FUNDAMENTAL PRINCIPLES FOR THE ILLUMINATION OF A PICTURE GALLERY

TOGETHER WITH THEIR APPLICATION TO THE ILLUMINATION OF THE MUNICIPAL MUSEUM AT THE HAGUE

DOOR

J. G. EYMERS

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PROEFSCHRIFT TER VERKRIJGING VAN DEN GRAAD VAN DOCTOR IN DE WIS- EN NATUURKUNDE AAN DE RIJKS UNIVERSITEIT TE UTRECHT OP GEZAG VAN DEN RECTOR MAGNIFICUS DR. C. W. VOLLGRAFF, HOOGLEERAAR IN DE FACULTEIT DER LETTEREN EN WIJSBEGEERTE, VOLGENS BESLUIT VAN DEN SENAAT DER UNIVERSITEIT TEGEN DE BEDENKINGEN VAN DE FACULTEIT DER WIS- EN NATUURKUNDE TE VERDEDIGEN OP MAANDAG 2 DECEMBER 1935, DES NAMIDDAGS TE 4 UUR

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JOHANNA GEERTRUIDA EYMERS

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AAN MIJN OUDERS

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Hooggeleerde Ornstein, Hooggeachte Promotor, ik acht het mij een voorrecht dat ik zovele jaren in verschillende functie's onder Uwe bekwame en bezielende leiding werkzaam heb mogen zijn. Dat ik in die tijd aan zo sterk uiteenlopende problemen heb mogen werken is voor mij van veel belang geweest. Ik verheug mij er op dat ik nog enkele jaren onder Uw leiding mag werken aan een toepassing der natuurkunde, welke voor mij grote aantrekkingskracht bezit.

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Beste Vermeulen, ik wil je bij deze gelegenheid gaarne zeggen dat ik dankbaar ben voor onze jarenlange prettige samenwerking. Dat ik bij onze werkverdeling als onderwerp voor mijn proefschrift datgene van onze gezamenlijke problemen mocht kiezen, wat mij het naaste stond, daarvoor ben ik je ten zeerste erkentelijk, te meer daar het mij bekend is, hoezeer dit onderwerp ook jouw belangstelling heeft.

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Het was mij een grote eer bij dit werk in contact te komen met den onvergetelijken kunstenaar Berlage.

CONTENTS

INTRODUCTION

In November 1932 Prof. Ornstein was requested to assist in designing a system of artificial lighting for the New Municipal Museum at the Hague, then already in course of being built. He entered upon this request and began to study the problems involved, in colaboration with Dr. E. F. M. v. d. Held, Dr. D. Vermeulen and the present writer. From the beginning it was clear, however that one cannot inquire into the matter in question, without including in one's considerations the very closely related problem of the lighting in daytime. The commission from the Hague town-council led, therefore, to directions, concerning the lighting, both in daytime and at night. In the following pages the various investigations carried out on this subject are expounded. In doing so I tried, on the one hand to treat the problem in as wide as possible, while on the other hand the particular solutions applied to the Hague Museum are also given. These solutions are not in every case the most advantageous ones, from a lightingengineering point of view. The latter gives definite directions as to the preferable dimensions of the rooms. Since, however, the plans of the Museum were already decided upon, and the actual building was already begun, it was too late to alter the dimensions of the rooms, though, for a number of them even, so slight a change as $\frac{1}{2}$ M. would have meant a considerable improvement. The lighting engineering directions given, extend also to the sculpture room, the glass cases and a few items of miner importance. In the following, however, I have confined myself to the chief problem: the illumination of the picture rooms.

To begin with, the question was asked: what is the most advisable illumination of a picture? One might feel inclined to answer: that illumination, prevailing while the picture was being painted. In many cases, however, this illumination cannot be realised in a museum. In all those cases, for example, in which pictures are painted from nature, in the open air, it is impossible and not desirable to reproduce the conditions as regards the intensity and the direction of incidence. It was, therefore, necessary to find another criterium. To this we were led by the consideration that a painter will, without exception, judge his work in his own studio too, so that one may assume the lighting conditions, there prevailing, to be the most advantageous, since they are, probably, also the conditions that can be reproduced the best in a gallery. We took them to form the right criteria.

