of time, but these were far less significant than the unyielding constraint for devotion to the thrice-blessed calling of natural philosopher.

Paradoxically but inevitably, then, this religious ethic, based on rigid theological foundations, furthered the development of the very scientific disciplines which later seem to confute orthodox theology.

The articulation of these several ideas, each the focus of strong sentiments, into a system which was all the more forceful precisely because it was psychologically rather than logically coherent, led to a long chain of consequences not least of which was the substantial destruction of this very system itself. Though the corresponding religious *ethic*, as we shall see, does not necessarily lose its effectiveness as a social force immediately upon the undermining of its theological foundations, it tends to do so in time. This sketch of the influence of science in the processes of secularization should serve to make intelligible the diverse, quite opposed rôles which religion and theology may play in their relations to science.

(49) This assumption is the one fundamental shortcoming of OLIVE GRIFFITH's otherwise excellent monograph, *Religion and Learning : A Study in Presbyterian Thought from* 1662 *to the Foundation of the Unitarian Movement* (Cambridge University Press, 1935). Her treatment unwarrantedly presupposes throughout that religious convictions are intrinsically static and change only through external pressures, whereas it is the contention of the present analysis that such changes are, in great part, the outcome of inherent tendencies which are gradually realized in the course of time. See my review of Dr. GRIFFITH's work in *Isis*, XXVI (1936), 237-39.

A religion—understood here, as throughout this essay, as those ethical and moral beliefs and practices which constitute a system of faith and worship, that is, as a religious ethic—may indirectly promote the cultivation of science, although specific scientific discoveries are at the same time vehemently attacked by theologians, who suspect their possibly subversive nature. Precisely because this pattern of interlocking and contradictory forces is so often unanalyzed, it is imperative that we distinguish clearly between the intentions and aims of religious leaders and the (frequently unforeseen) consequences of their teachings (50). Once this pattern is clearly understood, it is not surprising or inconsistent that LUTHER particularly, and MELANCHTHON less strongly, execrated the cosmology of COPERNICUS. In magisterial mood, LUTHER berates the Copernican theory : "Der Narr will die ganze Kunst Astronomiae umkehren. Aber wie die heilige Schrift anzeigt, so hiess Josua die Sonne still stehen, und nicht das Erdreich." (51) Likewise, CALVIN frowned upon the acceptance of numerous scientific discoveries of his day, whereas the religious ethic which stemmed from him inevitably inspired the pursuit of natural science (52).

(50) As Mr. TAWNEY put it, " So little do those who shoot the arrows of the spirit know where they will light." *Religion and the Rise of Capitalism*, p. 277. But CALVIN could also say : " Dieu a ressuscité les sciences humaines qui sont propres et utiles à la conduite de nostre vie, et, en servant à nostre utilité, peuvent aussi servir à sa gloire." *Cf.* OTTO RODEWALD, *Johannes Calvins Gedanken über Erziehung Bünde* (Westphalia : ZIEGEMEYER & Co., 1911), pp. 37 ff.

(51) Quoted by DOROTHY STIMSON, *The Gradual Acceptance of the Copernican Theory* (New York, 1917), p. 39. As Dean STIMSON suggests (p. 99), such denunciations were less influential than those of the Catholic clergy, largely because of the Protestant doctrine of the right to individual interpretation. This was one effective source of secularization.

(52) In view of this analysis, it is surprising to note the statement *credited* to MAX WEBER, that the opposition of the Protestant Reformers is sufficient reason for not linking Protestantism with scientific advance. See *Wirtschaftsgeschichte* (München : DUNCKER & HUMBLOT, 1924), p. 314. This remark is especially unanticipated since it does not at all accord with WEBER's discussion of the same point in his other works. *Cf. Gesammelte Aufsätze zur Religionssoziologie* (Tübingen : J. C. B. MOHR, 1922), Vol. I, pp. 564, 141 ; *Wissenschaft als Beruf* (München : DUNCKER & HUMBLOT, 1921), pp. 19-20. The explanation may be that the first is not WEBER's statement, since the *Wirtschaftsgeschichte* was compiled from classroom notes by two of his students, who may have neglected to make the required distinctions. It is unlikely that WEBER would have made the elementary error of confusing the opposition to scientific discoveries of the

This failure to foresee some of the most fundamental social effects of their teachings was not solely the result of the Reformers' ignorance. It was rather an outcome of that type of non-logical thought which deals primarily with the motives rather than the probable results of behavior. Righteousness of motive is the basic concern; other considerations, including that of the probability of attaining the end, are precluded. Action enjoined by a dominant set of values *must* be performed. But, with the complex interaction which society constitutes, the effects of action ramify. They are not restricted to the specific area in which the values were originally centered, occurring in interrelated fields specifically ignored at the outset. Yet it is precisely because these fields are in fact interrelated that the further consequences in adjacent areas react upon the basic system of values. It is this usually unlooked-for reaction which constitutes a most important factor in the process of secularization, of the transformation or breakdown of value-systems. This is the essential paradox of social action—the " realization " of values may lead to their renunciation. We may paraphrase GŒTHE and speak of " Die Kraft, die stets das Gute will, und stets das Böse schafft." (53)

Insofar as the attitudes of the theologians dominate over the, in effect, subversive religious ethic—as did CALVIN's authority largely in Geneva until the first part of the eighteenth century—scientific development may be greatly impeded. For this reason, it is of no small importance to discriminate between the early and late periods of Calvinism. The implications of these dogmas found expression only with the passage of time. But upon the relaxation of this hostile influence and with the influx of an ethic, stemming from it and yet differing significantly, science

Reformers with the unforeseen consequences of the Protestant ethic, particularly since he expressly warns against the failure of such discrimination in his *Religionssoziologie*. Nor would he have been apt to identify the attitudes of the Reformers themselves with those of their followers as the Protestant movement developed. See further the comment of TROELTSCH (*op. cit.*, Vol. II, pp. 879-80), to the effect that although CALVIN was himself antagonistic to some scientific discoveries, the consequence of his doctrine was to provide a ferment of opinion directly favorable to the espousal of science.

(53) See ROBERT K. MERTON, " The Unanticipated Consequences of Purposive Social Action," *American Sociological Review*, Vol. I (1936), 894-904.

takes on new life, as indeed was the case in Geneva from about the middle of the eighteenth century (54). This development was particularly retarded in Geneva because there the authority resting in CALVIN himself, rather than in the implications of his religious system, was not soon dissipated.

The Integration of Religion and Science

It is thus to the religious ethos, not the theology, that we must turn if we are to understand the integration of science and religion in seventeenth century England.

Perhaps the most directly effective belief in this ethos for the sanction of natural science held that the study of nature enables a fuller appreciation of His works and thus leads us to admire and praise the Power, Wisdom and Goodness of God manifested in His creation. Though this conception was not unknown to medieval thinkers, the consequences deduced from it were entirely different. For example, ARNALDUS of VILLANOVA, in studying the products of the Divine Workshop, adheres strictly to the medieval scholastic ideal of determining the properties of phenomena from *tables* (in which, according to the canons of logic, all combinations of chance were set forth) (55). But in the seventeenth century, the contemporary emphasis upon empiricism led to the investigation of nature primarily through experience (56). This difference in interpretation of substantially the same doctrine can only be understood in the light of the different values permeating the two cultures. Cloistered contemplation was forsaken; active experimentation was introduced.

The Royal Society was of inestimable importance, both in the propagation of this new point of view and in its actual application.

(54) See ALPHONSE DE CANDOLLE, *Histoire des sciences et des savants depuis deux siècles* (Geneva-Basel : H. GEORG, 1885), pp. 335-36.

(55) WALTER PAGEL, " Religious Motives in the Medical Biology of the XVIIth Century," *Bulletin of the Institute of the History of Medicine*, Vol. III (1935), 112.

(56) *Ibid.*, pp. 214-15. It is not maintained, of course, that this empiricist bent derived solely from Puritanism. As we shall see, at least one other source was economic and technological. But Puritanism did contribute an added force to this development which has often been overlooked.

These achievements gain added stature by contrast with the lethargy of the English universities. It is well known that the universities were the seats of conservatism and virtual neglect of science, rather than the nurseries of the new philosophy. It was the learned society which effected the association and social interaction of scientists with such signal results. The *Philosophical Transactions* and similar journals largely did away with the previously prevailing and unsatisfactory mode of communicating new scientific ideas through personal correspondence. Associated with the popularity of science was the new tendency to write even scientific works in the vernacular—so especial a characteristic of BOYLE—or, in any case, to have English translations of the esoteric Latin and Greek. It was this type of cumulative interaction between science and society which was destined to mould a climate of opinion in which science stood high in public esteem, long after its religious justification had been forgotten.

But in the seventeenth century, this justification was of sterling importance, not only in preparing the social atmosphere for a welcome acceptance of scientific contributions, but also in providing an ultimate aim for many of the scientists of the period. For a BARROW, BOYLE or WILKINS, a RAY or NEHEMIAH GREW, science found its rationale in the end and all of existence—His glorification and the Good of Man. Thus, from BOYLE :

> ... the knowledge of the Works of God proportions our Admiration of them, they participating and disclosing so much of the inexhausted Perfections of their Author, that the further we contemplate them, the more Footsteps and Impressions we discover of the Perfections of their Creator; and our utmost Science can but give us a juster veneration of his Omniscience (57).

(57) *Usefulness of Experimental Natural Philosophy*, pp. 51-52. BOYLE continues in this vein. " ... God loving, as he deserves, to be honour'd in all our Faculties, and consequently to be glorified and acknowledged by the acts of Reason, as well as by those of Faith, there must be sure a great Disparity betwixt that general, confus'd, and lazy Idea we commonly have of his Power and Wisdom, and the distinct, rational and affecting notions of those Attributes which are form'd by an attentive inspection of those Creatures in which they are most legible, and which were made chiefly for that very end." p. 53. *Cf.* RAY, *Wisdom of God*, p. 132; WILKINS, *Natural Religion*, p. 236 ff; ISAAC BARROW, *Opuscula*, Vol. IV, pp. 88 ff. *Cf.* NEHEMIAH GREW, *Cosmologia Sacra* (London, 1701), who points out that God is " the Original, and Ultimate End " and that " we are *bound* to study His works." pp. 64, 124. SPRAT, speaking for the

RAY carries this conception to its logical conclusion, for if Nature is the manifestation of His power, then nothing in Nature is too mean for scientific study (58). The universe and the insect, the macrocosm and microcosm alike, are indications of " divine Reason, running like a Golden Vein, through the whole Leaden Mine of Brutal Nature."

On such bases as these, then, was religion invoked as a sanctioning power of science. But it is necessary to place this and the similar connections previously noted in a proper perspective. This is imperative if we are to correct an unavoidable implication of this discussion, namely, that religion was the independent and science the dependent variable during this period, although as was remarked at the outset, this is not in the least our intention.

The integration of the Puritan ethic with the accelerated development of science seems undeniable, but this is simply to maintain that they were elements of a culture which was largely centered about the values of utilitarianism and empiricism (59). It is perhaps not too much to say, with LECKY, that the acceptance of every great change of belief depends less upon the intrinsic force of its doctrines or the personal capabilities of its proponents

Royal Society, explicitly defines the place of science in the means-end schema of life. " It cannot be deny'd, but it lies in the Natural Philosophers hands, best to advance that part of Divinity [knowledge] : which though it fills not the mind, with such tender, and powerful contemplations, as that which shews us Man's Redemption by a Mediator, yet it is by no means to be pass'd by unregarded : *but is an excellent ground to establish the other.*" *History...*, p. 83; also pp. 132-33, *et passim.*

(58) *Op. cit.*, p. 130. " If Man ought to reflect upon his Creator the glory of all his Works, then ought he to take notice of them all, and not to think anything unworthy of his Cognizance. And truly the Wisdom, Art and Power of Almighty God, shines forth as visibly in the Structure of the Body of the minutest Insect, as in that of a Horse or Elephant... Let us not then esteem any thing contemptible or inconsiderable, or below our notice taking; for this is to derogate from the Wisdom and Art of the Creator, and to confess our selves unworthy of those Endowments of Knowledge and Understanding which he hath bestowed upon us." MAX WEBER remarks this same attitude of SWAMMERDAM, whom he quotes as saying : " ich bringe Ihnen hier den Nachweis der Vorsehung Gottes in der Anatomie einer Laus." *Wissenschaft als Beruf*, p. 19. This constant tendency of leading scientists themselves to relate their studies to dominantly religious ideas gives proof that religion as a social force was considerable and that its high estimation of any activity was of moment.

(59) See ERNST TROELTSCH, *Die Bedeutung des Protestantismus für die Entstehung der Modernen Welt*, p. 80 ff., for a most lucid exposition of this point.

than upon the previous social changes which are seen—*a posteriori*, it is true—to have brought the new doctrines into congruence with the dominant values of the period. The reanimation of ancient learning; the hesitant, but perceptibly defined, instauration of science; the groping, yet persistent, intensification of economic tendencies; the revolt against scholasticism;—all helped bring to a focus the social situation in which the Protestant beliefs and scientific interests found acceptance (60). But to realize this is simply to recognize that both Puritanism and science were components of a vastly complicated system of mutually dependent factors. If some comprehensible order is to be attained, a fraction of this complex situation must be substituted for the whole; a defensible procedure only if this provisional formulation is not confused with a " complete explanation."

The integration of religious values and many of those basic to the contemporary scientists' activity is not fully evidenced by the fact that so many of the leading scientists and mathematicians of the day--for example, OUGHTRED, BARROW, WILKINS, WARD, RAY, GREW, *etc.*—were also clerics. Such service in the church may have been—though other evidence leads us to doubt it in these instances—a matter of economic consideration since the clerical life provided a fairly adequate income and ample leisure for the pursuit of science. Moreover, it must be remembered that every person appointed to a college fellowship had to be in holy orders. Hence such " external " considerations, are at best suggestive, not convincing. They are clearly less significant than those disclosed by a study of the lives of the outstanding scientists. BOYLE, though he never took orders, was deeply religious : not only did he devote large sums for the translation of the Bible and establish the BOYLE lectures in theology, but he learned Greek, Hebrew, Syriac and Chaldee that he might read the Scriptures in the original ! (61) For a similar reason

(60) LECKY, *op. cit.*, Vol. I, p. 6; SOMBART, *Quintessence...*, pp. 269 ff.

(61) BOYLE was Governor of the Corporation for the Propagation of the Gospel in New England, established by Parliament in 1649. On the deep and sincere religiosity of BOYLE, *cf.* GILBERT BURNET, *Lives and Characters* (London, 1833), pp. 351-60, for an account by a contemporary and friend; W. WHEWELL, *Bridgewater Treatise* (London, 1852), p. 273. See H. T. BUCKLE, *History of Civilization in England* (New York : BONI, 1925), p. 210.

did NEHEMIAH GREW, the estimable botanist, study Hebrew, as he states in his *Cosmologia Sacra*. NAPIER and NEWTON assiduously pursued theological studies and for the latter, science was in part highly valued because it revealed the divine power (62).

Religion, then, was a prime consideration and as such its teachings were endowed with a power which stands forth with striking emphasis. Moreover, there is no need of entering into the matter of the motivations of individual scientists to trace this influence for such indications are really supererogatory for our study. Irrespective of the possibility of tracing its direct influence upon specific individuals, it is apparent that the religious ethic, considered as a social force, so consecrated science as to make it a highly respected and laudable focus of attention.

It is this *social* animus which facilitated the development of science by removing the incubus of derogatory social attitudes and instilling favorable ones instead. It is precisely this social

(62) *Cf.* LOUIS T. MORE, *Isaac Newton: A Biography* (New York : CHARLES SCRIBNER'S Sons, 1934), p. 134; EDWIN A. BURTT, *The Metaphysical Foundations of Modern Physical Science*, pp. 281-83. Of some interest is the attitude towards NEWTON'S work in theology displayed by PARETO and LOMBROSO. The former states that it appears incredible, though true, that the great NEWTON could have written a book on the Apocalypse. *Traité...*, Vol. I, p. 354. CESARE LOMBROSO is much more extreme. " NEWTON himself can scarcely be said to have been sane when he demeaned his intellect to the interpretation of the Apocalypse." *The Man of Genius* (London : SCOTT, 1891), p. 324. PARETO and LOMBROSO might have cavilled similarly concerning JOHN NAPIER, the inventor of logarithms, who likewise deemed the writing of a book on the Apocalypse of greater importance than his work in mathematics. *Cf.* ARTHUR SCHUSTER and ARTHUR E. SHIPLEY, *Britain's Heritage of Science*, pp. 6 ff. These declarations of astonishment and dismay over the " inconsistencies " of seventeenth century scientists neglect both the nonlogical linkages in human conduct and the particular value-context of the age. Once these are taken into account, NEWTON'S diverse interests appear quite compatible within the given social context. It is significant that the influence of Puritan attitudes can be seen in the instances of BARROW and his successor NEWTON. *Cf.* BARROW'S *Of Industry*, pp. 2 ff., where, in typically Puritan terms, he exalts the serious and steady application of mind in the prosecution of reasonable designs for the accomplishment of some considerable good. Time must be employed usefully, and games, gaming, theatre-going, poetry, *etc.* must be eschewed. NEWTON likewise had a contempt for the " merely beautiful " and preferred the strictly " useful." His library represents an " almost puritanical selection "—there are no books of humor and practically none of literature, while in poetry there is represented only the Puritan bard, MILTON. *Cf.* R. DE VILLAMIL, *Newton: the Man* (London : G. D. KNOX, 1931). pp. 10-16.

influence which would seldom be noticed by the individual scientists upon whom it impinged (63). Yet since religion directly exalted science, since religion was a dominant social force, since science was obviously held in higher social esteem during the latter part of the century, we must infer that religion played an important rôle in this changed attitude, particularly because of so much external corroborative evidence. This minimum of inference is inescapable.

Community of Tacit Assumptions in Science and Puritanism

Up to this point we have been concerned, in the main, with the directly felt sanction of science by the Protestant ethic. Now, while this was of great importance, there was still another relationship which, subtle and difficult of apprehension though it be, was perhaps of equal significance. Puritanism was one element in the preparation of a set of largely implicit assumptions which made for the ready acceptance of the characteristic scientific temper of the seventeenth and subsequent centuries. It is not simply that Protestantism promoted free inquiry, *libre examen*, or decried monastic ascetism. These oft-mentioned characteristics touch only the bare surface of the relationship.

It has become manifest that in each age there is a system of science which rests upon a set of assumptions, usually implicit and seldom, if ever, questioned by most of the scientific workers of the time (64). The basic assumption in modern science, that is, in the type of scientific work which becoming pronounced in the seventeenth century has since continued, " is a widespread, instinctive conviction in the existence of an *Order of Things*,

(63) The difficulty of an individual clearly perceiving the influence of social forces upon his own behavior is expounded by EDUARD SPRANGER. " It is possible to understand... a historical character better than he does himself; partly because he has not made himself the object of theoretic reflection... and because he is unaware of all the facts which are necessary to the understanding of oneself." *Types of Men*, p. 367.

(64) WHITEHEAD, *Science and the Modern World*, chapter I; A. E. HEATH in ISAAC NEWTON : *A Memorial Volume*, edited for the Mathematical Association by W. J. GREENSTREET (London : G. BELL, 1929), p. 133; E. A. BURTT, *The Metaphysical Foundations of Modern Physical Science*.

and, in particular, of an Order of Nature." (65) This belief, this faith, for at least since HUME it must be recognized as such, is simply " impervious to the demand for a consistent rationality." (66)

In the systems of scientific thought of GALILEO, of NEWTON and of their successors, the testimony of experiment is the ultimate criterion of truth, but as has been suggested, the very notion of experiment is ruled out without the prior *assumption* that Nature constitutes an intelligible order, that when appropriate questions are asked, she will answer, so to speak. Hence this assumption is final and absolute (67). Now, as Professor WHITEHEAD has so well indicated, this " faith in the possibility of science, generated antecedently to the development of modern scientific theory, is an unconscious derivative from medieval theology." (68) But this conviction, prerequisite condition of modern science though it is, was not sufficient to induce its development. What was needed was a constant interest in searching for this order of nature in an empirical and rational fashion, *i.e.*, an *active interest* in this world and in its occurrences plus a specifically empirical approach. With Protestantism religion provided this interest --it actually imposed obligations of intense concentration on secular activity with an emphasis on experience and reason as bases for action and belief. The good works which for the sects influenced by Calvinism provided conviction of grace are not to be confused with the Catholic conception of " good works." In the Puritan case it involved the notion of a transcendental god and an orientation to the " other world," it is true, but it also demanded a mastery over this world through a study of its processes; while in the Catholic instance, it demanded complete absorption, save for an unbanishable minimum, in the supersensuous, in an intuitive love of God.

It is just at this point that the Protestant emphasis upon reason

(65) WHITEHEAD, *op. cit.*, p. 5.

(66) *Ibid.*, p. 6.

(67) *Cf.* E. A. BURTT in ISAAC NEWTON : *A Memorial Volume*, p. 139. For a classic exposition of this scientific faith, see ISAAC NEWTON's Rules of Reasoning in Philosophy, in the *Principia* (ANDREW MOTTE, trans.) (London, 1803). Vol. II, p. 160 ff.

(68) See WHITEHEAD, *op. cit.*, p. 19 and preceding for a discussion of this development.

and experience is of prime importance. In the Protestant system of religion, there is the unchallenged axiom, *gloria Dei*, and, as we have seen, the scheme of behavior which was non-logically linked with this principle tends to assume a utilitarian tinge. Virtually all conceptions other than this are subject to, nay, demand, the examination of reason and experience. Even the Bible as final and complete authority was subject to the interpretation of the individual upon these bases, for though the Bible is infallible, the " meaning " of its content must be sought, as will be remembered from BAXTER's discussion of this point. The similarity between the approach and intellectual attitude implicit in the religious and scientific systems is of more than passing interest. This religious point of view could not but mould an attitude of looking at the world of sensuous phenomena which was highly conducive to the willing acceptance and, indeed, preparation for, the same attitude in science. A similarity of this sort is noted by a recent commentator on CALVIN's theology.

> Die Gedanken werden objektiviert und zu einem objektiven Lehrsystem aufgebaut. Es bekommt geradezu ein naturwissenschaftliches Gepräge; es ist klar, leicht fassbar und formulierbar, wie alles, was der äusseren Welt angehört, klarer zu gestalten ist als das, was im Tiefsten sich abspielt (69).

The conviction in immutable law is as pronounced in the doctrine of predestination as in scientific investigation : " the immutable law is there and must be acknowledged " (das unabänderlich Gesetz ist da und muss anerkannt werden) (70). The similarity between this concept and the scientific approach is also clearly drawn by HERMANN WEBER :

> ... die Lehre von der Prädestination in ihrem tiefsten Kerne getroffen zu sein, wenn mann sie als Faktum im Sinne eines naturwissenschaftlichen Faktums

(69) HERMANN WEBER, *Die Theologie Calvins* (Berlin : ELSNER, 1930), p. 23.

(70) *Ibid.*, p. 29. The significance of the doctrine of God's foreknowledge for the reinforcement of the belief in natural law is remarked by BUCKLE, *op. cit.*, p. 482. It is significant that the first writer who maintained that even lotteries are governed by purely natural laws was a Puritan minister, THOMAS GATAKER, in his curious little book, *On the Nature and Use of Different Kinds of Lots* (London, 1619). This assumption, which ran over the barriers of religious differences, is not unrelated to the later development of " political arithmetic " by GRAUNT, PETTY and HALLEY.

begreift, nur dass das oberste Prinzip, das auch jedem naturwissenschaftlichen Erscheinungskomplex zugrunde liegt, die im tiefsten erlebte gloria dei ist (71).

The willingness of the Protestant leaders to have reason and experience " test " all religious beliefs, save the basic assumption, which just as in science, is simply accepted as a matter of faith, is in part grounded upon the previously mentioned conviction of the inherent consistency, congruence and mutually confirmatory nature of all knowledge, sensuous and super-sensory. It would seem, then, that there is, to some extent, a community of assumptions in Protestantism and science : in both there is the unquestioned basic assumption upon which the entire system is built by the utilization of reason and experience. Within each context there is rationality, though the bases be naive and non-rational (72). The significance of this fundamental similarity is profound though it could hardly have been consciously recognized by those whom it influenced : religion had, for whatever reasons, adopted a cast of thought which was essentially that of science so that there was a reinforcement of the typically scientific attitudes of the period. This society was permeated with attitudes toward natural phenomena which were derived from both science and religion and which unwittingly enhanced the continued prevalence of conceptions characteristic of the new science.

The " Crucial Experiment "

But it is not sufficient verification of our hypothesis to indicate the favorable social attitudes to science induced by the Protestant ethic. Nor, yet again, to indicate that the consciously felt motivation of many eminent seventeenth century scientists was

(71) *Ibid.*, p. 31. See WHITEHEAD, *op. cit.*, Chapter I, for a statement of similar characteristics of modern science.

(72) A modern logician has aptly remarked that the social sciences must locate the irrational (rather, non-logical) sources of both rational and irrational thought. *Cf.* RUDOLF CARNAP, " Logic," in *Factors Determining Human Behavior* (Harvard Tercentenary Publications, 1937), p. 118. Certainly Puritanism was not " the source " of modern science, but apparently it acted to stimulate such thought. *Cf.* WALTER PAGEL's similar comparison of the " irrationality and empiricism " of seventeenth century religion and science. *Op. cit.*, p. 112.

provided by this ethic. Nor, still further, that the cast of thought which is characteristic of modern science, namely, the combination of empiricism and rationalism and the faith in the validity of one basic postulate, an apprehensible order in Nature, bears an other than fortuitous congruence with the attitudes involved in Protestantism. All these facts can but provide formidable evidence of a certain probability of the connection we are tracing. The most significant test of our hypothesis, the *experimentum crucis*, as it were, is to be found by translating the Protestant ethic into action and noting to what extent, if at all, actual behavior coincides with that to be expected if these beliefs proved truly effective (73). If these doctrines were not infused with the motive power of sentiment, if they were not deep-abiding convictions which derived their force from the prevalent demand for conviction of personal salvation, then behavior will differ from pious affirmations. If, on the other hand, the Protestant ethic involved an attitudinal set favorable to science and technology in so many ways, then we should find amongst its adherents a greater propensity for those fields of endeavor than one would expect on the basis of their representation in the total population. Moreover, if, as has been frequently suggested (74), the impression made by these ethical teachings has lasted long after much of their theological basis has been largely disavowed (75), then even after the seventeenth century, this connection of Protestantism and science should subsist to some degree. The following chapter, then, will be devoted to further empirical data which may provide an experiential test of our hypothesis.

(73) Compare PARETO's discussion of the methodological value of dealing with " virtual movements," *Traité de sociologie générale*, Vol. I, pp. 58-59. *Cf.* LECKY, *op. cit.*, Vol. I, p. 21.

(74) *Cf.* GEORGIA HARKNESS, JOHN CALVIN : *The Man and His Ethics* (New York : Holt, 1931), p. 7, which is a highly competent study of the influence of the Calvinist ethic upon society. As TROELTSCH puts it : " The present-day world does not live by logical consistency, any more than any other; spiritual forces can exercise a dominant influence even where they are avowedly repudiated." *Die Bedeutung des Protestantismus*, p. 22.

(75) Two recent novels—GEORGE SANTAYANA's *The Last Puritan* and JOHN P. MARQUAND's *The Late* GEORGE APLEY—portray the persistence of these patterns of behavior among present day families with a Puritan tradition.

CHAPTER VI

PURITANISM, PIETISM AND SCIENCE : TESTING AN HYPOTHESIS

The story of the Royal Society has often been told, but only recently have the social origins of its founders and early members been studied. Although the Society developed from an antecedent interest in science, its subsequent achievements provided an appreciable impetus to further scientific advance. Moreover, it constituted the first scientific organization in England and in this connection, it affords singularly appropriate materials for our purposes. If Puritanism was as closely linked with science as we have been led to suspect, then the composition of this pioneer group should reflect this linkage.

Puritan Elements in the Royal Society

The inception of this group is found in the occasional meetings of devotees of science in 1645 and immediately thereafter. Among the leading spirits were JOHN WILKINS, JOHN WALLIS, JONATHAN GODDARD, and soon afterwards, ROBERT BOYLE and Sir WILLIAM PETTY, upon all of whom religious forces seem to have had a singularly strong influence. WILKINS was raised at the home of his maternal grandfather, JOHN DOD, an outstanding non-conformist theologian, and " his early education had given him a strong bias toward puritanical principles." (1) WILKINS' influence as Warden of Wadham College was profound; under it came WARD, ROOKE, WREN, SPRAT and WALTER POPE (his half-brother), all of whom were original members of the Royal

(1) EDWIN LANKESTER, (ed.), *Memorials of* JOHN RAY, pp. 18-19. P. A. W. HENDERSON, *The Life and Times of* JOHN WILKINS (London : BLACKWOOD & Sons, 1910), p. 36. Moreover, after WILKINS took holy orders, he became chaplain to LORD VISCOUNT SAY AND SEALS, a resolute and effective Puritan. WILKINS married CROMWELL's sister, ROBINA, but this did not prevent him from attaining an Anglican bishopric in later years.

Society (2). JOHN WALLIS, to whose *Arithmetica Infinitorum* NEWTON was avowedly indebted for many of his leading mathematical conceptions (3), was a clergyman with strong leanings toward Puritanism. The piety of BOYLE has already been remarked; the only reason he did not take holy orders, as he said, was because of the " absence of an inner call." (4)

THEODORE HAAK, the German virtuoso who played so prominent a rôle in the formation of the Royal Society, was a pronounced Calvinist. DENIS PAPIN, who during his prolonged stay in England contributed to notably science and technology, was a French Calvinist compelled to leave his country to avoid persecution. THOMAS SYDENHAM, sometimes called " the English Hippocrates," was an ardent Puritan who fought as one of CROMWELL's men. (5) SIR WILLIAM PETTY was a moderate Puritan; he had been a follower of CROMWELL (6), and in his writings he evinced clearly the influences of Puritanism. Of SIR ROBERT MORAY, described by HUYGHENS as the " soul " of the Royal Society, it could be said that " religion was the mainspring of his life, and amidst the courts and camps he spent many hours a day in devotion " (7).

I is hardly a fortuitous circumstance that the leading figures of this nuclear group of the Royal Society were divines and eminently religious men, though it is not quite accurate to maintain, as did Dr. RICHARDSON, that the beginnings of the Society were

(2) THOMAS G. JACKSON, *Wadham College, Oxford* (Oxford : Clarendon Press, 1893), pp. 115-16.

(3) In a letter, dated 24 October 1676, to HENRY OLDENBURG, secretary of the Royal Society, NEWTON acknowledges his indebtedness to this work for the ideas which led to the Method of Infinite Series, the Quadrature of Curves and the generalization of the Binomial Theorem.

(4) *Dictionary of National Biography*, Vol. II, p. 1028. This reason, effective also for SIR SAMUEL MORLAND's turning to mathematics rather than to the ministry, is an example of the direct working of the Protestant ethic which, as exposited by BAXTER, held that only those who felt an " inner call " should enter the clergy, and that orders could better serve society by adopting other accredited secular activities. It is in such instances as these that the direct religious enhancement of scientific development is cogently disclosed, whereas for the most part it must be inferred. On MORLAND, see the " Autobiography of SIR SAMUEL MORLAND," in J. O. HALLIWELL-PHILLIPS' *Letters Illustrative of the Progress of Science in England* (London, 1841), p. 116.

(5) Cf. JOSEPH F. PAYNE, THOMAS SYDENHAM, pp. 7-8, *passim.*

(6) The Protector saw fit to appoint PETTY to a chair in anatomy at Oxford,

(7) *D. N. B.*, Vol. XIII, p. 1299.

amongst a small group of learned men in which Puritan *divines* predominated (8). But quite clearly is it true that the originative spirits of the Society were markedly influenced by Puritan conceptions.

Dean DOROTHY STIMSON, in a recently published paper (9), has independently arrived at the same conclusion. She points out that of the ten men who constituted the "invisible college" in 1645, only one, SCARBROUGH was definitely royalist. About two of the others there is some uncertainty, though MERRET had a Puritan training. The others were all definitely Puritan. Moreover, among the original list of members of the Royal Society in 1663, 42 of the 68 for whom information pertaining to religious leanings is available, were clearly Puritan. Inasmuch as the Puritans comprised a relatively small minority in the English population, the fact that they constituted 62 per cent of the initial membership of the Society becomes even more striking. Hence, Dean STIMSON concludes : "That experimental science spread as rapidly as it did in seventeenth century England seems to me to be in part at least because the moderate Puritans encouraged it." (10)

In a more recent work (11), Professor RICHARD FOSTER JONES adds further evidence to the same effect. His extensive survey of seventeenth century writings on the contemporary natural philosophy reveals clearly the affinity between Puritanism, Baconianism and the new science. Moreover, as Professor JONES demonstrates, this relationship was widely recognized at the time. Many worthies of that day took the occasion to comment upon the close connection between the reformers of religion

(8) C. F. RICHARDSON, *English Preachers and Preaching* (New York : MACMILLAN Company, 1928), p. 177.

(9) DOROTHY STIMSON, "Puritanism and the New Philosophy in 17th Century England," *Bulletin of the Institute of the History of Medicine*, III (1935), 321-34. Dean STIMSON's brief, but meticulous and convincing, study proposes "the theory that Puritanism was an important factor, hitherto little regarded, in making conditions favorable to the new philosophy heralded by BACON and in promoting the type of thinking that helped to arouse interest in science and to create a ready reception for the work of the geniuses produced in that century." See also Dean STIMSON's "COMENIUS and the Invisible College," *Isis*, XXIII (1935), 373-388.

(10) *Ibid.*, p. 334.

(11) *Ancients and Moderns*, *op. cit.*

and of science (12). In fact, one of STUBBE's devices for discrediting the Royal Society was to point out its strongly Puritan cast! As Professor JONES has suggested: "The part which the Puritans played in furthering the values of science has so faded from view that it is hard to realize how conscious of the fact the Restoration was." (13)

The distinctive tendency of English scientists to engage in cooperative enterprise was not unrelated to the Puritan interest in such efforts. Following BACON's ambitious scheme for such cooperation, such Puritans as DURY, HARTLIB and PETTY repeatedly urged the need for such effective modes of interaction (14). The stage was set during the period of the Commonwealth. It was not mere chance, then, that the nucleus of the Royal Society was formed at this time.

This correlation of profound interest in both religion and science—which would perhaps have been incongruous in later times—was a thoroughly consistent aspect of the pervasive Protestant ethic. For this scheme of orientation embraced an undisguished emphasis upon utility as well as control of self and the external world, which in turn involved a preference for the visual, manual and concretely manageable rather than the purely logical and verbal. The Puritan advocacy of experimental science was not, however, the result of a reasoned process. Rather it was the inevitable outcome of an emotionally consistent circle of sentiment and beliefs linking into a chain of non-logic various designated activities which satisfied these sentiments. For persons imbued with such attitudes, the pursuit of science takes on the cast of a self-evident value. From this it need not be inferred that the Royal Society could have arisen only if these religious sanctions were present, but, on the other hand, it seems clear that such positive attitudes did much to encourage this development.

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(12) *Ibid.*, pp. 220-23, 239, 253, 264. MARCHAMONT NEDHAM, JOHN TWYSDEN, THOMAS SPRAT, MERIC CASAUBON and, most vociferously, HENRY STUBBE were among those who noted the Puritan espousal of science.

(13) *Ibid.*, p. 270.

(14) *Ibid.*, pp. 97, 157-58, *passim*.

The New Education : Things not Words

Nor was this relationship evidenced only within the Royal Society. LOCKE, the philosopher who most clearly formulated the current doctrines of utilitarianism and empiricism was educated in a Calvinist atmosphere by his father, and later at Oxford under the Puritan JOHN OWEN (15). The same emphasis was likewise manifested in the type of education which they fostered and, in part, introduced. The " formal grammar grind " of the schools was criticized by them almost as much as the formalism of the church. " The movement toward educational reform was essentially Puritan." (16) Plans for changing the current type of education presupposed antagonism toward the authority of the ancients, confidence in experimental learning and faith in the future.

> ... the members of the " reforming " party in the schools were generally to be found among the " reforming " party in the Church; for the Puritans, driven by persecution to Holland and Switzerland, had there come into contact with the strongest forces making for progress... Eager in the pursuit of the new knowledge which was rapidly opening out, the Puritans were enthusiastic also in their determination to apply the great principle enunciated by BACON, that since observation (use of the senses) and not scholastic philosophy is the true way to learning everyone can, with the aid of the right method, be taught everything (17).

Among these Puritans was SAMUEL HARTLIB who so consistently sought to introduce the new *realistic*, utilitarian and empirical education into England. HARTLIB formed the connecting link between the various Protestant educators in England and Europe

(15) See TROELTSCH, *Social Teachings*, Vol. II, pp. 636-37. It is of some interest that, as Dr. PARKER indicates, LOCKE's writings were widely read in the academies, whereas they were censured at Oxford in 1703, and his *Essay* proscribed.

(16) JONES, *op. cit.*, p. 124. Even the hide-bound universities temporarily succumbed to the Puritan interest in science. During the period of Puritan hegemony in Cambridge, many of the former studies were almost completely suspended and as HEYWOOD, an undergraduate at Trinity at the time that the Calvinist HILL was master, wrote : " My time and thought were more employed in practical divinity; and experimental truths were more vital and vivifical to my soul." See J. B. MULLINGER, *Cambridge Characteristics in the Seventeenth Century*, p. 181.

(17) IRENE PARKER, *Dissenting Academies in England* (Cambridge University Press, 1914), pp. 24-25.

who were earnestly seeking to spread the academic study of science. It was to HARTLIB that MILTON addressed his tractate on education, and SIR WILLIAM PETTY dedicated his " Advice... for the Advancement of some particular Parts of Learning," namely science, technology and handicraft. Moreover, it was HARTLIB who was instrumental in broadcasting the educational ideas of JOHN AMOS COMENIUS and finally in bringing him to England.

The Bohemian Reformist, COMENIUS, was one of the most influential educators in the seventeenth century. Basic to the system of education which he promulgated were the norms of utilitarianism and empiricism : values which could only lead to an emphasis upon the study of science and technology, of *Realia* (18). In his most influential work, *Didactica Magna*, he summarizes his views thus (19) :

> The task of the pupil will be made easier, if the master, when he teaches him anything, show him at the same time its practical application in everyday life. This rule must be carefully observed in teaching languages, dialectic, arithmetic, geometric, physics, etc.

> ... the truth and certainty of science depend more on the witness of the senses than on anything else. For things impress themselves directly on the senses, but on the understanding only mediately and through the senses... Science, then, increases in certainty in proportion as it depends on sensuous perception.

COMENIUS found welcome among Protestant educators in England who held the same views; individuals such as HARTLIB, JOHN DURY, JOHN WILKINS and THEODORE HAAK (who apparently suggested the meetings which culminated in the Royal Society) (20). At the request of HARTLIB, COMENIUS came to England for the express purpose of making BACON's " Solomon's House " a reality. As COMENIUS himself remarked : " Nothing seemed more certain than that the scheme of the great VERULAM, of

(18) WILHELM DILTHEY, " Pädagogik : Geschichte und Grundlinien des Systems," *Gesammelte Schriften* (Leipzig and Berlin : B. G. TEUBNER, 1934), Band IX, p. 163.

(19) JOHN AMOS COMENIUS, *The Great Didactic*, trans. by M. W. KEATINGE (London : A. & C. BLACK, 1896), pp. 292, 337; see also pp. 195, 302, 329, 341, *et passim*.

(20) *Cf.* ROBERT F. YOUNG, COMENIUS *in England* (Oxford University Press, 1932), pp. 5-9.

opening in some part of the world a universal college, whose one object should be the advancement of the sciences, would be carried into effect." (21) But this noble aim was frustrated by the social disorder attendant upon the rebellion in Ireland. However, the Puritan design of advancing science was not entirely without fruit. CROMWELL founded the only new English university instituted between the Middle Ages and the nineteenth century, Durham University, "for all the sciences." (22) And in both Oxford and Cambridge, during the height of the Puritan influence there, the study of science was considerably augmented (23).

Likewise, it was the Puritan HEZEKIAH WOODWARD, a friend of HARTLIB, who largely emphasized realism (things not words) and the teaching of science (24). In order to initiate the study of the new scientific studies on a much more widespread scale than had hitherto obtained, the Puritans instituted a number of Dissenting Academies. These were schools of university standing opened in various parts of the kingdom. One of the earliest of these was established by CHARLES MORTON who was himself a student at Wadham at the time that the nuclear group of the Royal Society was meeting there. At MORTON's Newington Green Academy pronounced stress was laid upon scientific studies. MORTON later went to New England where he was chosen Vice-President of Harvard College, and where he introduced his *compendium physicae*.

At the influential Northampton Academy, another of the Puritan educational centres, mechanics, hydrostatics, physics, anatomy and astronomy had an important place in the curriculum. These studies were pursued largely with the aid of actual experiments and observations (25). The same emphasis was found in virtually all of the Dissenting Academies : the treatises of the

(21) *Opera Didactica Omnia* (Amsterdam, 1657), Book II, preface.

(22) On CROMWELL's interest in education, and that of the Puritans generally, see the account by F. H. HAYWARD, *The Unknown* CROMWELL (London : ALLEN & UNWIN, 1934), pp. 206-30, 315, *et passim*.

(23) JAMES B. MULLINGER, *Cambridge Characteristics in the Seventeenth Century*, pp. 180-81, *et passim*.

(24) PARKER, *Dissenting Academies in England*, p. 39.

(25) *Ibid.*, pp. 78-87.

ancients were largely supplanted by those of the moderns : GRAVESANDE, ROHAULT, GASSENDI, NEWTON and LOCKE (26).

But the marked emphasis placed by the Puritans upon science and technology may perhaps best be appreciated by a comparison between the Puritan academies and the Universities. The Universities, even after they had introduced scientific subjects, continued to give an essentially classical education; the truly " cultural " studies were those which if not useless, were at least definitely non-utilitarian. The academies, in contrast, held that a truly liberal education was one which was " in touch with Life " and which should therefore include as many utilitarian and empirical subjects as possible. As Dr. PARKER puts it :

> ... the difference between the two educational systems is seen not so much in the introduction into the academies of " modern " subjects and methods as in the fact that among the Nonconformists there was a totally different system at work from that found in the Universities. The spirit animating the Dissenters was that which had moved RAMUS and COMENIUS in France and Germany and which in England had actuated BACON and later HARTLIB and his circle (27).

Continental Counterparts

This comparison of the Puritan academies in England and Protestant educational developments on the Continent is well warranted. The Protestant academies in France devoted much more attention to scientific and utilitarian subjects than did the Catholic institutions (28). When the Catholics took over many

(26) See H. MCLACHLAN, *English Education under the Test Acts* (Manchester University Press, 1931), esp. Appendix I, listing books read in the early Academies.

(27) *Ibid.*, pp. 133-34; see the similar comment of G. N. CLARK, *The Later* STUARTS, pp. 22-23. JONES (*op. cit.*, p. 120) presents a valuable summary of the Puritan views. " ' The Advancement of Learning ' becomes the ' Advancement of Piety and Learning.' Divinity is to be banished. Experiments are to take the place of classical science. Humanistic studies in general, with the possible exception of history, are to yield in importance to such practical and useful subjects as mathematics, geography, chemistry, and the like. Vocational courses are to be introduced because of their value to the individual and to mankind." DURY, PETTY, JOHN HALL, NOAH BIGGS, JOHN WEBSTER were among those to stress these aims.

(28) P. DANIEL BOURCHEMIN, *Étude sur les académies protestantes en France au XVII^e siècle* (Paris : GRASSART, 1882), p. 445 ff.

of the Protestant academies, the study of science was considerably diminished (29). Moreover, as we shall see subsequently, even in the predominantly Catholic country of France, a large proportion of the scientific contributions were being made by Protestants. Similarly, Protestant exiles from France in other countries included a relatively large number of scientists and inventors (30).

HENRI JUSTEL perhaps best typifies the leading rôle played by Huguenots in the development of French science (31). JUSTEL was in constant communication with the outstanding contemporary Protestant scientists, foremost among whom was CHRISTIAN HUYGHENS. He corresponded with OLDENBURG, the secretary of the Royal Society and son-in-law of the Reformist educator, JOHN DURY. His rôle as scientific correspondent and intermediary did much to facilitate the spread of interest in science.

Of course, the mere fact that an individual is *nominally* a Catholic or a Protestant has no bearing upon his attitude toward science. Only in so far as his thought and behavior is actuated and directed by their respective values does his religious affiliation become significant. Thus, it was only when PASCAL became thoroughly converted to the teachings of JANSENIUS, as embodied in the *Discours sur la réformation de l'homme intérieur*, that he perceived the " vanity of science." For JANSENIUS characteristically taught that above all we must beware of that vain love of science, which though seemingly innocent, is actually a snare " leading men away from the contemplation of eternal truths to rest in the satisfaction of the finite intelligence." (32) Once

(29) M. NICHOLAS, " Les académies protestantes de Montauban et de Nîmes," *Bulletin de la société de l'histoire du protestantisme français*, IV (1858), 35-48.

(30) DAVID C. A. AGNEW, *Protestant Exiles from France*, 2 folio volumes (Edinburgh : 1866), p. 210 ff., *et passim*. These included the physician and chemist THEODORE TURQUET DE MAYERNE, DENIS PAPIN, the CHAMBERLENS (four generations of physicians), ABRAHAM DE LA PRYME, the mathematician ABRAHAM DE MOIVRE, JEAN THEOPHILUS DESAGULIERS, LEWIS PAUL (inventor of the spinning frame), JOHN DOLLOND (inventor of the achromatic telescope) and many others.

(31) HARCOURT BROWN, " Un cosmopolite du grand siècle : HENRI JUSTEL," *Bulletin de la société de l'histoire du protestantisme français*, 1933, pp. 187-201; *Scientific Organizations in Seventeenth Century France* (1620-1680) (Baltimore : WILLIAMS & WILKINS Co., 1934), Chap. VIII.

(32) ÉMILE BOUTROUX, PASCAL (trans. by E. M. CREAK) (Manchester : SHERRATT & HUGHES, 1902), p. 16.

PASCAL was converted to such beliefs, he resolved " to make an end of all those scientific researches to which he had hitherto applied himself." (33) Interpretations of correlations between religious affiliations and scientific interest are, then, subject to an important qualification. Nominal adherence to one or the other of these creeds will exercise little influence on conduct and may disturb the association in question.

New Science in New England

Puritanism was not less closely linked with science in the New World. The correspondents and members of the Royal Society who lived in New England were " all trained in calvinistic thinking." (34) " The founders of Harvard sprang from this [Calvinistic] culture, not from the literary era of the Renaissance or from the scientific movement of the seventeenth century, and their minds were more easily led into the latter than the former channel of thought." (35) This same predilection has also been noted by Professor MORISON, who indicates that the Puritan clergy in New England were foremost in their espousal and promotion of the new astronomy and science in general (36).

Meagre as the scientific production of colonial New England was, it none the less outstripped that of the other colonies.

(33) *Ibid.*, p. 17; *cf.* JACQUES CHEVALIER, PASCAL (New York and London : LONGMANS GREEN & Co., 1930), p. 143. *Cf.* PASCAL's *Pensées* (trans. by O. W. WIGHT) (Boston, 1884), p. 224, No. XXVII. " *Vanity of the Sciences.* The science of external things will not console me for ignorance of ethics in times of affliction; but the science of morals will always console me for ignorance of external sciences."

(34) DOROTHY STIMSON, " Puritanism and the New Philosophy in 17th Century England," *Bulletin of the Institute of the History of Medicine*, III (1935), 332.

(35) PORTER G. PERRIN, " Possible Sources of *Technologia* at Early Harvard," *New England Quarterly*, VII (1934), 724. On the basis of an examination of several hundred Puritan sermons, Professor SAMUEL ELIOT MORISON has declared, however, that the cardinal doctrine of Calvinism, predestination, was not stressed by the New England Puritans prior to JONATHAN EDWARDS. But he does hold that their theology was " of the Calvinistic family." See his ***Puritan Pronaos : Studies in the Intellectual Life of New England in the Seventeenth Century*** (New York University Press, 1936), pp. 10, 155-56.

(36) SAMUEL E. MORISON, " Astronomy at Colonial Harvard," *New England Quarterly*, VII (1934), 3-24; *cf* also his ***Puritan Pronaos***, Chap. X.

Moreover, an examination of the lists of the Royal Society reveals a preponderance of Puritans among the colonists elected Fellows : one from the Carolinas; Virginia, three; Pennsylvania, three (one of whom was BENJAMIN FRANKLIN); and New England, eleven (37).

Direct contact, as well as correspondence, served to transfer the new science to the New World. SAMUEL LEE (38) and CHARLES MORTON were among those science-minded Puritans who emigrated to New England. MORTON's *Compendium Physicae*, which was adopted at Harvard as a textbook in Physics, introduced a comprehensive, if imperfect, summary of the new science. " MORTON... was the principal agent for spreading in New England the scientific discoveries of the ' century of genius...' " (39) The younger JOHN WINTHROP, elected a member of the Royal Society at the first regular election, apparently visited HARTLIB, DURY and COMENIUS in London. It seems that he extended an invitation to COMENIUS to found a scientific college in the colonies; an invitation which evidently bore no fruit. (40) Some years later (in 1683), the Puritan INCREASE MATHER (President of Harvard College from 1684-1701) did found a " Philosophical Society " at Boston (41), which lasted about a decade. COTTON MATHER maintained a profound interest in the new science, using all the familiar arguments of RAY, BOYLE, DERHAM, and GREW to place this interest in a religious setting (42).

The scientific content of Harvard's educational program derived in large part from the Protestant PETER RAMUS (43). In the

(37) MORISON, *Puritan Pronaos*, pp. 234-35; 266. FREDERICK E. BRASCH, " The Royal Society of London and Its Influence upon Scientific Thought in the American Colonies," *The Scientific Monthly*, XXXIII (1931), 338.

(38) See THEODORE HORNBERGER, " SAMUEL LEE (1625-1691), a clerical channel for the flow of new ideas to seventeenth-century New England," *Osiris*, I (1936), 341-55.

(39) S. E. MORISON, *Harvard College in the Seventeenth Century* (Cambridge : Harvard University Press, 1936), Vol. I, pp. 238 ff.; 249.

(40) R. F. YOUNG, *Comenius in England*, pp. 7-8.

(41) *Ibid.*, p. 95.

(42) See KENNETH B. MURDOCK, *Selections from Cotton Mather* (New York, 1926), Introd.; THEODORE HORNBERGER, " The Date, the Source, and the Significance of COTTON MATHER's Interest in Science," *American Literature*, VI (1935), 413-20; also Professor HORNBERGER's recent brochure, *Science and the New World* (1526-1800) (San Marino : H. E. HUNTINGTON Library, 1937).

(43) PERRIN, *op. cit.*, pp. 723-24, who also observes that " RAMUS's interest

sixteenth century RAMUS had formulated an educational curriculum which in contrast to that of the Catholic universities, lay great stress on the study of the sciences (44). His ideas were welcomed in the Protestant universities on the Continent, at Cambridge (which had a greater Puritan and scientific element than its sister university Oxford) (45), and later at Harvard, but were firmly denounced in the various Catholic institutions (46). The Reformation spirit of utilitarianism and " realism " (empiricism) probably accounts largely for this favorable reception of RAMUS's views. The community of intellectual interests among Dissenters is further suggested by the resemblance between the Harvard curriculum and that of Rathmell Academy (47).

Pietist Realism

Dr. PARKER notes that the Puritan academies in England " may be compared with the schools of the Pietists in Germany, which under FRANCKE and his followers prepared the way for the *Realschulen*, for there can be no doubt that just as the Pietists carried on the work of COMENIUS in Germany, so the Dissenters put into practice the theories of COMENIUS' English followers,

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in science was augmented by BACON's influence, apparently a genuine force in the colonies, preparing them for Sir ISAAC NEWTON."

(44) ZIEGLER, *Geschichte der Pädagogik*, Vol. I, p. 108. ZIEGLER indicates that while the contemporary French Catholic institutions devoted only one-sixth of the curriculum to science, RAMUS devoted fully one-half of his educational program to scientific subjects.

(45) DAVID MASSON, *Life of Milton*, properly calls Cambridge the alma mater of the Puritans. In listing twenty leading Puritan clergymen in New England, MASSON found that seventeen of them were alumni of Cambridge, while only three came from Oxford, Vol. II, p. 563; see also STIMSON, *op. cit.*, p. 332; CHARLES E. MALLET, *A History of the University of Oxford* (London : METHUEN & Co., 1924), Vol. II, p. 147. During the Commonwealth, however, Puritan influence had installed WARD, WALLIS, PETTY, GODDARD and WILKINS in positions at Oxford. *Cf.* JONES, *op. cit.*, p. 114.

(46) HEINRICH SCHREIBER, *Geschichte der Albert-Ludwigs-Universität zu Freiburg*, 3 volumes (Freiburg, 1857-68), Vol. II, p. 135. For example, at the Jesuit University of Freiburg, RAMUS could only be referred to if he were refuted, and " no copies of his books are to be found in the hands of a student."

(47) S. E. MORISON, *Harvard College in the Seventeenth Century*, Vol. I, p. 166, n. 3.

HARTLIB, MILTON and PETTY." (48) The significance of this comparison is profound, for as has been frequently indicated, the ethical principles of Puritanism and Pietism are almost identical. COTTON MATHER had recognized the close resemblance of those two Protestant movements, saying that " ye *American puritanism* [is] so much of a piece with ye *Frederician pietism* " that they may be considered as almost identical (49). Pietism, except for its greater enthusiasm, might almost be called the continental counterpart of Puritanism. Hence, if our hypothesis of the association between Puritanism and interest in science and technology is warranted, the same association should obtain among the Pietists. And such was markedly the case (50).

The Pietists in Germany and elsewhere entered into a close alliance with the " new education " : the study of scientific and technologic subjects, of *Realia* (51). The two movements had in common the realistic and practical point of view, combined with an intense aversion to the speculation of Aristotelian philosophers and theologians. Fundamental to the educational views of the Pietists were the same deep-seated utilitarian and empirical attitudes which actuated the Puritans (52). It was on the basis of these views that the Pietist leaders, AUGUST

(48) PARKER, *op. cit.*, p. 135.

(49) KUNO FRANCKE, " COTTON MATHER and AUGUST HERMANN FRANCKE," *Harvard Studies and Notes*, V (1896), 63. See also the same observation so cogently made by MAX WEBER, *Protestant Ethic*, pp. 132-35.

(50) *Cf.* MAX WEBER, *Religionssoziologie*, Vol. I, p. 533. " Nützliche Realkenntnisse, vor allem empirisch-naturwissenschaftliche und geographische Orientierung, nüchterne Klarheit des realistischen Denkens und Fachwissen als Zweck der Erziehung sind planmässig zuerst von puritanischen, speziell in Deutschland von pietistischen Kreisen gepflegt worden. Einerseits als der einzige Weg der Erkenntnis von Gottes Ruhm und Vorsehung in dessen Schöpfung, andererseits aber als Mittel, im Beruf die Welt rational bemeistern und zu Gottes Ehre seine Schuldigkeit tun zu können."

(51) FRIEDRICH PAULSEN, *German Education: Past and Present* (trans. by T. LORENZ) (London : T. F. UNWIN, 1908), p. 104 ff.

(52) *Cf.* TROELTSCH, *Social Teachings*, Vol. II, p. 958. " ... the ideals of Pietism with regard to education are exactly the same as those of Puritanism." ALFRED HEUBAUM, *Geschichte des deutschen Bildungswesens seit der Mitte des siebzehnten Jahrhunderts*, 2 volumes (Berlin : WEIDMANNsche Buchhandlung, 1905), Vol. I, p. 90. " Ziel der Erziehung [of Pietism] ist praktische Verwendbarkeit des Zöglings im Gemeinwohl." " Der starke Einfluss des utilitaristischen Moments... vermindert die Gefahr der Übertreibung des religiösen Moments und sichert der Bewegung für die nächste Zukunft ihre Bedeutung."

HERMANN FRANCKE, the Bohemian, JOHN AMOS COMENIUS, and their followers emphasized the study of science and technology.

FRANCKE repeatedly notes the desirability of acquainting students with practical scientific knowledge (53). Both FRANCKE and his colleague, CHRISTIAN THOMASIUS, set themselves in opposition to the strong educational movement developed by CHRISTIAN WEISE which involved primarily training in oratory and classics, and sought " to introduce the neglected modern disciplines, which served their purposes more adequately; such studies as biology, physics, astronomy and the like." (54)

Wherever Pietism spread its influence upon the educational system there followed the large-scale introduction of scientific and technical subjects (55). Thus, FRANCKE and THOMASIUS built the foundations of the University of Halle, which was the first German university to introduce studies in the sciences on a markedly large scale (56). The leading professors, such as FRIEDRICH HOFFMAN (professor of medicine), ERNST STAHL (professor of chemistry and famous for his influential phlogiston theory), SAMUEL STRYK (professor of history) and, of course, FRANCKE, all stood in the closest relations with the pietist movement. All of them characteristically sought to ally science with its practical applications. The utilitarian character of their teachings is perhaps best expressed by THOMASIUS who states that " not the useless knowledge of Latin, but usefulness in life is the test of man's wisdom." (57)

Not only Halle, but other pietistic Universities manifested

(53) During walks in the field, says FRANCKE, the instructor should " nützliche und erbauliche Geschichten erzählen oder sonst etwas aus der Physik von den Geschöpfen und Werken Gottes vorsagen." " ... im Naturalienkabinet diente dazu, die Zöglinge in ihren Freistunden durch den Anstaltarzt mit naturwissenschaftlichen Erscheinungen, mit Mineralien, Bergarten, hier und da mit Experimenten bekannt zu machen." Quoted by HEUBAUM, *op. cit.*, Vol. I, pp. 88, 89.

(54) HEUBAUM, *op. cit.*, Vol. I, p. 136.

(55) *Ibid.*, Vol. I, pp. 176-77 ff.

(56) KOPPEL S. PINSON, *Pietism as a Factor in the Rise of German Nationalism* (Columbia University Press, 1934), p. 18; HEUBAUM, *op. cit.*, Vol. I, p. 118; "Halle war die erste deutsche Universität von ganz eigenartigem wissenschaftlichen und nationalen Gepräge..."

(57) CHRISTIAN THOMASIUS, " Vom Nachahmung der Franzosen," *Deutsche Literaturdenkmale des* 18. *und* 19. *Jahrhunderts* (Stuttgart, 1894), No. 51, p. 25.

the same emphasis. Königsberg, " having come under the pietistic influence of the University of Halle," through the activities of FRANCKE's disciple, GEHR, early adopted the natural and physical sciences in the modern sense of the seventeenth century (58). The University of Göttingen, another offshoot of Halle, was famous primarily for the great progress which it effected in the cultivation of the sciences (59). The Calvinistic University of Heidelberg was likewise prominent for instituting such a large measure of scientific study (60). Finally, the University of Altdorf, which was perhaps the most conspicuous example of the cultivation of science, was a Protestant university subject to pietistic influence (61). HEUBAUM summarizes the situation by saying that the essential progress in the teaching of science and technology occurred in Protestant, and more precisely, in pietistic universities (62).

This association of Pietism and science, which we have been led to expect from our hypothesis, did not confine itself to the universities. The same pietist predilection for science and technology was just as marked in secondary school education. The *Pädagogium* of Halle introduced the " subjects of mathematics and natural science, history and geography; stress being laid, in all cases, on the use of object-lessons and on practical applications." (63) JOHANN GEORGE LEIB, JOHANN BERNHARD VON ROHR, and JOHANN PETER LUDEWIG (Chancellor of Halle University), all of whom had come under the direct influence of FRANCKE and Pietism, advocated schools of manufacture, physics, mathematics and economics, in order to study " how manufacture might be ever more and more improved and excelled." (64) They wished that the outcome of these

(58) HEUBAUM, *op. cit.*, Vol. I, p. 153.

(59) *Ibid.*, Vol. I, p. 247; PAULSEN, *German Education*, pp. 120-21.

(60) ORNSTEIN, *The Rôle of Scientific Societies*, p. 228; HEUBAUM, *op. cit.*, Vol. I, p. 60.

(61) S. GÜNTHER, " Die mathematischen Studien und Naturwissenschaften an der nürnbergischen Universität Altdorf," *Mitteilungen des Vereins für Geschichte der Stadt Nürnberg*, Heft 3, p. 9.

(62) HEUBAUM, *op. cit.*, Vol. I, p. 241; see also PAULSEN, *op. cit.*, p. 122; J. D. MICHAELIS, *Raisonnement über die protestantischen Universitäten in Deutschland* (Frankfurt und Leipzig, 1768), Vol. I, section 36 ff.

(63) PAULSEN, *German Education*, p. 127.

(64) HEUBAUM, *op. cit.*, Vol. I, p. 184.

suggestions might be a so-called *Collegium physicum-mechanicum* and economic, mechanical and scientific *Werkschulen*.

It is a significant fact, and one which lends additional weight to our hypothesis, that the *ökonomisch-mathematische Realschule* was completely a pietist product. This school which was centered about the study of mathematics, the natural sciences and economics, and which was avowedly utilitarian and " realistic " in temper, was planned by FRANCKE (65). Moreover, it was a Pietist and a former student of FRANCKE, JOHANN JULIUS HECKER, who first actually organized a *Realschule* (66). SEMLER, SILBERSCHLAG, and HÄHN, the directors and co-organizers of this first scientific and technologic school, were all Pietists and former students of FRANCKE (67).

Educational Interests and Religious Affiliation

The tendency for Protestants to prefer scientific and technologic studies, which we are led to expect from the hypothesis we are developing, is markedly evident when we examine the available data concerning the allocation of educational interests by religion. We have already seen this tendency in the seventeenth century but it is pertinent to inquire whether it obtained in later periods. Schemes of orientation and patterns of behavior often persist long after the original motivations have disappeared. Our hypothesis may thus be further tested by comparing the proportions of Protestants and Catholics who attend the schools

(65) ALFRED HEUBAUM, " CHRISTOPH SEMLERS Realschule und seine Bezeihung zu A. H. FRANCKE," *Neue Jahrbücher für Philologie und Pädagogik*, II (1893), 65-77. See also THEOBALD ZIEGLER, *Geschichte der Pädagogik*, 2 volumes, (München : C. H. BECK, 1895), Vol. I, p. 197, who observes : " ... einem inneren Zusammenhang zwischen der auf das Praktische gerichteten Realschule und der auf das Praktische gerichteten Frömmigkeit der Pietisten fehlte es ja auch nicht, nur eine ganz einseitig religiöse und theologische Auffasung des Pietismus kann das verkennen : im Geist der praktischen Nützlichkeit und Gemeinnützigkeit ist dieser dem Rationalismus vorangegangen und mit ihm eins gewesen, and aus diesem Geist heraus ist zu Franckes Zeiten in Halle die Realschule entstanden."

(66) PAULSEN, *German Education*, p. 133.

(67) Upon the basis of this and other facts, ZIEGLER proceeds to trace a close " Kausalzusammenhang " between Pietism and the study of science in the schools. *Cf. op. cit.*, Vol. I, p. 196 ff.

primarily devoted to science and those which, in the main, deal with other subjects.

All available evidence points in the same direction. Protestants, without exception, form a progressively larger proportion of the study body in those schools which emphasize scientific training (68), whereas Catholics concentrate their interests on classical and theological training. For example, in Prussia the following distribution was found (69).

TABLE 9

Attendance at Secondary Schools Differentiated by Religious Affiliations of the Students—Prussia, 1875-76

Religious Affiliation	Pro-gym-nasium	Gym-nasium	Real-Schule	Ober-realsch.	Höhere Bürger-schule	Total	General Popula-tion
Protestants.	49.1	69.7	79.8	75.8	80.7	73.1	64.9
Catholics..	39.1	20.2	11.4	6.7	14.2	17.3	33.6
Jews......	11.2	10.1	8.8	17.5	5.1	9.6	1.3

This greater propensity of the Protestants for the scientific and technical studies accords with the implications of our hypothesis concerning the interests engendered by the Protestant ethic. That this distribution of interests is typical may be gathered from the fact that other investigators have noted similar tendencies in other instances (70). It is unlikely that these

(68) The characteristic feature of the *Gymnasium* is the classical basis of their curricula. Demarcated from these schools are the *Realschulen*, where the sciences predominate and where the modern languages are substituted for the classical tongues. *The Realgymnasium* is a compromise between these two types, having less classical instruction than the *Gymnasium* with more attention paid to science and mathematics. The *Oberrealschulen* and *höhere Bürgerschulen* are both *Realschulen;* the first with a nine-year course, the second, with a six-year course. *Cf.* FREDERICK L. BOLTON, *The Secondary School System of Germany* (New York : APPLETON & Co., 1900), p. 3 ff.

(69) ALWIN PETERSILIE, " Zur Statistik der höheren Lehranstalten in Preussen," *Zeitschrift des königlich Preussischen Statistischen Bureaus*, XVII (1877), 109. These and similar statistics suggest that it would be well worth while to determine the factors predisposing Jews toward higher education. But we are not concerned with this problem.

(70) *Cf.* EDOUARD BOREL, *Religion und Beruf* (Basel : WITTMER & C[ie], 1930), pp. 93 ff, who remarks the unusually high representation of Protestants in the technical professions in Basel; JULIUS WOLF, " Die deutschen Katholiken in Staat und Wirtschaft," *Zeitschrift für Sozialwissenschaft*, IV [n. f.] (1913),

distributions represent a spurious correlation resulting from differences in rural-urban distribution of the two religions, as may be seen from the pertinent data for the Swiss canton, Basel-Stadt. For 1910 and following—the period to which EDOUARD BOREL's study, with results similar to those of PETERSILIE, refers—the Protestants constituted 63.4 % of the total population of the canton, but only 57.1 % of the population of the city-proper of Basel, and 84.7 % of the rural population (71).

MARTIN OFFENBACHER's careful study, *Konfession und soziale Schichtung*, includes an analysis of the association between religious affiliation and the allocation of educational interests in Baden, Bavaria, Württemberg, Prussia, Alsace-Lorraine and Hungary. The statistical results in these various instances are of the same nature : Protestants, proportionately to their representation in the population at large, have a much higher attendance at the various secondary schools, with the difference becoming especially marked in the schools primarily devoted to the sciences and technology. In Baden (72), for example, taking an average of the figures for the years 1885-95 :

	Protestants	Catholics	Jews
	%	%	%
Gymnasien	43	46	9.5
Realgymnasien	69	31	9
Oberrealschulen	52	41	7
Realschulen	49	40	11
Höhere Bürgerschulen	51	37	12
Average for the five types of schools	48	42	10
In the general population—1895	37	61.3	1.5

199, notes that " die Protestanten ihren ' naturgemässen ' Anteil überschreiten gilt für die wissenschaftliche und sonstige intellektuelle Betätigung (mit Ausnahme des geistlichen Berufs) ..." In 1860, AD. FRANTZ had already noted the same fact. *Cf.* his " Bedeutung der Religionunterscheide für das physische Leben der Bevölkerungen," *Jahrbücher für Nationalökonomie und Statistik*, XI (1868), 51. *Cf.* also similar results for Berlin in *Statistisches Jahrbuch der Stadt Berlin*, XXII (1897), 468-72. BUCKLE, *op. cit.*, p. 482, notes that " Calvinism is favourable to science." *Cf.* also WEBER, *Protestant Ethic*, pp. 38, 189; and TROELTSCH, *Social Teachings...*, Vol. II, p. 894.

(71) *Cf.* " Die Bevolkerung des Kantons Basel-Stadt," *Mitteilungen des Statistischen Amtes des Kantons Basel-Stadt*, 1932, 48-49, and the same publication for the years 1910 and 1921.

(72) MARTIN OFFENBACHER, *Konfession und soziale Schichtung* (Tübingen und Leipzig : J. C. B. MOHR, 1900), p. 16.

Despite the fact that the *Realschulen* curricula are primarily characterized by their stress on the sciences and mathematics as contrasted with the relatively little attention paid to these studies in the *Gymnasien*, it should be noted that the *Gymnasien* also prepare for scientific and scholarly careers. But, in general, the attendance of Protestants and Catholics in the *Gymnasien* represents diverse interests. Available evidence suggests that the relatively high incidence of Catholics at the *Gymnasien* is due to the fact that these schools prepare for theology as well; while the Protestants generally use the instruction of the *Gymnasien* as a preparation for the other learned professions. Thus, in the three academic years, 1891-94, 226 or over 42 % of the 533 Catholic graduates of the Baden *Gymnasien* subsequently studied theology, while of the 375 Protestant graduates, only 53 (14 %) turned to theology, while 86 % went into the other learned professions (73).

Similarly, the Catholic apologist, HANS ROST, though he wishes to establish the thesis that " the Catholic Church has been at all times a warm friend of science," is forced to admit on the basis of his data, that the Catholics avoid the *Realschulen*, that they show " eine gewisse Gleichgültigkeit und Abneigung gegen diese Anstalten." The reason for this, he goes on to say, is " dass die Oberrealschule und das Realgymnasium nicht zum Studium der Theologie berechtigen : denn diese ist häufig die Triebfeder bei den Katholiken zum höheren Studium überhaupt." (74)

Thus, the statistics point to a marked tendency for Protestants, as contrasted with Catholics, to pursue scientific and technical studies. In general, this can also be seen in the statistics for Bavaria (75), for the years 1891-95 :

	Protestants %	Catholics %	Jews %
Total population	28.2	70.7	.9
Gymnasien	27.3	68.1	4.2
Progymnasien	44.4	49.4	6.0
Realgymnasien	54.4	34.8	10.5
Realschulen	41.8	49.5	8.1

(73) H. GEMSS, *Statistik der Gymnasialabiturienten im Deutschen Reich* (Berlin : WEIDMANN, 1895), pp. 14-20.

(74) HANS ROST, *Die wirtschaftliche und kulturelle Lage der deutschen Katholiken* (Koln : BACHEM, 1911), pp. 167 ff.

(75) OFFENBACHER, *op. cit.*, p. 17.

And, likewise, in Württemberg (76), an average of the years 1872-79 and 1883-98, gives us the following figures :

	Protestants %	Catholics %	Jews %
Total population—1880	69.1	30.0	.7
Gymnasien	68.2	28.2	3.4
Lateinschulen	73.2	22.3	3.9
Realschulen	79.7	14.8	4.2

Preponderance of Protestant Scientists

Uniformly, then, available statistics indicate the undue tendency, on the basis of proportion in the total population, of Protestants to turn to scientific and technologic studies, as would be expected if our hypothesis is valid. But there are further and conclusive tests to be applied. What are the relative frequencies of Protestants and Catholics among scientists? The relevant data are scarce and refer primarily to outstanding scientists, but those studies which do bear on this point come to similar conclusions : proportionately speaking, Protestants constitute an overwhelming majority of the leading scientists.

HAVELOCK ELLIS, in his study of British genius, does not treat this point directly, but affords some significant suggestions. In the three kingdoms, England, of course, and not simply because of the fact that it is almost completely Protestant, produces the greatest number of scientists of note (77). It is quite likely that the religious factor is of secondary importance in this instance, but what is more significant is the contrast between Protestant Scotland and Catholic Ireland. The former produces

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(76) *Ibid.*, p. 18. These data are corroborated by the study of LUDWIG CRON, for Germany, 1869-93, *Glaubenbekenntnis und höheres Studium* (Heidelberg : A. WOLFF, 1900). ERNST ENGEL also found that in Prussia, Posen, Brandenburg, Pomerania, Saxony, Westphalia and in the Rhine Province, there is a higher incidence of Evangelical students in those schools which provide a maximum of natural science and technical subjects. *Cf.* his " Beiträge zur Geschichte und Statistik des Unterrichts," *Zeitschrift des Königlich Preussischen Statistischen Bureaus*, IX (1869), 99-116; 153-212.

(77) *A Study of British Genius* (London : HURST & BLACKETT, 1904), p. 66.

twenty-one of the outstanding scientists on ELLIS' list as against one for Ireland. As ELLIS puts it :

> In science Scotland stands very high, Ireland extremely low... In order to realize the extraordinary preponderance of the Scotch over the Irish contingent, it must be remembered that until the present century the population of Ireland has been much larger than that of Scotland, and it may be noted that the one purely Irish man of science (TYNDALL) was of original English origin (78).

Of peculiar interest is the fact that this situation is reversed in the case of great actors and actresses. " ... the Scotch virtually do not appear at all, and the relative preponderance of the Irish is enormous." (79) This provides an unexpected confirmation of our hypothesis of the influence of the Protestant ethic. It will be remembered that this ethic involved an antagonism toward the theatre which, though it may easily be over-emphasized, was none the less powerful. This distribution of notable actors, inverse to that of scientists, found in a Catholic and a Protestant country, is precisely that which is to be expected from the practical application of such an attitude. The different allocation of interests as between the two groups is quite significant. Moreover, corroborative evidence on this point is furnished by the findings of ODIN.

ALFRED ODIN, in his careful study of French men of letters, indirectly provides some data relevant to our inquiry. He compares the number of eminent men of letters contributed by the three essentially Protestant cantons of Switzerland, that is, Geneva, Vaud and Neuchâtel, with the three almost exclusively Catholic cantons of Berne, Fribourg and Valais. The former have produced 147 French-writing littérateurs, of whom 35 were men of high talent, giving index figures according to ODIN's schema, of 52 1/2 and 12 1/2. In contrast, the Catholic cantons have produced only eight men of letters, on ODIN's list, of whom but one was highly talented, giving indices of 5 and .06 (80).

Furthermore, from 1539 to 1825, ten percent of all French men of letters were Protestant, but during this period the Protestant proportion of the population was from two to three

(78) *Ibid.*, pp. 66-67.

(79) *Ibid.*, p. 75.

(80) *Genèse des grands hommes* (Paris : Librairie universitaire, 1895), 2 volumes, Vol. I, pp. 477-78.

percent (81). These figures, moreover, are minimal since ODIN arbitrarily classified all doubtful cases as Catholic. Now, this apparent propensity of Protestants for " littérature " and the like would at first blush seem to contradict our hypothesis, since the Protestant ethic was antagonistic to such pursuits; but only until we examine the data more precisely, when we find, on the contrary, that there is a marked congruity. For, of these Protestant " men of letters " more than 52 percent were what ODIN calls the " *érudits*," " *spéculatifs*," *etc.*, that is, historians, philosophers, philologists, sociologists, jurists, and so on, whereas there is an " exceptional paucity of poets (4.7 %), dramatists (1.6 %) and actors (0 %)." (82) Thus, even within the field of letters, the predominant emphasis of the Protestants is on scientific and technical subjects, rather than on classical and literary matters, properly so-called. This accords fully, it will be recalled, with the findings of ELLIS concerning the differences between the Scotch and Irish.

Of added interest is the fact that about one-third (23 of 72) of those Protestant writers, the profession of whose father is known, were sons of clergymen. (83) Thus, in instances where the full force of the Protestant ethic was more apt to be felt as compared with the bulk of the Protestant population, and where opportunity existed for the cultivation of liberal studies, the representation is particularly high. It is manifestly impossible to compare these figures with the interests of the *sons* of Catholic clergy (since vows of celibacy preclude the very existence of such persons) but it is significant that Protestant pastors represent a much higher percentage of the Protestants on ODIN's list than do the Catholic clergy of the total number of Catholics (84). This is especially notable since the proportion of Catholic clergy to the Catholic population is greater than that of Protestant clerics to the Protestant population.

Of indirect, and not especially significant, bearing upon our study is GALTON's *English Men of Science*, based upon the replies of notable members of the Royal Society to a naïvely formulated

(81) *Ibid.*, Vol. I, pp. 480-81; Vol. II, Table XX, Plate XIV.
(82) *Ibid.*, Vol. I, p. 484.
(83) *Ibid.*, Vol. I, p. 485.
(84) *Ibid.*, Vol. I, p. 487; Vol. II, Table XXI, Plate XV.

questionnaire. Of every ten men of science, seven were of the established Church of England or of Scotland, while the other three either had no religious affiliation or were adherents of other Protestant sects. Roman Catholics were hardly represented (85), which is not surprising when one considers the small minority of the English population which they represented. Characteristic of GALTON's ingenuous inquiries is the following : " Has the religious creed taught in your youth had a deterrent effect on the freedom of your researches?" Of the eighty-one responses to this question, ninety percent answered " no " with varying degrees of emphasis and less than ten percent implied or stated expressly that it had had a deterrent effect. (86) The value of these results is impaired, first, by the small number of responses and second, by the basic assumption of the unquestioned competence of individual scientists to ascertain the highly subtle and largely unperceived influences of the religious milieu in which they were raised. This amounts to averaging a number of responses, probably erring in one direction, in the hope of arriving at a correct mean picture. However, to the extent that GALTON's researches do possess validity, it will be noted that they reinforce the hypothesis here in question.

There remains one study which has most carefully and circumstantially treated the association of certain religious affiliations with interest and accomplishment in science. If the foregoing investigations provide slight probabilities that the connection we have traced does in fact obtain, CANDOLLE's well-known *Histoire des Sciences et des Savants* increases these probabilities considerably. CANDOLLE finds that although in Europe, excluding France, there were 107 million Catholics and 68 million Protestants, on the list of scientists named foreign associates by the Academy of Paris, from 1666 to 1883, there were only eighteen Catholics as against eighty Protestants ! (87) But,

(85) FRANCIS GALTON, *English Men of Science* (London, 1874), p. 126.

(86) 39 Answered " no " without any additional comment; 12, " none " with emphasis; 14, " none " with various classes of reasons why it had not; 8 claimed it had had a good effect and not a bad; while only 8 suggested or explicitly remarked that their respective religious creeds had had an unfavorable effect upon their research. *Ibid.*, pp. 135-36.

(87) ALPHONSE DE CANDOLLE, *Histoire des Sciences et des Savants* (Geneva-Basel : H. GEORG, 1885) (2nd ed.), p. 329.

as CANDOLLE himself suggests, this comparison is not conclusive, since it omits French scientists, who are frequently Catholics. To correct that bias, he examines the list of foreign members of the Royal Society of London for two periods when there were more French scientists included than at any other time, in 1829 and 1869. In the former period, the total number of Protestant and Catholic scientists is about equal, while in 1869, the number of Protestants actually exceeds that of Catholics. But, outside the kingdom of Great Britain and Ireland, there were in Europe 139 1/2 million Catholics and only 44 million Protestants (88). In other words, though in the general population there were more than three times as many Catholics as Protestants, there were actually more Protestant than Catholic scientists of note.

However, there are yet more significant data than these which are based on different populations, where influences of political regimes and other non-religious factors may be suspected to prevail over the actual influence of religion. A comparison of closely allied populations serves largely to eliminate these extraneous factors, but the results are the same. Thus, on the list of foreign associates of the Academy of Paris, there is not a single Irish or English Catholic, although their proportion in the population of the three kingdoms exceeds a fifth. Likewise, Catholic Austria is not at all represented, while in general Catholic Germany is similarly lacking in the production of scientists of note relative to Protestant Germany. Finally, in Switzerland, where the two religions are largely differentiated by cantons, or mixed in some of them, and where the Protestants are to the Catholics as three to two, there have been fourteen foreign Associates, of whom not one was Catholic ! The same differentiation exists, for the Swiss and for the English and Irish of the two religions, in the list of the Royal Society of London and the Royal Academy of Berlin (89).

With the examination of these materials we complete the empirical test of our hypothesis. Puritanism, and ascetic

(88) *Ibid.*, p. 330. *Cf.* I. FĂCĂOARU, *Soziale Auslese* (Klausenberg : HUBER, 1933), pp. 138-39. " Die Konfession hat einen grossen Einfluss auf die Entwicklung der Wissenschaft gehabt. Die Protestanten wiesen überall eine grössere Zahl hervorragender Männer auf."

(89) *Ibid.*, pp. 330-31.

Protestantism generally, emerges as an emotionally consistent system of beliefs, sentiments and action which played no small part in arousing a sustained interest in science. To use the word " education " in its primitive sense, we may say that Puritanism was a basic component of the scientific education of this period. Patently, this is not to deny the importance of a host of other factors—economic, political, and above all the self-fertilizing movement of science itself—which served to swell the rising scientific current. No doubt, too, these associated factors outweighed the religious component in certain historical situations. The burgeoning of science in sixteenth century Italy testifies to this. But the rise of science which antedated the Reformation or developed quite independently of it does not negate the significance of ascetic Protestantism in this respect. Rather, it attests that other circumstances may equally conduce to the espousal of science and that these factors may be sufficiently effective to overcome the antagonism involved in the existing religious system.

Furthermore, if for the purposes of investigation, the relations between Puritanism and science have been isolated from a wider social context, the concrete importance of this context is not thereby denied. It may well be argued that ascetic Protestantism itself is the product of more pervasive cultural changes (90). In this research, however, we are not concerned with such far-reaching questions. In any case, it is evident that the formal organization of values constituted by Puritanism led to the largely unwitting furtherance of modern science. The Puritan complex of a scarcely disguished utilitarianism; of intramundane interests; methodical, unremitting action; thoroughgoing empiricism; of the right and even the duty of *libre examen;* of anti-traditionalism —all this was congenial to the same values in science. The happy marriage of these two movements was based on an intrinsic compatibility and even in the nineteenth century, their divorce was not yet final.

This section of our study may be summarized in more general terms as a culture case-study of the non-logical roots of intellectual development.

(90) This is essentially the position of Professor P. A. SOROKIN in his *Social and Cultural Dynamics* (New York : American Book Co., 1937), esp. Vol. II.

CHAPTER VII

Science, Technology and Economic Development : Mining

In the last three chapters we have considered the relations between certain changes in the value system, particularly as expressed in Puritanism, and the growth of interest in science and technology. A parallel has been suggested between the norms governing the activities of the Puritan and of the scientist. But if this congeniality of the Puritan and the scientific temper partly explains the increased tempo of scientific activity during the later seventeenth century, by no means does it account for the particular foci of scientific and technologic investigation. Which forces guided the interests of scientists and inventors into particular channels? Was the choice of problems a wholly personal concern, completely unrelated to the socio-cultural background? Or was this selection significantly limited and guided by social forces? If so, what was the extent of this influence? (1) Without attempting to answer these questions fully, this and the two chapters following are devoted to an examination of empirical materials bearing on these problems.