A systematical inquiry into the factors, governing the illumination of a gallery, leads to definite demands as to that illumination. Once these are formulated, the question becomes, how far they can be met with and to what constructive directions they lead. The treatment, given below, will make it clear, that one cannot dispense in this connection with a number of lighting-engineering data. These however were not available at the time, and, therefore, various investigations had to be carried out of a physical-technical nature, for example those, concerning the colour and intensity of daylight, the relevant properties of various kinds of glass and the reflective power of pictures. The methods themselves applied in these investigations are a matter, apart from the lighting system, finally constructed in the museum. They are, however, in themselves of lighting-engineering interest. For convenience, these methods together with the systematical treatment of the measurements, form therefore the subject matter of the appendix, while the results of these investigations and their direct application of the lighting of the museum in question are given in Chapter I to V inclusive. Thanks to this procedure, these chapters contain therefore the discussion of the problems, purely from a museum-technical point of view, without any interruptions concerning the measuring technique, while those, who are more specially interested in the physical and technical details of the measurements, will find them, all together, in the appendix.

FIRST CHAPTER

GENERAL CONDITIONS NECESSARY FOR THE ILLUMINATION OF A PICTURE-ROOM

Any project for the illumination, daylight and artificial of a picture gallery must necessarily be based in the first place on the knowledge of the most appropriate illumination of a picture.

Now, as a rule, a painter while at work on a picture cannot and, therefore, does not take into consideration the surroundings in which that picture will ultimately be hung. These are unknown to him but for a few exceptions where the pictures are being painted by special order, in which case, however, they seldom find their way into a picture gallery. Let us start therefore, from the assumption that the illumination of the picture while it was being judged in the studio, was as favourable as possible. We are then confronted by the problem how to reproduce that illumination. In order to solve this, we must know by which factors the nature of that illumination is determined. These factors turn out to be:

1. The *colour* of the incident light.
   In the majority of cases the painter uses north light for his work.
2. The *intensity* of the incident light.
   As an average for the illuminating intensity in a studio, during the painting, one may take 150 Lux.
3. The *direction* of the incident light.
   Most right-handed painters prefer overhead light slanting from the left in widely diverging rays on to the picture.
4. *Reflections.*
   On the canvas in a studio, these are restricted to a minimum.

The question is therefore: to what extent can we reproduce the above conditions in a picture-gallery? Here, at the outset complications arise from the fact that the pictures in a gallery hang in rooms. For, beside the problem of the most appropriate illumination, required by the picture as such, one must now also reckon with the influence of the room on the picture and of the room on the spectator, both these factors demanding a further detailed examination.

As regards, namely, the question what illumination is required by the spectator of the surroundings, for the picture and for himself, so as to obtain the most favourable conditions for viewing it, one must bear in mind that it is partly physiological and partly psychological, whereas the other factors are physical.

A further complication arising from the arrangement of a picture-gallery is that one can only enter more closely into an examination of these factors after having decided whether each of the pictures shall be illuminated in the way specially required for it (here „illuminated" is used in its widest sense, meaning the illumination of the picture together with that of its surroundings) or whether the illumination shall be such that any of the pictures can hang anywhere in the rooms of the gallery. When one has to deal with very large and very special pictures, the first mentioned way of illuminating is obviously to be chosen but as regards the great majority of pictures, one can but choose the second solution, the more so with a view to the possibility of a varying grouping of the pieces, temporary exhibitions etc.

Our general considerations will, therefore, deal with this second way of illuminating. This does not, however, involve a restruction of our problem; indeed, from our treatment of various possible constructions, the best way to obtain the solution for any special case will become at once apparent.

It will be clear from the above that, in order to obtain the right colour and direction of the light one would preferably illuminate the rooms by means of windows in the upper part of their northern walls. But in the first place an awkward consequence of this solution would be that only a very narrow margin would be left as regards the possible orientation of the building, and secondly by this position of the windows only the opposite walls would be illuminated adequately. For these two reasons this fenestration can only be applied in a few exceptional cases f.i. Special Gallery at Millbank; in general it is not sufficiently economical, and one must therefore look for a compromise. To this, one is led by the following considerations, starting from the questions:

1°. What is the specific nature of the north light?

Would it be feasable, perhaps, to use the light from the whole sky indiscriminately?

From an investigation of the dependence of light from the sky on wavelength we know that, as far as the *northern* sky is concerned, it is given for the visible region on the average by an equi-energy spectrum, that is to say, that the energy is practically the same at all wavelengths. (Here we have added „on the average" because the dependence is partly also influenced by the type and degree of cloudiness). When one determines, however, the dependence of the light from the *whole* sky on wavelength, it appears that in the direct radiation of the sun the red and yellow parts of the spectrum predominate over the blue part. Now the intensity of the direct sunlight varies widely. The diffuse light from the sky is not subject to strong fluctuations. Whereas, relatively speaking, the direct sunlight varies considerably. Consequently at a spot illuminated by both the light from the sky and the direct sunlight, the intensity, as well as the colour of the resulting illumination, will also vary strongly. Taken separately — the intensity fluctuations are perhaps the more important but that does not concern us here. For, whenever these variations are directly observed —, i.e. whenever, owing to the construction of the room, or to some other cause, a shadow pattern of some kind is projected on the wall (the shadowed parts receiving the scattered light from the sky only, and the parts immediately next to them the light from the sky and the sun), we have to deal with the combined effect of these intensity- and colour variations, an effect, which by many people is thought particularly annoying.