The Growth of Mining

However engrossed he may have been in his work, the seventeenth century scientist could scarcely remain oblivious to the profound economic growth of his time. There occurred a striking

(1) " ... if we wish to understand why science has taken on the complexion it has, we shall have to ask ourselves some questions about the nature of the forces that have directed scientific attention to certain fields, to the exclusion of others." Professor H. Levy in Julian Huxley's *Science and Social Needs* (New York : Harper & Brothers, 1935), p. 15. *Cf.* Erwin Schrödinger, *Science and the Human Temperament*, trans. by James Murphy and W. H. Johnston (New York : W. W. Norton, 1935), p. 87; also pp. 99-100. " ... there must always be a large number of alternative experiments—and very practical experiments too—which we do not think of at all, simply because our interest is attracted in other directions."

change in the scale and amplitude of economic enterprise. Capitalism, well-defined, widely-extended, is moving in. The once popular view that capitalistic enterprise first followed upon the largely apocryphal Industrial Revolution (2) is now properly discredited. In closer accord with the facts is the view that at least the extractive industries, the textile manufacture and the metal trades of the seventeenth century all exhibited, in varying degree, the characteristics of capitalism (3). The growth of markets and a pronounced division of labor became associated with the markedly increased incidence of capitalistic undertakings, of large-scale production, to such a degree, that this change may well be compared to that which occurred toward the close of the eighteenth century (4).

Associated with the inroads of capitalism is a complex of interests, wants and activities, a far-reaching process of rationalization (5), and an application of scientific and empirical technical

(2) The classical exposition of this view is found in ARNOLD TOYNBEE'S *The Industrial Revolution in England* (London, 1884).

(3) E. LIPSON, *The Economic History of England* (London : A. & C. BLACK, 1931), Vol. II, p. 8 ff.

(4) See J. U. NEF, *The Rise of the British Coal Industry*, 2 volumes (London : GEO. ROUTLEDGE & Sons, 1932). This is perhaps the most elaborate and painstaking account of any British industry of this period, and certainly, of the coal industry. NEF observes : "... such information as has been found suggests that, while the expansion in coal mining was undoubtedly more rapid than that in other industries, this expansion is not an isolated phenomenon in early British economic history, the importance of which has not yet been fully appreciated. This industrial development not only involved a remarkable growth in the output of many commodities; there were also technical improvements and changes in organization, which, together with the evidence of rapid growth, leads us to suggest very tentatively that the late sixteenth and seventeenth centuries may have been marked by an industrial revolution only less important than that which began towards the end of the eighteenth century." Vol. I, p. 165.

(5) Though Professor ROBERTSON is justified in his contention that economic rationalism *was known* in the Middle Ages, and even in ancient Greece, it does not follow that the scale upon which it was present is sufficient to warrant his imputing the existence of wide-spread capitalism to those periods. PISANO'S *Liber Abbaci* (1202) is evidence of this rationalism, but does not justify the substantial identification of early Venetian capitalism and that of seventeenth century England. In the earlier periods, moreover, rationalism was not coupled with an intense motivation for breaking through the traditional order; an anti-authoritarian feature of ascetic Protestantism which led to a positive attitude toward innovation. *Cf.* H. M. ROBERTSON, *Aspects of the Rise of Economic Individualism* (Cambridge University Press, 1933), pp. 35-36 *et passim*; TALCOTT PARSONS, *Journal of Political Economy*, 43 (1935), 688-96.

knowledge to industrial processes (6). It is hardly an historical accident that the last year of the sixteenth century saw not only the publication of GILBERT's *De Magnete*, the first important scientific work produced in England and the augury of the new era of science, but also the chartering of the East India Company, the first English joint-stock company of importance and herald of the forthcoming bourgeois age.

Foremost among the economic enterprises of this period rank the extractive industries—the mining of coal, iron, tin, and copper—and textile industries. Though coal was occasionally used as a fuel in Roman Britain it did not become widely used until the latter part of the sixteenth century (7). Previous to that period, the use of coal in England had hardly justified any considerable mining, but by the beginning of the seventeenth century, coal was considered as part of the principal resources of the kingdom (8). The growth in coal production is reflected in the statistics of coal production assembled by NEF (9).

TABLE 10

Estimated Annual Production of the Principal Mining Districts (In Tons)

Coal Field	1551-60	1681-90	1781-90	1901-10
Durham and Northumberland	65,000	1,225,000	3,000,000	50,000,000
Scotland	40,000	475,000	1,600,000	37,000,000
Wales	20,000	200,000	800,000	50,000,000
Midlands	65,000	850,000	4,000,000	100,180,000
Cumberland	6,000	100,000	500,000	2,120,000
Kingswood Chase	6,000		140,000	
Somerset	4,000	100,000	140,000	1,100,000
Forest of Dean	3,000	25,000	90,000	1,310,000
Devon and Ireland	1,000	7,000	25,000	200,000
Total	210,000	2,982,000	10,295,000	241,910,000
Approximate increase		14 fold	3 fold	23 fold

(6) *Cf.* WERNER SOMBART, *Der moderne Kapitalismus*, 2 volumes (Leipzig: DUNCKER & HUMBLOT, 1902), Vol. I, Chap. XV; MAX WEBER, *Wirtschaft und Gesellschaft*, pp. 96-102; 124-29.

(7) NEF, *op. cit.*, Vol. I, p. 3 ff; LIPSON, *op. cit.*, Vol. II, pp. 112-13.

(8) NEF, *op. cit.*, Vol. I, p. 14 ff; *cf.* also DANIEL DEFOE, *The Complete English Tradesman* (London, 1727), Vol. II, p. 134 ff.

(9) NEF, *op. cit.*, Vol. I, pp. 19-20; see also LIPSON, *op. cit.*, Vol. II, p. 115.

These figures eloquently confound the usual view which places the revolution in the use of fuel in the latter eighteenth century. Moreover, an even more marked acceleration is apparent in the coal trafic at Newcastle and London during the late sixteenth and the seventeenth centuries : a multiplication of nineteen-fold in the former port, thirty-fold in London (10).

The increase in the use of coal was to a notable extent an outgrowth of the heightened scarcity and price of fire-wood (11); a development which was sufficient to do away with the prejudice against the " new fewl." Moreover, household consumption of coal was enhanced by the introduction of new fire-places (12). The change in the attitude toward the use of coal was further rationalized by indicating the extent to which maritime transport was stimulated by the fast-growing trade. ROBERT KAYLL, in an oft-quoted comment, rejoices that the " Newcastle voyages, if not the only, [are] yet the especial, nursery and school of seamen." (13) The validity of this statement is evidenced by the following statistics of the water transport of coal (14).

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(10) NEF, *op. cit.*, Vol. I, pp. 20-21; 123. *Cf.* LIPSON's statistics on the northern coal trade measured by the quantity of coal shipped from the Tyne and Wear. *Op. cit.*, Vol. II, p. 114.

1609	250,909 tons
1660	537,000 tons
1700	653,000 tons

(11) The following price indexes are quoted from WIEBE, *Zur Geschichte der Preisrevolution des 16. und 17. Jahrhunderts*, p. 375, by NEF, *op. cit.*, Vol. I, p. 158.

	1451-1500	1531-40	1551-60	1583-92
General Prices	100	105	132	198
Price of Firewood	100	94	163	277
	1603-12	1613-22	1623-32	1633-42
General Prices	251	257	288	291
Price of Firewood	366	457	677	780

(12) WILLIAM PETTY, *Economic Writings*, (C. H. HULL, ed.) (Cambridge University Press, 1899), Vol. II, p. 393 ff; C. POVEY, *A Discovery of Indirect Practices in the Coal Trade* (London, 1700).

(13) *The Trades Increase* (London, 1615), p. 25. LIPSON, *op. cit.*, Vol. II, p. 117, quotes COKE, " ' We glory much that the Newcastle trade in our home vent on coals, above all other trades, employs our shipping and mariners.' " The same attitude is evidenced by SIR PAUL NEILE who in 1663 protested that the use of " burning balls " as employed at Liége, " would prove prejudicial to shipping." THOMAS BIRCH, *The History of the Royal Society of London*, 4 volumes (London, 1576), Vol. I, p. 177. The significance of this enhanced shipping will be discussed subsequently.

(14) NEF, *op. cit.*, Vol. I, p. 79.

TABLE 11

Estimated Annual Trade in Water-borne Coal (In Tons)

	To	1541-50	1681-90
Shipped by Sea	The East and South-East Coasts of England	22,000	690,000
	Foreign Countries and the Colonies	12,000	150,000
	The West and South-West Coasts of England (including Wales)	4,000	80,000
	Ireland		60,000
	Scotland	3,000	50,000
Shipped by River	River Valleys	10,000	250,000
	Total	51,000	1,280,000

From this brief summary it may be seen that the coal industry expanded to an extent unknown previous to the seventeenth century. Furthermore, this expansion entailed a marked increase of the mercantile marine; a development which had significant repercussions upon the direction of scientific interests, as we shall see.

The increase in the production of tin, though by no means commensurate with that of coal, was marked after the middle of the seventeenth century. By this time the countries importing tin from England included almost all the European states; a trade in which the carriers were almost solely English (15). Evidence of the expansion of this industry is provided by the statistics of tin production in Cornwall and Devon (16).

1603......	1,320,030 lbs.	1647......	432,268 lbs. (Civil War Period).
1613......	1,369,032	1667......	2,040,750
1625......	1,682,370	1677......	3,009,782
1638......	1,200,625	1687......	3,271,290

(15) GEORGE R. LEWIS, *The Stanneries* (Boston and New York : HOUGHTON MIFFLIN & Co., 1908), p. 64.

(16) Adapted from *ibid.*, Appendix J.

The salt and glass industries likewise underwent a revolutionary expansion from 1560 to 1700 : " the increase in output... was only less rapid than the increase in the output in coal." (17) An exceptionally marked growth in the glass industry in the two decades prior to 1662 is noted by MERRET (18). The annual output of glass by the end of the seventeenth century was about 100,000 cases, or 10,000 tons, although before 1560 probably not one-fifteenth as much glass had been produced (19).

NEF presents evidence of a similar expansion in the alum and copperas, saltpetre, soap and beer brewing trades (20). The first seventy years of the seventeenth century witnessed the maximum development of the lead-mines, especially those of Mendip (21). In like fashion, iron-mining showed significant growth in this period, though the production of pig and bar iron was somewhat restricted by the shortage of charcoal (22). The only exceptions to this general advance in the metallurgic industries were those of brass and copper. Although these materials were needed for ordnance, there was a marked decline in their production after the Civil Wars; a decline which was halted only in the 1690's when a revival occurred (23).

Associated Technical Problems

What were the relations of these marked increases in the production of the extractive and metallurgic industries to the development of science and technology? In the first place, it is evident that many new technical problems were brought to the fore (24). Chief among these problems, as is apparent

(17) NEF, *op. cit.*, Vol. I, pp. 174 ff; p. 184.

(18) A. NERI, *Art of Glass*, translated by CHRISTOPHER MERRET (London, 1662), translator's preface.

(19) NEF, *op. cit.*, Vol. I, p. 183.

(20) *Ibid.*, Vol. I, p. 185 ff.

(21) J. W. GOUGH, *The Mines of Mendip* (Oxford : Clarendon Press, 1930), p. 112 ff.

(22) LIPSON, *op. cit.*, Vol. II, p. 155 ff.

(23) HENRY HAMILTON, *The English Brass and Copper Industries* (London : LONGMANS, GREEN & Co., 1926), p. 75 ff; p. 277 ff.

(24) In the discussion of the technical and scientific problems raised by certain economic developments, I follow closely the technical analysis of Professor B. HESSEN in his provocative essay, " The Social and Economic Roots of NEWTON's ' Principia,' " in *Science at the Cross Roads* (London : KNIGA,

from the persistent demands for its solution, was the efficient exploitation of deep mines. The most important handicaps to such exploitation were three : the presence of water in the mines, the limited supply of other than foul air and the difficulty of raising the ore to the surface.

These problems first became acute with the great increase in the depth of mines; a development which did not become marked until the late sixteenth and the seventeenth centuries. As LEWIS notes, it was at this time that one finds " unmistakable signs that mining was being pursued at depths which taxed to their utmost the rude machines for drainage then in vogue." (25) Not only was the problem of drainage thus rendered intense, but also that of ventilation.

> The ventilation of the tin works was probably not a pressing question until the sixteenth or seventeenth century, when long galleries began to be driven and shafts extended in depth. The old lode workers were much troubled by foul air, and went as far from the shaft only as the air would allow them to breathe (26).

These problems were vexing to the owners of collieries who constituted an extensive and influential class of entrepreneur. They invited and even demanded the application of inventive ability to these problems. The extent to which questions connected with the coal industry absorbed the attention of inventors is clearly manifested by a compilation of patent statistics for this period. Of 317 patents issued in England from 1561 to 1688, about 75 % (43 % directly; 32 % indirectly) were concerned with some aspect of this industry (27).

1932), pp. 147-212. Professor HESSEN's procedure, if carefully checked, provides a very useful basis for determining empirically the relations between economic and scientific development. These relations are probably different in an other than capitalistic economy since the rationalization which permeates capitalism stimulates the development of scientific technology. *Cf.* SOMBART, *Der moderne Kapitalismus*.

(25) LEWIS, *op. cit.*, p. 9. " ... pits were sunk 40, 50, and even 60 fathoms, and at once the question of drainage assumed the overwhelming importance that has clung to it ever since." *Cf.* A. WOLF, *History of Science, Technology, and Philosophy in the XVIth and XVIIth Centuries*, p. 551.

(26) LEWIS, *op. cit.*, pp. 12-13.

(27) Compiled by NEF, *op. cit.*, Vol. I, p. 254, from E. W. HULME, " The History of the Patent System Under the Prerogative and at Common Law," *Law Quarterly Review*, XII (1896), 141 ff; XVI (1900), 44 ff; and from the Patent Specification files in the Patent Office, London.

TABLE 12

Patents for Inventions, England, 1561-1688

Patents	1561-70	1571-90	1611-40	1660-88	Total
1. In which the relation to the coal industry is certain :					
Drainage of mines	3	3	14	23	136
Sounding for mines	—	—	1	—	
Lighting in mines	—	—	—	1	
Better furnaces, etc.	2	3	21	29	
Special treatment of coal	—	1	7	3	
Smelting	—	1	16	8	
2. In which there is a strong reason to suspect at least an indirect relation to the coal industry :					
Better means of communication (canals, harbor dredging, etc.)	1	3	15	16	99
Manufacturing processes	8	13	14	29	
3. In which a relation to coal is unlikely :					
Manufacturing processes / Agriculture	3	6	39	28	82
Agriculture				6	

It will be noted that 43, or about 14 % of the total of 317 patents, were devoted to solving the problem of mine drainage. PRICE observes similarly that about 20 % of the inventions patented between 1620 and 1640 were for water-raising and draining devices (28). This is a telling indication of the degree to which this one difficulty engaged the attention of inventive interest.

This relation between a problem raised by economic development and *technologic* endeavor is clear-cut and definite. It represents a connection which has frequently been observed in contemporary society as well. A predisposition to attend to those problems which are generally conceded to be of primary importance—and importance in the realm of technology is often concretely allied with economic estimations—does not presuppose that inventors

(28) WILLIAM H. PRICE, *The English Patents of Monopoly* (Boston and New York, 1906), p. 63.

are exclusively motivated by financial reward (29). Whatever the mainsprings of inventive activity, the fields in which it is exercised are not selected at random. We see that even during the earlier part of the seventeenth century, when individual innovators, far from engaging in coöperative enterprise, were working largely independently of one another, diffuse social and economic forces led to convergence toward a limited number of problems.

Although the choice of problems was partly limited by the state of empirical and scientific knowledge,—manifestly inventions presupposing an elaborate knowledge of, say, physical chemistry or electro-magnetism are initially ruled out—within this context current economic developments played a decisive rôle. Once this process was initiated, emulation served to reinforce it. The greatest value was of course imputed to those inventive achievements which aided the English quest for economic dominance; in the fields of textile manufacture, agriculture, mining and shipping. Precisely because of this imputed esteem, there occurred what Professor THOMAS calls " perseveration " or a " stepping-up " of patterns of innovation in these spheres (30). The process is self-sustained, for as the cumulative efforts of inventors to solve particular problems lead to larger increments of advance, the value imputed to such activity is likewise enhanced. This, in turn, serves only to intensify the predisposition of the inventor to direct his attention to these areas of research and application (31). It is this process which leads to inventive energies being engrossed by a relatively limited set of problems.

(29) *Cf.* F. W. TAUSSIG, *Inventors and Money-Makers* (New York : MACMILLAN Co., 1930).

(30) W. I. THOMAS, *Primitive Behavior* (New York : McGRAW-HILL Book Co., 1937), pp. 9 *et passim.*

(31) At a certain point, several orders of factors limit the perpetuation of this process. First among these is the progressive limitation of the possibilities of continued invention within a restricted field, with an asymptotic approach to the exhaustion of possibilities. Rapid technologic advance also engenders " premature " obsolescence of equipment—premature, that is, from the standpoint of the entrepreneur who has not fully exploited his older equipment. The economic advantages to be derived from the use of new inventions decrease as there is a growth in the capital investment which must be sacrificed. But these limiting factors had not begun to operate in the seventeenth century. See R. K. MERTON, " Fluctuations in the Rate of Industrial Invention," *The Quarterly Journal of Economics*, XLIX (1935), 454-74.

Technological changes during this century were in fact relatively slight, partly because scientific knowledge was as yet insufficiently elaborated to permit its effective application on a large scale. On the other hand, the inventive fever was rampant. This was truly an " age of projects," technological as well as commercial (32). Insofar as this interest led to effective inventions, these were canalized by a vigorous economic development which offered the most imperative problems for solution. The shifting cultural emphasis was simultaneously expressed in economic and technologic growth. Alternatives for invention were narrowed down to the relatively few dictated by economic exigencies (33).

Though the promising field of innovation was largely cultivated by the empiric, the inventor and the scientist were often one. Not least among these was HOOKE, the first " curator of experiments " of the Royal Society, who was at once a considerable scientist and probably the most prolific inventor of his age. His recently published diary discloses the varied pressure exerted upon him by the Society, the King and interested nobles to devote his studies to " things of use." (34) HOOKE would frequently repair to GARAWAYS or JONATHANS, the coffee-houses in Change Alley, where, with CHRISTOPHER WREN and others of their company, he would discuss " planetary motion " over a pot of tea while at nearby tables more mundane speculation engrossed the attention of stock-jobbers and lottery touts. Problems considered at GARAWAYS were often made the subjects of special inquiry by the Society. HOOKE was ordered to " consider of the engine [for blowing the fire in the brass works of Tivoli]

(32) *Cf.* JOSEF KULISCHER, *Allgemeine Wirtschaftsgeschichte* (München und Berlin : R. OLDENBOURG, 1928-29), Vol. II, p. 181. " Von der Mitte des 17. Jahrhunderts bricht, nach LAMPRECHT, ein Zeitalter an, wo ' ein allgemeines Erfindungseifer, man möchte fast sagen, ein wahres Erfindungsfieber sich erhebt.' "

(33) That this process continues to the present day is suggested by KUZNETS. " Why is progress not uniform in all branches of production, with the inventive and organizing capacity of the nation flowing in an even stream into the various channels of economic activity? What concentrates the forces of growth and development in one or two branches of production at a given time, and what shifts the concentration from one field to another as time passes? " S. S. KUZNETS, *Secular Movements in Production and Prices* (New York, 1930), p. 5.

(34) *The Diary of* ROBERT HOOKE, ed. by H. W. ROBINSON and W. ADAMS (London : TAYLOR & FRANCIS, 1935), pp. 157, 337, *et passim.*

to produce air by the fall of water." (35) In connection with the theoretical researches on air which he was conducting in collaboration with BOYLE, he added " a suggestion concerning the rarefying of chimneys, or the ways of ordering the combustible materials so, as that with a smaller consumption of the fuel, a greater heat may be given, than is done by the common ways yet in use." (36) Other trades were not neglected. As curator of the Society, he was asked to examine and, if possible, to suggest improvements in the processes of brick-, glass-, soap-, salt-making and sugar-refining (37). Hearing of a method of " softening steel," HOOKE was authorized to offer a reward for the secret (38). At a later meeting of the Society, WREN produced his new contrivance " for a more convenient winding up of weights by ropes, and serving for wells, mines and cranes." (39) In this direct fashion the Society furthered its design of prosecuting new inventions and putting them to use. It served as an effective agent for directing the attention of natural philosophers to tasks of economic importance.

Derived Scientific Interests

A further relation obtains between economic and scientific development. This derives from the varying degrees of connection between science and technology; a connection which was more pronounced in the seventeenth century than we are often led to believe.

The drainage of mines through the utilization of pumps, especially piston pumps, and water-conducting equipment, requires extensive investigation in the field of hydrostatics and aerostatics. The previous empirical devices embodied in the pumps used in the copper and silver mines of Bohemia and

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(35) R. T. GUNTHER, *Early Science in Oxford* (Oxford, 1930), Vol. VI, p. 234. This volume, " The Life and Work of ROBERT HOOKE," is a reprint of the several accounts by WALLER, WARD and AUBREY as well as the sections in BIRCH's minutes of the Royal Society which pertain to HOOKE.

(36) *Ibid.*, Vol. VI, p. 90; *cf.* pp. 91, 97.

(37) *Ibid.*, Vol. VI, pp. 90, 283, 316, 318.

(38) *Ibid.*, Vol. VI, p. 177.

(39) *Ibid.*, Vol. VI, p. 365.

Hungary were inadequate for draining the deeper pits in England (40). In the sixteenth century, the suction pump had departed little from ancient Roman devices, if we are to judge by AGRICOLA's description (41). It was necessary to utilize scientific knowledge in a practical manner if this problem was to be solved; hence it is not surprising to find such eminent scientists as TORRICELLI, HERIQUE and PASCAL, and more intimately connected with English endeavors, WILKINS, MORAY, HUYGHENS, PAPIN, BOYLE and HOOKE making significant contributions to this field (42).

BOYLE, keenly aware of the practical needs of his day, published " Inquiries touching Mines "; inquiries of the sort, OLDENBURG tells us, which " are necessary to beget sound Knowledge, and to excite profitable Inventions." (43) Prominent among the mining problems which BOYLE considered important were freeing the mines from water and from damps, devising instruments for breaking rocks, improving methods for raising and conveying ore and for ascertaining the depth and run of ore. It was precisely toward these pressing problems that an appreciable part of scientific and technical research was oriented.

That the exigency of solving these problems was well recognized by contemporary scientists is attested by their repeated instructions to Englishmen travelling on the Continent that they observe the European techniques in mining and metallurgy. Thus, Sir THOMAS BROWNE wrote to his son, EDWARD, that he examine the methods prevalent in Hungary and Germany (44). The consequence of this advice is to be found in a number of accounts of mining procedures published in the *Philosophical Transactions* (45).

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(40) NEF, *op. cit.*, Vol. I, p. 242.

(41) WOLF, *History of Science*, p. 512; *cf.* the whole of Chap. XXII in connection with mining.

(42) *Cf.* BIRCH, *History of the Royal Society of London*, *passim*. These volumes comprise the minutes of the Royal Society from December 1660 to 1688, thus providing a useful record of the scientific interests of the period.

(43) ROBERT BOYLE, " Articles of Inquiries touching Mines," *Philosophical Transactions*, I (1666), 330-43; HENRY OLDENBURG, in preface to the second volume of *Philosophical Transactions*, II (1667), 410.

(44) *The Works of Sir* THOMAS BROWNE, ed. by GEOFFREY KEYNES (London, 1931), Vol. VI, p. 44.

(45) Dr. EDWARD BROWNE, " Concerning Damps in the Mines of Hungary," *Philosophical Transactions*, IV (1669), 965-67; " A Relation concerning the

The fact finding travellers, such as RAY and WILLUGHBY, sent out by the Royal Society, were encouraged to make similar observations (46). Likewise, NEWTON in his letter of advice to his friend, FRANCIS ASTON, who was about to travel in Europe, suggested :

> Observe the products of nature in several places, especially in mines, with the circumstances of mining and of extracting metals or minerals out of their ore and refining them; and, if you meet with any transmutations out of one species into another (as out of iron into copper, out of any metal into quicksilver, out of one salt into another, or into an insipid body, etc.) those above all others will be worth your noting, being the most luciferous, and many times lucriferous, experiments too in philosophy (47).

The problem of establishing " a circulation of Air in the coal-chamber " engrossed the attention not only of colliery-owners, but also of empirical inventors and scientists. Characteristically, the preëminent natural historian, ROBERT PLOT, states that " the knowledge of the means whereby they [mining-damps] seem to be occasion'd, may not perhaps be thought less profitable to the Philosopher, than the cure of them to the Collier." (48) Less noteworthy members of the Royal Society, such as HENRY POWER, Sir PETER COLLITON and Sir JOHN HOSKYNS took up this matter. Devices for ventilation were discussed in the first volume of the *Transactions* by Sir ROBERT MORAY (49). This subject is closely tied up with investigations in aerostatics. It is thus significant to note that among the first experiments proposed to the Royal Society were those of BROUNCKER and BOYLE

Quick-silver Mines in Friuli," *ibid.*, IV (1669), 1080-85; " Concerning the Mines, Minerals, Baths, &c. of Hungary, Transylvania, Austria," *ibid.*, V (1670), 1189-98; " Concerning the Copper-Mine at Herrin-ground in Hungary," *ibid.*, V (1670), 1042-51.

(46) *Cf. e.g.*, JOHN RAY, *Travels through the Low Countries, Germany, Italy and France... To which is added an Account of the Travels of* FRANCIS WILLUGHBY (London, 1738—2nd ed.).

(47) In the subsequent part of this letter, NEWTON outlines in some detail the particular observations concerning mining technique which he wishes ASTON to make. *Cf.* the letter, dated 18 May 1669, quoted by L. T. MORE, ISAAC NEWTON, p. 51.

(48) *The Natural History of Staffordshire* (Oxford, 1686), pp. 133 and ff. *Cf.* also PLOT's earlier work, *The Natural History of Oxfordshire* (Oxford, 1677), p. 60 ff.

(49) " Adits and Mines wrought at Liege without Air-Shafts," *Phil. Trans.*, I (1665-66), 79-81.

(both of whom were interested in the problem of mine ventilation), in aerostatics and aerodynamics (50).

WREN turned his attention to an invention which might be of great value for raising ore from mines and presented the Society with a description of " an instrument for drawing up great Weights from deep Places." (51) LISTER, the physician and naturalist, who first conceived a geological map, sought to devise metallurgical methods which would be more profitable than those in common use. He was likewise concerned with improving the techniques of ventilating mines (52). In similar fashion, MERRET, JESSOP, HOOKE, MORAY, PAPIN, PLOT, POWLE, POPE, POVEY, JOHN WEBSTER, BEAUMONT, CONYERS, COLWALL, GLANVILL, and WILLIAM JACKSON, numbering among them some of the leading naturalists of the day, contributed papers on some practical phase of mining and metallurgy (53).

Perhaps a more vivid picture of the extent to which the foremost group of English scientists were occupied with practical problems in mining and metallurgy is afforded by the list of " histories " —in the Baconian sense—which they had assembled by 1667.

The History of English Mines, and Oars [*sic*] : and particularly two several Histories of Tinneries and Tin-working.

The Histories of Iron-making... of Refining : of making Copperas : of making Allum : of Saltpeter : of making Latten : of Lead : of making Salt out of Sea-water : of refining Gold : of making Pot-Ashes : of making Ceruse : of making Brass... (54).

Thus, during the first phase of the Royal Society accounts had been written of the techniques used in all of the leading metallurgical industries; accounts which frequently included suggestions for improvements and estimations of the profitableness of the various procedures.

Mineralogy, in the hands of such eminent investigators as PLOT, MERRET, SINCLAIR, CHARLES LEIGH, LISTER and JOHN WOODWARD, had well-defined practical implications. MERRET,

(50) BIRCH, *History of the Royal Society*, Vol. I, pp. 8-9.

(51) *Parentalia*, compiled by CHRISTOPHER WREN [son of Sir CHRISTOPHER WREN], (London, 1750), p. 246.

(52) *Phil. Trans.*, X (1675), 391-93; XVII (1693), 697-99; 737-40; 865-70.

(53) See *Phil. Trans.*, 1666-1702, *passim.*

(54) SPRAT, *History of the Royal Society*, p. 258.

for example, not only attended to mineralogy but investigated various methods of refining ores (55). BOYLE, who in many of his writings pleaded for a recognition of the practical utility of science (56), occupied himself with experiments to test the compressibility of water, a matter which is directly related to methods of pumping water from mines (57). In 1686, he described a special compression pump which in principle approximates closely to modern pumps (58). One sphere in which research was assiduous concerns the theory of the velocity of fluids. BOYLE, HOOKE, NEWTON, HALLEY—the greatest scientists of the day—carried on constant experimentation in this field. One experiment in particular—treated in NEWTON'S *Principia* (Bk. II, Prop. 37)—of the efflux of fluid through a hole in a full vessel was explicitly held by HALLEY to establish " severall things of great use in Hydraulicks as ye proportioning of pipes to the barrills of pumps." (59)

HOOKE, that irascible and erratic genius, conducted frequent researches in aero- and hydrostatics, which were explicitly noted to be of importance for the construction of water-pumps and the ventilation of mines. Both HOOKE and BOYLE investigated the rôle of air in respiration and at several meetings of the Royal Society HOOKE introduced experiments concerning the quantity of air which would serve for a certain number of respirations, making use of a bladder and a " large rarefying engine." (60) DENIS PAPIN, who was primarily a technologist directly concerned with the construction of machines for the raising of water or the driving of mill-works, was an assistant to the sterling scientist,

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(55) See his *Pinax rerum Naturalium Britannicum* (London, 1667), which is a noteworthy landmark in mineralogy, though it suffers in its botanical discussion from a too rigid adherence to the tradition of the herbalists. *Cf.* BIRCH, *op. cit.*, Vol. I, p. 10; *Phil. Trans.*, XII (1678), 1046-52.

(56) *Cf.* BOYLE'S *Works*, Vol. I, p. 359; Vol. II, p. 632; Vol. III, p. 141, p. 167, *passim*.

(57) *Cf.* EDMUND HOPPE, *Geschichte der Physik* (Braunschweig : F. VIEWEG & Son, 1926), p. 84.

(58) BOYLE, *Experiment. nov. physico-mech. : continuatio II* (London, 1686), p. 5. *Cf.* HOPPE, *op. cit.*, p. 104.

(59) *Correspondence and Papers of Edmund Halley*, edited by E. F. MACPIKE (Oxford : Clarendon Press, 1932), pp. 149-50. This experiment also linked hydrodynamics theory with military technology, as is indicated in Chapter IX.

(60) GUNTHER, *op. cit.*, Vol. VI, pp. 99, 309, *et passim;* WOLF, *op. cit.*, p. 62.

HUYGHENS. In fact, the air-pump with a plate and bell glass substituted for the usual flask-like receptacle with a stop-cock which is usually ascribed to PAPIN (61), was, as he himself acknowledged, previously invented by HUYGHENS in 1661 (62). GEORGE SINCLAIR, who made valuable scientific researches concerning air-pressure (63), was also directly concerned with the necessity for a constant supply of fresh air in mines (64).

The prehistory of the steam engine clearly illustrates the modes of interaction between science and technology. The convergence of the two streams of development led to their mutual benefit. It has often gone unrecognized that the precursors of WATT were not solely empirical mechanicians but illustrious scientists actively engaged in research with well-marked practical implications. The origin of modern interest in atmospheric pressure appears to have been an immediate technical problem. It is held that the discovery of atmospheric pressure was initiated by the inquiries of engineers in the service of COSMO DE MEDICI (65). GALILEO was asked to account for the failure to raise water to a greater height than approximately 32 feet by means of a common suction pump with a long suction-pipe. He suggested a variation of the familiar *horror vacui* doctrine, but subsequent experiments indicated that the answer lay in the weight of the atmosphere. His pupil, TORRICELLI, took up the problem at that point and in 1643 introduced the famous experiment in which he ascertained the resistance of a vacuum by a vertical column of mercury. PASCAL reinforced the Torricellian thesis by his experiments proving differential atmospheric pressure on mountains and lowlands.

About 1650, OTTO VON GUERICKE, at one time an army engineer, produced his air-pump. A few years later (1654), he demonstrated publicly the utility of this pump by raising great weights; a matter of great importance in the practice of mining. Hearing

(61) For example, by HOPPE, *op. cit.*, p. 104.

(62) ERNST GERLAND, *Leibnizens und Huyghens' Briefwechsel mit Papin* (Berlin : Königliche Akademie der Wissenschaften, 1881), p. 138.

(63) In his *Ars nova* (Rotterdam, 1669).

(64) See his *Hydrostaticks*, pp. 291-92.

(65) JOHN BOSSUT, *A General History of Mathematics* (London, 1803), pp. 252-53; ROBERT L. GALLOWAY, *The Steam Engine and Its Inventors* (London, 1881), p. 2; *cf.* KULISCHER, *Allgemeine Wirtschaftsgeschichte*, Vol. II, pp. 454-55.

of this success, BOYLE, in conjunction with HOOKE, contrived an air-pump in 1658-59, which they materially improved in 1667. HUYGHENS and PAPIN furthered this development (66), as did HAUTEFEUILLE. In a memoir addressed to the Royal Academy of Sciences in 1680, HUYGHENS described his invention of the first motive engine consisting of a cylinder and piston (67). He was evidently aware of the technical purposes to which this might ultimately be put, for he stated that there had long existed a need for a contrivance through which gunpowder might be utilized as a source of power, apart from its use in warfare (68). By utilizing the force of gunpowder and atmospheric pressure, this contrivance could be used for raising weights from great depths.

By this time PAPIN was in England, collaborating with BOYLE in a series of experiments in aerostatics. In 1679, he demonstrated his famous Digester to the Royal Society (69). He proposed several plans for raising water from mines (70). His last suggestion embodied the statement of a practicable method for using atmospheric pressure continuously for the transmission of power over a considerable distance. He likewise suggested the production of a vacuum under a piston by the condensation of steam, stressing in the same memoir the small cost of power thus derived (71). The uses to which he proposed to put this power reflect the leading economic and technical interests of the day : mining, military echnology and shipping (72).

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(66) See DENIS PAPIN, *Nouvelles expériences du vuide, avec la description des machines qui servent à les faire* (Paris, 1674).

(67) GALLOWAY, *op. cit.*, pp. 20 ff.

(68) CHRISTIANI HUYGHENII ZULICHEMII, *Reliqua Opera*, 2 volumes (Amsterdam, 1728), Vol. I, p. 280. Similar considerations were at the root of the frequent experiments with gunpowder conducted by members of the Royal Society. HOOKE was especially assiduous in this respect. *Cf.* BIRCH, *op. cit.*, Vol. I, pp. 295, 302, 333 *et passim.*

(69) BIRCH, *op. cit.*, Vol. III, p. 486. WATT made use of PAPIN's Digester in experiments on the force of steam. *Cf.* GALLOWAY, *op. cit.*, p. 138.

(70) Published in *Philosophical Transactions.*

(71) DENIS PAPIN, " Nova methodus ad vires motrices validissimas levi pretio comparandas," *Acta Eruditorum* (1690), 410-14; *cf.* GALLOWAY, *op. cit.*, pp. 39 ff. HOOKE had evidently arrived at much the same conclusion; *cf.* GUNTHER, *op. cit.*, Vol. VI, p. VIII.

(72) He aimed to apply this power to the raising of water and ore from mines; to project bullets over great distances and to propel ships against the wind. PAPIN, *ibid.*, p. 414.

SAVERY's engine does not properly belong to this development of atmospheric engines, but NEWCOMEN's contrivance does. NEWCOMEN was well aware of the scientific research on atmospheric pressure—he had communicated with HOOKE on this subject—and his engine embodied the ideas of both HOOKE and PAPIN. It may be seen, without tracing the development of the steam engine further, to what extent pure science and technology were mutually influenced. The largely independent discoveries of TORRICELLI and GUERICKE; of BOYLE and MARIOTTE and possibly also of HOOKE and PAPIN derived from the intense concentration of contemporary scientists on a relatively limited sector of mechanics. This focus of interest was apparently associated with the demands of technology which were rendered all the more urgent by economic developments.

The ramifications of NEF's statement that " there is a clear relation between the appearance of the extremely influential British School of ' natural philosophers ' and the growth of the British coal industry " should now be clear. There appeared in the seventeenth century a well marked pursuit of scientific studies which, directly and indirectly, were related to practical problems of mining. The natural philosophers sought, in OLDENBURG's words, " the marriage of Nature and Art, [whence] a happy issue may follow for the use and benefit of Humane Life." This is not meant to imply that all, or even the greater part, of scientific research was related to mining. If the allocation of subjects discussed at the meetings of the Royal Society is any criterion about 18 per cent of the total projects discussed were concerned with mining and metallurgy (73).

Modes of Economic Influence

It would seem, then, that a certain proportion of theoretical " pure " science is directly concerned with problems which derive from practical exigencies. It also sets up derivative studies

(73) See table on page 563. The geometric mean of the " percentage of scientific attention " devoted to these fields at meetings of the Royal Society in 1661, 1662, 1686 and 1687 is 17.5.

which are related only in a very indirect fashion to the immediate problems of technique. In this connection, however, it is important to distinguish the subjective attitudes of individual scientists from the social rôle played by their research. Clearly, many scientists of this period viewed their works as an " end-in-itself "; they were sufficiently enamoured of their subject to pursue it for its own sake, with no consideration of the immediate practical significance of their investigations (74). Nor is there any implication that all individual researches are necessarily linked to technical tasks. The significant point is that much of the scientific research of this period was oriented—not always with deliberate intent on the part of the scientist—toward subjects which were profoundly useful for technical development; subjects which because of the social and economic emphasis of the period came to the attention of scientists as worthy of further study.

Thus the relation between science and economic needs is seen to be twofold : direct, in the sense that certain scientific research is advisedly and deliberately pursued for utilitarian ends, and indirect, in so far as certain subjects, because of their technologic importance, are sufficiently emphasized to be selected for study though the scientists are not necessarily cognizant of their practical significance.

On the basis of the materials already examined, one is led to question SOMBART's generalization that seventeenth century technology was almost divorced from the contemporary science; that the scientist and inventor had gone their separate ways from the time of LEONARDO DA VINCI to the eighteenth century (75).

(74) *Cf.* the comment of Professor H. LEVY in JULIAN HUXLEY's *Science and Social Needs*, p. 20. " It does not seem to me that science becomes ' pure ' because there are individual scientific workers whose personal motive in carrying through investigation is that they desire simply to extend the boundaries of knowledge. The existence of such a motive does not necessarily enable them to lift themselves outside their historic social epoch, but it may mean that they will concentrate their attention on problems more remote from direct application."

(75) WERNER SOMBART, *Der moderne Kapitalismus*, Vol. I, pp. 466-67. In view of PAPIN's close connection with Huyghens and the Royal Society, it is difficult to understand SOMBART's grounds for citing him as an example of the " technological empiric." SOMBART, Vol. I, pp. 473-75. SOMBART's general opinion is adopted by FRANZ BORKENAU, *Der Uebergang vom feudalen zum bürgerlichen Weltbild* (Paris : F. ALCAN, 1934), pp. 2 ff.

To be sure, the alliance of the two was probably not so close as in later periods (76). But SOMBART's assertion that seventeenth century technology was essentially that of the empiric seems largely unfounded in view of the many instances of scientists turning their theoretical knowledge to practical account. WREN, HOOKE, BOYLE, HUYGHENS, PASCAL, HALLEY,—to mention but a few outstanding cases—devoted themselves to the prosecution of both theory and practice. What is even more important, scientists were almost uniformly confident of the practical fruits which their continued industry would ensure (77). It was this belief, quite apart from the question of its truth, which influenced their choice of problems. The grain of truth in SOMBART's thesis is reduced to the fact that these scientists were concerned not with furthering the development of industrial machinery for factory use—this had not developed sufficiently to claim their attention—but with inventions which implemented commerce, mining and military technique. In these fields, there is little evidence that " sich die Wege der Naturwissenschaftler und der Techniker geschnitten hatten."

In terms of either the motivation of scientists or of historical development, science can scarcely be considered simply as the outcome of economic or technologic needs. *Homo sapiens* does not trace his ancestry exclusively from *homo faber*. Yet it may now be suggested that within the context of a rationalized social and economic structure, the requirements of industrial technology which derive from economic development exert a powerful, though not exclusive, influence on the direction of scientific activity. Such influence may be exercised directly through social organizations specifically set up for that purpose. The modern industrial research laboratory and subsidies for scientific investigation granted by industry, state and private foundations

(76) But, as Dr. GILFILLAN's survey of the evidence suggests, even in more recent times the scientist has seldom devoted himself to technologic innovation. The modern professional inventor is typically a non-scientist who profits from the growing store of pure science which lends itself to practical application. See S. C. GILFILLAN, *The Sociology of Invention* (Chicago : FOLLETT Pub. Co., 1935), esp. pp. 86 ff.

(77) BORKENAU has in part perceived these necessary distinctions. " Die Naturwissenschaft des 17. Jahrhunderts stand nicht im Dienste der *Industriellen Produktion*, obwohl sie das seit BACONS Zeiten gewünscht hätte." *Op. cit.*, p. 3.

are now the most prominent agents which to a considerable degree determine the foci of scientific interests. But this represents only a formal organization of influences which have long been manifest. Even those pure scientists who do not come under the immediate aegis of such agencies are to some degree influenced by them since their interest is apt to be attracted to those areas of research to which their colleagues are devoting their efforts. Moreover, such control over scientific interests may also be exerted, though not so obviously perhaps, by the diffuse, unorganized forces which impinge upon the scientist as a member of a collectivity with certain intellectual interests and practical wants or needs.

To be sure, the widely accepted notion that " need " precipitates appropriate inventions and directs scientific interests demands severe qualification. Although, as ROSSMAN has indicated, invention in military fields frequently responds to the stimulus of war needs (78), and various disasters have effectively focused attention upon the need for devices to prevent the recurrence of such accidents (79), it is equally true that a multitude of human " needs " have gone unsatisfied throughout the ages. Moreover, countries which are generally considered to be the most needy of inventions, such as Amazonia and India, have, in fact, relatively little invention (80). In the technical domain, needs, far from being exceptional, are so general that they explain little. Each invention *de facto* satisfies a need or is an attempt to achieve such satisfaction.

Another consideration is pertinent. Need is an elliptical term which in this context always implies realization or consciousness of need. In other words, where an observer from a culture which has an established tradition of attempts to improve material welfare and to control nature may often detect a need in another society, that need *may not exist* for the members of the society under observation, precisely because of a difference in values and aims. Failure to recognize this fact represents the same kind

(78) JOSEPH ROSSMAN, " War and Invention," *American Journal of Sociology*, XXXVI (1931), 625-33.

(79) P. B. PIERCE, " The Genesis of Inventions : Discussion," *Transactions of the Anthropological Society of Washington*, III (1885), 165.

(80) S. C. GILFILLAN, *The Sociology of Invention*, p. 48.

of fallacy which is often implicit in the use of the concept "culture lag," when it is maintained that a given situation "calls for" certain cultural changes. Such judgments are valid only within certain value-contexts which assume that changes of a specific type are needed to effect an *imputed* goal. But it is only when the goal is actually part and parcel of the culture under consideration that one may properly speak of a need directing inventive interest in certain channels.

The fact is that need is not sufficient in itself to induce invention but acts as a precipitating and directive influence. Moreover, it plays this rôle only if the cultural context is one which places a high value upon innovation, which has a tradition of successful invention and which customarily meets such needs through technological invention rather than through other expedients. For, as Professor SOROKIN has suggested, certain economic pressures may be eliminated by migration of "surplus" population, by war, plundering and similar expedients. Likewise, military technology was substantially undeveloped by the Romans; their military supremacy resting primarily upon discipline and military strategy and tactics. Economic and military needs, then, may be satisfied by other than technologic means. But given the routine of fulfilling these wants by technologic invention, a pattern which was becoming established in the seventeenth century; given the prerequisite accumulation of technical and scientific knowledge which provides a basic fund from which to derive means of meeting the felt need; and it may be said that, in a limited sense, necessity is the (foster) mother of invention (81).

The directive influence of economic requirements may operate in an even more specific fashion. Scientists and inventors may be led to focus their interest not only on broad fields of economic activity but to select for investigation the particular problems

(81) It is more often the case, as VEBLEN has remarked, that invention is the mother of necessity. The ulterior consequences of the more important mechanical inventions have been neither foreseen nor intended, though they have commonly demanded a whole series of institutional and technological adjustments. See THORSTEIN VEBLEN, *The Instinct of Workmanship* (New York : MACMILLAN Co., 1914), pp. 316 ff.

which in their national economy are most pressing (82). Thus, in a country where fuel is plentiful and cheap but labor relatively high—in the United States, for example—there would be a greater tendency to effect technologic devices for reducing labor costs than to increase the efficiency of fuel consumption. In other areas, the contrary tendency may be found. This hypothesis may be readily checked—although its validity is not explored in this study—by a comparison of economic needs and the directions of scientific and technologic research in various societies.

In the seventeenth century, there appeared the beginnings of social organizations designed, at least in part, to bring pressing economic and military needs to the attention of scientist and inventor alike. Of course, earlier centuries had occasionally witnessed the nominally similar patronage of the scientist by kings or princes who were willing to seek any alliance which spelled profit or power. LEONARDO DA VINCI, to take a relatively late example, found himself in the service of Florence, Milan and Rome. But with the growth of science, more systematic efforts were made to harness this potential energy and thus to ensure practical benefits. The development of scientific societies was not unrelated to this interest in enlisting the scientist in the service of industry, commerce and army. For the rising bourgeoisie, science and technology held out a promise which was not to be ignored; for the scientist and inventor, economic developments introduced or emphasized problems which, if attacked and solved, promised some financial reward and more prestige.

(82) *Cf.* G. DE LEENER, " Sur les directions imposées par le milieu aux inventions techniques." *Archives sociologiques* (Institut Solvay), 1911, No. 190, Bulletin 12.

CHAPTER VIII

SCIENCE, TECHNOLOGY AND ECONOMIC DEVELOPMENT : TRANSPORTATION

One notable aspect of the economic expansion of this period was the need for more adequate means of transportation and communication. The growth of the coal trade particularly evoked the growth of the merchant marine (1), since water-transport was so much cheaper than that by land (2). Foreign trade had first reached considerable proportions in England in the second half of the sixteenth century (3). St. Helena, Jamaica, the East American coast, were but the beginnings of England's great colonial expansion. The growth of internal trade also enhanced the need for improved facilities for land and river transport : proposals for turnpikes and canals were common in the seventeenth century (4).

Growth of Transportation

The increase in foreign-trade, due in part to colonization,

(1) NEF, *op. cit.*, Vol. II, p. 79. " At the end of the seventeenth century nearly 1,300,000 tons [of coal] or more than forty per cent of the estimated British production of 3,000,000 tons per annum, appears to have been carried by water..." *Cf.* LIPSON, *op. cit.*, Vol. II, p. 118.

(2) The difference between costs of land and water transportation is strikingly, though perhaps exaggeratedly, indicated by PETTY. " The water carriage of goods round about the Globe of the Earth is but about double to the price of Land Carriage from Chester to London of the like goods." " Experiments to be made relating to Land-Carriage," *Phil. Trans.*, XIV (1684), 666.

(3) HENRI SÉE, *Modern Capitalism*, trans. by H. B. VANDERBLUE and G. F. DORIOT (New York : ADELPHI Co., 1928), p. 53; J. E. T. ROGERS, *The Economic Interpretation of History* (London, 1888), p. 317 ff.

(4) N. S. B. GRAS, *An Introduction to Economic History* (New York and London : HARPER & BROS., 1922), p. 221 ff; E. A. PRATT, *Inland Transport and Communication in England* (London, 1912), Chap. XIV. The Turnpike Act of 1663, the construction of the first turnpike in England from London to York in 1696, and several proposals for canals indicate the contemporary interest in improving avenues of transport.

was assuming world-wide proportions. The best available, though defective, statistics bear testimony to the growth of commerce (5). Associated with this was of course the increase

FOREIGN TRADE OF ENGLAND

	Exports	Imports
1613..........	£2,487,435	£2,141,151
1622..........	2,320,436	2,619,315
1663..........	2,022,812 (London alone)	4,016,019 (London alone)
1700..........	6,477,402	5,970,175

of the mercantile marine. WHEELER, writing at the very beginning of the seventeenth century, states that for approximately sixty years, not four ships of over 120 tons carrying capacity had sailed in the Thames (6). Sir WILLIAM MONSON writes that at ELIZABETH's death there were not above four merchant ships of 400 tons each in England (7). Under the Commonwealth, the number of ships, particularly those of heavy tonnage, increased rapidly, partly in response to the impetus provided by the Dutch War (8). ADAM ANDERSON notes that the tonnage of English merchant ships in 1688 was double that in 1666 (9), and SPRAT claims a similar duplication during the preceding two

(5) See LIPSON, *op. cit.*, Vol. II, p. 189.

(6) JOHN WHEELER, *Treatise of Commerce* (Middelburgh : RICHARD SCHILDERS, 1601), p. 23.

(7) Sir WILLIAM MONSON, *Naval Tracts* (London : A. & I. CHURCHILL, 1703), p. 294.

(8) M. OPPENHEIM, *A History of the Administration of Royal Navy and of Merchant Shipping* (London, 1896), p. 302 ff; W. LAIRD CLOWES, *et al.*, *The Royal Navy*, 5 volumes (London, 1898), Vol. II, p. 107 ff. The following statistics adapted from OPPENHEIM's data (pp. 330-37) which do not include 17 additional ships for which tonnage figures are not available, testify to the large number of ships built from 1649 to 1659.

Net Tonnage	Number of Ships	Net Tonnage	Number of Ships
-100	15	600-700	7
100-200	2	700-800	15
200-300	16	800-900	—
300-400	3	900-1000	—
400-500	5	1000-1100	2
500-600	14	over 1100	2

(9) ADAM ANDERSON's *Origin of Commerce* (Dublin, 1790), Vol. III, p. 111 *Cf.* LIPSON, *op. cit.*, Vol. II, p. 190.

decades (10). Likewise, the official report concerning the Royal Navy, submitted by SAMUEL PEPYS in 1695, remarks the notable naval expansion of the seventeenth century. In 1607, the Royal Navy numbered forty ships of 50 tons and upwards; the total tonnage being about 23,600, with 7,800 manning the ships. By 1695, the corresponding figures were over 200 ships, with a tonnage of over 112,400 and with more than 45,000 men (11).

A substantial element in the heightened tempo of shipbuilding and the increased size of ships was, as SOMBART has suggested, military necessity. Though the growth of the merchant marine in this period was marked, it was but slight in comparison with that of the royal navy (12). The increase, both in the size and number of vessels, was much more rapid in the war fleet, as is evidenced by the comparative statistics assembled by SOMBART (13). Military exigencies often prompted increased speed in shipbuilding as well as improvements in naval architecture (14).

Shipbuilding was furthered by militaristic interests in three ways: more and larger ships were demanded, and above all, they were required within a shorter period. The requirements of the merchant marine could have been satisfied by handicraft *(handwerksmässige)* methods of shipbuilding for yet another century. But these methods became discountenanced by the growing demands of the war marine; first in the construction of warships themselves, and then of all ships, as the merchant marine was drawn into the stream of development... (15)

Though SOMBART is prone to exaggerate the rôle of military exigencies in fostering more efficient methods of shipbuilding, it appears clear that this factor combined with the increased need for a larger merchant marine to accelerate such developments. In any event, available statistical data indicate a marked expansion in both mercantile and military marine from the late sixteenth century on (16).

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(10) SPRAT, *History*, p. 404.

(11) Adapted from ANDERSON, *op. cit.*, Vol. III, p. 149.

(12) WERNER SOMBART, *Krieg und Kapitalismus* (München : DUNCKER & HUMBLOT, 1913), p. 180 *et passim*.

(13) *Ibid.*, p. 179 ff.

(14) CLOWES, *op. cit.*, Vol. II, p. 136.

(15) *Ibid.*, p. 191.

(16) " Nos recherches [based on an examination of port-books] montrent à l'évidence que le commerce et la navigation de l'Angleterre faisaient de grands progrès au déclin du XVI[e] et pendant la première moitié du XVII[e] siècle. On n'exagère guère en disant que la navigation anglaise a quadruplé, sinon quin-

Associated Problems of Technology

This marked growth in water transportation was characteristically accompanied by increased emphasis upon a number of associated technical problems. In the first place, the increase of commercial voyages to distant points—India, North America, Africa, Russia—stressed anew the need for accurate and expedient means for determining position at sea : of finding latitude and longitude (17). Throughout the course of the century, repeated efforts were made by scientists to contribute to the solution of this pressing problem. Both mathematics and astronomy were signally advanced through such efforts.

NAPIER's invention of logarithms (18), expanded by HENRY BRIGGS, ADRIAN VLACQ (in Holland), EDMUND GUNTER and HENRY GELLIBRAND, was of incalculable aid to astronomer and mariner alike. Possibly ADAM ANDERSON reflects the general attitude toward this achievement when he remarks that " logarithms are of great special utility to mariners at sea in calculations relating to their course, distance, latitude, longitude, etc." (19)

SPRAT, the genial historiographer of the Royal Society, asserted that the advancement of navigation constituted one of the chief

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tuplé de 1580 jusqu'à 1640." O. A. JOHNSON, " L'acte de navigation anglais du 9 octobre 1651," *Revue d'histoire moderne*, IX (1934), 13.

(17) HESSEN, *op. cit.*, pp. 157-58; *cf.* R. K. MERTON, " Some Economic Factors in Seventeenth Century English Science," *Scientia*, Sept. 1937, pp. 142-52.

(18) Published in his *Mirifici logarithmorum canonis descriptio* (Edinburgh, 1614). It is significant that BRIGGS, who was the first to make NAPIER's work appreciated and who in 1616 suggested the base 10 for the system of logarithms, wrote several works on navigation. *Cf.* DAVID E. SMITH, *History of Mathematics*, 2 volumes (Boston and New York : GINN & Co., 1923), Vol. I, pp. 391-92. Likewise, that GELLIBRAND was probably the first Englishman to correct GILBERT's error that magnetic declination " is constant at a given place," by discovering the " secular variation of the declination." *Cf.* his work, *A Discourse Mathematical on the Variation of the Magneticall Needle* (London, 1635).

(19) *Op. cit.*, Vol. II, p. 346. *Cf.* CLOWES, *op. cit.*, Vol. II, p. 28: ANDERSON notes likewise Sir HENRY SAVILE's " noble establishment [in 1630] of two professors of mathematics in the University of Oxford; one of which was for geometry, and the other for astronomy... Both which branches of mathematics are well known to be greatly beneficial to navigation and commerce." Vol. I, p. 377. SETH WARD, CHRISTOPHER WREN and DAVID GREGORY were some of the early Savilian professors of astronomy; HENRY BRIGGS and JOHN WALLIS held the professorships of geometry.

activities of the Society (20). A ballad written shortly after the Society began to meet at Gresham College reflects the popular appreciation of this interest, as is manifest in the following excerpt.

> This College will the whole world measure,
> Which most impossible conclude,
> And navigation make a pleasure,
> By finding out the longitude :
> Every Tarpaulian shall then with ease
> Saile any ship to the Antipodes (21).

It was this interest in the improvement of navigation which, according to FLAMSTEED, the first Astronomer Royal, led directly to the construction of the Greenwich Observatory. A Frenchman, LE SIEUR DE ST. PIERRE, visited England and proposed " improved " methods of determining longitudes at sea. FLAMSTEED, in an official report, indicated, however, that this project was not practical, since " the lunar tables differed from the heavens." This report being shown to CHARLES II, " he, startled at the assertion of the fixed stars' places being false in the catalogue; said with some vehemence, ' he must have them anew observed,

(20) *History of the Royal Society*, p. 150. This statement is corroborated by an excerpt quoted by WELD from a manuscript volume of ROBERT HOOKE's *Papers* in the British Museum, Additional MSS. 4441. (Dr. HARCOURT BROWN corrects this citation to be Sloan 1039, f. 112 and dates it some time after 1677. *Cf.* BROWN, *Scientific Organizations in Seventeenth Century France*, p. 187 fn.) " First it is earnestly desired that all observations that have been already made of the variation of the magneticall needle in any part of the world, might be communicated, together with all the circumstances remarkable in the making thereof; of the celestiall observations for knowing the true meridian, or by what other means it may be found... But from a considerable collection of such observations, Astronomy might be made available of that admirable effect of the body of the earth toacht by a loadstone, that if it will (as is probable it may) be usefull for the direction of seamen or others for finding the longitude of places, the observations collected, together with good navigation, which they [the Royal Society] engage to doe soe soon as they have a sufficient number of such observations..." *Cf.* CHARLES R. WELD, *A History of the Royal Society*, Vol. I, p. 149.

(21) *In praise of the choice company of Philosophers and Witts, who meet on Wednesdays, weekly, at Gresham College.* By W[ILLIAM?] G[LANVILL]. *Cf.* WELD, *op. cit.*, Vol. I, pp. 79-80 fn. *Cf.* DOROTHY STIMSON, " Ballad of Gresham College," *Isis*, XVIII (1932), 103-17, who suggests that the author was probably JOSEPH GLANVILL.

examined, and corrected, for the use of his seamen.' " (22) Whereupon it was decided, both to erect the Observatory that more accurate observations might be made and to appoint FLAMSTEED the Astronomer Royal.

The Meaning of Economic Influence

It will not be amiss to take pause at this juncture in order to clarify the sense in which economic factors " influenced " the direction of scientific research. Clearly, as we have already observed, prospects of personal economic gain seldom motivated the activities of scientists. Perhaps the one outstanding exception to this rule involved HOOKE, who made no effort to dissemble his concern with monetary returns. His agreement with BROUNCKER, BOYLE and MORAY held that in return for three-quarters of the profits derived therefrom (not exceeding 4.000£) he would " discover to them the whole of his Invention to measure the parts of Time at Sea as exactly as they are at Land by the *Pendulum* Clocks invented by Monsieur HUYGHENS." To safeguard these profits, the draft of an act of Parliament was drawn up whereby ship-masters would pay a per tonnage rate for the use of this invention. HOOKE's own words best exemplify his strong economic interest (23).

> This Treaty with me had been finally concluded for several Thousand Pounds, had not the inserting of one Clause broke it off, which was, *That if after I had discover'd my Invention about the finding the Longitude by Watches (tho' in themselves sufficient) they, or any other Person should find a way of improving my Principles, he or they should have the benefit thereof during the term of the Patent, and not I.* To which Clause I could no ways agree, knowing ' twas easy to vary my Principles an hundred ways; ... Upon this point our treaty was broken off, and I concealed the further discovery of any of the more considerable parts of my inventions for the regularity of time keepers; as hoping I might find some better opportunity of publishing them, together with my way for finding the longitude of places; for which I hoped to have had some benefit for all the labour, study, and charge I had been at for the perfecting thereof &c.

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(22) FRANCIS BAILY, *An Account of the Rev*[d]. JOHN FLAMSTEED; *compiled from his own manuscripts* (London, 1835), p. 37.

(23) ROBERT HOOKE, *A description of helioscopes, and, some other instruments* (London, 1676), postscript; *cf.* also his *Diary*, pp. 159, 160, *et passim.*

Yet, even this " purely economic " instance involved HOOKE's sentiments of propriety, justice, and fair play as well as considerations of private gain. Moreover, if we consider the complex structure of which this case is but a part, it becomes manifest that non-economic considerations are paramount. Not least among these was the improved status attending achievement in a sphere which was growing in social repute and esteem. Scientific prowess carried with it the privilege of mingling with persons of rank; it was, to some extent, a channel for social mobility. HOOKE, the son of a humble curate of Freshwater, found himself the friend of noblemen and could boast of frequent chats with the King.

Meeting officially as the Royal Society or foregathering at coffeehouses and private quarters, the scientific coterie discussed without end technical problems of immediate concern for the profit of the realm. Contributions to these discussions constituted in large part, the measure of one's worth. In short, the dominant picture is not that of a group of " economic men " jointly or severally seeking to improve their economic standing, but one of a band of curious students coöperatively delving into the arcana of nature. Economic developments posed new questions and opened up fresh avenues of research, coupling with this a marked pressure for the solution of these problems. This proved fairly effective since the scientist's sense of achievement was not exclusively in terms of scientific criteria. Scientists were not immune from the desire for social acclaim, and discoveries which promised profitable application were heralded far beyond the immediate circle of virtuosi. The untutored reactions of the " general public " to the different orders of scientific research might be represented by the contrasting responses of CHARLES II to the " weighing of ayre," the fundamental work on atmospheric pressure which to his limited mind was nothing but childish diversion and idle amusement, and to directly utilitarian researches on finding the longitude at sea, with which he was " most graciously pleased." Attitudes such as these served to guide a considerable part of scientific work into fields which might bear immediate fruits (24).

(24) See, for example, ADAM ANDERSON's brief evaluation of the Royal Society. " ... its improvements in astronomy and geography are alone sufficient to exalt

Problem of the Longitude

It is this engrossing problem of finding the longitude, with the attendant scientific research, which perhaps best illustrates the extent to which practical considerations tended to focus scientific interest upon certain fields. In the first place, there can be no doubt that the contemporary astronomers were thoroughly impressed with the practical advantages to be derived from discovering a satisfactory way of finding the longitude, particularly at sea. Time and time again, in their astronomical writings, they evidence this predominant interest. ROOKE, CHRISTOPHER WREN, HOOKE, HUYGHENS, HENRY BOND, HEVELIUS, WILLIAM MOLINEUX, NICOLAUS MERCATOR, LEIBNIZ, NEWTON, FLAMSTEED, HALLEY, LA HIRE, G. D. CASSINI, BORELLI,—practically all of the leading astronomers and virtuosi of the day repeatedly testify to this fact.

The various methods proposed for finding longitude either on land or sea led to the following investigations (25).

1. Computation of lunar distances from the sun or from a fixed star. (First widely used in the first half of the sixteenth century, and again in the latter seventeenth century.)

a) Computation of the irregularities of the moon's motion through the Plinian period. (Pursued by HALLEY and then by LE MONNIER.)

2. Observations of the eclipses of the satellites of Jupiter. (First proposed by GALILEO in 1610; and pursued by ROOKE, HALLEY, G. D. CASSINI, FLAMSTEED, and others.)

(3) Observations of the moon's transit of the meridian. (Generally current in the seventeenth century.)

(4) The use of pendulum clocks, and other chronometers, at sea. (HUYGHENS, HOOKE, MESSY, SULLY, and others.)

NEWTON clearly outlined these various procedures, as well as the scientific problems which they entailed, upon the occasion

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its reputation, and to demonstrate its great utility even to the mercantile world, without insisting on its many and great improvements in other arts and sciences, some of which have also a relation to commerce, navigation, manufactures, mines, agriculture, &c." *Origin of Commerce*, Vol. II, p. 609.

(25) *Cf.* ANDREW MACKAY, *The Theory and Practice of Finding the Longitude at Sea or Land*, 2 volumes (London, 1810), Vol. I, pp. 217-18; WILLIAM WHEWELL, *History of the Inductive Sciences*, Vol. I, pp. 434 ff; USHER, *A History of Mechanica Inventions*, Chap. X.

of DITTON's claim of the reward for an accurate method of determining *longitude* at sea (26). The profound interest of English scientists in this subject is initially marked by an article in the first volume of the *Philosophical Transactions*, describing the use of pendulum watches at sea (27). As SPRAT put it, the Society had taken the problem of longitude " into its peculiar care." HOOKE attempted to improve the pendulum and, as he says, " the success of these [trials] made me further think of improving it for finding the Longitude, and... quickly led me to the use of Springs instead of Gravity for the making a Body vibrate in any posture..." (28) A notorious controversy then raged about HOOKE and HUYGHENS concerning priority in the successful construction of a watch with spiral balance spring (29). Howsoever the question of priority be settled —for this dispute has but little direct bearing on our problem— the very fact that two such eminent scientists, among others,

(26) L. T. MORE, ISAAC NEWTON, p. 562.

(27) Major HOLMES, " A Narrative concerning the Success of Pendulum Watches at Sea for the Longitude," *Phil. Trans.*, I (1665), 52-58.

(28) *The Posthumous Works of* ROBERT HOOKE, by RICHARD WALLER (London, 1705), Introduction.

(29) GALILEO had apparently described a pendulum clock in 1641, HUYGHENS' invention in 1656 was independently conceived. HUYGHENS went on to invent the watch with a spring mechanism. *Cf.* HUYGHENS' description of his invention in the *Phil. Trans.*, XI (1675), 272; reprinted from the *Journal des Sçavans*, Feb. 25, 1675. This led to the notorious dispute between HOOKE and OLDENBOURG (who defended HUYGHENS' priority in actual construction). OLDENBURG maintained that " though Mr. HOOKE had some years before caused some watches to be made of this kind, yet without publishing to the world a description of them in print; and it is certain that none of those had succeeded." OLDENBURG may have been correct in his latter charge, but was certainly not in his former statement, since an account, however inadequate, had been published in SPRAT's *History*. *Cf. Phil. Trans.*, XI (1675), 440; ROBERT HOOKE, *Lampas* (London, 1676), postscript. It is of interest that HOOKE, at the meeting of the Royal Society following that at which HUYGHENS' communication concerning his " new pocket watch " was read, mentioned " that he had an invention for finding the longitude to a minute of time, or fifteen minutes in the heavens, which he would make out and render practical, if a due compensation were to be had for it." Whereupon Sir JAMES SHAEN promised " that he would procure for him a thousand pounds sterling in a sum, or a hundred and fifty pounds per annum. Mr. HOOKE declaring that he would choose the latter, the council pressed him to draw up articles accordingly, and to put his invention into act." *Cf.* BIRCH, *op. cit.*, Vol. III, p. 191. There is no record of HOOKE ever having done so. For further details concerning this matter, see WALLER, *op. cit.*, Introd.

focussed their attention upon this subject is itself suggestive (30). These simultaneous inventions are a resultant of two fundamental forces : the intrinsically scientific which provided the theoretical materials employed in solving the problem in hand and the non-scientific, largely economic, factor which served to direct interest toward this general subject.

The problem of finding the longitude continued to fire scientific research in other directions as well. Thus, BORELLI, of the Royal Academy of Sciences at Paris, published an offer, both in the *Journal des Sçavans* and the *Philosophical Transactions*, to explain his method of making large glasses for telescopes or even to send telescopes to all persons who were not in a position to make them, that they might " observe the eclipses of the Satellites of Jupiter which happen almost every day, and afford so fair a way for establishing the Longitudes over all the Earth." Moreover, " the Longitudes of places at Sea, Capes, Promontories, and divers Islands being once exactly known by this means, would doubtless be of great help and considerable usefulness to Navigation." (31)

It is precisely these observations of the satellites of Jupiter, with their acknowledged practical implications, which clearly illustrate the rôle of utilitarian elements in furthering scientific advance. For it may be said, without danger of exaggeration, that GIOVANNI DOMENICO CASSINI's astronomical discoveries were largely a resultant of practical as well as of purely scientific interest. In almost all of CASSINI's papers in the *Transactions* he emphasizes the value of observing the moons of Jupiter for determining longitude, by means of the method first suggested

(30) The frequency of disputes concerning priority which, to my knowledge, first becomes marked in the sixteenth century, constitutes an interesting problem for further research. It implies a lofty estimation of " originality " and of competition; values which were largely foreign to the medieval mind which commonly sought to cloak the truly original under the tradition of earlier periods. The entire question is bound up with the rise of the concepts of plagiarism, patents, copy-rights and other institutional modes of regulating " intellectual property." One phase of this development which was current in the seventeenth century was the practice of " challenges " issued by certain scientists to the scientific fraternity to solve certain problems. See MAX SCHELER's comments in his *Versuche zu einer Soziologie des Wissens*, p. 104.

(31) *Phil. Trans.*, XI (1676), 691-92.

by GALILEO (32). It is perhaps not too much to say that from this interest flowed his discovery of the rotation of Jupiter, the double ring of Saturn, and the third, fourth, fifth, sixth and eighth satellites of Saturn (33), for, as he suggests, astronomical observations were directly encouraged because of their practical implications. LAWRENCE ROOKE, who was one of the organizers of the Royal Society, noted the " nautical value " of observing these same phenomena (34). FLAMSTEED frequently remarked the usefulness

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(32) *Cf.* LEONARDO OLSCHKI, GALILEI *und seine Zeit* (Halle : M. NIEMEYER, 1927), pp. 274, 438 and his chapter on " Die Briefe über geographische Ortbestimmung." Though in theory this method is possible, it did not enable sufficient precision to be of practical use. In the paper discussing his discovery of an unusually permanent spot in Jupiter and fixing the period of the planet's rotation, CASSINI observes that " a Travellour... may make use of it [the rotation] to find the Longitudes of the most remote places of the earth." *Phil. Trans.*, VII (1672), 4042. In discussing the inequality of the time of rotation of the spots in different latitudes, he indicates the importance of this fact for more precisely determining the longitude. *Ibid.*, XI (1676), 683. The announcement of his discovery of the third and fourth satellites of Saturns begins thus : " The Variety of wonderful Discoveries, which have been made this Century in the Heavens, since the invention of the Telescope, and the great Utility that may possibly be drawn therefrom, for perfecting natural Knowledg, and the Arts necessary to the Commerce and Society of Mankind, has incited Astronomers more strictly to Examine, if there were not something considerable that had not been hitherto perceived." Translated from the *Journal des Sçavans*, April 22, 1686; reprinted in *Phil. Trans.*, XVI (1686), 79. In presenting CASSINI's tables for the eclipses of the first satellites of Jupiter, it is remarked that beyond doubt observations of these eclipses best enable portable telescopes to find the longitude. " And could these satellites be observed at Sea, a Ship at Sea might be enabled to find the Meridian she was in, by help of the tables Monsieur CASSINI has given us in this volume [*Recueuil d'observations faites en plusieurs Voiages pour perfectionner l'Astronomie & la Geographie*], discovering with very great exactness the said Eclipses, beyond what we can yet hope to do by the Moon, tho' she seem to afford us the only means Practicable for the Seaman. However before Saylors can make use of the Art of finding the Longitude, it will be requisite that the Coast of the whole Ocean be first laid down truly, for which this Method by the Satellites is most apposite : And it may be discovered, by the time the Charts are compleated; or else that some Invention of shorter Telescopes manageable on Ship-board may suffice to shew the Eclipses of the Satellites at Sea..." *Phil. Trans.*, XVII (1694), 237-38. The latter part of this quotation definitely and lucidly illustrates the way in which scientific and technical research is "called forth" by economic needs.

(33) The third (Tethys) and fourth (Dione) satellites were discovered in 1684; the fifth (Rhea) in 1672; the sixth (Titan) and eighth (Japetus) in 1671..

(34) See " Mr. ROOK's Discourse concerning the Observations of the Eclipses of the Satellites of Jupiter " reprinted in SPRAT, *History of the Royal Society*,

of observing the satellites of Jupiter, because their eclipses " have been esteemed, and certainly are a much better expedient for the discovery of the Longitude than any yet known." (35) It thus becomes clear how certain problems evoked through economic needs tended to focus the attention of astronomers upon the observation of the planets.

A further indication of the complex, indirect, but none the less clear-cut way, in which the requirement of finding the longitude at sea induced scientific development along particular lines, is afforded by HUYGHENS' introduction of the mathematical theory of the pendulum. In his *Horologium Oscillatorium* (Paris, 1673), which CAJORI ranks second only to NEWTON's *Principia*, HUYGHENS devotes the first section to a description of his pendulum clock, which he esteemed primarily for its use in finding the longitude(36). But the variation in the pendulum's motion rendered it insufficiently constant to be useful for this purpose. He was hence faced with this question : In what curve should a pendulum swing in order that the period of oscillation may be independent of the amplitude? Pendular oscillations are truly isochronous, he discovered, only when they occur along a cycloidal arc. But that the cycloid might be so employed, he felt the obligation to consider curves further, particularly those curves which by their evolution generate other curves. From this work resulted the comparison of the length of curves with straight lines, which he acknowledged to have prosecuted further than his immediate purpose required, and which led him to repeat WILLIAM NEILE's determination of the length of a curve by mathematics (37).

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pp. 183-90. ROOKE was Gresham professor of Astronomy from 1652 to 1657; and Gresham professor of Geometry from 1657 until his death in 1662.

(35) *Phil. Trans.*, XII (1683), 322. FLAMSTEED expounded this view even more pointedly in other papers on the same subject. See *Phil. Trans.*, XV (1685), 1215; XVI (1686), 199. In a subsequent paper on these satellites, the characteristic observation is made by FLAMSTEED that observations of them afford an admirable expedient for finding the longitude. *Ibid.*, XIII (1683), 405-7.

(36) HUYGHENS makes this clear in his instructions for the use of the watch, translated and printed in the *Phil. Trans.*, IX (1669), 937-39. *Cf.* also the account of the invention in the *Journal des Sçavans*, cited *supra*. LEIBNIZ also invented a portable watch " principally designed for the finding of the longitude." *Cf.* his paper in the *Phil. Trans.*, X (1675), 285-88.

(37) *Cf.* review of HUYGHENS' work in *Phil. Trans.*, VIII (1673), 6067-71. WREN likewise rectified the cycloid. *Cf.*, *ibid.*, VIII (1673), 6146-50. NEWTON

Thus, by logically developing the subsidiary problems involved in the initial project, HUYGHENS was led to amplify considerably mathematical and mechanical knowledge. Such developments as these led the enthusiastic SPRAT to acclaim HUYGHENS' achievements in " practical mathematicks." This example clearly illustrates the fashion in which abstruse developments even in " pure mathematics " may be related, though at a considerable remove, to economic requirements.

NEWTON was likewise deeply interested in finding a solution to the problem of determining the longitude (38). Early in his career, he wrote a now famous letter of advice to his friend, FRANCIS ASTON, who was planning a trip on the Continent, in which among other particulars he suggested that ASTON " inform himself whether pendulum clocks be of any service in finding out the longitude" (39). Both HOOKE and HALLEY wrote to NEWTON suggesting that he continue certain phases of his research because of its utility for navigation (40).

In 1694, NEWTON sent his well-known letter to NATHANAEL HAWES outlining a new course of mathematical reading for the neophyte navigators in Christ's Hospital, in which he criticised the current course, saying in part, that " the finding the difference of Longitude, Amplitude, Azimuts and variation of the compass is also omitted, tho these things are very usefull in long voyages, such as are those to the East Indies, and a Mariner who knows them not is an ignorant" (41). In August

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made use of this work in his *Principia*. See the ANDREW MOTTE edition, 2 volumes (London, 1729), Vol. I, p. 199 ff. HUYGHENS' " rule " excited widespread interest among English scientists. See *e.g.* HOOKE's letter to BOYLE, dated 15 December, 1664, in BOYLE, *Works*, Vol. V, p. 453.

(38) Compare the perspicuous comments of Professor P. M. S. BLACKETT, in JULIAN HUXLEY's *Science and Social Needs*, pp. 211-12. See also J. D. BERNAL, " Science and Industry," *The Frustration of Science*, p. 43.

(39) L. T. MORE, *Isaac Newton*, p. 51, quotes the letter.

(40) HOOKE, in a letter to NEWTON (6 Jan. 1680), writes : " ... the finding out the proprietys of a curve made by two such principles will be of great concerne to mankind because the invention of the longitude by the heavens is a necessary consequence of it." Letter quoted by W. W. ROUSE BALL, *An Essay on Newton's " Principia,"* (London : MACMILLAN, 1893), p. 147. Likewise, HALLEY, in his letter of 5 July 1687, writes : " I hope... you will attempt the perfection of the Lunar Theory, which will be of prodigious use in navigation, as well as of profound and subtile speculation." Quoted in *ibid.*, p. 174.

(41) NEWTON's letters to HAWES are published in J. EDLESTON, *Correspondence*

1699, NEWTON made public an improved form of his sextant (42), (independently invented by HADLEY in 1731) which in conjunction with lunar observations, may enable the finding of longitude at sea. He had already presented his lunar theory in the third book of the *Principia*. Furthermore, it was upon NEWTON's recommendation that the Act of 1714 was passed for a reward to such persons as should devise a method of finding the longitude at sea (43). In the course of these practical functions, NEWTON was indicating his awareness of the utilitarian implications not only of much of his own scientific work, but also that of his contemporaries.

NEWTON's lunar theory was the climactic outcome of scientific

of Sir ISAAC NEWTON *and Professor* COTES (London, 1850), pp. 279-99. It is of significance to note the scientific preparation which NEWTON deemed necessary for a properly trained mariner, for it includes a smattering of a substantial part of the types of research most prominently prosecuted in the physical sciences and mathematics.

1. Plane and solid geometry.
2. Algebra.
3. Spherical trigonometry (" the foundation of a great many usefull problems in Astronomy, Geography and Navigation.")
4. Rudiments of geography, hydrography and astronomy.
5. Methods of finding latitude and longitude (including " the finding the difference of the Longitudes of Shores by the Eclipses of Jupiters Satellites " and " knowledge of the tides.")
6. Mechanics (" The principles of reasoning about force & motion, particularly about the five mechanical powers, the stress of ropes and timber, the power of winds, tides, bullets and bombs, according to their velocity and direction against any plane, the line w[ch] a bullet describes, the force of weights and springs and the power of fluids to press against immersed bodies, and bear them up, and to resist their motion...")

It will be noted that in this list NEWTON mentions the subjects and problems with which not only he was chiefly concerned in the course of his own scientific career, but which also claimed an appreciable proportion of scientific investigation generally. He indicates further that he was far from unaware of the practical implications of the greater part of his abstruse discussions in the *Principia;* for example, his theory of the tides, the determination of the trajectory of a projectile, his lunar theory, his work in hydrostatics and hydrodynamics.

(42) MORE, *op. cit.*, p. 487.

(43) EDLESTON, *op. cit.*, p. LXXVI. The importance attributed to the solution of this problem may be gauged from the fact that similar awards were offered by other governments. The Dutch had sought to persuade GALILEO to apply his talents to its solution; PHILIP III of Spain also offered a reward and in 1716, the REGENT DUKE of ORLÉANS established a prize of 100,000 francs for the discovery of a practicable method. *Cf.* WHEWELL, *History of the Inductive Sciences*, Vol. I, p. 434.

concentration on this subject, partly so focussed because of its utility in determining the longitude (44). HALLEY, who had decided that the various methods for determining longitude were all defective and had declared that " it would be scarce possible ever to find the Longitude at sea sufficient for sea uses, till such time as the Lunar Theory be fully perfected," constantly prompted NEWTON to continue this work (45). ROOKE, for example, had remarked the desirability of observing the eclipses of the moon for this object (46). DAVID GREGORY, in his *Elements of Physical and Geometrical Astronomy* (1702), inserted NEWTON's lunar theory as applied by him to practice, wherein eight of the lunar equations were calculated (47). FLAMSTEED, and more diligently, HALLEY, from 1691 to 1739, endeavored to rectify the lunar tables sufficiently to attain " the great object, of finding the Longitude with the requisite degree of exactness" (48). Observations of the eclipses of the moon were recommended by the Royal Society for the same purpose (49).

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(44) As WHEWELL suggests : " The advancement of astronomy would perhaps have been a sufficient motive for this labor [in attempting to perfect the lunar theory]; but there were other reasons which would urge it on with a stronger impulse. A perfect Lunar Theory, if the theory could be perfected, promised to supply a method of finding the Longitude of any place on the earth's surface; and thus the verification of a theory which professed to be complete in its foundations, was identified with an object of immediate practical use to navigators and geographers, and of vast acknowledged value." *Op. cit.*, Vol. I, p. 434.

(45) *Correspondence and Papers of* EDMOND HALLEY, p. 212.

(46) *Cf.* his article, " A Method of observing Eclipses of the Moon," *Phil. Trans.*, I (1667), in which he states : " Eclipses of the Moon are observed for two principal Ends; One *Astronomical*, ... the other *Geographical*, that by comparing among themselves Observations of the same Ecliptical phases, made in divers places, the difference of Meridians, or Longitudes of those places may be discovered." " I shall propound a Method particularly designed for the accomplishment of the Geographical end..."

(47) WHEWELL, *op. cit.*, Vol. I, p. 435.

(48) WHEWELL, *op. cit.*, Vol. I, p. 436-37.

(49) " The Royal Society being desirous to contribute what they may to the rectifying of Geography, and determining the Longitudes of Places, amongst others did recommend the procuring an Eclipse [of the moon] at Moscua..." *Phil. Trans.*, XVII (1693), 453-54. Studies of the motions of the moon continued to be made by such eminent astronomers as EULER, CLAIRAUT and D'ALEMBERT. TOBIAS MAYER corrected EULER's tables in 1753 sufficiently, he thought, to merit the English prize for the discovery of the longitude. BRADLEY, and his assistant, GAEL MORRIS, long laborated at the lunar method for attaining this end. *Cf.* WHEWELL, *op. cit.*, Vol. I, p. 438.

Further Scientific Research

Another field of investigation which received added attention because of its probable utility is the study of the compass and magnetism in general. Thus, SPRAT specifically relates such investigations by WREN to economic needs when he states that " in order to Navigation he [WREN] has carefully pursu'd many Magnetical Experiments" (50). WREN himself, in his inaugural address as Gresham professor of astronomy, strikes the same keynote. The study of the magnetic variation is to be pursued diligently for it may prove of great use to the navigator, who may thus be enabled to find the longitude, " than which former Industry hath hardly left any Thing more glorious to be aim'd at in Art" (51). LA HIRE, remarking that nothing is so troublesome on long sea voyages as the variation of the needle, states that this led him to devise a new sort of compass which might possibly obviate this difficulty (52). HENRY BOND, HEVELIUS, WILLIAM MOLINEUX and NICOLAUS MERCATOR were likewise interested in the study of magnetic phenomena with the aim of solving the problem of the longitude (53). HALLEY, in the famous paper in which he made known his theory of four magnetic poles and of the periodic movement of the magnetic line without declination, emphasized repeatedly the utilitarian desirability of studying the variation of the compass, for this research " is of that great concernment in the Art of Navigation : that the neglect thereof, does little less than render useless one of the noblest Inventions mankind has ever yet attained to." This great utility, he argues, seems a sufficient incitement " to all philosophical and Mathematical heads, to take under serious consideration the several Phenomena..." He presents his new hypothesis in order to stir up the scientists of the age that they might " apply themselves more attentively to this useful speculation" (54). It was for

(50) *History of the Royal Society*, pp. 315-16.