If, however, proper care is taken that the direct sunlight shall never fall on the canvas, or, what comes to the same, if the direct sunlight is mixed *completely* with the scattered light from the sky, the drawback arising from the strong variation of the former light is for the greater part overcome.

It is true that when the sun shines, the colour of the incident light will still be influenced by it, but thanks to the mixing, to a much smaller extent that would be the case if it fell directly on the canvas. This change of colour is, moreover, the same all over the surroundings. If, therefore, one is prepared to accept this change of colour, one can indeed use the light from the whole sky, so that by this concession one is free as regards the orientation of the building. The intensity fluctuations will be discussed in detail later on.

2°. Since, as mentioned above, the illumination must satisfy the condition that all the walls of a picture-gallery shall be equally suitable for the pictures, one must give up the idea of letting the light fall through windows in the upper part of the walls. The substitute for it is to use a horizontally placed skylight, provided the latter serves at the same time to bring about the right direction of the incident light. As regards this direction, I may remark the following:

If the incident light consists of pencils of small opening the strong shadows of the frames, as well as of the roughness of the paint (the latter shadows being of course strongly dependent on the painting-technique applied) will become prominent, whereas, in the case of a completely diffuse illumination, no shadows at all will be formed. Now both these effects are undesirable, but the latter is much more objectionable than the former. Indeed, it is not exclusively by the colour, but also by the direction and thickness of a brush-stroke, that a certain effect is aimed at, so that shadows, if not too strong, can by no means be dispensed with. For this reason the opening of the light-pencils incident on the picture may not be too small.

3°. We shall now pass on to the consideration of the intensity of the incident light in a room or gallery. It is well known that in a studio the adequate intensity is 100 to 150 Lux. But now the question arises whether this intensity will also be the most appropriate for a gallery. In order to settle this question numerous experiments have been carried out. To obtain information from different sources in our country professionals (painters, directors of picture galleries, art-critics) and non-professionals have been consulted. A number of pictures, of widely varying styles, were examined, taking good care that the colour of the light, which obviously plays a very important part in this matter, was the same in every case. As was to be expected the opinions were divided according to the nature of the pictures (modern and ancient, of a light and of a dark hue, etc.), but one may state as a general result that an illuminating intensity of about 100 Lux was considered to be the most appropriate.

The same question was also the subject of an enquity in Japan, (1), where the nature of the pictures as well as the techniques are so completely different from ours. In this case also, the opinion was asked of professionals and non-professionals, 40 persons in all; the result for the most suitable illuminating intensity turned out to be

140 Lux for Japanese pictures and 87 Lux for ordinary oil-paintings and watercolours.

In the case of the experiments carried out in Holland there appeared besides, to exist a small group of persons, who did not wish for a stronger illumination than 20 Lux.

Since, however, this intensity is within the region, where the Purkinje-effect is very prominent, and where, consequently, all colours are distorted, one can for the time being, safely discard their opinion; it is, indeed, straining the point too far to assume that this colour distortion was the effect aimed at by the painter.

Summarising, we may draw the conclusion that daylight illumination can be applied to a picture-room by means of a glass roof, provided the latter satisfies certain conditions. The principle of this way of illuminating is already old. It was often put into practice by simply making the roof of transparent glass. This solution has, however, various serious disadvantages; a wall of a room illuminated with this arrangement receives at one time the radiation of the blue sky, at another time the light from white clouds or perhaps even the direct light of the sun. This involves very strong changes as regards the colour as well as the brightness and the direction of the incident light. Moreover, these changes are not only dependent on the time but also on the place in the room. A picture on one of the walls may at one and the same time be easily subject to an illumination differing widely from that of a picture hanging on another wall of that same room. Finally, at instants when the direct sunlight falls upon a picture the intensity of the illumination can be many times too strong, as regards the most favourable conditions for viewing it, as well as the detrimental effect the of light on the picture itself.

In many cases these difficulties have been overcome more or less by making the roof of frosted glass or by stretching a linen cloth underneath the roof. For both these methods it is true that the light is to a certain extent scattered and absorbed, but if the incident light has a certain direction of preference this will still continue to predominate considerably. The drawbacks, mentioned above will therefore be weakened but by no means removed. The only real way out is to use for the glass roof a material suitable for bringing about a complete mingling of the directed sunlight and the scattered light from the sky.