(51) Printed in *Parentalia*, p. 206.

(52) *Phil. Trans.*, XVI (1687), 344-50. " This put me upon finding out some means independent from Observations to discover the variations at Sea."

(53) *Cf. Phil. Trans.*, *passim*. *E.g.*, III (1668), 790; V (1670), 2059; VIII (1674), 6065.

(54) " A Theory of the Variation of the Magnetical Compass," *Phil. Trans.*, XIII (1683), 208-21. See also his addendum to this paper, *ibid.*, XVII (1693), 563-78.

the purpose of enriching this " useful speculation " that HALLEY was given the temporary rank of a captain in the navy and the command of a ship in which he made three voyages. The outcome was HALLEY's construction of the first isogonic map (55).

Thus we are led to see that the scientific problems emphasized by the manifest value of finding the longitude were manifold. If the scientific study of various possible means of achieving this goal was not always dictated by the practical utility of the result, it is none the less probable that part of the continued diligence exercised in these fields was due to such considerations. In the last analysis it is impossible to determine even approximately the degree to which practical concerns focussed scientific attention upon certain problems. All that can conscionably be suggested is a certain correspondence between the subjects most intensively investigated by the contemporary scientists and the problems raised or emphasized by economic developments. It is an inference—frequently supported by the explicit statements of the scientists themselves—that these economic requirements, or more properly, the technical needs resulting from such requirements, provoked research in particular fields. The finding of the longitude—particularly at sea, which afforded the greatest difficulties—was one problem which, engrossing the attention of many scientists, furthered profound developments in astronomy, geography, mechanics, and the invention of clocks and watches.

Another practical problem of considerable moment in navigation is determining the time of the tides. As FLAMSTEED indicated in a note appended to his first tide-table, the error in the almanacs amounted to about two hours; hence a scientific correction was highly desirable for the Royal Navy and other navigators (56). Accordingly, from time to time, he drew up several tide-tables accommodated to ports not only in England, but also in France and Holland (57). This work was the continuation of an interest in providing a theory of the tides emphasized by the Royal

(55) L. A. BAUER, " HALLEY's earliest equal variation chart," *Terrestrial Magnetism*, I (1896), 20; *Correspondence of* EDMOND HALLEY, p. 8.

(56) *Phil. Trans.*, XIII (1683), 10-15.

(57) *Phil. Trans.*, XIV (1684), 458, 821; XV (1685), 1226; XVI (1686), 232, 428.

Society from its very inception. The first volume of the *Transactions* included several papers presenting observations of the time of the tides in various ports. BOYLE, SAMUEL COLEPRESSE, JOSEPH CHILDREY, HALLEY, HENRY POWLE, and most notably, JOHN WALLIS, made contributions to this subject.

NEWTON took up the task as a further basis for the verification of the general law of attraction, and as THOMSON remarks, " his theory of the tides is not less remarkable either for the sagacity involved, or for its importance to navigation." His theory accounted for the most evident aspects of the tides : the difference of the spring and neap tides and of the morning and evening tides, the effect of the moon's and sun's declination and parallax, and the tides at particular places, making use of the observations of COLEPRESSE, HALLEY and others to check his calculated results (58). HALLEY, seeking as always to minister to the marriage of theory and practice, was not slow to inform the Lord High Admiral of the " generall use to all shipping " to be derived from these researches (59). It was not, however, until the work of EULER, BERNOULLI, and D'ALEMBERT, and later of LAPLACE, LUBBOCK and AIRY, that the theory could be applied with sufficiently approximate accuracy to promise service for practical purposes. Again, one can correlate scientific interests—in this instance, the study of so esoteric a subject as the theory of attraction—and economic exigencies.

Another problem of grave concern for maritime affairs was the depletion of forest preserves to the extent that eventually unseasoned wood had to be used for the construction of ships (60). Timber had become relatively scarce, both because of its use as fuel for industrial purposes, and its rapid consumption in the naval wars and the rebuilding of London. The solution to the fuel problem was partially solved by the use of coal for various industries—such as brass and copper casting, brewing, dyeing and iron-ware, though not for the production of raw

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(58) *Principia, op. cit.*, Bk. III, Prop. XXIV, XXXVI, XXXVII; *cf.* WHEWELL, *op. cit.*, Vol. I, p. 457 ff.

(59) *Correspondence*, p. 116.

(60) R. G. ALBION, *Forests and Sea Power* (Harvard University Press, 1926), Chap. III; ANDERSON, *Origin of Commerce*, Vol. III, p. 4.

iron (61). The depletion of timber so jeopardized shipbuilding that the commissioners of the Royal Navy appealed to the Society for suggestions concerning " the improvement and planting of timber." EVELYN, GODDARD, MERRET, WINTHROP, ENT, and WILLUGHBY contributed their botanical knowledge toward the solution of this problem; their individual papers being incorporated in EVELYN's well-known *Sylva* (62). Not unrelated to such practical urgencies, then, is the fact that one of the " chief activities " of the Society was the " propagating of trees."

Furthermore, says SPRAT, the members of the Society " have employ'd much time in examining the Fabrick of ships, the forms of their Sails, the shapes of their Keels, the sorts of Timber, the planting of Firr, the bettering of Pitch, and Tarr, and Tackling" (63). These technical subjects lead directly not only to the study of silviculture and allied botanical studies, but also to investigations in mechanics, hydrostatics, and hydrodynamics. For, as NEWTON noted in his letter to HAWES, such problems as the determination of the stress of ropes and timber, the power of winds and tides, and the resistance of fluids to immersed bodies of varying shapes are of great utility for the mariner (64).

Moreover, when one compares the requisites of a man-of-war as enumerated by Sir WALTER RALEGH at the beginning of the century with the types of research conducted by the Royal Society, it becomes apparent that all the major problems had become the object of scientific study. RALEGH lists these six desirable qualities of a fighting ship (65) : strong build, speed, stout scantling, ability to fight the guns in all weathers, ability to lie easily in a gale, and ability to stay well.

Contemporary scientists attempted to devise means of satisfying

(61) Despite the numerous attempts, by members of the Royal Society such as Sir ROBERT MORAY and others, to produce iron with sea-coal, it was not until 1738 that this process was successfully developed. DUD DUDLEY's claim in 1621 to have accomplished this technical feat is dubious, and, in any event, did not result in economically significant production. *Cf.* W. H. PRICE, *English Patents of Monopoly*, p. 110.

(62) See Appendix A, I, *a*, 3.

(63) SPRAT, *op. cit.*, p. 150.

(64) *Cf. supra*, fn. 41.

(65) In his *Observations on the Navy*, quoted by CLOWES, *op. cit.*, Vol. II, p. 3.

all these requirements. In many instances they were led to solve derivative problems in " pure science " in the hope of using this further knowledge for this purpose. Thus, GODDARD, PETTY and WREN investigated methods of shipbuilding with the object of improving existing procedures (66). Further, HOOKE was ordered by the Society to determine the most " stout scantling " by testing the resistance of the " same kinds of wood, of several ages, grown in several places, and cut at different seasons of the year" (67). At times in coöperation with BOYLE, HOOKE performed numerous experiments to " try the strength of wood," and of twisted and untwisted cords. It may well be that HOOKE's law *(ut tensio sic vis)* was a later theoretical outcome of these experiments.

In order to discover ways of increasing the speed of ships, it is necessary to study the movement of bodies in a resistant medium, one of the basic tasks of hydrodynamics. Accordingly MORAY, GODDARD, BROUNCKER, BOYLE, WREN and PETTY were concerned with this problem (68). In this instance, the connection between a given technical task and the appropriate " purely scientific " investigation is explicit. PETTY both wrote that " the fitts of the Double-Bottome [ship] do return very fiercely upon mee," and experimented in hydrodynamics to determine the velocity of " swimming bodies" (69). But a more clear-cut connection is established by SPRAT in describing the instruments of the Society :

> [There are] several instruments for finding the velocity of swimming Bodies of several Figures, and mov'd with divers strengths, and for trying what Figures are least apt to be overturn'd, in order to the making of a true theory, of the Forms of Ships, and Boats for all uses (70).

CHRISTOPHER WREN, whom NEWTON called one of " the greatest Geometers of our times," also investigated the laws of hydrodynamics precisely because of their possible utility for

(66) See Appendix A, I, *a*, 5.

(67) BIRCH, *op. cit.*, Vol. I, p. 460.

(68) See Appendix A, I, *b*, 1.

(69) *The Petty-Southwell Correspondence*, ed. by the MARQUIS of LANSDOWNE (London : CONSTABLE & Co., 1928), p. 117; BIRCH, *op. cit.*, Vol. I, p. 87.

(70) SPRAT, *op. cit.*, p. 250. *Cf.* HOOKE's letter to BOYLE, in the latter's *Works*, Vol. V, p. 537.

improving the sailing qualities of ships (71). NEWTON, in his theorem showing the manner in which the resistance of a fluid medium depends upon the form of the body moving in it, adds : " which proposition I conceive may be of use in the building of ships" (72).

The Society maintained a continued interest in under-water devices, ranging from diving bells to HOOKE's proposal of a full-fledged submarine which would move as fast as a wherry on the Thames ! (73) A committee on diving considered leaden " diving boxes," which were tested in the Thames and, with more convenience to the spectators than the diver, in a tub set up at one of the weekly meetings. WILKINS laid great store on the feasibility and advantage of submarine navigation which would be of undoubted use in warfare, would obviate the uncertainty of tides and might be used to recover sunken treasures (74). HOOKE linked many of his experiments on respiration with the technical problems deriving from such efforts.

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(71) " It being a Question amongst the Problems of Navigation, very well worth resolving, to what Mechanical powers the Sailing (against the wind especially) was reducible; he [WREN] shew'd it to be a Wedge : And he demonstrated how a transient Force upon an oblique Plane, would cause the motion of the Plane against the first Mover. And he made an Instrument, that Mechanically produc'd the same effect, and shew'd the reason of Sayling to all Winds.

The Geometrical Mechanics of Rowing, he shew'd to be a Vectis on a moving or cedent Fulcrum. For this end he made Instruments, to find what the expansion of Body was towards the hindrance of Motion in a Liquid Medium; and what degree of impediment was produc'd, by what degree of expansion : with other things that are the necessary Elements for laying down the Geometry of Sailing, Swimming, Rowing, Flying, and the Fabricks of Ships." SPRAT, *op. cit.*, p. 316. Once again we see how the immediate technical end leads to the study of derivative problems in science.

(72) *Principia*, *op. cit.*, Vol. II, p. 119 (Bk. II, Sect. VII, Prop. XXXIV, Scholium).

(73) HOOKE does not refer to CORNELIUS DREBBEL's submarine of 1624, though he could hardly have been ignorant of it.

(74) WILKINS, *Mathematical Magick*, Bk. II, Chap. V. As early as 1551, TARTAGLIA had suggested an effective means for raising sunken ships to the water's surface. *Cf.* OLSCHKI, GALILEO *und seine Zeit*, p. 108. Several patents had been granted for " diving engines " since at least 1631. By the help of one of these engines " and good luck," says ANDERSON, Sir WILLIAM PHIPPS " fished up " nearly 200,000£ sterling in pieces of eight from a Spanish fleet which had been sunk off the West Indies. *Origin of Commerce*, Vol. III, p. 73. HOOKE and HALLEY, as well as several others, responded to this success with new contrivances for recovering treasures from the deep.

WILKINS introduced the " umbrella anchor " to the Royal Society; an invention devised " to stay a ship in a storm" (75). Further experiments were prosecuted by the Society with the design of improving the floating qualities of ships (76). WREN proposed " a convenient way of using artillery on ship-board "; an objective which RALEGH had deemed most desirable (77). PETTY, fondly hoping " to pursue the improvement of shipping upon new principles," built several of his " double-bottomed boats " with which the Society was well pleased (78). Unfortunately, his most ambitious effort, the St. Michael the Archangel, failed miserably, which led PETTY to conclude that both the fates and the King were opposed to him.

The Society periodically debated means of preserving ships " from worms " (79); a problem which had proved greatly disturbing both to the commissioners of the Royal Navy and private ship-owners. NEWTON had evidenced interest in this same vexing problem in his letter to ASTON whom he asked to determine " whether the Dutch have any tricks to keep their ships from being all worm-eaten" (80). No appreciable progress resulted from these discussions, however (81).

In general, then, it may be said that the contemporary scientists, ranging from the indefatigable virtuoso PETTY to the nonpareil

(75) BIRCH, *op. cit.*, Vol. I, p. 216.

(76) *Ibid.*, Vol. I, p. 469, *passim*.

(77) WREN's scheme is contained in a manuscript listed in ***Parentalia*, *op. cit.***, p. 240. Other of his manuscripts were concerned with finding the velocity of a ship in sailing, the improvement of gallies, an instrument to note the soundings in shallow water and the recovery of wrecks in deep water.

(78) PETTY-SOUTHWELL *Correspondence*, *op. cit.*, pp. 86, 128; BIRCH, *op. cit.* Vol. I, p. 131.

(79) BIRCH, *op. cit.*, Vol. IV, p. 496.

(80) The letter is quoted by MORE, *op. cit.*, p. 51.

(81) The practice of sheathing ships with lead was current in the Spanish Navy since the middle of the sixteenth century, but the first ship of the Royal Navy so treated was the Phœnix in 1670. This served inadequately both to preserve ships' bottoms and to increase speed. In 1696, the difficulty, " one of the most troublesome problems of the age," was partially removed by the invention of a sheathing composition. A thorough-going practical solution was not forthcoming until the eighteenth century although as early as 1625 Letters Patent were granted to WILLIAM BEALE for a cement designed to preserve the hulls of ships from barnacles. ANDERSON, *Origin of Commerce*, Vol. II, p. 418. *Cf.* CLOWES, *op. cit.*, Vol. II, pp. 240-41.

NEWTON, definitely focussed their attention upon technical tasks made prominent by problems of navigation and upon derivative scientific research (82). The latter category, however, needs careful delimitation. While it is true that a congeries of scientific investigation may be traced to technical demands, it is equally evident that much of this research can be understood as a logical development of foregoing scientific advance. It is only because the scientists themselves point to the practical implications of their work that one becomes inclined to accept the appreciable directive influence of practical problems. Even that " purest " of disciplines, mathematics, held little interest for NEWTON save as it was designed for application to physical problems (83).

Some attention was likewise paid to inland transportation although to a less extent than to maritime transport, possibly because of the greater economic significance of the latter. The growing interior traffic demanded considerable improvement. Such improvements, said DEFOE, are " a great help to Negoce, and promote universal Correspondence without which our Inland Trade could not be managed" (84). Travelling merchants, who might carry as much as a thousand pounds of cloth, extended their trade all over England (85), and required bettered facilities. Because of " the great increase of carts, waggons, &c., by the general increase of our commerce," says ADAM ANDERSON, the King (somewhat optimistically, no doubt) ordered in 1662 that all common highways be enlarged to eight yards (86). Characteristically, contemporary scientists also sought to overcome technical difficulties (87). PETTY, with his keen interest in economic

(82) J. E. T. ROGERS remarks in this connection : " Navigation, once a knack, is now an art; the astronomer, the metereologist, the physicist, have been pressed into the service of trade, and the man who at first sight is merely a student of knowledge for the sake of it, is constantly discovering and arranging facts, which the economist... discovers to have played their part in reducing the cost of production and exchange. *The Economic Interpretation of History*, p. 257.

(83) See *Principia*, Author's Preface. *Cf.* BURTT, *Metaphysical Foundations of Modern Physical Science*, p. 210; MORE, *op. cit.*, p. 161.

(84) D[ANIEL] D[EFOE], *Essays Upon Several Projects* (London, 1702), p. 73 ff.

(85) DANIEL DEFOE, *Tour of Great Britain* (London, 1727), Vol. III, pp. 119-20.

(86) ANDERSON, *Origin of Commerce*, Vol. II, pp. 622, 628.

(87) *Cf.* JOSEF KULISCHER, *Allgemeine Wirtschaftsgeschichte*, Vol. II, p. 521 ff.

affairs, devised several chariots guaranteed to " passe rocks, precipices, and crooked ways" (88). WREN endeavored to perfect coaches for " ease, strength, and lightness " and, as did HOOKE, invented a " way-wiser " to register the distance travelled by a carriage (89). WILKINS, possibly following STEVIN's invention of a half century earlier, described a " sailing Chariot, that may without Horses be driven on the Land by the Wind, as ships are on the Sea" (90). Likewise, the Society delegated HOOKE, at his own suggestion, to carry on " the experiment of land-carriage, and of a speedy conveying of intelligence" (91). These efforts evidence the attempts of scientists to contribute technological props to business enterprise; these particular instances being devoted to making possible the extension of markets, one of the primary characteristics of capitalism.

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(88) PETTY-SOUTHWELL *Correspondence*, pp. 41, 51, 125. " And it seems to mee [writes PETTY] that this carriage can afford to carry fine goods betweene Chester and London for lesse than 3*d* in the pound." With all due honesty, PETTY admits that " this Toole is not exempt from being overthrowne," but adds comfortingly, " but if it should bee overthrowne (even upon a heape of flints) I cannot see how the Rider can have any harme."

(89) *Parentalia*, pp. 199, 217, 240.

(90) JOHN WILKINS, *Mathematical Magick*, Bk. II, Chap. II.

(91) BIRCH, *op. cit.*, Vol. I, pp. 379, 385; *Cf.* HOOKE, *Diary*, p. 418. This subject was discussed at some fifteen meetings of the Society within a three-year period. The penny-post was not set up in London until 1683. *Cf.* ANDERSON, *op. cit.*, Vol. III, p. 88.

CHAPTER IX

SCIENCE AND MILITARY TECHNIQUE (1)

It was not until the seventeenth century that England attained its position of military and commercial leadership. Frequent recourse to force of arms attended this rise to power. Not only were there fifty-five years of actual warfare during this century, but also the greatest revolution in English history. Coincident with this prolonged warfare occurred a number of changes in military technique. The dominance of fire-arms —both muskets and artillery—over side-arms first became marked at this time (2). The period represents a turning-point in the history of armaments : swords and pikes disappeared almost completely as weapons of importance (save as they are incorporated in the removable bayonet about 1680) and firearms were used almost exclusively (3). Especially notable was the enhanced use of heavy artillery, for in this field occurred a change of scale which raised or emphasized many new technical problems. Ever since the early fourteenth century, cannon or " firepots " had been used in warfare, but it was not until three centuries later that they became clearly dominant (4).

Growth of Armaments

This is reflected in the armaments accumulated by the English fighting forces. In 1632, the military stores of the Royal Navy

(1) Compare my preliminary report, " Science and Military Technique," *The Scientific Monthly*, XLI (1935), 542-45.

(2) PAUL SCHMITTHENNER, *Krieg und Kriegführung* (Potsdam : Akademische Verlagsgesellschaft, 1930), pp. 268-80.

(3) FERDINAND TÖNNIES, " Die Entwicklung der Technik: soziologische Skizze," in *Festgaben für* ADOLPH WAGNER (Leipzig, 1905), p. 137. This change in technique is reflected in the markedly larger casualties, proportionate to the size of the fighting forces, which occurred in this century as compared with the foregoing period. *Cf.* P. A. SOROKIN, *Social and Cultural Dynamics*, Vol. III.

(4) WERNER SOMBART, *Krieg und Kapitalismus*, p. 85.

included 81 brass and 147 iron-picees, but in March and April of 1652—in preparation for the Dutch War—the Commonwealth demanded immediately 335 guns to equip only part of the Navy (5). In December of the same year, the department of ordnance required an additional 1500 iron-pieces, weighing 2,230 tons, the same number of carriages,. 117,000 round and double-headed shot, 5,000 hand grenades and 12,000 barrels of corn powder (6). In 1683, there were about 8,396 cannon on English warships, with approximately 350,000-400,000 cannon balls (7). Further, in 1694-95, thirty " machines " or " infernals " —a modification of the fireship used by GIAMBELLI in 1585 in the Schelde—arranged so as to explode very destructively, were utilized by the Navy (8).

These demands probably not only enhanced the early capitalistic development of the copper, tin and iron industries which furnished raw materials for armament, but also proved a " great stimulant of improved technique in the foundry" (9). Furthermore, the increased efficiency of artillery necessitated the revision and improvement of fortifications which in turn set up technical problems engrossing the attention of engineers and scientists (10).

Associated Technological Demands : Interior Ballistics

LEONARDO was one of the first in modern times to combine military engineering and scientific prowess, as is evidenced by his polygonal fortress, steam cannon, breech-loading cannon,

(5) M. OPPENHEIM, *A History... of the Royal Navy*, pp. 289, 360.

(6) *Ibid.*, p. 361; SOMBART, *Krieg und Kapitalismus*, p. 89.

(7) SOMBART, *op. cit.*, pp. 108-9.

(8) CLOWES, *op. cit.*, Vol. II, pp. 249, 476 ff.

(9) LEWIS MUMFORD, *Technics and Civilization* (New York : HARCOURT, BRACE & Co., 1934), pp. 90-91, quoting ASHTON. *Cf.* SOMBART (*op. cit.*, p. 114) who observes : " ... die Fortschritte, die auf dem Gebiete der Eisenverarbeitung vom 16.-18. Jahrhundert gemacht wurden... dem Bedürfnis nach besseren Kanonenrohren entsprungen sind." *Cf.* also LUDWIG BECK : " der Geschützguss hat mit am meisten zur Förderung der Technik der Eisengiesserei beigetragen; er gab auch die Veranlassung zur Einführung des Flammofenschmalzens." *Die Geschichte des Eisens in technischer und kulturgeschichtlicher Beziehung*, 5 vols. (Braunschweig, 1884-1903), Vol. III, p. 748.

(10) The following discussion is heavily indebted to HESSEN, *op. cit.*, pp. 163-66, *cf.* MUMFORD, *op. cit.*, p. 88; MAX JÄHNS, *Ueber Krieg, Frieden und Kultur* (Berlin, 1893), pp. 72-76.

rifled firearms and wheel-lock pistol (11). Likewise, TARTAGLIA, VANUCCI BIRINGUCCIO, HARTMANN, GALILEO, DESCARTES, TORRICELLI, LEIBNIZ, VON GUERICKE, PAPIN, NEWTON, JOHANN and DANIEL BERNOULLI, EULER, MAUPERTUIS and many other illustrious scientists devoted some effort to the solution of problems in military technique (12).

GALILEO's dialogues on motion seem especially to have been related to current military interests. As BENJAMIN ROBINS observed, TARTAGLIA's views on the trajectory of a projectile provoked many disputes " which continued until the time of GALILEO, and perhaps gave rise to his celebrated *Dialogues* on

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(11) USHER, *A History of Mechanical Inventions*, p. 183 ff; F. M. FELDHAUS, *Die Technik* (Leipzig and Berlin, 1914), columns 394, 406.

(12) TARTAGLIA, in his *Della nuova scienza* (1537), and *Quesiti et invenzioni diversi* (1546), attempted to determine the trajectory of a projectile and was probably the first to assert the greatest range of projectiles was at an elevation of 45 degrees. VANUCCI BIRINGUCCIO, in his *De la pirotechnia* (Venice, 1540), deals with possible improvements in the boring of cannon. GEORG HARTMANN, in 1540, invented a scale of calibres which provided a standard for the production of guns and furthered the empirical laws of firing. GALILEO, in his *Discorsi... intorno à due nuove scienze* (Leiden, 1638), pointed out that the trajectory of a projectile described a parabola (ignoring air resistance). This theory was doubted by the scientist and soldier, DESCARTES. TORRICELLI, in his *De motu gravium et naturaliter projectorum* (Florence, 1641), concerned himself in great detail with the problems of the trajectory, range and fire zone of projectiles. LEIBNIZ, as is evidenced in his posthumously discoverd writings, was greatly concerned with various aspects of military problems, such as " military medicine," " military mathematics " and " military mechanics." LEIBNIZ also worked on a " new air-pressure gun." OTTO VON GUERICKE, in his *Experimenta Nova* (1672) described a large " air-pressure gun," as did DENIS PAPIN, in the *Phil. Trans.*, XV (1685), 21. PAPIN continued his work along this line, summarizing it in his article, " Sur la force de l'air dans la poudre à canon," *Nouvelles de la république des lettres*, 1706. NEWTON, in his *Principia*, Bk. II, sect. I-IV attempted to calculate the effect of air-resistance upon the trajectory of a projectile. JOHANN BERNOULLI, pointed out NEWTON's error in determining this with the result that it was eliminated in the second edition of the *Principia*. BERNOULLI, in his *Dissertatio de effervescentia et fermentatione* (Basel, 1690), also studied the expansion of gun-powder gases. EULER continued the theory that the parabola best approximates the actual trajectory of a projectile; a subject which was dealt with in some detail by MAUPERTUIS, in his " Ballistique arithmétique," *Mémoires de l'académie des sciences de Paris*, 1731. *Cf.* MAX JÄHNS, *Geschichte der Kriegswissenschaften*, 4 vols. (München, 1890), Vol. I, p. 629; Vol. II, pp. 1008, 1180, 1242, 1626-27; THEODOR BECK, *Beiträge zur Geschichte des Maschinenbaues* (Berlin, 1900), pp. 111-126; FELDHAUS, *op. cit.*, columns 393, 403; HESSEN, *op. cit.*, p. 163.

motion." (13) Moreover, the fact that GALILEO introduced this work with an acknowledgment of the assistance rendered by the Florentine arsenal suggests a further connection (14). In WHEWELL's opinion, " practical [military] applications of the doctrine of projectiles no doubt had a share in establishing the truth of GALILEO's views" (15).

But all this simply indicates that prominent scientists have at times been directly engaged with problems of military technique. To appreciate more fully the significance of this factor in the choice of scientific problems for concentrated investigation requires a detailed study of the imperatives introduced by such practical exigencies.

The technical and scientific problems set by the development and wide-spread adoption of artillery were briefly these. Interior ballistics involves a study of the formation, temperature and volume of the gases into which the powder charge is converted by combustion, and the work performed by the expansion of these gases upon the gun, carriage and projectile (16). Formulae for the velocity imparted to a projectile by the gases of given weights of gun powder and for their reaction upon the gun and carriage must be computed to determine the correct relation of the weight of charge to the projectile's weight and length of bore, the velocity of recoil, *etc.* Another basic problem is the determination of the least weight with the maximum stability of the gun.

Not only such nineteenth century scientists as GAY-LUSSAC, CHEVREUL, GRAHAM, PIOBERT, CAVALLI, MAYEVSKI, OTTO, NEUMANN, NOBLE and ABEL but also many earlier investigators were concerned with these problems. Of obvious fundamental importance for interior ballistics is the relation between pressure and volume of gases. RICHARD TOWNELEY suggested the hypothesis " that supposes the pressures and expansions to be in reciprocal proportion," HOOKE's experimental results tallied with this conjecture and in 1661 BOYLE definitely established the law

(13) *Mathematical Tracts of the late* BENJAMIN ROBINS, edited by JAMES WILSON, 2 volumes (London, 1761), Vol. I, pp. 41-42.

(14) *Cf.* HESSEN, *op. cit.*, p. 164.

(15) WHEWELL, *History of the Inductive Sciences*, Vol. I, p. 331.

(16) JAMES M. INGALLS, *Interior Ballistics* (New York, 1912), Chap. I.

which bears his name (17). The law was independently established by MARIOTTE some fourteen years later. All but TOWNELEY were definitely interested in connecting their researches with the expansion of gases derived from the discharge of gunpowder. One of the earliest proposals which BOYLE submitted to the Royal Society requested " that it might be examined what is really the expansion of gunpowder, when fired" (18).

This same problem was investigated in detail by LEEUWENHOEK who, although he resided in Holland, may be considered as affiliated with English science, by virtue of the 375 papers which he sent to the Royal Society, of which he was a member. His experiments in interior ballistics dealing with " the quantity of air produced by the blast " and published in the *Transactions*, aroused sufficient interest to be repeated with modifications before the Society at least a dozen times by PAPIN (19). At one of the early meetings of the Society, both BOYLE and BROUNCKER, the latter of whom was especially interested in ballistics, suggested experiments on air-pressure and the expansion of gases. One of the proposed experiments dealt with the inflammation and combustion of a charge of powder (20) : a problem basic to the noted memoirs in interior ballistics by NOBLE and ABEL read before the Royal Society in 1874 and 1879, respectively (21).

Sir ROBERT MORAY introduced to the Society Prince RUPERT's gun-powder, " in strength far exceeding the best English powder," as well as a new gun invented by the same royal scientist (22). MORAY likewise suggested a series of experiments in gunnery which were broadcast in the *Transactions* (23). These trials aimed to determine the relation between the quantity of powder, calibre of gun and the carrying distance of the shot. Similar

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(17) WOLF, *History of Science*, pp. 239 ff.

(18) BIRCH, *op. cit.*, Vol. I, p. 455.

(19) *Phil. Trans.*, XVII (1693), 754-60; BIRCH, *op. cit.*, Vol. IV, pp. 470, 494, 496, 517, *et passim*. On the continent JOHANN BERNOULLI, who investigated problems of exterior ballistics as well, was likewise concerned with this subject. *Cf.* his *Dissertatio de effervescentia et fermentatione* (Basel, 1690).

(20) BIRCH, *op. cit.*, Vol. I, p. 9.

(21) INGALLS, *op. cit.*, p. 33.

(22) BIRCH, *op. cit.*, Vol. I, p. 281 ff., p. 332.

(23) *Phil. Trans.*, II (1667), 473-77.

experiments were conducted by the sometime Savilian professor of astronomy, JOHN GREAVES (24).

The Royal Society listed among its scientific apparatus " several instruments for examining the recoiling, true carriage, and divers other properties of Guns," as well as " several Engines for finding, and determining the force of Gun-powder" (25).

FRANCIS HAUKSBEE also experimented with the expansion of gases under various conditions demonstrating the approximate expansion which occurs after the explosion of gunpowder (26). HAUKSBEE's results were used in the fundamental work on ballistics published by BENJAMIN ROBINS in 1742 (27), especially in his propositions " to determine the elasticity, and quantity of this elastic fluid, produced from the explosion of a given quantity of gunpowder." This fundamental problem of interior ballistics engrossed to a considerable degree the attention of seventeenth century English scientists as is evidenced by frequent experiments performed before the Royal Society (28).

Exterior Ballistics

But perhaps even more attention was devoted to scientific problems closely allied with exterior ballistics, which is concerned with the motion of a projectile after it leaves the gun. It treats of the trajectory (or curve described by the centre of gravity of the projectile in its movement) and the relation between the velocity of the projectile and the resistance of the air (29). The most notable experiments in exterior ballistics in the last two centuries were those by ROBINS, HUTTON, DIDION, POISSON,

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(24) *Phil. Trans.*, XV (1685), 1090-92. This report, however, was posthumously published; the experiments were conducted at Woolwich, 18 March 1651.

(25) SPRAT, *op. cit.*, p. 250.

(26) FRANCIS HAUKSBEE, *Physico-Mechanical Experiments on Various Subjects* (London, 1709), especially pp. 81 ff.

(27) *Mathematical Tracts*, Vol. I, especially Propositions I-VII.

(28) See Appendix A, III, *b*, 1. Some of the most active members of the Society participated in these experiments : e.g., HENSHAW, MORAY, BROUNCKER, HOOKE, NEILE, CHARLETON, POVEY, GODDARD, BOYLE, PAPIN, *etc.* The Society continued its interest in this subject throughout the eighteenth century.

(29) *Cf.* ORMOND M. LISSAK, *Ordnance and Gunnery* (New York : JOHN WILEY & Sons, 1915), pp. 357 ff.

HELIE, BASHFORTH, MAYEVSKI and SIACCI, but these were in turn largely based upon scientific work of the preceding period.

The theoretical work of TARTAGLIA, COLLADO, GALILEO and TORRICELLI on the motion of projectiles entered into the currents of both science and military technology. There appeared a number of books which attempted to utilize this scientific research for practical purposes (30), most of them based on GALILEO's theorem that the trajectory of a projectile is parabolic. Leading scientists likewise continued research along this line, turning to a number of directly related and more distantly derivative problems.

The determination of the trajectory of a projectile is linked with a number of scientific problems which engrossed, to a considerable extent, the attention of some of the leading scientists of the day. Experimentation with the motion of a pendulum in air or water enables one to test an hypothetical law of the resistance of media to bodies moving in them (31). From the time of GALILEO to the epochal work of ROBINS on the subject, the resistance of the air to bullets and shot moving through it was considered as increasingly important in the estimation of the trajectory. Although GALILEO was cognizant of the influence of this resistance he exerted relatively little effort to determine its extent in contrast to the ever greater attention devoted to this problem by WALLIS, NEWTON, BERNOULLI and EULER (32).

The explanation of the path of projectiles in a vacuum involves the first and second laws of motion. The parabolic motion of

(30) Some of the more notable of these works were : WILLIAM BOURNE, *The Arte of shooting in great ordnance* (London, 1643); JOHN ELDRED, *The Gunner's Glasse* (London, 1646); ROBERT ANDERSON, *The Genuine Use and Effects of the Gunne* (London, 1674); and his *To Hit a Mark* (London, 1690); Mons. BLONDEL, *L'Art de Jetter les Bombes* (à La Haye, 1685); and THOMAS BINNING, *A Light to the Art of Gunnery* (London, 1689). Many inventors, notable among whom was the MARQUIS of WORCESTER, sought to improve the existing means of bombardment. See his *A Century of the Names and Scantlings of such Inventions, as at present I can call to mind to have tried and perfected...* (London, 1663), Numbers 24, 29, 64-67.

(31) NEWTON, *Principia*, Bk. II, Section VI, Prop. XXXI.

(32) GALILEO GALILEI, *Dialogues concerning Two New Sciences*, trans. by HENRY CREW and ALFONSO DE SALVIO (New York : The MACMILLAN Company, 1914), Fourth Day, Theorem I (pp. 252 ff.). WALLIS maintained that deviations from the estimated trajectory were largely due to this resistance. *Cf.* JÄHNS, *Geschichte der Kriegswissenschaften*, Vol. II, p. 1243.

projectiles was linked with experiments on the jet which spouts from an orifice in a vessel full of fluid; experiments which attained popularity because they enable the curve described to become visible (33). As we shall see, CASTELLI, TORRICELLI, MERSENNE, MARIOTTE, HALLEY and NEWTON explicitly linked such experiments in hydrodynamics to exterior ballistics.

The actual path of projectiles deviates from GALILEO's parabolas partially owing to the rotation of the earth. HOOKE, NEWTON, and in France, MERSENNE and PETIT attempted to determine the influence of this rotation (34).

Thus, affiliated with research in exterior ballistics are a number of derivative scientific problems in which scientists of the time were deeply interested. It will be seen that the connection between the pure and applied aspects of this scientific research is explicitly drawn by the investigators themselves, suggesting that, to some extent at least, their interest was focussed upon these subjects because of the practical utility derivable therefrom. Such influences may operate in an equally pervasive, but less obvious, fashion by providing the dynamic-mechanistic (35) core of values by which scientific research was governed. The effort to attain mathematical precision in artillery fire was a model for the industrial arts and a link with the current science. In any event, military needs, as well as the other technologic needs previously described, tended to direct scientific interest into certain fields.

Detailed Considerations

Thus, HOOKE definitely linked certain of his researches with military technology. The study of the free fall of bodies—so

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(33) WHEWELL, *op. cit.*, Vol. I, pp. 341-42.

(34) J. F. W. GRONAU, *Historische Entwicklung der Lehre vom Luftwiderstande* (Danzig, 1868), pp. 20-28.

(35) Mechanical in contrast to organic. Seventeenth century scientists ought " isolates " (samples) which could be treated, *for all practical purposes*, as if they were utterly representative of the physical world from which they had been abstracted. *Cf.* BORKENAU, *Der Übergang vom feudalen zum bürgerlichen Weltbild*, pp. 6-10, *passim*; MUMFORD, *Technics and Civilization*, pp. 46-47.

(36) BIRCH, *op. cit.*, Vol. I, pp. 195-97.

essential to exterior ballistics in its early stage of theory—was continued by HOOKE in his experiments with the fall of " steel " bullets (36). He followed this investigation with some experiments performed before the Royal Society designed to determine the resistance of air to projectiles. This resistance, he maintained, could be determined by " shooting horizontally from the top of some high tree," as well as " perpendicularly upward " and by " shooting bullets... horizontally : and so to observe both what time they spend in passing such and such a length; and likewise with what force they hit a mark or body, placed at several distances from the instrument that shoots" (37). His suggestion that bullets be fired vertically upward represented an effort to ascertain the effect of the rotation of the earth upon the path of projectiles.

HOOKE continued his experiments by constructing an " engine for determining the force of gunpowder by weight,"—the resulting experiments proving of sufficient general interest to be repeated at several meetings of the Society (38). The definite relation between military technology and pure science is made explicit by HOOKE's researches. He spent considerable time in experimenting with the free fall of bodies and attempting to determine the velocity " of a bullet, shot out of a musket" (39). The connection is made evident in his " experiment for finding the velocity of a bullet by means of the instrument for measuring the time of falling bodies" (40).

EDMOND HALLEY, who, it has frequently been said, stands second only to NEWTON among English astronomers of this period, constantly related his scientific research to practical needs. We have already seen the marked extent to which his work in astronomy was linked with the immediate practical demands of navigation. His researches in mechanics, and more important still, his encouragement of WALLIS' and NEWTON's work in this field, likewise seem to have been largely influenced by practical concerns. HALLEY may be considered as perhaps the clearest example of a seventeenth century scientist who found justification for his scientific labors in the immediate fruits which they afforded.

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(37) *Ibid.*, Vol. I, p. 205.
(38) *Ibid.*, Vol. I, p. 205.
(39) *Ibid.*, Vol. I, pp. 465, 474.
(40) *Ibid.*, Vol. I, p. 461. GALILEO, of course, had implied the same connection.

Familiar as he was with the scientific discoveries of his fellow investigators, HALLEY explicitly linked the most abstruse theories of science to immediately practical aims. Thus, having seen NEWTON's *Propositiones De Motu* (which constituted the first draft of the greater part of the first two books of the *Principia*), HALLEY applied these doctrines to the motion of cannon shot (41). Cognizant of the economic, as well as technical, advantages to be derived from his mathematical and mechanical formulation of the approximate trajectory of projectiles, HALLEY suggested that his " rule may be of good use to all Bombardiers and Gunners, not only that they may use no more Powder than is necessary to cast their Bombs into the place assigned, but that they may shoot with more certainty..." (42) In this respect, HALLEY was truly a child of the utilitarian age in which he lived : he constantly reiterates the economic advantages which obtain from the proper utilization of scientific knowledge. The practically-minded scientists of that period were acutely aware of the undue cost of gunpowder (43) and HALLEY repeatedly attempted to apply his scientific knowledge with the aim of reducing this cost. Thus, in a further article on this subject, HALLEY again emphasized the economy of powder which might be effected by an accurate knowledge of the rules of aiming cannon (44); and in a paper read before the Royal Society he emphasized the fact " that the fittness of the shott to the bore of a piece was of great consequence in Gunnery, [and] that he was well assured, that, by observing this, more powder might be saved, than would pay for the turning our great cannon shott..." (45)

(41) E. HALLEY, " A Discourse Concerning Gravity, and its Properties, wherein the Descent of Heavy Bodies, and the Motion of Projects is briefly, but fully handled : Together with the Solution of a Problem of great Use in Gunnery," *Trans.* XVI (1686), 3-21.

(42) *Ibid.*, p. 17.

(43) See JOHN WILKINS, *Mathematical Magick*, Book I, p. 81, who discourses of the costliness of cannon shot and suggests the eminent desirability of devising ways of reducing this expense.

(44) E. HALLEY, " A Proposition of General Use in the Art of Gunnery," *Phil. Trans.*, XIX (1695), 68-72. " ... a considerable advantage is in the saving the King's Powder, which is so great and numerous Discharges, as we have so lately seen, must needs amount to a considerable value." p. 68.

(45) Read 2 July 1690. Reprinted from the Journal Books of the Royal Society in *Correspondence and Papers of* EDMOND HALLEY, p. 219.

This insistent reiteration of the economic significance as well as the practical applications of scientific and mathematical theory is a noteworthy reflection of that spirit of economic rationalism which has become increasingly apparent since at least the seventeenth century. Scientists seek not only technical efficiency, but consider as well the economic advantages of a strictly rational adaptation of means to ends (46). It is an expression of the attitude justly ascribed to Newtonians of instituting an " active and practical science having for its end the assurance, by the knowledge of natural laws, of our domination over nature," plus the conception of a rationalized economy (as found in the discussions of HOBBES and LOCKE) (47).

HALLEY linked scientific research to military technology in many other instances. Pointing out that England, being an island, " must be masters of the Sea, and superior in navall force to any neighbour," he described a method of enabling a ship to carry its guns in bad weather (48). Likewise, at the instigation of the Royal Society, he examined " Signor ALBERGHETTI's tables for shooting bombs," pointing out the laudable use made of the work of GALILEO, TORRICELLI and others in these tables (49).

HALLEY likewise linked the researches in hydrodynamics of TORRICELLI, MARIOTTE and NEWTON to exterior ballistics. He pointed out, as was well recognized by the scientists of the time, that the theory of the velocity of fluids (as established through experiments on the efflux of fluid through a hole in a vessel full of fluid) could be applied to determine " the Velocity imprest

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(46) BERNHARD BAVINK is correct in his contention that technology as such, to say nothing of science, is stripped of economic considerations of cost, scarcity, etc. But concretely, the two are very closely related. It is especially notable that scientists had begun to take the cost factor into account since this suggests that economic elements had thoroughly permeated their choice of problems. See BAVINK, *Ergebnisse und Probleme der Naturwissenschaften* (Leipzig : S. HIRZEL, 1930), pp. 517-18. MAX WEBER incisively draws the same distinction and adds : " Die ökonomische Orientiertheit der heute sog. technologischen Entwicklung ist eine der Grundtatsachen der Geschichte der Technik." *Wirtschaft und Gesellschaft*, pp. 32-33.

(47) See ÉLIE HALÉVY, *La formation du radicalisme philosophique*, 3 volumes (Paris : F. ALCAN, 1901), Vol. I, p. 3 ff.

(48) Read before the Royal Society 14 December 1692. Quoted in *Correspondence and Papers of* EDMOND HALLEY, pp. 165-65.

(49) *Ibid.*, pp. 167-68.

on a bullet by the explosion of the Pouder" (50). The work of MARIOTTE in his *Traité du mouvement des eaux et des autres corps fluides*, upon which NEWTON animadverted in the second book of the *Principia*, was reëxamined with the view of establishing the velocity of cannon shot. As we shall see, NEWTON who, in his correspondence with HALLEY, evidenced his appreciation of the connection here involved, spent considerable time in experimenting with this problem in hydrodynamics.

HALLEY likewise encouraged WALLIS' researches on the resistance of air to projectiles, advising WALLIS that NEWTON was working on the same problem (51). The outcome was WALLIS' paper published in the *Transactions* in which he stated that a " cannon bullet " projected horizontally describes a trajectory " which resembles a Parabola deformed "; this deformation, he claimed, being largely due to the resistance of the air (52). It follows, therefore, that it is decidedly necessary to determine the precise influence of this resistance; a subject which was intensively treated by NEWTON and which temporarily culminated in the work of ROBINS, although the actual path of projectiles is mathematically almost unmanageable.

WALLIS was the first to state correctly the theory of impact (53), which was misunderstood by GALILEO and erroneously discussed by DESCARTES in his *Principia* of 1644. Almost at the same time, but in a less complete fashion, CHRISTOPHER WREN discovered the empirical laws of impact for elastic bodies (54), while HUYGHENS communicated his much more detailed analysis less

(50) *Ibid.*, pp. 147-48; 222-23.

(51) See his letter to WALLIS, dated London December 11, 1686 in which he writes : " Mr. ISAAC NEWTON about 2 years since gave me the inclosed propositions, touching the opposition of the Medium to a direct impressed Motion..." The letter is reprinted in *Correspondence and Letters of* EDMOND HALLEY, *op. cit.*, pp. 74-75. See also his later letter, *ibid.*, pp. 80-81.

(52) JOHN WALLIS, " A Discourse concerning the Measure of the Airs resistance to Bodies moved in it," *Phil. Trans.*, XVI (1687), 269-80.

(53) WALLIS communicated his paper to the Royal Society on November 26, 1668. It was published in the *Phil. Trans.*, III (1668), 864-68 (" A Summary Account given by Dr. JOHN WALLIS of the General Laws of Motion."

(54) WREN's results were communicated on December 17, 1668; *cf. Phil. Trans.*, IV (1669), 925-28.

than a month thereafter (55). These experiments on impact *assume* the third law of motion, as NEWTON observes in the *Principia* (56), though NEWTON was the first clearly to formulate the principle of action and reaction. This is not only a basic law in mechanics but is necessary for the understanding of the phenomenon of recoil in gunnery. WALLIS, as we have seen, was involved in research on exterior ballistics, WREN was concerned with the invention of " offensive and defensive engines " and with convenient ways " of useing Artillery on Ship-board," (57) while HUYGHENS contributed to practically every phase of military technology (58).

This work on the theory of direct impact is another instance where scientific effort was apparently influenced, not so much by the direct and explicit relation to practical needs, but rather by a focussing of interest upon certain fields which had clear-cut relations to immediate technologic problems. Research concerning the impact of elastic and inelastic bodies was probably *directly* stimulated by the felt deficiency in the principles of mechanics but it is also evident that practical problems tended to emphasize interest in this sphere of investigation. The third law of motion was as applicable to the phenomenon of recoil as the first two laws were to the trajectory of projectiles. The keen awareness of these scientists of contemporary practical needs reinforces the probability that they were not uninfluenced in their selection of problems by these requirements.

NEWTON was as well aware of the relation of his work to these practical needs as was ROBINS who so successfully used his results for direct application to ballistics. NEWTON's treatment of the problem of the solid of least resistance, as he stated, could not only be applied to the determination of the form of ships, but is also important for determining the trajectory of projectiles (59).

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(55) HUYGHENS' account was received by OLDENBURG on January 4, 1669 A much more detailed account in found in his posthumously published *Tractatus de motu corporum ex percussione* (1703).

(56) NEWTON, *Principia*, Book I, Scholium to Law III (p. 32 ff. of MOTTE ed.).

(57) CHRISTOPHER WREN, *Parentalia*, pp. 198, 240.

(58) See, for example, his *Discours de la cause de la pesanteur* (Leiden, 1690).

(59) See *Principia*, Book II, Prop. XXIV, Scholium. ROBINS subsequently also recognized the importance of this research for both ship-building and exterior ballistics. *Cf.* ROBINS' *Mathematical Tracts*, Vol. I, pp. 199, 217; also

He concluded that the resistance is proportional to the square of the velocity, the density of the fluid, and the surface of the sphere. NEWTON attempted, though unsuccessfully, to deduce the law of resistance from the velocity of efflux; an attempt which both MARIOTTE and HALLEY had linked to exterior ballistics. NEWTON devoted a considerable part of the second book to a discussion of the resistance of different media to projectiles. In section VI he tests assumed laws of resistance by determining the motion of pendulums in air and water. Section VIII presents propositions which permit the deduction that the resistance of the air to projectiles is nearly as the square of the velocity.

ROGER COTES, NEWTON's disciple who edited the second edition of the *Principia*, similarly occupied himself with the motion of projectiles (60). He also corrected several casual errors in NEWTON's work on the same subject (61).

From the following account it seems probable that the needs generated by military technology influenced the foci of scientific interests to an appreciable degree (62).

A. R. FORSYTH, " NEWTON's Problem of the Solid of Least Resistance," in ISAAC NEWTON, 1642-1727 (ed. by W. J. GREENSTREET), pp. 75-86.

(60) ROGER COTES, *De descensu gravium de motu pendulorum in cycloide et de motu projectilium* (Cambridge, 1720), pp. 30-37; also, " De motu projectilium," *Opera miscellanea* (Cambridge, 1722), pp. 87-91.

(61) In definition V, NEWTON in writing of a ball shot horizontally from the top of a mountain for a distance of two miles before it reaches the ground had, in the first edition, made his calculations as though it were oblique projection. This was corrected by COTES, as was an error in Prop. X, Bk. II, pertaining to the approximate determination of the motion of a projectile in the air. See COTES' letters in EDLESTON, *op. cit.*, pp. 4-5, 9.

(62) A list of the most important papers on gunnery and projectiles published in the *Transactions* in the latter seventeenth and eighteenth centuries may serve to indicate the extent to which prominent English scientists were directly concerned with the field of military technology.

Sir ROBERT MORAY, " Experiments at Woolwich, March 18, 1651, for trying the force of great guns," XV (1685), 1090.

E. HALLEY, " Solution of a problem of great use in gunnery," XVI (1685), 3.

E. HALLEY, " A proposition of general use in the art of gunnery, showing the rule of laying a mortar to pass in order to strike any object above or below the horizon," XIX (1695), 68.

BROOK TAYLOR, " Some propositions respecting the parabolic motion of projectiles, written in 1710," XXXI (1721), 151.

" Report of the Committee of the Royal Society appointed to examine some questions in gunnery," XLII (1742), 172.

BENJAMIN ROBINS, " An account of a book, entitled, New Principles of Gunnery, But the extent of this influence is still problematical. It is by no means certain that much the same distribution of interests would not have occurred, irrespective of this external pressure. Many of these problems likewise flowed directly from the intrinsic developments of science. It may be argued that the disinterested search for truth coupled with the logical concatenation of scientific problems is sufficient to account for the particular direction of research. In point of fact, however, a cumulating body of evidence leads to the conclusion that *some* rôle must be accorded these factors external to science, properly so-called. The following chapter is devoted to the effort to determine, as precisely as possible (although we can at best hope for only a very crude estimate) the extent to which military, economic and technical influences were operative.

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containing the determination of the force of gunpowder, and an investigation of the resisting power of the air to swift and slow motions," XLII (1743), 437.

THOMAS SIMPSON, "The motion of projectiles near the earth's surface considered, independent of the properties of the conic sections," XLV (1748), 137.

CHARLES HUTTON, "The force of fired gunpowder, and the initial velocities of cannon balls, determined by experiments; from which is also deduced the relation of the initial velocity to the weight of the shot, and the quantity of powder," LXVII (1778), 50.

BENJAMIN THOMPSON, "New experiments on gunpowder," LXXI (1781), 229.

BENJAMIN COUNT of RUMFORD, "Experiments to determine the force of fired gunpowder," LXXXVII (1797), 222.

CHAPTER X

Extrinsic Influences on Scientific Research

The question of the relative importance of intrinsic and external factors in the determination of the foci of scientific interest has long been debated. One camp of theorists has pledged itself to the conviction that science has virtually no autonomy of its own. The direction of scientific advance is held to be almost exclusively the outcome of external, particularly of economic, pressure. Joining issue with these extremists are others who argue that the pure scientist is shut off from the social world in which he lives and that his subjects of research are determined by the strict necessity which inheres in each logic-tight compartment of science. Each of these points of view is justified by an appeal to carefully selected cases which nominally bear out one or the other of these conflicting opinions.

In a recently published lecture, Dr. Sarton mediates between these views and poses the problem in respect to mathematics as follows (1) :

> There is no doubt that mathematical discoveries are conditioned by outside events of every kind, political, economic, scientific, military, and by the incessant demands of the arts of peace and war. Mathematics did never develop in a political or economic vacuum. However, we think that those events were only some of the factors among others, factors the power of which might vary and did vary from time to time. It might be almost decisive in one case, and ineffectual in another.

Mutatis mutandis, the same might be said of science generally. Of especial importance is the suggestion that the influence of these extrinsic conditioning factors is not constant for this implies that we cannot extend our findings for the seventeenth

(1) George Sarton, *The Study of the History of Mathematics* (Cambridge Harvard University Press, 1936), pp. 15-16.

century without further ado to the history of science in general (2). But this does not preclude a systematic examination of the extent to which such factors pervaded scientific research during the latter part of the seventeenth century.

A Statement of Procedure

The minutes of the Society as transcribed in BIRCH's *History of the Royal Society* provide one basis for such a study. A feasible, though in many ways inadequate, procedure consists of a classification and tabulation of the researches discussed at these meetings, together with an examination of the context in which the various problems came to light. This should afford some grounds for deciding roughly the extent to which extrinsic factors operated directly or indirectly.

Since BIRCH's transcription extends only through the meetings of 1687, this provides one temporal limit of our study. Meetings during the four years 1661, 1662, 1686 and 1687 are considered. There is no reason to suppose that these did not witness " typical " meetings. Moreover, even this brief span may disclose shifts in the degree of social and economic influences during this period.

The classification employed is empirical rather than logical. Items were classified as " directly related " to social or economic demands when the individual conducting the research explicitly indicated some such connection or when the immediate discussion of the investigation evidenced an appreciation of some such relation. Items classified as " indirectly related " comprise researches which had some clear-cut connection with current practical needs, usually intimated in the context, but which were not definitely so related by the investigators.

Researches which evidenced no relations of this sort were classified as " pure science." In this category were classified many items which have conceivable relations with practical exigencies but which were not tacitly or overtly connected with

(2) Much the same conception is expressed by MAX SCHELER, *Versuche zu einer Soziologie des Wissens*, pp. 29 ff.

such intrinsic influences. Thus, investigations in the field of meteorology could very easily be related to the practical desirability of forecasting the weather but when these researches evidently derived from antecedent scientific problems they were classified as pure science (3). Likewise, much of the work in anatomy and physiology was undoubtedly of value for medicine and surgery, but the same criteria were employed in the classification of these items. It is probable, therefore, that if any bias was involved in this classification, it was in the direction of over-estimating the scope of pure science.

Two checks were used to guard this rough and only grossly quantitative determination of social and economic influences. One was to have the items independently classified by two persons. The consistency of results, using the same criteria of classification, was so high as to suggest that there was, in this respect at least, less subjectivism than might at first be suspected. The second check is the presentation of a few representative examples under each category; a sample of which is presented in Appendix A.

In any event, it is obvious that this procedure provides only a gross approximation to the extent of extrinsic influences upon the selection of subjects for scientific study. The results purport merely to suggest the relative extent of the influences which we have traced in a large number of concrete instances. The empirical classification used in this tabulation follows (4) :

A. Research related to socio-economic needs.
- I. Marine transport and navigation.
  - *a.* directly related research.
    1. studies of the compass : magnetic deviation.
    2. maritime maps and hydrography.
    3. methods of determining ship's position at sea : longitude and latitude.
    4. studies of the times of tides.
    5. methods of ship-construction and invention of ship accessories.

(3) On the other hand, such an item as the following was classified as " directly influenced." " Mr. HOOKE shewed an instrument to measure the velocity of the air or wind, as follows... The use of which may be of very great consequence in the sailing and steering a ship upon the sea, and for examining the power and strength upon the land in order to the theory of shipping, for which it was designed." BIRCH, *op. cit.*, Vol. IV, pp. 225-26.

(4) *Cf.* HESSEN, *op. cit.*; also Appendix A.

b. indirectly related research.
1. studies of the movement of bodies in water : to improve the floating qualities of vessels.
2. observations of heavenly bodies in order to determine latitude and longitude.
3. studies in botany and silviculture in so far as they pertain to the provision of ship timber.

II. Mining and metallurgy.
a. directly related research.
1. methods of raising ores.
2. experiments with water-pumps and water-conducting equipment.
3. methods of mine ventilation and controls of "damps."
4. metallurgy.
5. general mining techniques.

b. indirectly related research.
1. methods of raising weights useful in raising ores.
2. problems of raising water in tubes and study of atmospheric pressure applicable to pumping water from mines.
3. studies of compression of air applicable to the ventilation of mines.

III. Military technology.
a. directly related research.
1. study of trajectory and velocity of bullets and shot.
2. processes of casting and improvement of guns.
3. relation of length of barrel of gun to range of bullet.
4. phenomenon of recoil.
5. experiments with gunpowder.

b. indirectly related research.
1. compression and expansion of gases applicable to the study of relations between volume and pressure in the gun.
2. strength, durability and elasticity of metals useful in determining the elastic strength of guns.
3. free fall of a body and conjunction of its progressive movement with its free fall, useful in determining the trajectory of bullets and shot.
4. movement of bodies through a resistant medium to obtain a closer approximation to the trajectory of projectiles influenced by the resistance of the air.

IV. Textile industry.
1. research which is definitely and explicitly related to this industry.

V. General technology and husbandry.

B. Pure Science.

This category includes research in the fields of mathematics, astronomy, physics, meteorology, chemistry, botany, zoölogy, anatomy, physiology, geology, geography, history and statistics (political arithmetic) which by the canons discussed in the text seem to bear no notable relation to practical needs.

The various items of research discussed at the meetings of the Royal Society were classified in these categories. The individual experiments which claimed the attention of members of the Society were arbitrarily counted as " units " in the tabulation, as previously described. The varying emphases on different problems demanding investigation may thus be determined, even though the quantitative indices may imply a degree of precision which manifestly has not been attained. This procedure represents an effort to provide " rules of evidence " for testing such statements as " the preëminent development of mechanics was due to the technical demands of the day." It would seem probable that by tabulating the various researches and deriving corresponding percentages for each category of the total amount of research we are obtaining an approximately accurate picture of the foci of scientific interest. The following table presents a synopsis of the results.

Summary of Results

From this tabulation it appears that less than half (41.3 %) of the various investigations conducted during the four years in hand were devoted to pure science. If we add to this the items which were only indirectly related to practical needs (7.4 % to marine transport, 17.5 % to mining, and 3.6 % to military techniques), then about seventy percent of this research had no practical affiliations. Since these figures are but grossly approximate, the results may be summarized by saying that from forty to seventy percent was in the category of pure science; and conversely that from thirty to sixty percent was influenced by practical requirements.

Again, considering only the research *directly* related to practical needs, it appears that problems of marine transport attracted the most attention. This is not surprising since the contemporary scientists were well aware of the problems raised by England's insular position—problems both military and commercial in nature—and were eager to rectify them (5). Of almost equal

(5) See, for example, EDMOND HALLEY's observation : " that the Inhabitants of an Island, or any State that would defend an Island, must be masters of the

TABLE 13

Approximate Degree of Social and Economic Influences upon the Selection of Scientific Problems by Members of the Royal Society of London

	1661		1662		1686		1687		Total for the four years	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Total	191	100.0	203	100.0	241	100.0	171	100.0	806	100.0
Pure Science	76	39.8	63	31.0	103	42.7	91	53.2	333	41.3
Science related to socio-economic needs	115	60.2	140	69.0	138	57.3	80	46.8	473	58.7
Marine Transport	17	8.9	41	20.2	39	16.2	32	18.7	129	16.0
directly related	10	5.2	18	8.9	25	10.4	16	9.4	69	8.6
indirectly related	7	3.7	23	11.3	14	5.8	16	9.4	60	7.4
Mining	63	33.0	48	23.6	38	15.8	17	9.9	166	20.6
directly related	4	2.1	5	2.4	10	4.1	6	3.5	25	3.1
indirectly related	59	30.9	43	21.2	28	11.7	11	6.4	141	17.5
Military Technology	18	9.4	23	11.3	32	13.3	14	8.2	87	10.8
directly related	15	7.9	13	6.4	22	9.1	8	4.7	58	7.2
indirectly related	3	1.5	10	4.9	10	4.2	6	3.5	29	3.6
Textile Industry	8	4.2	5	2.4	9	3.7	4	2.3	26	3.2
General Technology and Husbandry	9	4.7	23	11.3	20	8.3	13	7.6	65	8.1

importance was the influence of military technique. As Professor SOROKIN's researches have shown, the seventeenth century witnessed more warfare than any other period (with the exception of the first quarter of the twentieth century) (6). Hence, problems of a military nature could be apt to leave their impress upon the culture of the period, including scientific development (7).

Likewise, mining which, as we have seen from the exemplary studies of NEF and other economic historians, developed so markedly in seventeenth century England, had an appreciable influence upon the selection of subjects for scientific analysis. In this instance, the greater part of scientific, as distinct from technologic, research was in the fields of mineralogy and metallurgy with the aim of discovering new utilizable ores and new methods of extracting metals from the ore.

It is interesting to note that in the latter years considered in this summary, there was an increasing proportion of investigation in the field of pure science. This may be accounted for in several ways. First, it is possible that at the outset the members of the Society were anxious to justify their activities (to the Crown and the general public) by deriving practical results as soon as possible. Hence they would be apt to concentrate their

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Sea, and superior in navall force to any neighbour that shall think fitt to attack it, is what I suppose needs no argument to enforce." In his paper, " A method of enabling a ship to carry its guns in bad weather," read before the Royal Society, 14 December 1692, and reprinted in *Correspondence and Papers of* EDMOND HALLEY, pp. 164-65. In Chapter VIII we have seen how conscious scientists were of the commercial benefits of improving navigation.

(6) *Social and Cultural Dynamics*, Vol. III.

(7) HALLEY in his " Discourse concerning Gravity, and its Properties," (*Phil. Trans.*, XVI [1686], 19) provides an example of the direct way in which such problems influenced the selection of subjects for scientific study. He writes : " The Tenth Proposition containes a Problem, untouch't by TORRICELLIUS, which is of the greatest use in Gunnery, and for the sake of which this *Discourse* was principally intended; It was first Solved by Mr. ANDERSON, in his Book of the Genuine use and effects of the Gunn, Printed in the Year 1674; but his Solution required so much Calculation, that it put me upon search, whether it might not be done more easily, and thereupon the Year 1678 I found out the rule I now publish, and from it the Geometrical Construction..." HALLEY also observes that in France, BUOT, RÖMER and DE LA HIRE were also working on this same problem. This brief quotation shows concisely the way in which problems, brought to scientists' attention because of their practical importance, engendered definite types of research.

attention upon investigations which would be most apt to lead to such useful effects. Furthermore, many of the problems which were at first advisedly investigated because of their practical importance may be later studied with no awareness of their practical implications. In these instances, though it would not be an exaggeration to ascribe the choice of these subjects to practical urgencies, it is impossible to determine whether they aroused attention because of their intrinsic scientific interest or because of their ultimate utility. It would be a matter of dubious inference to denote these as influenced by socio-economic needs and hence they were, more or less arbitrarily, classified as " pure science." Therefore, the results, if they are at all biassed, are weighted on the side of pure science.

On the basis of the data presented in the last three chapters it may be tentatively maintained that socio-economic needs influenced considerably the selection of subjects of investigation by scientists in seventeenth century England. Speaking roughly, about thirty to sixty percent of the contemporary researches seem, directly or indirectly, to have been so influenced.

Addendum

In a recently published paper, Professor G. N. CLARK has suggested that Professor HESSEN's essay on " The Social and Economic Roots of NEWTON's *Principia* " over-simplifies the social and economic aspects of the science of this period (8). CLARK points out that at least six major classes of influence outside of science proper were operative : economic life, war, medicine, arts, religion and most important of all, the disinterested search for truth. With this revision, I am in substantial agreement, as the foregoing discussion indicates. Of these factors, we have considered all but the arts and medicine. The arts were not treated in this connection primarily because they seem to have been remotely connected with scientific development, except,

(8) G. N. CLARK, " Social and Economic Aspects of Science in the Age of NEWTON," *Economic History*, III (1937), 362-79. We have already indicated that the preceding three chapters of the present study, despite certain differences of interpretation, are heavily indebted to HESSEN's work.

as we have seen in Chapter II, that both may be held to be intimately related with an extensive development of naturalism and (*not* in the epistemological sense) realism (9). Researches on optics may have been occasionally stimulated by interest in the arts, but this influence was clearly of secondary importance. The requirements of medicine, on the other hand, were much more effective in guiding research in the biological sciences. The sole reason for not dealing with this relationship was one of curtailing the scope of the present study. A detailed and thorough study of this subject would undoubtedly repay investigation. Finally, it may be suggested, that the importance of religion is *primarily*, though not exclusively, one of influencing the degree of interest in science generally rather than of canalizing research in certain directions.

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(9) For an extensive discussion of this subject, see P. A. SOROKIN, *Social and Cultural Dynamics*, Vol. I.

CHAPTER XI

Some Social and Cultural Factors in Scientific Advance

Any attempt to formulate a comprehensive sociological theory of scientific development at this time must be considered premature. There is not yet available a body of monographic studies adequate to the requirements of such a theory. None the less, it is not, perhaps, entirely without value to describe briefly further orders of factors which were apparently involved in the scientific developments which we have examined. This will at least serve the twofold purpose of conveniently summarizing certain of our results and of suggesting related problems for further study.

Society, Civilization and Culture

Professor Alfred Weber has introduced a useful distinction between three orders of sociological phenomena: society, civilization and culture (1). Society refers to the patterns of interaction between persons particularly as they may be thought of as the outcome of natural drives and conditions. The social structure abstracted from considerations of technique and values falls in this category. Weber's conception of the social corresponds roughly to what Scheler called *Realfaktoren:* sex, race, state, politics and economics (2).

(1) Alfred Weber, "Prinzipielles zur Kultursoziologie," *Archiv für Sozialwissenschaft und Sozialpolitik*, XLVII (1920), 1-49; also his *Kulturgeschichte als Kultursoziologie* (Leiden: A. W. Sijthoff, 1935). R. M. MacIver adopts much the same distinction in "The Historical Pattern of Social Change," *Authority and the Individual*, vol. II of Harvard Tercentenary Publications (Cambridge: Harvard University Press, 1937), pp. 126-53; *cf.* R. K. Merton, "Civilization and Culture," *Sociology and Social Research*, XXI (1936), 104-13.

(2) *Cf.* Alexander von Schelting, "Zum Streit um die Wissenssoziologie," *Archiv für Sozialwissenschaft und Sozialpolitik*, LXII (1929), esp. 18 ff.

Concretely permeating society, but theoretically distinct from it, are the realms of civilization and culture. The first consists of the body of empirical and scientific knowledge and the collection of technical means for the control of man and nature which are found in every society. Culture comprises the scheme of values, of normative principles and ideals which serve to define the good and bad, the permissible and forbidden, the beautiful and ugly, the sacred and profane.

The factors involved in the development of civilization (science and technology) may be conveniently grouped in the two categories of society and culture, which, although considered separately, are of course in a state of mutual dependence.

Population Density

A large number of theories purport to trace some relationship between population density and the rate of scientific and technological advance. Most of these assert that there is a positive correlation between high population density and scientific progress (3). PAUL JACOBY has even attempted to reduce the relation to a formula. Since the frequency of geniuses and of their inventions and discoveries is directly related to density of population and urbanization, one may formulate the expression of a law, $u = f(xy)$ in which the density $= x$, urban ratio $= y$, and the frequency of genius $= u$. (4) According to ADOLPHE COSTE, one of the most extreme of these theorists, " the inevitable increase and the progressive concentration of populations... is the determining condition without which inventiveness could not be exercised." (5) FELDHAUS, CORNEJO, and VIERENDEEL have expressed much the same opinion (6).

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(3) A survey of many of these theories is to be found in P. A. SOROKIN, *Contemporary Sociological Theories* (New York : Harpers, 1928), pp. 388-95, 409-12. *Cf.* R. K. MERTON, " Science, Population and Society," *The Scientific Monthly*, XLIV (1937), 165-71.

(4) PAUL JACOBY, *Études sur la sélection dans ses rapports avec l'hérédité chez l'homme* (Paris, 1904), p. 542 ff.

(5) ADOLPHE COSTE, *Les principes d'une sociologie objective* (Paris : F. ALCAN, 1899), pp. 102-3.

(6) F. M. FELDHAUS, *Die Technik der Antike und des Mittelalters* (Potsdam:

There are several reservations to such theories. In so far as the variable of population density has been dealt with in an atomistic and mechanical fashion, these theses are disproved by the fact that the correlation is concretely negative or absent in many societies. Thus, LEVASSEUR's criticism that certain provinces in China with a higher density than some areas in France should show more inventiveness than the latter, if these theories were valid, applies only if density is treated as an *isolated factor* which *concretely* evokes the same result, whatever the cultural and civilizational context. But, as will become evident, if population density is considered as but one social element in a complex figuration, and if its significance is correspondingly circumscribed, then such strictures are no longer applicable.

In any event, it is not sufficient for these theories merely to indicate the more or less tangible correlation between density and invention and discovery. There still remains a description of the mechanisms and processes through which this association is effected. In brief, what are the characteristics of high density of population which are apt to lead to the increased cultivation of technology and science?

The answers of these demographers fall into two categories: an increase of the need for new inventions and an intensification of social interaction. The concept of sheer need as a precipitant of invention is very widely accepted despite the obvious limitations of the idea (7). We have already seen that necessity may be one element directing the attention of scientists and inventors toward particular problems. But necessity remains sterile unless there is an adequate accumulation of knowledge for the solution of the problem and a group of individuals who concern themselves with such matters. In short, necessity plays a considerable rôle in the foci of interest but is of secondary importance in stimulating advance generally.

The second process through which population density is asserted

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Akademische Verlagsgesellschaft, 1931), p. 25; MARIANO-H. CORNEJO, *Sociologie générale*, 2 volumes (Paris : GIARD & BRIÈRE, 1911), Vol. I, p. 415; A. VIERENDEEL, *Esquisse d'une histoire de la technique* (Paris : VROMANT & Cie, 1921), Vol. I, pp. 11-12.

(7) See, for example, the early work of JOHN RAE, *The Sociological Theory of Capital* (New York : MACMILLAN, 1905) (1st edition 1834), pp. 148-49.

to provoke advance in science and technology is that of increasing social interaction. But this very statement indicates that population density *as such* does not bear any uniform relation to scientific development, since variations in the degree of social interaction may be effected through means other than growing population. For example, a sparsely settled area with highly developed means of communication and transportation may have more intensive social interaction than such densely populated countries as China. Hence, since population density is only an occasional concomitant of social interaction and indirectly of marked scientific development, it becomes an avowedly tenuous factor in such development. The relationship of social interaction and scientific advance will be discussed in a later section.

Population Density in Seventeenth Century England

Population statistics for this period are precarious and at best represent only rough approximations. Evidence concerning population changes may be garnered from the calculations of contemporary political arithmeticians as well as from later estimates. There is substantial agreement between the sets of data.

The growth of population in England during this period was probably greater than in any other European country (8). GREGORY KING, whose estimate is more reliable than that of DAVENANT or of DEFOE, puts the population of England in 1696 at about 5,500,000 (9). This figure does not differ markedly from the later estimate by FINLAISON (10) who places the population at about 5,200,000 in 1700, nor from the second estimate of RICKMAN which is about six million for the same

(8) G. N. CLARK, *The Seventeenth Century*, pp. 5 ff.

(9) KING's calculations were based upon (1) the number of inhabited houses, (2) the number of people to each house and (3) the number of transients and vagrants. See his *Natural and Political Observations and Conclusions upon the State and Condition of England* (London, 1696), p. 409 ff; reprinted in GEORGE CHALMERS, *An Estimate of the Comparative Strength of Great-Britain* (London, 1802).

(10) Printed in J. R. McCULLOCH, *Statistical Account of the British Empire* (London, 1837), p. 402.

time (11). Rickman's work is especially important since it provides the only estimate of the growth of population before 1700 which can be considered at all accurate. His figures, which follow, are based upon the threefold calculation of baptisms, burials and marriages. In spite of differences in the various estimates all agree in setting the *increase* of population during the century at about twenty-five percent (12).

1570	4,160,321
1600	4,811,718
1630	5,600,517
1670	5,775,646
1700	6,045,008

It would appear from the fragmentary evidence which is available that this general population increase was especially centered in the cities. Following the example of Macaulay, estimates of the rate of urbanization which occurred during this period have usually been minimized, but as Nef has indicated, there is reason for believing that the increase in urban population during the sixteenth and seventeenth centuries was only less notable than that which occurred after 1700 (13). According to the computations of Sir William Petty the population of London doubled between 1636 and 1676 (14). Gregory King's figures indicate that the population of London quadrupled in the seventeenth century, while the more conservative estimates of Gras and Sombart hold that it trebled (15). Westerfield

(11) John Rickman, *Report* on the 1841 Census.

(12) *Cf.* Sombart, *Der moderne Kapitalismus*, Vol. II, p. 183 ff.

(13) Nef, *The Rise of the British Coal Industry*, Vol. I, pp. 106-7; *cf.* William Cunningham, *The Growth of English Industry and Commerce*, 2 volumes (Cambridge University Press, 1892), Vol. II, p. 172 ff.

(14) William Petty, *Political Arithmetick* (London, 1690), p. 11 ff.

(15) King, *op. cit.*, p. 419, presents the following estimates of the population of London :

1585	132,480
1621	264,960
1695	529,920

N. S. B. Gras estimates London's population at about 200,000 in 1600 and at over 500,000 in 1700; while Sombart's figures are 250,000 and 674,350 respectively. *Cf.* Gras, *An Introduction to Economic History*, p. 183; Werner Sombart, *Luxus und Kapitalismus* (München und Leipzig, 1913), p. 27.

likewise observes that urbanization occurred at an especially rapid rate throughout the century (16).

One of the primary results of this agglomeration of population was an increase of the absolute need for certain inventions. The concentration of large numbers of people in relatively small areas multiplies and makes manifest many problems which must be solved if only for survival under the new conditions. Techniques must be discovered for increasing the food supply, improved means of transportation must be devised for the conveyance of food and other necessities from outlying areas to the centres of population, problems of housing and sanitation must be solved; in short, a manifold of new situations demands new responses if these imperative needs are to be met, however inadequately. These needs, as we have seen (in Chapters VII-X) serve to direct technologic and scientific research into fields appropriate for the solution of these problems.

The demand for food in urban centres stimulated improved methods of cultivation (17). In the course of the century, agricultural improvements, though many of them were of dubitable value, were increasingly suggested and somewhat less frequently introduced. DAVID RAMSAY and THOMAS WILDGOSSE were granted patents in 1618 for inventions for " ploughing of land without horses or oxen " and for " improving of barren grounds." (18) RAMSAY secured another patent in 1630 for his " discovery " of a method " to make earth more fertile than usual." (19) GABRIEL PLATTES invented a " setting instrument " for sowing corn (20); while some time later the celebrated JETHRO TULL introduced his famous drill-plough (21).

The Royal Society, as usual keenly aware of the practical needs of the day, established a " Georgicall Committee " which was

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(16) RAY B. WESTERFIELD, " Middlemen in English Business," *Transactions of the Connecticut Academy of Art and Sciences*, XIX (1915), 410. *Cf.* JOAN PARKES, *Travel in England in the 17th Century*, (Oxford Univ. Press, 1925), Chap. I.

(17) E. LIPSON, *The Economic History of England*, Vol. II, p. 413 ff.

(18) RYMER, *Foedera*, Vol. XVII, p. 121.

(19) *Ibid.*, Vol. XIX, p. 240.

(20) SAMUEL HARTLIB, *His Legacy of Husbandry* (London, 1655), pp. 183-84.

(21) T. H. MARSHALL, " JETHRO TULL and the New Husbandry," *The Economic History Review*, II (1930), 41-50.

to examine and improve the current agricultural practices. " This attempt... is in itself a significant fact both in agricultural history and in the history of English science. It shows us how keenly interested the scientific researches of those days were in matters of practical utility, and that a brave attempt was made to link up book-learning and scientific research with the experience of practical farmers" (22).

A problem which was especially intensified by increasing urbanization as well as the growing practice of " future delivery " which demanded delivery at a specified time is that of the transportation of food and other goods. As LIPSON observes, the English towns in general, and London particularly, drew their supplies from a wide area (23). The consequent growth of traffic emphasized the inadequacy of the existing means of transport. Thus PETTY, in his enumeration of the " works wanting in this nation," emphasized the importance of making rivers navigable and highways " broad, even and firm" (24). As we have seen in an earlier chapter, the high cost of land transport turned the attention of inventors and scientists toward the improvement of water transportation. Various devices for dredging were invented, prominent among which was JOHN GILBERT's " water-plough for the taking up of land, gravel, &c. out of the river Thames and other rivers and havens" (25). As early as 1624, there was an effort to make the Thames navigable " for the conveyance of Oxford free-stone, by water, to the city of London; and of coals and other necessaries, from London to Oxford, now coming, at a dear rate, only by land-carriage" (26). The research activities of members of the Royal Society who sought to meet these practical needs have been described.

The rapid growth of cities necessitated the invention of devices for augmenting the water-supply. Thus, the power-driven pump erected in London by PETER MAURICE in 1582 proved

(22) REGINALD LENNARD, " English Agriculture under CHARLES II : The Evidence of the Royal Society's ' Enquiries,' " *The Economic History Review*, IV (1932), 28.

(23) LIPSON, *op. cit.*, Vol. II, p. 438.

(24) WILLIAM PETTY, *Economic Writings*, Vol. I, pp. 29-30; *cf.* LIPSON, *op. cit.*, Vol. II, p. 442.

(25) RYMER, *Foedera*, Vol. XVII, p. 102.

(26) ADAM ANDERSON, *Origin of Commerce*, Vol. II, p. 406.

inadequate as the city expanded (27). DAVID RAMSAY was granted a patent (1618) " for the raising of water from any low place to the houses of nobles and gentlemen, and to cities and towns," while JOHN GILBERT invented a device for the same purpose (28).

It would appear from these data that the needs generated by an increasing population and associated growth of commerce and trade tended to focus inventive interest in certain fields. Though many of these needs were evident before this period their urgency was previously far less marked. Solutions which previously were simply convenient and generally desirable now became, under the novel conditions afforded by the concentration of pupulation, imperative for purposes of existence under these conditions. Moreover, inventions acquired a greater economic value as the number of concrete problems met by each invention increased. The " cost " of finding an invention remains the same, whatever the extent of its use after discovery, but with an increasing population each invention is more widely useful than before (29). Thus, the economic value of new methods of making rivers navigable was considerably increased by the growing traffic which would be benefited by such innovations. This increased usefulness of invention which accompanied its more widespread use by a large population tends to influence cultural values so that inventors and scientists are esteemed more highly. Insofar as this change in valuation occurs there is a greater tendency for more individuals to adopt these fields as a life-work, thus increasing the rate of invention. In short, this interlocking of social processes and cultural values results in a societal complex which is increasingly favorable to invention. This is not to say that these developments continue without limits, for the economic and social consequences of increased invention may lead to a self-defeating complexity (30). However, these limits were not approached in England during the period under consideration.

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(27) WOLF, *History of Science*, pp. 532-34.

(28) RYMER, *Foedera*, Vol. XVII, pp. 102, 121.

(29) GILFILLAN, *Sociology of Invention*, pp. 58-59.

(30) *Cf.* R. K. MERTON, " Fluctuations in the Rate of Industrial Invention," *Quarterly Journal of Economics*, XLIX (1935), 465 ff.; P. A. SOROKIN, " The Principle of Limits," *Publications*, American Sociological Society, 1932, pp. 19-28.

Increasing population density may thus facilitate the advance of technology and science primarily in two ways : first by evoking certain new needs (or emphasizing old ones) which has the effect primarily of *directing* inventive interest in certain channels rather than of accelerating the rate of invention; and second, by inducing a higher estimation of inventive activities because of the greater economic value of invention among large populations. Another means through which the growing density of population is said to accelerate invention, namely, by increasing social interaction, does not necessarily arise from heightened density alone, and may hence be considered as a factor independent of the concentration of population.

Social Interaction

It has been indicated in the foregoing section that a large population has a greater number of inventive minds than a smaller group (keeping ethnic and cultural factors constant). It is the absolute number of such inventors, rather than their proportion to the entire population, which is of primary significance for the rate of innovation (31). But, on the other hand, the mere number of " potential " inventors (i.e., individuals who have the capacity for invention) will not notably affect the rate of invention unless there is free communication between the inventors, a system of cultural values which places a high estimation upon innovation and an accumulation of knowledge which is at the ready disposal of the would-be inventors. The last two conditions are cultural and civilizational, respectively, and we have chosen to discuss them separately. But, the first of these factors, the kind and extent of social interaction is perhaps the most important *social* element in the rate of invention.

A high degree of social interaction involves a number of processes which facilitate cultural change generally, and development in science specifically. The direct interaction which is afforded by face-to-face contacts is no more important than the circulation

(31) *Cf.* R. S. Woodworth, " The Mechanism of Progress : A Theory of Inventiveness," *Scientific American Supplement*, LXIX (1910), 279.

of opinions, theories and facts which is made possible by various means of communication. Thus, both travel and communication stimulate and foment cultural change. Conversely, the relative lack of interaction is associated with what TEGGART calls " the processes which are manifested in fixity, persistence, stagnation and conventionality." In such instances there is an absence of those intrusive factors which disrupt crystallized ideas and invoke all manner of change. The escape from traditionalism and the willing acceptance of the new is closely related to the rate, number and intensity of contacts.

Obviously the contact of mind with mind (within certain cultural contexts) tends to stimulate observation and originality. Ideas and experiences which would otherwise have remained strictly personal, may, through the medium of interaction, become elements of innovation and discovery. Observations may be made by one scientist for which he has no explanation. Were these observations not communicated to other investigators they would then have no significance for scientific development. But once they are submitted to others for explanation, once there is social interaction, there is a possibility (which is more probable, the more minds there are in contact) that these observations can be unified and systematized by a theory.

Thus, JEAN RICHER went from Paris to Cayenne (French Guiana) in 1671 to make astronomical observations for the purpose of finding the longitude. He found that his pendulum clock which had kept correct time in Paris fell two and a half minutes behind mean solar time daily. The pendulum was shortened but upon his return to Paris, RICHER found that it was too short. He could not account for this phenomenon but upon its being communicated to HUYGHENS, this brilliant theorist ascribed the phenomenon partially to the greater centrifugal tendency of the earth in Cayenne. Thus, RICHER's observation which, had it not been communicated to others would have had no bearing for the contemporary scientific advance, led to the theory that the same body receives different accelerations by gravity at different places on the earth (32).

(32) MAXIMILIEN MARIE, *Histoire des sciences mathématiques et physiques* (Paris, 1884), Vol. V, pp. 102-5.

Incidentally, this same experience furnishes an illustration of the complex interlocking of the sociological factors which affect science. It is true, as has just been indicated, that the explanation of this phenomenon was found as a result of interaction between RICHER and HUYGHENS; an explanation worked out in detail in the latter's *Horologium Oscillatorium.* But one may push the question further and ask how it happened that the original observation could have been made by RICHER, and independently by HALLEY? The answer to this query indicates the intervention of other social elements. It will be remembered that the aim of devising a means for determining longitude at sea was constantly stimulated by the needs of navigation and ultimately of commerce. This led to numerous expeditions being financed by various governments for the determination of the longitudes of important places throughout the world. It was upon such expeditions that both RICHER and HALLEY made their observations of the shortening of the pendulum near the Equator. It thus becomes evident how, in an admittedly roundabout and complex fashion, social and economic factors converged to make possible HUYGHEN's abstract theory of the differential acceleration by gravity according to position on the earth.

Perhaps one of the most noteworthy examples in which interaction led to the introduction into the stream of scientific development of ideas which otherwise might have remained private involves NEWTON's *Principia.* As is well known, the greater part of NEWTON's thoughts on gravitation were completed in 1666. For various conjectural reasons, the most probable being that he had not yet decided that the attraction of a spherical body may be considered as concentrated at its centre (33), NEWTON put his work aside. It was only after his and Dr. DONNE's visit to WREN in 1677, and HOOKE's letter of 24 November 1679 asking NEWTON to comment on HOOKE's theory of celestial motions, that NEWTON temporarily returned to problems of gravitation (34). And it was only because " NEWTON was stimulated by HALLEY's visit of 1684 to return to the whole question of gravity..." that the *Principia* was finally published.

(33) *Cf.* FLORIAN CAJORI, " NEWTON's twenty years' delay in announcing the law of gravitation," in *Sir* ISAAC NEWTON, pp. 127-91.

(34) W. W. R. BALL, *An Essay on* NEWTON'*s Principia*, pp. 140, 155.

Social interaction is related to the development of science in several other ways. Science is public and not private knowledge; and although the idea of " other persons " is not employed explicitly in science, it is always tacitly involved (35). In order to prove a generalization, which for the individual scientist, on the basis of his own private experience, may have attained the status of a valid law which requires no further confirmation, the investigator is compelled to set up critical experiments which will satisfy the other scientists engaged in the same coöperative activity. This pressure for so working out a problem that the solution will satisfy not only the scientist's own criteria of validity and adequacy, but also the criteria of the group with whom he is actually or symbolically in contact, constitutes a powerful social impetus for cogent, rigorous investigation. The work of the scientist is at every point influenced by the intrinsic requirements of the phenomena with which he is dealing and perhaps just as directly by his reactions to the inferred critical attitudes or actual criticism of other scientists and by an adjustment of his behavior in accordance with these attitudes.

Thus, J. J. FAHIE quotes GALILEO as having written that " ignorance had been the best teacher he ever had, since in order to be able to demonstrate to his opponents the truth of his conclusions, he had been forced to prove them by a variety of experiments, though to satisfy his own mind alone he had never felt it necessary to make any" (36). Or, to take another instance, BOYLE would probably never have discovered the law bearing his name were it not for the criticism of his " New Experiments... touching the Spring of the Air " made by FRANCISCUS LINUS. After an examination of BOYLE's earlier work, LINUS declared that the air is definitely insufficient to achieve such great effects as counterpoising a mercurial cyclinder of twenty-nine inches. LINUS maintained that the mercury hangs by invisible threads (funiculi) from the upper end of the tube. " This criticism incited BOYLE to renewed research,"

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(35) N. R. CAMPBELL, *Physics: the Elements* (Cambridge University Press, 1920), p. 246.

(36) J. J. FAHIE, " The Scientific Works of GALILEO," in *Studies in the History and Method of Science*, ed. by CHARLES SINGER, (Oxford : Clarendon Press, 1921), Vol. II, p. 251.

says CAJORI (37), which finally lead to the experimental validation of the theory that supposes the pressures and expansion to be in reciprocal proportion (38). The history of the establishment of this law also illustrates the consequence of social interaction which we have previously discussed; namely, the provision of new contexts which render significant previously meaningless observations. HOOKE had in 1660 made similar experiments upon the rarefaction of the air, but he did not organize these results into any generalization. It was only in the following year, when he heard of BOYLE's hypothesis, that he repeated these experiments over a greater range with results substantially according with the law. In other words, these observations were imbued with significance through contact with other scientists.

The rôle of criticism is further illustrated by HOOKE's animadversions upon NEWTON's theory of light which resulted in the latter submitting a large number of considerations which he had not raised in his initial papers. NEWTON was compelled to institute a number of additional experiments to test aspects of his theory which he had not previously considered. In this sense is " conflict the gadfly of thought."

A telling indication of this process is found in the fact that scientific theories and laws are presented in a rigorously logical and " scientific " fashion (in accordance with the rules of evidence current at the time) and *not* in the order in which the theory or law was derived. This is to say, long after the theory has been found acceptable by the individual scientist on the basis of his *private* experience he must continue to devise a proof or demonstration in terms of the approved canons of scientific verification present in his culture. As POINCARÉ has indicated, most important scientific discoveries have been devined before they have been demonstrated. But intuition, howsoever powerful an instrument of invention it may be, is never a sufficient basis

(37) *A History of Physics*, p. 72.

(38) *New Experiments Physico-Mechanicall, touching the Spring of the Air, Whereunto is added A Defence of the Author's Explication of the Experiments against the Objections of* FRANCISCUS LINUS *and* THOMAS HOBBES (Oxford, 1662), p. 100. The title of the book indicates the effectiveness of criticism in evoking continued and more rigorously executed research.

for a doctrine to become incorporated as a part of science. Demonstration is still necessary.

JEAN PIAGET has described the differences between one's private way of developing his thoughts and the order in which they are presented to others (39). The logical and empirical ramifications of a doctrine must be worked out before it is accepted by others; implications must be pursued far beyond the point where an individual, not in contact with similarly equipped critics, might be content to rest his analysis. In this way, social interaction provides a definite incentive for highly rigorous scientific investigation. As PIAGET has observed, children gradually learn to socialize their beliefs by logical and factual proof only as a result of conflicts of opinion between them. When simple affirmations or denials are seen, through a series of disconcerting experiences, to possess no cogency, " reasons " are gradually submitted to justify their beliefs. On a higher plane, the same process is found in scientific development. The greater the number of critical minds surveying the evidence the more exacting is the compulsion to work out the ramifications of a theory so that it will become scientifically acceptable.

These, then, are the chief ways in which increasing social interaction facilitates scientific advance. It is of moment, therefore, to determine whether such interaction notably increased during the period which witnessed such a rapid development of science.

During the seventeenth century, means of transportation and communication were both considerably improved and more widely used (40). Thus, the stagecoach, which was introduced into London in 1608, spread rapidly into the country and by 1685, there was a system of stage-coach service between London and important termini all over England, reaching even to

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(39) JEAN PIAGET, *Judgment and Reasoning in the Child* (London : K.-PAUL, 1929), Chaps. V, IX; " Principal Factors Determining Intellectual Evolution " in *Factors Determining Human Behavior*, Volume I of Harvard Tercentenary Publications (Harvard University Press, 1937), pp. 32-48. *Cf.* J. W. WOODARD, *Intellectual Realism and Culture Change* (Hanover N. H. : Sociology Press, 1935), Chap. IV.

(40) SOMBART, *Der moderne Kapitalismus*, Vol. I, pp. 510-12.

Edinburgh (41). Similar was the development in communication. Although a postal service for the conveyance of *state* letters had been extant since the beginning of the sixteenth century, it was not until the middle of the next century, that one general post office of England for private mail was established (42). And what was perhaps even more important, international postal relations were continually improved so that by the end of the century, communication with the Continent was constant and regular (43). These extensive developments in communication and transport, fostered mostly by the commercial class in the interest of trade, also promoted intercourse in the domain of thought.

This increase of social interaction facilitated the development of science in no small measure. It is true that scientists and scholars had frequently followed extensive itineraries, but their travels had been much more limited prior to this period. As one investigator summarizes it :

> Rougly speaking, in the two half-centuries preceding and succeeding the year 1600, the practice of the upper classes of sending sons abroad as part of their education became successively an experiment, a custom, and, finally, a system. By the middle of the seventeenth century this system had become a thoroughly set system, and the " Grand Tour " a topic for hack-writers (44).

Thus, such eminent scientists as HARVEY, who studied medicine under FABRICIUS at Padua; BARROW, who spent four years in continental travel; BOYLE, who engaged in the Grand Tour for six years; HALLEY, who on his continental tour observed near Calais the comet of 1680 and whose observations were of great service to NEWTON in fixing its orbit; RAY, WILLUGHBY and many

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(41) WESTERFIELD, *op. cit.*, p. 363 ff. Coaches increased so rapidly between 1625 and 1635 that KING CHARLES issued an order of council to restrain their further increase. ANDERSON, *Origin of Commerce*, Vol. II, p. 413.

(42) J. C. HEMMEON, *The History of the British Post Office* (Cambridge : Harvard University Press, 1912), p. 23 ff.

(43) *Ibid.*, p. 31; Chap. VII. By 1691 the following system was organized. " On Monday and Thursday letters went to France, Italy and Spain, on Monday and Friday to the Netherlands, Germany, Sweden and Denmark. On Tuesday, Thursday and Saturday, mails left for all parts of England, Scotland, and Ireland..."

(44) E. S. BATES, *Touring in 1600 : A Study in the Development of Travel as a Means of Education* (Boston : HOUGHTON MIFFLIN CO., 1911), p. 26.

others all broadened their scientific background by personal contact with continental scientists. A list of English students, chiefly in medicine at the University of Padua—probably the most progressive institution in Italy—is impressive evidence of the large-scale contact of English and continental science. The number of such students increased notably in the course of the seventeenth century (45).

Dr. FRANTZ has recently described in considerable detail the achievements of the traveller in the latter part of the century, whose observations, guided by instructions of the Royal Society, proved of considerable value to the contemporary science (46).

In England proper, interaction between scientists was facilitated by the formation of the Invisible College and the resulting Royal Society. This provided a definite means for that exchange of ideas and theories which is so definitely stimulating to original research. As the historian of the Society put it : " ... in Assemblies, the Wits of most men are sharper, their Apprehensions readier, their Thoughts fuller, than in their Closets." (47) The Society intensified and multiplied the face-to-face contacts of scientists through its very organization. And as we have seen, such interaction tends to stimulate experimental verification of hypothesis and in general to restrain speculation by compelling repeated experience. It is in this vein that LAPLACE observes : " whereas the individual man of science may be easily tempted to dogmatize, a scientific society would very soon come to grief through the clash of dogmatic views. Moreover, the desire to convince others leads to a mutual agreement not to assume anything beyond the results of observation and of calculation. (48) "

Moreover, correspondence between scientists, which constituted the only means of scientific communication in the early seventeenth century, was facilitated by improvements in postal service. The voluminous correspondence of such " professional intelligencers "

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(45) JOSEPH ALOYSIUS ANDRICH, *De natione anglica et scota universitatis Patavinae* (Padua, 1892).

(46) R. W. FRANTZ, *The English Traveller and the Movement of Ideas*, 1660-1732 (University of Nebraska Studies, Vols. XXXII-XXXIII, 1933).

(47) SPRAT, *The History of the Royal-Society*, p. 98.

(48) PIERRE SIMON DE LAPLACE, *Précis de l'histoire de l'astronomie* (Paris, 1821), p. 99.

and scientists as MERSENNE, PEIRESC, COLLINS, WALLIS, BOYLE, HUYGHENS, and OLDENBURG testifies to the felt need for interaction between the various investigators (49). Spatial separation between scientists is not of great moment if there are ready means of communication since the content of science and mathematics can be fully expressed in logical forms and can therefore be transferred in writing.

The scientific journal met this need admirably. The *Philosophical Transactions* published accounts of many of the leading researches of the day and though many articles were included which testify to the unbounded curiosity rather than the mature judgment of certain virtuosi, the primary function of the journal was more than fulfilled. Indeed, as is indicated in the preface to the *Transactions* in 1683, these accounts " proved a very good ferment for the setting of men of uncommon thoughts in all parts awork." Frequent controversies over moot theoretical issues directed experimental interest to the testing of the conflicting theories; new hypotheses were broadcast; recent scientific works were critically reviewed; and plans for initiating research along certain lines were made public. The result was a distinct increase not only of interest in science, but also of scientific achievement.

The Cultural Context

Throughout this discussion it has been repeatedly emphasized that the generalization of the relationships between the degree and kind of social interaction and developments in science and echnology hold only for such relationships within certain cultural contexts. Such qualifications are always necessary in scientific exposition; there is a constant requirement to indicate how much of the " environment " is included in generalizations so that the " neutral " environment may for theoretical purposes be ignored. This necessity for explicitly defining the context within which generalizations apply has been frequently overlooked by social scientists. The fallacy is the same as would be involved in

(49) *Cf.* ORNSTEIN, *The Rôle of Scientific Societies*, Chap. VII; HARCOURT BROWN, *Scientific Organizations in Seventeenth Century France, passim.*

stating, without further qualification, that the pressure of a gas is inversely proportional to its volume, for if the concrete environment, such as a very high compression of the gas or a very low temperature, is not taken into account (*i.e.* is not " neutralized "), BOYLE's law will *not* correspond to the facts. For such reasons, the environment of these social relationships, that is, the cultural context, must be examined to determine the limits of the generalizations which we have discussed.

It has fast become increasingly fashionable to observe that science is, after all, a social activity. Science demands the interplay of many minds, of present thinkers and past thought; it likewise entails a more or less formally organized division of labor; it presupposes disinterestedness, integrity, and honesty of the scientists and is thus oriented toward moral norms; and finally, verification of scientific conceptions is itself a fundamentally social process. But the dependence of science upon society may be traced to even more basic considerations than these. Science, as all large-scale activity which involves the continued interaction of many persons, must above all be countenanced by society if it is to find any systematic development. Otherwise put, the very existence of science and scientists presupposes that they occupy some positive level in the social scale of values which is the final arbiter of the prestige attached to various pursuits.

The persistent development of physical science occurs only in societies of a definite order, subject to a peculiar complex of tacit presuppositions and institutional constraints. What is for us in the modern age a normal phenomenon, demanding no explanation, and securing for us a long chain of self-evident cultural values has been in other times and still is in many places abnormal and infrequent. Scientific pursuits may continue only when the drift of interested and capable persons toward the various scientific disciplines is continuous and unfailing; and this vocational espousal of science is assured only through regulated and canalizing forces operating in certain directions rather than by the haphazard proclivities of individuals striking out to satisfy their several interests.

It is, then, a question of no small moment to ascertain the nature and functioning of those controls which bring into play motivations for scientific careers, which select and bring into sharp focus certain scientific disciplines and reject or blur others, which throw bold emphasis upon certain problems to the virtual neglect of others.

The general or diffuse value-complex of a society may involve implicit or avowed attitudes toward cultural change ranging from one pole of extreme antagonism to the other of unmitigated favor (50). The first conceptual type corresponds to what PARETO calls *neophobie :* an exaggerated antagonism to innovation which it is thought will disturb the customary uniformities (51). At the other pole is a positive evaluation of change with an associated readiness to welcome innovation generally. In the first limiting type of society stability depends upon the utmost conservation of fixed usages and ideas so that persistence of the group is ensured by firmness and tenacity of social relations. In the second type, stability is based upon a ready adaptability to changing circumstances and conditions (52). The first type is characterized by " custom-imitation " (in TARDE's terminology), *i.e.* traditionalized, largely unchanging patterns of behavior and of thought; the second by " mode-imitation," *i.e.*, with a marked premium upon change. Between these polar types is a continuum of diffuse attitudes which approximate to one or the other extreme.

One of the elements in the value-complex of a " flexible " society is that of " dynamic ideologies " as CARLI calls it (53). The mass of these ideologies consists in a " faith in possibilities " *(la fede nelle possibilità) ;* in a conviction that the immediate future holds more in prospect for society than was previously accomplished. It was this faith in progress which, becoming progressively marked in seventeenth century England, exerted a great influence upon the positive estimation of change. GEORGE HAKEWELL, BACON, HOBBES, BOYLE, GLANVILL and many others

(50) These types are presented, in a first approximation, as though the cultural values were homogeneous for all the members of the society; an assumption which is probably contrary to fact. This departure from the fact of social differentiation and corresponding differences in value and outlook does not vitiate our immediate purposes.

(51) PARETO, *Traité de sociologie générale*, Vol. I, p. 599. Compare P. A. SOROKIN's " ideational " and " sensate " forms of culture with the ideal-types which are sketched here. See his *Social and Cultural Dynamics*.

(52) GEORG SIMMEL, *Soziologie* (Leipzig : DUNCKER & HUMBLOT, 1908), pp. 574 ff.

(53) F. CARLI, *L'Equilibrio delle nazioni* (Bologna, ZANICHELLI, n. d.), p. 132.

turned from the conviction that the world was degenerate and designed for destruction to the belief in an imminent and unequalled brilliant future (54). Not only did this note of progress rise from the writers who were primarily concerned with the advancement of science, but also from those who defended revealed religion against its many enemies. This widespread conception of the inevitability of progress entered an effective wedge for a favorable attitude toward change in all compartments of culture, including science.

Customarily associated with this favorable attitude toward change is a complex of norms of which the main compartments are utilitarianism, individualism (which implicitly involves antagonism to authority) and rationalized empiricism. There occurs a lost of respect for traditionalized norms and a notable tendency to regard conventional values from a utilitarian, (economically) rationalized standpoint. Social activities are evaluated in respect of their instrumental efficiency in promoting current aims.

In the " rigid " or traditional society there is little belief in mundane progress. The group is backward-looking rather than forward-looking. There is a sense of stability in the existing situation which precludes any interest in changing it. Either the desirable possibilities of man are not to be fulfilled in this world at all, in which case there is a primary interest in otherworldliness; or, if these possibilities are realizable here on earth, they have been already fulfilled. Fixed values are endowed with a " sacred " sanction which does not admit the application of utilitarian criteria. Individualism, with its disruptive implications, is avoided. Pecuniary, rationalistic evaluation plays little part in determining the type of behavior which is to be approved (55).

Seventeenth century England approximated much more closely to the flexible type of society than to the traditional. Moreover,

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(54) *Cf.* PRESERVED SMITH, *A History of Modern Culture* (New York : HENRY HOLT & Company, 1930), Vol. I, pp. 145 ff; 254 ff.

(55) Compare HOWARD BECKER, *Ionia and Athens : Studies in Secularization* (unpublished doctoral dissertation, University of Chicago, 1930), pp. 4-10.

within this context, it is possible to discern during the course of the century an increasingly manifest trend toward greater individuation, utilitarianism and discounting of tradition. In religion, the acceptance of individualistic criticism induced by the Reformation, was based upon the principles of " the rightful duty of free inquiry " and the " priesthood of all believers" (56). The first principle was associated with an iconoclastic attitude not only toward certain religious ceremonies but also, in so far as it was carried over into other realms of culture, toward traditionalism generally. By the second half of the century, public opinion was being liberated from both ecclesiastical and dynastic fetters (57). The age was characterized by a " spirit of free liberal inquiry " which increasingly made light of precedent and the authority of distinguished names (58). Relatively speaking, traditionalism was waning.

Utilitarianism

We have already seen (in Chapters IV-VI) that Puritanism was one of the most influential movement which was unwittingly propagating, in a religious context, this set of values. Implicitly and at times avowedly, a strict utilitarianism formed a basic presupposition of the Puritan convictions.

Perhaps the most telling indication of the degree to which this culture was integrated about the values of a mechanistic utilitarianism is found in the implicit assumption of the scientific method which became so firmly established at that time. One of the primary characteristics of that method, as WHITEHEAD, BURTT, BORKENAU and others have indicated, consisted of a neglect of the qualitatively unique, the individually variable aspects of phenomena with the focus of attention upon the recurrent, quantitatively comparable aspects. Utilitarianism has thus penetrated the very core of the scientific assumptions of the

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(56) G. P. GOOCH, *English Democratic Ideas in the Seventeenth Century* (Cambridge University Press, 1898), p. 9 ff.

(57) GERALD B. HERTZ, *English Public Opinion after the Restoration* (London : T. F. UNWIN, 1902), pp. 13, 150, *passim.*

(58) W. C. SYDNEY, *Social Life in England*, 1660-90 (London, 1892), pp. 444-45.

age. The individual event in all its uniqueness, which may be of interest to the aesthete or moralist as an " end," as a completed object which is attended to precisely because of its individual characteristics, is regarded by the scientist as an instance of a universal, as being instrumental to the establishment of law and regularity if its immediacy is ignored. It is regarded in terms of what it makes possible rather than in intrinsic terms. Again, this attitude is integrated with the assumption of an intelligible order in nature, since this order is " inductively " determined precisely by so regarding phenomena in their spatial-temporal characteristics as examples of the assumed regularity.

Whatever the faults of pragmatic analysis, it has amply justified its contentions by forcing us to realize that every " fact " in a naturalistic system is a *selection* from the unorganized whole of " reality " and a rejection of the " irrelevant " on the basis of implicit or avowed human criteria (59). If the rationale of science since at least the seventeenth century has been the apprehension of nature in such terms as to make possible its control (an aim which is admittedly not consciously avowed by each scientific investigator) it is necessary that phenomena be construed in such fashion that the uniquely heterogeneous may be reduced to quantitatively homogeneous and hence predictable developments. For if phenomena were regarded in terms of their unique aspects, each event would be everlastingly new, unpredictable and uncontrollable. And conversely, if our primary interest is the " will to power," if we wish to predict and control, our attention must be concentrated on " repeated elements "; each case must be viewed as an index of a law or regularity conformable to our previous (similarly abstractive) experience. Once phenomena are in this fashion reduced to order, once they are reduced to a common unit, they become manageable.

These same norms become increasingly manifest in the educational field. Traditionalism was more firmly rooted in the universities at the beginning of the century than in later decades. Until about 1630, the official university statutes declared that Bachelors and Masters of Arts who did not faithfully follow Aristotle were liable to a fine of five shillings for every point of

(59) F. C. S. SCHILLER, *Studies in Humanism* (London : MACMILLAN, 1907), p. 158.

divergence or for every fault committed against the *Organon* (60). New advances were flouted. But by 1641, the Parliament invited COMENIUS (KOMENSKY) to establish a new college based upon Baconian precepts. Increasingly, there developed a positive evaluation of almost all educational changes; an attitude integrant with political and religious divergences which were loosening other ties of tradition (61).

The same complex of individualism, secularization and utilitarianism was evidenced in philosophy. At the beginning of the century, BACON had enunciated the note of utilitarianism in his dicta that " knowledge is power " and that the essential end of knowledge is " the improvement of man's estate." The fruits or practical applications of an inductive philosophy constitute its ultimate justification. In similar fashion, a deep-rooted utilitarianism is basic to HOBBES' philosophy. " The end of knowledge is power; and... the scope of all speculation is the performance of some action, or thing to be done" (62). LOCKE is, if possible, even more emphatic in this respect. Man should concern himself with the pursuit of only such knowledge as " may be of use to us" (63). The enhancement of the " handsome conveniences of life," so often mentioned by LOCKE, is in the last analysis the basic criterion of the value of man's thought and action. LOCKE's whole system is instinct with utilitarianism, as is that of his friend, Lord SHAFTESBURY, who wrote that " if there are any sciences that are worthy of esteem, they are what must relate to the well-being of mankind in societies" (64).

But a crude utilitarianism is not an unfailing cultural basis for

(60) P. BENJAMIN, *Intellectual Rise of Electricity*, p. 333.

(61) IRVINE MASSON, *Three Centuries of Chemistry*, pp. 22-25.

(62) THOMAS HOBBES, *Works*, Vol. I, p. 7.

(63) JOHN LOCKE, *Essay concerning Human Understanding*, Introduction, section 5. See also the following extracts from LOCKE's Journal published in LORD PETER KING, *The Life of* JOHN LOCKE, 2 volumes (London, 1830). " The end of study is knowledge, and the end of knowledge practice or communication." [Vol. I, p. 171] " ... the principal end why we are to get knowledge here, is to make use of it for the benefit of ourselves and others in this world." [Vol. I, p. 182] " That which seems to me to be suited to the end of man, and lie level to his understanding, is the improvement of natural experiments for the conveniences of this life." [Vol. I, p. 198.]

(64) In a letter to LOCKE, dated 29 September 1694, quoted by KING, *op. cit.*, Vol. I, p. 347.

the espousal of science. In its extreme form, the norm of utility, narrowly interpreted, imposes a limitation on science, since it then finds science desirable only insofar as it is directly profitable. The intellectual myopia involved in this point of view precludes any attention to basic studies which do not promise immediate fruits. Pietism was not far removed from this attitude. Schools and universities were largely to limit their curricula to subjects which might find direct application, religious, technologic or economic. Another instance of the extent to which a rabid utilitarianism threatens to stultify the growth of science is provided by LOCKE, who observes that " we have no reason to complain that we do not know the nature of the sun or stars... and a thousand other speculations in nature, since, if we knew them, they would be of no solid advantage to us" (65).

A tacit recognition of this danger has led scientists persistently to repudiate the application of utilitarian norms to their work. Was this not the source of that possibly apocryphal toast at a dinner for scientists in Cambridge : " To pure mathematics, and may it never be of any use to anybody " ? Utility is to be an acceptable by-product but not the chief goal of science. For as usefulness becomes the exclusive criterion of scientific achievements, the bulk of problems which are of intrinsic scientific importance can no longer be prosecuted. The scientist's exaltation of pure science is thus seen to be a defence (66) against the invasion of norms which limit possible directions of potential growth and threaten the stability and continuance of scientific research as a valued social activity.

But with the rise of the modern era, when science had not yet

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(65) LOCKE's Journal in KING, *op. cit.* Vol. I, p. 163. *Cf.* BOYLE, who states : " I should not have neer so high a value as I now cherish for Physiology, if I thought it could onely teache a Man to discourse of Nature, but not at all to master Her; and served onely with pleasing Speculations, to entertain his Understanding without at all increasing his Power." Quoted by JONES, *Ancients and Moderns*, pp. 211-12.

(66) Another such conflict is introduced when loyalties to other institutions, *e.g.*, the state, are demanded of the scientist *qua* scientist. The intrusion of such demands similarly threaten to interfere with the autonomy of the institutions of scientific research; hence the reaction of the scientist who seeks to preserve his professional integrity against the demands of " Nazi science," etc. The writer is at present preparing a study of such relations between science and ambient social institutions.

attained social autonomy, the emphasis on utility served as a support. Science was socially countenanced, even esteemed, largely because of its potential use. The varying rôle of the canon of utility is simply a further instance of the familiar paradox that the same cultural value in different settings may lead to directly contradictory results. In the seventeenth century, the most effective sponsor of science was the utilitarian standard; today, it occasionally acts as a curb on science.

The Belief in Progress

With the seventeenth century the idea of progress became widely current, if we may judge from those philosophical and intellectual élite who proved articulate (67). Until approximately this time, secular thought had been turned predominantly toward the past (68), toward an ancient Golden Age, or, in the religious version, toward some Paradise in the world beyond.

The prevalence of this doctrine is an integral part of a culture which witnessed great scientific and technologic advance (69). As RENÉ HUBERT has pointed out, a sociological analysis of theories of progress is primarily concerned with the reasons why, at given times, certain groups and individuals have believed in the possibility or even the reality of progress (70). By fulfilling this function, we shall be in a position to see the pervasive and far-reaching ways in which the prevalence of this doctrine is definitely integrated with a culture which actually witnessed an amazing advance in science.

At the very outset of the century, BACON evidenced an intellectual optimism which continued to prevail. Observing the advances in navigation and discovery which had been made in the recent

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(67) JULES DELVAILLE, *Essai sur l'histoire de l'idée de progrès jusqu'à la fin du XVIII^e siècle* (Paris : FÉLIX ALCAN, 1910), p. 224 ff; J. J. THONISSEN, *Quelques considérations sur la théorie du progrès indéfini* (Paris, 1860), pp. 82-116; R. F. JONES, *Ancients and Moderns*, pp. 121-22, *et passim*.

(68) CARL BECKER, " Progress," *Encyclopedia of the Social Sciences*, Vol. XII, p. 496; GEORGES SOREL, *Les illusions du progrès* (Paris : MARCEL RIVIÈRE, 1927), pp. 30-32.

(69) SOROKIN, *Social and Cultural Dynamics*, Vol. II, pp. 370 *et passim*.

(70) RENÉ HUBERT, " Essai sur l'histoire de l'idée de progrès," *Revue d'histoire de la philosophie et d'histoire générale de la civilisation*, 1935, fasc. 8 et 9, pp. 1 ff.

past, he suggested that these " may plant also great expectation of the further proficiencies and augmentation of the sciences" (71). In an often-quoted passage, he remarks that " the old age of the world is to be accounted the true antiquity; and this is the attribute of our own times, not of that earlier age of the world in which the ancients lived" (72). We have progressed (and very likely, shall continue to progress) through the accumulation of knowledge and technical apparatus far beyond the levels attained in the past. It can now be seen how BACON's doctrine of progress is linked with the values of the ambient culture, for the criteria of progress, as he conceived it, are essentially utilitarian and practical. Progress consists in the development of instruments and means for attaining given ends, for increasing man's control over nature, and hence increasing his comfort and happiness. As BURY has well indicated (73), to a Christian dreaming of the City of God, this doctrine would seem trivial and meaningless, for it implied that earthly felicity was in any sense desirable. But an inconvenient eschatology could be easily transmuted into a doctrine of mundane progress. The Calvinist doctrine of a progressive sanctification, according to which the individual who has been predestined to grace may progressively trace his election through practical proofs of achievement, was congenial to a belief in social progress generally (74).

These ideas were echoed throughout the century. Among the most popular expositions of this utilitarian and optimistic attitude were those of JOSEPH GLANVILL (75). Surveying the

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(71) *De dignitate et augmentis scientiarum*, Book II, Chap. X (p. 437 in *The Philosophical Works of* FRANCIS BACON [ELLIS and SPEDDING ed.]) (London : GEORGE ROUTLEDGE & Sons, 1905).

(72) *Novum Organum*, Book I, Aphorism LXXXIV. This observation, with its optimist implications, was frequently made throughout this period. GILBERT, GALILEO, CAMPANELLA, BRUNO and PASCAL, among others, spread the same doctrine.

(73) J. B. BURY, *The Idea of Progress* (London : MACMILLAN & Co., 1924), pp. 58-59.

(74) *Cf.* TROELTSCH, *Social Teachings*, Vol. II, p. 604.

(75) JOSEPH GLANVILL, *Plus Ultra : or, the Progress and Advancement of Knowledge since the Days of* ARISTOTLE, *In an Account of some of the most remarkable late Improvements of Practical, Useful Learning : To Encourage Philosophical Endeavours* (London, 1668). This lengthy title itself indicates the two aspects of the theory of progress to which we have referred : a deep-seated utilitarianism

notable scientific advance of the first part of the century, GLANVILL welcomes the control of nature which the new science affords and looks forward to further impending progress. " We must seek and gather, observe and examine, and lay up in bank for the ages that come after." So rapid has been the developments of recent years, says GLANVILL, that we may feel certain that the future will see even greater acceleration of knowledge. He implies the sort of utilitarian optimism which was to find its culmination two centuries later in the positivist conviction that virtually everything is amenable to scientific research and hence that knowledge and the subjugation of nature must continue indefinitely. The optimism which accompanied this belief in progress finds expression in the words of one JEREMY SHAKERLY : " And indeed what shall we mortals now despair of? within what bounds shall our wits be contained? " (76)

SPRAT, in his *History of the Royal-Society*, expresses the same sentiments. The coöperative enterprise of numbers of scientists will further advance our knowledge and hence man's comfort. Nor was this outlook restricted to the contemporary scientists, as Professor CRANE has shown in a brief, but searching, analysis (77). This progressivism was likewise found among the partisans of religion who felt that if secular knowledge could show such marked advances, religious thought could do likewise. The extent to which these dominant attitudes had penetrated even religious thinking is perhaps best illustrated by the writings of JOHN EDWARDS, at the very close of the century.

EDWARDS surveys the recent advances in secular knowledge and concludes that there is no reason whatever for assuming that progress is not also to be found in " divine Knowledg" (78).

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and an optimist outlook which invites further endeavor. *Cf.* also his *On Modern Improvements of Useful Knowledge* (London, 1675).

(76) Quoted by JONES, *op. cit.*, p. 128.

(77) RONALD S. CRANE, " Anglican Apologetics and the Idea of Progress," *Modern Philology*, XXXI (1934), 273-306.

(78) JOHN EDWARDS, *A Compleat History or Survey of all the Dispensations and Methods of Religion, from the beginning of the World to the Consummation of all things*, two volumes (London, 1699), Vol. II, p. 615. " Diligent Researches at home, and Travels into remote Countries have produced new Observations and Remarks, unheard-of Discoveries and Inventions. Thus we surpass all the times that have been before us; and it is highly probable that those that

An approach to perfection in the one field implies the possibility of a similar improvement in the other. EDWARDS expresses a prevalent reason for his conviction : " there is a great probability of the World's increasing in Knowledg hereafter, because we see it hath done so already" (79). Examples of such progress are readily forthcoming; the three most prominent instances being the inventions of the compass, gunpowder and printing (80).

In discussing the significance of these advances, EDWARDS evinces, at times in startling form, the unquestioning acceptance of norms of strict utilitarianism. The compass is useful because it enables us to visit the " spacious world " and infinitely increases trade and commerce. But it is in his discussion of gunpowder and guns that EDWARDS pushes his utilitarianism to its extreme; these inventions are useful, efficient and economical; hence, they are good (81).

> We have a more compendius and speedy, a more thrifty and frugal [!] way of killing our Enemies than by Bows and Arrows, by Javelins, Battel-axes and Speers. The modern Mortar-pieces will end the Quarrel sooner than the Roman Battering Rams... Seeing then there will be in this World, till it be better, occasion of War, and Controversies cannot be decided but by Blood, it is well that there is now a way whereby Victory may be got with less expence of Time and Blood than formerly : which is the Fruit of this Invention of Gunpowder and the Engines that convey and discharge it.

What more concise depiction of norms of frugality, efficiency, utility, intellectual optimism and secular spirit can be found in a religious work on the history of religious thought? Thrift and efficiency are virtues; hence improved armaments are highly valued. EDWARDS and his contemporaries apparently did not realize that by stressing utilitarian criteria of value they were bringing into disrepute the very religion which they were supporting; a religion which could seldom produce earthly evidence of its usefulness. Religionists were digging the grave of religion by willingly invoking the secular norm of use.

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succeed, will far surpass these... And why a proportionable Improvement in Divine Knowledg, and in Moral and Christian Endowments may not be expected, I confess I don't understand. Can there be any Reason given why God should not prosper Religion as well as Arts?"

(79) *Ibid.*, Vol. II, p. 621 ff.

(80) These examples of progress had become stereotyped since at least the time of CARDAN. They are cited by BODIN, LE ROY, CAMPANELLA, BACON, *etc.*

(81) *Ibid.*, Vol. II, p. 623.

What is the significance of the dominant acceptance of the idea of progress in this period? In which ways does this acceptance bear upon the contemporary advance in science and invention? In what respects is there a readily apprehensible consistency between the optimism implied in progressivist ideas and the accelerated development of science? The answers to these questions should throw more light upon our fundamental problem : the determination of the conditions which were integrally associated with scientific advance during this period.

One basis for the prevalence of the idea of progress at this time is apparent. Men surveying the recent advances in the arts and sciences could find immediate grounds for maintaining that in certain (instrumental) respects society had progressed. And it is true that the periods in which science and technology have notably advanced have likewise been times when theories of progress were widely accepted (82). The awareness of contemporary advances in certain fields may tend to induce the acceptance of a progressivist outlook; the success of the recent past makes certain accomplishments appear to be imminent probabilities. And conversely, the " faith in possibilities " carries with it " dynamic ideologies " which provoke and intensify attempts to achieve certain goals (83). If, on whatever grounds, valid or not, it is believed that success will probably crown one's efforts, there is an added incentive for the diligent pursuance of the given activity (84). But this attitude is found only in one type of progressivist theory; the type prevalent in the seventeenth century which states the possibility or probability of progress, but *not* its inevitability. For when the theory develops in this fashion, as it did in the nineteenth century, so that progress is considered an inexorable law of nature which willy-nilly continues indefinitely, then there is ***implied*** a fatalist or quietist attitude. Why should one bother to exert oneself if progress must occur in any case?

(82) *Cf.* HUBERT, *op. cit.*, p. 46.
(83) F. CARLI, *L'Equilbrio delle nazioni*, pp. 132-41.
(84) BACON had well understood this. As he said, " far the greatest obstacle to the progress of science and to the undertaking of new tasks and provinces therein, is found in this—that men despair and think things impossible." Men must have hope " to induce any alacrity or to whet their industry in making trial." *Novum Organum*, Book I, Aphorism XCII.

Thus, it is clear that in this sense there is a congruity between the acceptance of progressivist ideas and the contemporary advance of science. This advance furnishes a basis for acquiescing in the faith in progress, while on the other hand, this faith itself furnishes an additional incentive for engaging in scientific research. But these are only the more obvious relations between these two aspects of the culture.

Another relationship is found in the fact that, due to the contemporary prestige of the physical sciences, frequent efforts were made to transfer the conclusions of these sciences to social phenomena (85). Thus, as BRUNETIÈRE has shown, the idea of the uniform operation of the laws of nature is an integral element of these theories of progress (86). By accepting the idea that " the same effect follows the same cause," it follows that if society has progressed in the past, it will continue to do so in the future. The law of acceleration was broadly transferred to apply to history : velocity (of social change) is proportional to the time. Hence, with the passage of time it is very likely that society will progress even more rapidly.

But perhaps the two must important elements in the culture which account for the acceptance of progressivism are changes in the social organization and the application of canons of utilitarianism. This was a period with rapidly increasing vertical mobility; the bourgeois class was coming into power. Wealth was becoming ever more effective as a means of obtaining prestige; commercial magnates were rising rapidly in the social scale; trade was becoming sufficiently estimable for the younger sons of the gentry and nobility to adopt it as an occupation (87). At this time, the parvenu had a new sense of his potentiality and power for his social destiny was no longer inexorably fixed. The profound political and social changes and the increasing social mobility which implies change, rather than a rigid mainte-

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(85) SOROKIN, *Contemporary Sociological Theories*, Chap. I.

(86) F. BRUNETIÈRE, *Études critiques sur l'histoire de la littérature française*, 5[e] série (Paris : HACHETTE & C[ie], 1889-1922), pp. 139-240.

(87) RAY B. WESTERFIELD, " Middlemen in English Business," pp. 400 ff; EDUARD BERNSTEIN, *Cromwell and Communism* (London : ALLEN & UNWIN, 1930), Chap. II.

nance of the *status quo*, engendered a belief in the improvement of man's estate here on earth, in progress (88).

The other basic factor in the acceptance of progressivist ideas was the application of the utilitarian norms which provided the orientation for that culture. Evidences of progress can most easily be obtained by the use of such criteria. One can detect the advance in instruments, scientific and technologic; in means of communication and transportation; in the instruments of warfare; in short, in all the utilitarian appurtenances of life. Thus, once granted a dominant respect for artifacts which are useful in this sense, there is an overwhelming provocation for firmly adhering to a belief in progress. In short, the doctrine of progress is closely integrated with any culture in which utilitarianism forms one of the basic norms and science undergoes a rapid development.

On the basis of the foregoing study, it may not be too much to conclude that the cultural soil of seventeenth century England was peculiarly fertile for the growth and spread of science.

R. K. MERTON.

(88) HUBERT, *op. cit.*, pp. 28 ff; 46.

APPENDIX A

The following illustrations of research conducted by members of the Royal Society are derived from the transcript of the minutes of the Society contained in THOMAS BIRCH's *History of the Royal Society of London*, 4 volumes, (London, 1757). All subsequent page citations in this appendix refer to this work. The examples cited are illustrative of the classification and tabulation of these investigations advanced in Chapter X of this essay. The classification is of course entirely empirical: no effort has been made to attain logical exhaustiveness. The sole object of this compilation is to determine relatively the amount of scientific research pursued by members of the Society which is devoted, directly or indirectly, to socio-economic needs.

A. RESEARCH RELATED TO SOCIO-ECONOMIC NEEDS

I. MARINE TRANSPORT AND NAVIGATION

a. DIRECTLY RELATED RESEARCH

1. ***studies of compass: magnetic deviation.***

" ... Dr. PETTY [was desired] to inquire in Ireland... concerning the variation of the compass..." I, 20.

" Mr. COLWALL mentioned, that Mr. BOND was very sure, that, according to his magnetical hypothesis, the variation of the needle at London was this year 1 deg. 4 min. westward. Mr. BALLE was desired to make an observation thereof." I, 309.

" It was ordered, that Sir ROBERT MORAY, Mr. BALLE, and Mr. HOOKE should... make an observation concerning the variation of the needle." I, 440.

" Dr. PELL was joined to the curators appointed... for making the observation of the variation of the magnetic needle in White-hall garden.

He mentioned, that he had written a finall exercitation upon Mr. GELLIBRAND's *Mathematical discourse upon the variation of the magnetic needle; together with the admirable diminution thereof lately discovered* [London : 1635]; and he was desired to communicate it to the society.

He intimated, that it was difficult to draw a standing astronomical meridian to compare with a magnetical meridian.

He likewise remarked, that it would be very proper to provide an exceeding good loadstone, to be kept at Trinity-House, for all mariners, who go to sea, to touch their needles upon for an uniform direction." I, 442.

" Mr. HALLEY made the observation of the variation of the needle upon the stone in the area of Gresham-college... [etc.] " IV, 489.

" ... a discourse was occasioned concerning the variation of the magnetic needle; and it was ordered, that the Society's correspondents should be written to, that they might procure observations to be made of the said variations in place as far distant as possible." IV, 490.

" Mr. HOOKE shewed a contrivance for nicely observing the variations of the magnetical needle..." IV, 494.

2. *maritime maps and hydrography*

" Sir ROBERT MORAY read the following account of *An experiment of the instrument for sounding of depths without a line or cord, made the 19th of March*, 1661-62, by the lord viscount BROUNCKER and himself, which was ordered to be registered, and a copy of it sent to the Trinity-house." I, 78.

" Mr. HOOKE, at the desire of the council, brought in an analysis of the whole matter of hydrography..." IV, 468.

" Dr. COX produced several maps and discourses concerning the great lakes, which are in North America, which he affirmed to have been surveyed by some Englishman, and found to be a great Mediterranean sea of above 500 miles round, ... Upon which Dr. COX proposed, that an advantageous settlement for the beaver-trade might be made in these lakes." IV, 518.

3. *methods of determining ship's position : longitude and latitude.*

" Dr. WILKINS mentioned Mr. STREETE's proposition of the longitude; and it was referred to the consideration of the lord viscount BROUNCKER [first president of the Royal Society and later a commissioner of the Royal Navy] and Sir ROBERT MORAY, before it should be presented to his majesty." I, 119; see also I, 124.

" Monsieur HUYGEN's letter to Sir ROBERT MORAY was read, dated at the Hague August 8, 1664, N. S. containing several philosophical matters; as of his new pendulum watch, which might probably serve for the observation of longitude..." I, 460.

" A chart of the voyage of the French Jesuits to the East-Indies wherein the longitudes of Siam and the adjoining parts were rectified, being produced, it was now shewn, that the said correction had been long since published in the *Philosophical Transactions*, particularly in February 1681-2; and after that in June 1683, where the very same rectification is to be found in two little treatises by Mr. HALLEY." IV, 517; see also IV, 206.

4. *studies of times of tides.*

[An experiment to be made by the Earl of Sandwich in his voyage to Lisbon as requested by the Society.] " Inquire after a true account of the ebbing and flowing between the Straits; and whether the tide flow always eastward at the shores, and at the middle; and how it varies, if it be not constant." I, 30.

" Mr. COLWALL moved, that the inquiry concerning the ebbing and flowing about the island of St. Helena might be recommended to some persons, who were going thither; and he was desired to send it as was stated by Mr. HOOKE." I, 120.

" Mr. AUBREY gave an account, that Sir JONAS MOORE had caused several curious observations about the time and hights of the tides at London-bridge to be made by means of a rod buoyed up at the bottom by cork, and so rising and falling with the water : which observations Mr. AUBREY conceived might be in the custody of Mr. FLAMSTEAD, or captain HANWAY... He was desired to do his endeavour to procure the sight of them for the Society.

He mentioned, that the greatest tide found on the coast of England is at Chepstow-bridge; and he moved, that Sir JOHN HOSKYNS might be desired to inquire into the circumstances of the tide at that place.

It was ordered, that the president should be desired to obtain from capt. COLLINS, who was then engaged in the survey of the sea-coast of England, a communication of his observations of the tides in the several ports, and especially the headlands." IV, 469.

" It was ordered that Mr. FLAMSTEAD's tide-table for the year 1687 be printed." IV, 502.

" Mr. WALLER's account of the tides at Bristol was produced." IV, 550.

5. *ship-construction and ship accessories.*

" Dr. GODDARD was added to Dr. PETTY and Mr. WREN for the experiments about shipping; and Sir KENELME DIGBY was desired to afford them his assistance; and they were requested to communicate to the society some experiment at their next meeting." I, 8.

" It was resolved, that Sir WILLIAM PETTY be put in mind to prosecute his demonstrations about ship-building." I, 45.

" Mr. WINTHROP brought in the following account of the manner of making Tar and Pitch in New England [and its utility for ship-building]; which was ordered to be registered." I, 99.

" Mr. WINTHROP read his paper concerning the conveniency of building of ships in some of the northern parts of America; which was ordered to be registered..." I, 112.

" Sir WILLIAM PETTY's second letter to the lord viscount BROUNCKER was read, giving a farther account of his new ship; as also an extract of another letter of his to Mr. GRAUNT, who was desired to let Sir WILLIAM know, that the society was well pleased with the invention :

And it was farther ordered, that those members, who were in Ireland, or any three of them, should be desired by the president, in the name of the society, to send them an account of this new ship, both as to her structure and sailing." I, 131.

" ... there happened much discourse about the way of preserving ships from the worms; and it was remarked, that sheathing with lead was the best expedient, and found to be so by the experience of Sir ANTHONY DEANE; but the carpenters finding it against their profit opposed it by affirming, that the iron of the pintles of the rudders of ships so sheathed were much more apt to be corroded by the sea-water than those sheathed with wood; which yet was a groundless supposition.

Dr. ROBINSON thought, that it might be worth examining these worms, and consequently proper for sheathing...

Mr. EVELYN was of opinion, that japanning or lackering might be a very good preservation for ships; against which it was objected, that the motion of the seams of a ship would be apt to crack the varnish, and so the worms might find entrance." IV, 496.

" Dr. WILKINS made mention of a certain instrument like an umbrella, to be used instead of an anchor in fathomless sea, and to stay a ship in a storm, or upon other occasions." I, 216.

b. INDIRECTLY RELATED RESEARCH

1. *studies of movement of bodies in water: to improve floating qualities of vessels.*

" Sir ROBERT MORAY was desired to try, whether the same weight, that will sink a board edgewise, will sink it flat-wise.

Dr. GODDARD [was desired] to prosecute his trials of sinking bodies under the surface of the water... [and] to try the velocity of sinking bladders in water..." I, 46.

" The lord viscount BROUNCKER gave an account of the sinking of a wooden ball in the water; and was desired with Mr. BOYLE to go to the sea, and try the experiment there." I, 78.

" Sir WILLIAM PETTY proposed a standard for knowing the velocity of swimming bodies." I, 87.

" There was also made the experiment of sinking a wooden ball with ball of lead... It was ordered, that at the next meeting these experiments be prosecuted with bodies of wood of several figures." I, 469; also, 470, 473-5.

2. *observations of heavenly bodies: to determine latitude and longitude.*

a) *distance between moon and fixed stars.*

[From the minutes of the Dublin Society communicated to the Royal Society.] " Mr. ALAND, a gentleman of Waterford communicated to the Society a method of finding the longitude by considering the distance of the moon from the sun, its latitude from the ecliptic, and distance from other planets... Ordered, that Mr. KING, Mr. TOLET, and Mr. ASHE do examine this method, and give an account thereof to the Society next meeting.

Mr. TOLET discoursed of the history, and several ways of finding the longitude hitherto thought of, with their particular inconveniences." IV, 411.

" Mr. HOOKE shewed a method of finding the latitude of places by help of a planisphere of the fixt stars, drawn after the gnomonic projection." IV, 530-1; also 532, 544.

3. *studies in botany and silviculture, in so far as they pertain to the provision of ship timber.*

" A proposition was offered by Sir ROBERT MORAY about the planting of timber in England, and the preserving of what was then growing." I, 110.

" A paper about the improvement and planting of timber, brought by Sir ROBERT MORAY from the commissioners of his majesty's navy, was read, and referred to the consideration of Mr. EVELYN, Dr. GODDARD, Dr. MERRET, and Mr. WINTHROP." I, 111.

[Dr. GODDARD] ... brought in his thoughts concerning the planting of timber in England, upon the proposition offered to the consideration of the society by the commissioners of his majesty's navy. Dr. ENT observed, that it was found by experience, that no oaks grow well but from acorns." I, 112.

" Dr. MERRET read his paper concerning the planting and conserving of timber...

Dr. ENT suggested, that sets of trees cut near the root, and then transplanted, will thrive very well...

Dr. WREN observed, that the grafting of a root upon a tree, and so setting it within the ground, makes it thrive very well." I, 114.

" Mr. WILLUGHBY produced his demonstration to prove, that the same area of ground planted with trees after a quincuncial figure, will hold more trees placed at the same distance from one another, than the square, in the proportion of 8 to 7." I, 115.

" Mr. EVELYN read his paper, in which he had put together the several suggestions offered by others in distinct papers, by way of answer to the queries of the commissioners of the navy; together with his own observations and apprehensions concerning the propagation of timber-trees; and he was desired to print the paper read by him." I, 117 [It appeared in book form under the title of *Sylva: Or, A Discourse of Forest-trees, and the Propagation of Timber in his Majesty's Dominions.* By 1729, it had passed through five editions.]

[Testing of ship materials.] " It was ordered, that the experiments of breaking several sorts of wood be prosecuted by Mr. HOOKE; and that they should be made upon the same kinds of wood of several ages, grown in several places, and cut at different seasons of the year." I, 460.

" Sir ROBERT GOURDON related, that Dr. PLOT had lately proposed to the king the barking of all timber, designed for the use of the navy, in the spring, and then to let the trees so barked until autumn before they are felled..." IV, 539 [*Cf.* PLOT's *Natural History of Staffordshire*, p. 382.]

II. MINING AND METALLURGY

a. DIRECTLY RELATED RESEARCH

1. *methods of raising ores.*

" A paper of Dr. PAPIN was read about applying his engine for raising water by the rarefaction of the air to the raising of any sort of weight out of deep mines." IV, 544.

" A paper of Dr. PAPIN was read concerning a way of applying the force of gun-powder to raise weights, and to other mechanical uses; of which he shewed the experiment." IV, 550.

2. *water-pumps and water-conducting equipment.*

" Dr. WILKINS undertook to inform the society concerning Mr. TOWGOOD's sucking pump 42 foot high." I, 152.

" Sir ROBERT MORAY presented the society from prince RUPERT with a certain waterraising engine, which was ordered to be tried." I, 279 [HOOKE, in a letter to BOYLE, notes that such an engine is noted in SCHOTTUS' *Mechanics*. *Cf.* BOYLE's *Works*, vol. V, p. 532.]

" Dr. PAPIN read a paper of his, containing an account of the contrivance of his water-engine for circulating water; which was ordered to be registered. He read likewise his thoughts concerning the water-engine at London-bridge, which raises water without intermission. He affirmed, that though the inward contrivance of that pump was concealed, he could make another, which should have the same effect, and produced a scheme of his invention." IV, 452.

" Dr. PAPIN read a farther discourse concerning his engine, that raises and circulates water.

Mr. POVEY remarked, that one Mr. DESSOUN had raised more water for the Earl of Winchelsea with an ordinary and easy wheel.

Dr. SOLOMON REISELIUS's letter to Mr. ASTON, dated at Stutgard, Octob. 8, 1685, concerning the Wirtemberg syphon, was read; whereby it appeared, that Dr. PAPIN had exactly conjectured at the composition of the same syphon." IV, 452-3.

" Mr. HOOKE shewed the draught and contrivance of a water engine at Hackney made by one Mr. ALDERSEY, wherein three pumps are moved by an axis with a triple crank by means of an over shot wheel." IV, 487.

" Dr. PAPIN presented to the Society his engine for the circulating of water by the rarefaction of the air." IV, 558 [*Cf. Philosophical Transactions*, December 1685, p. 1274.]

3. *methods of mine ventilation and control of ' damps '.*

" Dr. POWER's paper of subterraneous experiments, and observations made of the damps of coal-mines, were read, and registered..." I, 133.

" Mr. VERMUYDEN mentioned a method used for the reviving of men suffocated in the coal-mines, by putting their heads in fresh earth; and was desired to give the account thereof in writing; as also of his other observations made concerning coal-mines..." I, 178.

" Dr. PAPIN shewed the experiment of the engine, that consumes smoke... The experiment succeeded according to expectation; and Sir PETER COLLITON suggested damps in mines; which the vice president [Sir JOHN HOSKYNS] approved, since the heavy matter of the damps lying undermost must of necessity come to the furnace, and so be dispersed by the fire." IV, 500.

" He [HOOKE] likewise remarked, that the manner of evacuating damps in the mines at Leige was after the manner of the French engine for consuming smoke." IV, 502.

4. *metallurgy*.

" Dr. MERRET was to bring in the history of refining..." I, 8.

" Sir ROBERT MORAY read... a relation of the *making of ceruss* [ceruse], from Mr. VERNATTI, upon which a committee consisting of Dr. GODDARD, Dr. PETTY, Dr. MERRET, Dr. WHISTLER, the lord viscount BROUNCKER, and Mr. AUSTEN, were appointed to examine the method of making of ceruss." I, 18 [*Cf. Philosophical Transactions*, XI, 935.]

" Mr. COLWALL read an account of the making of green copperas, and produced a basket of the copperas stones. After reading this account, Sir ROBERT MORAY was desired to write to the jesuits of Liege, about their manner of making copperas there. It was ordered, that Mr. COLWALL's account be registered; and that the society have copies of it, in order to form questions upon it. It was observed upon this occasion, that Chemnitz in Hungary produced the best vitriol." I, 22.

" Mr. POVEY was desired to deliver in an account of brass." I, 31.

" Mr. COLWALL read his *Relations concerning the making of alum*, for which he received the thanks of the society, and his paper was ordered to be registered." I, 41 [*Cf. Phil. Trans.* XI, 1052.]

" Mr. OLDENBURG [was desired] to write about the account of making steel and lattin plates." I, 52.

" Mr. POWLE promised to bring in an account of iron, from the ore to the bar... Mr. ELLISE to inquire into the making of lead." I, 66.

" He [Sir ROBERT MORAY] mentioned likewise a proposal likely to be speedily referred to them [the Society], of making iron with sea-coal. And having formerly been engaged himself in that experiment of making iron with sea-coal, he declared his judgment, that he conceived the attempt not feasible, on account, as he supposed, of the abundance of sulphur in sea-coal, which destroys that quality in iron, which renders it tenacious. The debate on this subject was adjourned till the person himself, who undertook the design, had made his trial." I, 116-117; also 119.

" A proposition was made by a person introduced by the amanuensis, of melting lead-ore with pit-coal, with less charge, and in a shorter time; yielding also a greater quantity of lead out of the ore than other methods do. It was thought proper, that he should state his proposition in writing, and confer with the lord viscount BROUNCKER and Sir ROBERT MORAY about it." I, 120.

" Mr. BOYLE being put in mind of having been formerly desired to consider and give an account of GLAUBER's way of discovering minerals, informed the society, that this was only by mixing some glass with the mineral, and that thereby the metal predominant in the ore is discovered." I, 349.

" Mr. HOSKYNS related, for the improvement of metals, that one WETHALL had raised a great estate from the mines of Mendip, by melting the ore after a particular manner, for the extracting much more metal out of the ore than ordinarily is done. He was desired to inquire farther after it." I, 446.

5. *general mining techniques.*

" Mr. POVEY being called upon for Mr. JONAS MOORE's way of breaking rocks with powder, Sir ROBERT MORAY related, from prince RUPERT, the following way of blowing rocks under-ground in mines... " I, 335.

" Dr. MERRET presented a discourse of his concerning the tin-mines and the working of tin in Cornwall; which was read, and ordered to be registered. [*Cf. Phil. Trans.* 1678, p. 949.]

" Mr. WATERHOUSE offered his service in engaging a friend of his in the west of England to give a good account of the mines there.

" Mr. BOYLE moved, that some persons, who had the opportunity, might be desired to make a trial with two weather-glasses put in a mine, one sealed, the other unsealed, to see what the heat of damps would work upon the one, and the pressure of air upon the other. Sir ROBERT MORAY, Mr. POVEY, and Dr. MERRET were desired to recommend this experiment both in Scotland and England." I, 345.

" Dr. COTTON produced several sorts of tin-ore, one of which was taken out of a place, where the people digging it were stifled with the damps of the mine... He brought in an account of this and other particulars about tin-mines, which was ordered to be registered..." I, 428.

" The earl of PEMBROKE informed the Society, that he had observed the iron plug used in Savoy to blow up rocks with gun-powder, to differ considerably from that in the repository, the cylinder of the former being split nearly in the diagonal; whereas the latter had only a small additional wedge." IV, 513.

b. Indirectly related research

1. *methods of raising weights: useful in raising ores.*

" He Hooke made an experiment of the force of falling bodies to raise a weight; but was ordered to try it by himself, and then to shew it again in public." I, 177.

" One Mr. Bullock, a carpenter, made a proposal to the Society of an invention of his in mechanics, whereby he pretended to be able to increase force to such a degree, as that two men should be able to move or raise as great a weight as as many oxen." IV, 501.

2. *problems of raising water in tubes and study of atmospheric pressure: applicable to pumping water from mines.*

" A discourse being held concerning the water's ascending in tubes or syphons, Dr. Henshaw made several experiments in one tube with water, spirit of wine, rose-water, spirit of salt, and spirit of vitriol." I, 18.

" Sir Robert Moray proposed to inquire by experiments, what bore maketh a jet of water rise highest; and of what figure the end of the pipe must be for that purpose..." I, 106.

" Dr. Wren proposed the experiment of forcing up water in two pipes of different diameters and equal altitudes; but having both in the lower and equal bores, the water in the larger pipe would be forced out by less strength than that in the smaller pipe. He was desired to bring in a description of this experiment, and something by way of account concerning it, at the next meeting." I, 115.

[Following the acceptance of Prince Rupert's water-raising engine.] " The Torricellian experiment was made with water in a glass cane about 40 foot long..." I, 279, 287, *et passim.*

" Dr. Papin shewed a way, by joining two syphons together, to work all the effects said in the book to be proper for the *Sypho Wurtembergicus.* He also proposed another way to do the same things by one syphon bent at the ends, as in the figure then produced." IV, 350.

" The latter part of Dr. REISELIUS's letter to Mr. HALLEY of October 8 was read, wherein... he excuses the not having tried sufficiently the effects of the Wirtemberg syphon, pretended by the inventor to be capable of evacuating water at the top thereof, and to run when above fifty feet high. This letter was ordered to be filed, and answered." IV, 513.

3. *studies of compression of air: applicable to the ventilation of mines.*

" Dr. GODDARD proposed a method of measuring the compression of the air. Mr. BOYLE was desired to hasten his intended alteration of his air-pump." I, 19.

" Dr. GODDARD proposed the experiment of what force would compress the air into less dimensions, and in what proportion." I, 106.

" Mr. HOOKE made the experiment of condensing air by the pressure of water; but the trial not agreeing with the hypothesis, it was ordered to be repeated at the next meeting." 1, 177.

III. MILITARY TECHNOLOGY

a. DIRECTLY RELATED RESEARCH

1. *study of trajectory and velocity of projectiles.*

" There was made an experiment for finding the velocity of a bullet by means of the instrument for measuring the time of falling bodies..." I, 461.

" Dr. CHARLETON and Mr. HOOKE reported of the experiment, which they had made of the velocity of a bullet, shot out of a musket, that, as near as they could observe, the bullet being discharged with prince RUPERT's powder, went above six score yards in half a second. It was ordered to be prosecuted with more exactness." I, 474; *cf.* 465.

[From the Society at Dublin.] " Mr. TOLET brought in a proposition in gunnery, sent from Mr. EDMUND HALLEY, with its construction and rule, but without a demonstration. He shewed the construction to hold true in all cases, but deduced another rule from thence." IV, 431.

[From a letter from WILLIAM MOLYNEUX to HALLEY, read at the meeting.] " You may remember that you obliged me with your rule for shooting on ascents and descents with the mortar-piece. The proposition is : the greatest random of a piece, the horizontal distance of an object, and the hight or descent from the horizontal line being given, to find the two elevations, or depression of the piece necessary to strike the given object... Doubtless you have seen Mons. BLONDEL's *Art de Jetter les Bombes*, a book wherein there is nothing material more than what was before him in GALILEO, except only this business of shooting on ascents and descents : after he had proposed the problem to Messieurs DE L'ACADÉMIE ROYALE DES SCIENCES, Mons. BUOT, Mons. ROMER, Mons. DE LA HIRE, and Mons. CASSINI employed their thoughts about it..." IV, 478.

2. *process of casting and improvement of arms.*

" Mr. OLDENBURG produced a letter, dated at Zurich, 17 Sept. 1662, giving an account of a new mixture of metals very useful for pistols and guns, highly esteemed in Germany, extremely light, and not subject to rusting or breaking. The following extract of this letter was ordered to be entered in the letter-book." I, 115.

" Mr. PALMER presented the society with a very artificial gun of CASPAR CALTHOF's [assistant to EDWARD SOMERSET, Marquis of Worcester, author of *The Century of Inventions*] contrivance, lodging at a time seven bullets and powder in proportion, and discharging them at seven several times. He had the thanks of the society... Sir ROBERT MORAY mentioned, that Prince RUPERT had contrived a gun exceeding all that had hitherto been invented of that kind, discharging several bullets with ease and without danger." I, 332.

" Dr. PAPIN brought in a draught of the manner of casting metals in vacuo, as follows : ' The art of casting metals is so useful in the world, that I hope the Royal Society will not dislike my endeavours to improve it by the following contrivance.' " IV, 343-4; also 347.

" There was shewn a wind-gun of a particular contrivance, which by having its receptacle once filled with compressed air would discharge four several bullets with so much force, as to bury the bullets in a deal board. The same gun would likewise be charged with gun-powder so, that without any farther trouble than putting in the ball, it would be sufficient to kill five times after this." IV, 494-5.

" An experiment was shewn by Dr. PAPIN of shooting by exhausting the air out of a barrel, to see the difference between shooting a bullet and a cylindrical slug, after this manner. And it was found, that the barrel being placed horizontal at three feet ten inches above the floor, the spherical bullet ranged forty seven feet two inches, and the slug, which was a cylinder of the same diameter and hight with the bullet, no more than thirty seven feet." IV, 539.

3. *relation of length of barrel of gun to range of bullet.*

" A paper of Dr. PAPIN was read concerning an experiment of shooting by the rarefaction of the air; and he shewed the said experiment of shooting with two exhausted barrels, a long and a short one; and it was found, that the longer barrel carried farthest, and that the velocity of the lead, being of about two ounces, out of the longer barrel was about seventy feet in a second of time." IV, 496.

" Part of a letter from Mr. LEEWENHOECK was read containing his observations upon the figure of the parts of the nitre after the explosion of the gun-powder; with several curious remarks about the manner of firing gun-powder, about the quantity of air produced by the blast, and about the length of a cannon to carry farthest." IV, 479.

4. *phenomenon of recoil.*

" 1660-1, January 2, the lord viscount BROUNCKER was desired to prosecute the experiment of the recoiling of guns, and to bring it in at the next meeting." I, 8 " January 23, the lord viscount BROUNCKER was desired to continue his experiment of recoiling." I, 12 " The lord viscount BROUNCKER was still continued for the experiment of recoiling of guns, and desired to try that, which was offered by Sir ROBERT MORAY concerning the plug." I, 16 " April 7. The lord viscount BROUNCKER made his experiments of the recoiling of guns; which succeeded according to expectation." " April 10. The lord viscount BROUNCKER was desired to give in writing an account of his experiments of the recoiling of guns." I, 20.

" An account of the lord viscount BROUNCKER's *experiments of the recoiling of guns* was read by Mr. ROOKE, and presented to the society. Upon which, public thanks were returned to his lordship, and he was desired to prosecute his experiments..." I, 33 [This account is reprinted in SPRAT's *History*..., pp. 233 ff.]

5. *experiments with gun-powder.*

" Mr. HENSHAW read his *History of the making of saltpetre*, for which thanks were returned to him; and it was ordered to be registered..." I, 41 [Reprinted in SPRAT, *History*..., 260.]

" Prince RUPERT sent the society a description, in High Dutch, of the method of making good gun-powder; which Mr. OLDENBURG was desired to translate, and Sir ROBERT MORAY to return their thanks to his highness." I, 69.

" He [Sir ROBERT MORAY] related, that prince RUPERT had made a new kind of gun-powder, in strength so far exceeding the best English powder, that trial being made with a powder-trier, it was found to be in the proportion of 21 to 2. It was desired, that a trial of it might be made before the society; and that the account of making it, formerly communicated, might be looked after, and registered, which was done..." I, 281.

" Mr. HOOKE shewed the figure of an engine for determining the force of powder by weight; and was desired to draw it again, and to add some explication to it.

" The lord viscount BROUNCKER was desired to consider of the powder-trials made by prince RUPERT, wherein eleven grains of powder put into a trier with a loose ferrel, raised a weight higher than as much more doth with a ferrel fixed." I, 295; also 297, 302, 333.

" Sir ROBERT MORAY promising to secure, for the next meeting, prince RUPERT's powder-tryer, the operator [HOOKE] was ordered to provide several sorts of powder for pistols, muskets, and cannon; and to make trial with all of them in the said tryer.

" Sir PAUL NEILE mentioned, that trial being made of prince RUPERT's powder, and common English powder, it was found, that whereas a charge of the English powder shot through three boards, and stuck in the fourth, prince RUPERT's powder passed through four boards and stuck in the fifth.

" Dr. CHARLETON promised to bring some of prince RUPERT's powder." I, 335.

" Sir ROBERT MORAY produced prince RUPERT's Powder-tryers, to try in them the difference of the force of several powders...

" The prince's powder having double the effect in the tryer with a long ferrel, to what it had with a fixed ferrel, it was referred to the president [BROUNCKER], to consider of the reason of it. The same kind of powder being found to differ in strength from the common English powder as about eleven to one, Sir ROBERT MORAY moved, that it might be considered, how to make such powder in England, since it might be carried in far less quantity to perform the same effects, that ordinary powder doth; and the charges of making it would not be so great, as to take away the advantages of it...

" Mr. POVEY mentioned, that powder sent to the Indies lost its virtue. Mr. HENSHAW offered this as the reason of it, that the air there being very moist, did by relaxing the salt of it spoil its strength, though by working it up again its goodness was restored.

" The operator was ordered to make such powdertryers as those of prince RUPERT...

" The operator was directed also to try the experiment in Mr. HOOKE's new powder-engine by himself, and then to do it before the Society at their next meeting." I, 338; also 342, 440.

b. INDIRECTLY RELATED RESEARCH

1. *compression and expansion of gases : relations between volume and pressure in the gun.*

" Dr. GODDARD made an experiment concerning the force, which presseth the air into less dimensions; and it was found, that 12 ounces contracted 1-24 part of air. The lord viscount BROUNCKER was desired to lend his glass to Dr. GODDARD, to make farther experiments about the force of pressing the air into less dimensions." I, 109.

" He [HOOKE] proposed an experiment to be made with the compressing engine, of applying a gun to it, to see, with what force it will be able to shoot a bullet, arrow, &c. The operator was ordered to prepare a gun for this purpose." I, 345.

" Mr. BOYLE proposed, that it might be examined, what is really the expansion of gunpowder, when fired." I, 455.

" Dr. PAPIN's experiment of firing gun-powder in vacuo, and concluding the quantity of air made by the blast, was referred to be shewn at the beginning of the next meeting." IV, 469

" Dr. PAPIN shewed his experiment of firing gun-powder *in vacuo*; but it was not succeeding by reason of some soot got in with the powder, it was ordered to be tried again at the next meeting.

" Mr. HOOKE gave an account of his firing gun-powder *in vacuo*...

" Part of a letter of Mr. LEEWENHOECK was read, containing several curious observations on cinnabar and gun-powder, and mentioning an experiment, proving the expansion of gun-powder to be into a space above 2000 times greater than the space, which it takes up before fired; for that a grain weight of powder containing 13 corns takes up as much room, when fired, as 2080 grains of water.

" Three papers of Dr. PAPIN were read relating to his experiment of firing gun-powder *in vacuo;* in one whereof he said, that by the experiment made after the last meeting was over, he found, that 9 grains of gun-powder produces as much air, as fills the space of a third part of a pound of water; from whence he concluded, that 9 grains of powder yields 2 and one-half times as much air as its own bulk; which is far short of Mr. LEEWENHOECK's experiment." IV, 470.

" ... a paper of Dr. PAPIN was read, concerning an experiment tending to shew the force, which a shot receives by the rushing of the air into an exhausted barrel..." IV, 494; also 517, 523.

2. *strength, durability and elasticity of metals : elastic strength of guns.*

" It was ordered, that at the next meeting experiments should be made of wires of several kinds of the same size, *viz.* silver, copper, iron, &c. to see what weight would break them; Mr. CROUNE being appointed curator of this experiment." I, 109 " The experiment of breaking a wire, by weights hanging upon it, was tried." I, 111; also, 115, 117-120.

" Dr. CROUNE brought in some account of the breaking of wires; the experiment whereof appearing as yet very uncertain, he was desired to prosecute the same, by trying several wires of different matter, and the same size, to see, whether the proportion of toughness in different metals may be found." I, 139.

3. *free fall of a body and conjunction of its progressive movement with its free fall : determination of trajectory of projectile.*

" The lord viscount BROUNCKER was desired to try the acceleration of falling bodies by pullies or otherwise." I, 46.

" The lord viscount BROUNCKER was reminded of making the experiment of proportioning bodies of different matter and bulk, to fall in the same time; Mons. HUYGENS affirming, that a ball of cork may be so big, as to fall with equal swiftness through the air as a ball of iron." I, 172.

" His [HOOKE's] account of the force of falling bodies [based upon experiments with falling bullets] was read, and ordered to be registered..." I, 195.

" The experiment of the velocity of descending bodies was tried with three leaden balls of different sizes; the diameter of one being 1 and 73-100 inch; of the second, 1 and 37-100 inch; of the third, 99-100 inch. The height of their descent was sixty-one feet; the time three vibrations of half seconds and 15" ' or 16" ' ... Mr. HOOKE was desired to find some convenient place in Westminster or Paul's for the prosecution of these experiments in a place free from wind..." I, 455-6; also 460.

" There was made an experiment for finding the velocity of a bullet by means of the instrument for measuring the time of falling bodies; which was so contrived, that the pendulum was set on moving by the bullet's passing out of the mouth of the carabin, and a board was put up for a mark at a determinate distance, and a string extended from that board to the pendulum, which was fixed just by the gun...

" It was ordered, that Mr. HOOKE should consider of a better way to try this experiment against the next meeting : and that Dr. CHARLETON and Mr. HOOKE be curators for finding the velocity of sounds with small and great guns, with and against the wind." I, 461 [*Cf.* the citation under III, *a*, 1, *supra.*]

" Mr. HALLEY read a discourse of his own, designed for a *Philosophical Transaction* [No. 179, p. 3], concerning the cause and properties of gravity, wherein he considers the several hypotheses concerning its impulses, and then mathematically deduces its consequences in the fall of heavy bodies, and the motion of projects." IV, 479.

4. *movement of bodies through a resistant medium : enables closer approximation to trajectory of projectiles as influenced by air resistance.*

" The following experiments, concerning the resistance of air to bodies moved through it, was [*sic*] brought in by Mr. HOOKE. ' For the finding out the resistance of the air to bodies moved through it, it will be necessary that

1. Trials should be made with pendulums of all sorts...

2. Trials should be made with several of these pendulums; first in the exhausted receiver, where being a much less quantity of air, it must necessarily less hinder those motions; and next, in the receiver, where the air is well compressed...

3. Trials should be made with bodies of several substances...

4. Trials should be made by shooting horizontally, from the top of some high tower, or the like.

5. Trials should be made by shooting bodies perpendicularly upward...

6. Trials should be made, by shooting bullets or other bodies horizontally... These trials likewise should be made with instruments of several strengths.' Mr. HOOKE was appointed curator of these experiments..." I, 205.

[From a letter by Dr. JOHN WALLIS to HALLEY, dated at Oxford, December 14, 1686, read at a meeting of the Society.] " By these papers of Mr. NEWTON, I find he hath considered the measure of the air's resistance to bodies moved in it; which is the thing I suggested in one of my late letters, and thereby saves me the labour of doing the same thing over again. For I should have proceeded upon the same principle; that the resistance (caeteris paribus) is proportional to the celerity (because in such proportion is the quantity of air to be removed in equal times) nor do I know from what more likely principle to take my measures therein. His computation from this principle I have not yet had leisure to examine; but do presume, a person of his accuracy hath not failed in his computation or deductions from it." IV, 514.

" A letter of Dr. WALLIS was read, concerning the resistance of the medium to bodies projected through it, as likewise to the fall of bodies : and it was ordered to be printed in one of the next *Philosophical Transactions* [January, February and March, 1687, No. 186.]" "It was ordered that Mr. NEWTON be consulted, whether he designed to treat of the opposition of the medium to bodies moving in it in his treatis *De Motu Corporum* then in the press." IV, 521.

" A paper of Dr. PAPIN was read concerning an experiment for trying the opposition of the air to a body moving in it...

" The minutes being read gave occasion to discourse concerning experiments formerly made about the opposition of the air to bodies moving in it : and it was ordered, that the Journal-books be consulted, to see what had been done in that matter." IV, 524-25.

" A letter of Dr. WALLIS to Mr. HALLEY, dated at Oxford March 4, 1686-7, was read, containing a farther illustration of his calculus of the opposition of the air to projects..." IV, 528.

IV. TEXTILE INDUSTRY

" Sir WILLIAM PETTY deliverd in the following history of clothing; which was ordered to be registered. *Of making cloth with sheeps wool...* [*etc.*] I, 55-65.

" Sir WILLIAM PETTY was desired to bring in the history of the dyers trade, which he promised to do." I, 41 " Sir WILLIAM PETTY brought in *An apparatus to the history of the common practices of dy[e]ing;* which was ordered to be registered." I, 83 [Reprinted in SPRAT, *History...*, p. 284 ff.]

" Mr. PALMER was desired to speak to Mr. GREGORY to come to the society, and inform them concerning the tinged silk stuffs." I, 86; 105.

" Mr. HAAK was desired to translate an Italian treatise concerning dy[e]ing." I, 83, " Sir GILBERT TALBOT, Dr. MERRET, Mr. HAAK, and Mr. HENSHAW were desired to assist in the translation of the Italian book about dy[e]ing." I, 109.

" Sir ROBERT MORAY recommended the improvement of silk-making heretofore begun in England. In order to which it was suggested, that white mulberries should be increased; for which their growth by cuttings put in good ground was by Col. LONG preferred as more speedy, before their propagation from roots. It was also mentioned, that eggs of silk-worms brought from abroad out of warmer countries, would thrive better; Monsieur MONCONYS affirming, that in France they send for eggs out of Italy, and offering himself to procure a good quantity of them; as also to give a full account of the way used in France in ordering silk-worms. Mr. HOWARD was desired to pursue the planting of mulber[r]ies." I, 245; also 256, 306.

" Mr. HOOKE described a method for dy[e]ing several colours on the same piece of cloth in pannels or squares, which he conceived to be the way used by the Indians to stain their callicoes." IV, 520.

V. GENERAL TECHNOLOGY (*including* HUSBANDRY)

" Dr. WREN proposed black lead as a better means than oil for preserving the pivots of the wheels of watches or clocks from grating or wearing out. Mr. PALMER suggested bell-metal to be better than any other on account of its hardness, for the pivots of wheels to run in." I, 76; also 167.

" Mr. BOYLE brought in a glass with a composition in it, instead of a foil, for the making of looking-glasses. "

" Mr. WINTHROP was desired to communicate in writing the manner of making pitch and tar." I, 87.

" It was ordered, that the thanks of the society be given to Dr. MERRET, for his pains in translating the Italian discourse *De Arte Vitrariâ*, upon the motion and desire of the society." I, 115.

" Mr. BRUCE and Mr. PELL were desired to bring in the description of the several wind-mills and water-mills, which they had observed in Holland and other parts, in order that it might be considered, how and wherein these engines shorten labour." I, 165 " Mr. BRUCE brought in an account of wind-mills in Holland; which was ordered to be registered. Mr. BRUCE was desired to procure from his friend in Holland a more particular description of these mills and their fabric. Mr. PELL took these papers of Mr. BRUCE with him, and promised to add to them his own observations concerning mills." I, 169.

" Sir ROBERT MORAY's paper about the way of making malt in Scotland was read, and ordered to be registered." I, 169.

" He [HOOKE] desired again, that those members, who were acquainted with the ways of ordering fewel to the best advantage, might bring in an account thereof, in order, that, upon consideration of what had been done hitherto in that matter, it might be farther considered how to improve it. Whereupon, several members suggested what came into their minds." I, 173.

" Mr. HOOKE's two papers were read, the one containing an account of some trials for finding out how much the pressure of the water is increased by the descent of heavier, or the ascent of lighter bodies therein; the other, containing an experiment concerning the different weight of cold and warm water... The uses of this experiment may be some such as these : First for profit : ... This contrivance, if prosecuted, might perhaps be very beneficial to brewers, dyers, and such other trades, as have occasion to make use of great quantities of water heated; as was lately intimated by Dr. GODDARD." I, 174-75.

" Sir ROBERT MORAY and Mr. HOSKYNS related the way of making the burning balls at Liege, &c. which is a thrifty kind of fewel, lasting long, and burning without smoke, and leaving no ashes.

" Sir PAUL NEILE suggested, that the practice of this thriftiness would prove prejudicial to shipping. Mr, HOOKE was ordered to consider of the several ways of ordering fewel, that had been suggested, in order to make an improvement thereof." I, 177.

" Sir ROBERT MORAY gave occasion to inquire of what importance the custom was of changing seed-corn every year; concerning which Col. LONG thought it a point of great advantage to change the ground from worse to better, and to sow lean and small corn in richer soil. He added, that though husbandmen seldom sow the same grain in the same ground; yet he knew barley to be sown upon the same land for several years together with good success. He observed farther, that corn will smut, if from one rich ground it be sown upon another rich ground; but not so much the second as the third and following years.

" Mr. BRERETON mentioned, that in Cheshire, in order to preserve corn from smut, as also from being eaten by birds, they steep it in brine sprinkled with lime. Mr. HOSKYNS said, that Col. SANDYS intended to bring gravel from the sea-shore out of Cornwall into Herefordshire, to manure the ground with.

" Sir ROBERT MORAY inquired, whether manuring the ground with lime, makes wheat more wholesome or not? Col. LONG said, that the sign of the wholesomeness of corn being to keep well; and corn grown from lime or other good natural manure, keeping better than from compost or dung, or other foul manure, it was manifest that liming the ground made the corn wholesome. He observed farther, that asparagus, and other herbs growing from rank manure, were not so good, nor so firm or well tasted, as those that grew from a good natural soil, or from a clean manure." I, 245-46.

" ... the following receipt to prevent the rot of sheep presented by Mr. BOYLE... was read, and ordered to be registered." I, 313.

" Sir ROBERT MORAY moving, that it might be considered, whether there might not be devised an engine fit to strike the whales with more ease and sureness, and at a greater distance than those now in use, it was ordered, that Dr. WILKINS and Mr. HOOKE should think of such an engine, that might be cheap and easy to be managed." I, 327.

" Dr. CROUNE communicated a letter written to him by Mr. NEWBURGH... about the fertilising of barren orchards by turning cattle into them, and foddering them all the winter. An extract of this letter was ordered to be entered [in the Letter-book]." I, 327.

" Mr. Howard promised to bring in an account of tanning and preparing all kinds of leather, after a new way; and upon his desire of having some of the society join with him therein, Mr. HENSHAW and Mr. COLWALL promised to do so.

" Dr. CROUNE was put in mind to bring in the history of hat-making, which he had long since undertaken to do; and Mr. HILL, the history of paper; and Mr. PROBY, an account of the statutes of England concerning manufactures, especially cloth-making and tanning..." I, 342.

" Mr. HOOKE being called in, and desired to suggest some experiments that might be acceptable and useful to the public, suggested, that the experiment of land-carriage, and of a speedy conveying of intelligence, might be considered of. " I, 379. "It was ordered, that Mr. HOOKE set down in writing and produce to the council his whole apparatus and management for speedy intelligence : And that Sir ROBERT MORAY and Mr. EVELYN give a visit to Col. BLOUNT, and confer with him concerning the improvement of land-carriage." I, 385.

B. PURE SCIENCE

This category includes research in the fields of mathematics, astronomy, physics, meteorology, chemistry, botany, zoölogy, anatomy, physiology, geology, geography, history and statistics (political arithmetic).

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