This condition determines to a great extent the construction of the picture-rooms. This condition determines the construction of the rooms to a great extent, but not entirely since, in this connection another condition plays also an important part, namely, that the distribution of the intensity shall be sufficiently uniform.

As regards this second condition, not only the evenness over the height of the picture itself is necessary but also the evenness over the length and height of the walls. As regards the former let us suppose that a light cloudy sky of a picture representing a landscape is illuminated about 2 or 3 times stronger than the dark scenery underneath. The „point of gravity" will then be displaced appreciable, which will have a slightly irritating effect and may spoil the impression of the picture. As regards the homogeneousness of the illumination over the height of the walls, when their top-part is darker, it will make the room look gloomy; if, on the other hand, it were too light, the attention of the visitor would be diverted in an upward direction. Experience has shown that the best solution in this respect is to make the brightness of the top part of the walls not more than twice that of the walls at the level of the pictures.

Finally, as regards the evenness of the lighting in the length direction of the walls, it has turned out that a gradual decrease in brightness down to half its value over a distance of 4 or 5 meter is already realised as annoying. In planning the building the architect must, therefore, take good care not to let the corners of the rooms and galleries be too dark. This can be attained either by slanting off the corners, or by some other special lighting-engineering device. The „awareness" of a given unevenness is, besides, dependent on the brightness itself. Between the limits of an adequate lighting of a picture-gallery, the less the lighting, therefore, the sooner a definite unevenness will be noticed. This is one reason the more, why also on dark days the illumination may not be less than the 100 Lux agreed upon.

Before, entering into the question as to what extent the physiological and psychological factors determine the further details of the construction we must first ascertain whether it is at all possible to satisfy those conditions as regards colour, brightness and homogeneousness. To this end it is, in the first place indispensable to have at one's disposal data on the colour and intensity of daylight at various hours of the day for various days of the year. These data were not apparently available in Holland. In the second place, one must know the lighting-engineering properties of substances likely to serve as diffusing media. These properties turned out to be only insufficiently known to dealers in these materials.

These two facts made it therefore necessary to set about investigating on our own account the spectral constitution of daylight as well as the properties of various substances.

SECOND CHAPTER

THE INVESTIGATION OF THE COLOUR AND INTENSITY OF DAYLIGHT AND THE OPTICAL PROPERTIES OF VARIOUS KINDS OF GLASS

§ 1. *The colour and intensity of daylight*

In order to obtain the necessary data concerning the colour and the intensity of daylight at various times of the day and for various days in the year the following investigations were carried out:

for two years, daily, at about 9, 12, 14 and 17 o'clock the brightness of a horizontal white surface exposed to the radiation of the entire hemisphere of the sky was measured as a function of the wavelength. The times, mentioned, were chosen so as to cover the usual visiting hours of a picture gallery. As for using the light from the entire hemipshere, considering that this investigation was begun on behalf of the planned construction of the new Municipal Museum at the Hague of which the roof, owing, to its favourable situation, receives the light from the whole hemisphere of the sky, we were bound to carry out our measurings under similar conditions.

For an account of the measuring method applied and of the way the results were obtained from those measurements the reader is referred to Appendix § 1. All measurements and the way to bring them into workable form, are to be found in (2). The following statements may be sufficient here. The results were obtained from the combination of our observations with metereological data referring to the same times. These data were kindly furnished by the Royal Dutch Met. Inst. at De Bilt. First we can calculate the colourvariations of the daylight. Secondly, as regards the intensity variations of daylight, it is possible with the aid of the sensitivity curve of the eye and of the mechanical lightequivalent to compute from the known functional connection between the intensity at a given moment and the wavelength the value of the illumination in Lux. It appeared that this value can be expressed as a function of the sun's altitude and the degree of cloudiness. Now, the average number of days on which the various degrees of cloudiness in our country in different months of the year is known from statistical data which have been collected at De Bilt for years. One can, therefore, determine the intensity of the daylight to be expected on the average in each month.

From the measurements mentioned above one can also deduce the very considerable fluctuations occuring occasionally in the course of one day or even within a few minutes. A change of intensity by a factor 10, within a few hours is by no means an exception!

The following examples may serve to illustrate this. Table A gives the intensity per cm² of the white surface as a function of the wavelenght on an arbitrarily chosen day. Table B gives the intensity variations at one and the same wavelength on a day with strongly varying cloudiness. The amounts of energy are expressed in ergs/Å.cm².sec.

TABLE A

Date 6th April 1932 Time 10.20	
Wavelength	Intensity
6800 Å	290
6600 „	310
6400 „	310
6200 „	320
6000 „	320
5800 „	340
5600 „	360
5400 „	380
5200 „	410
5000 „	470
4900 „	480
4800 „	580
4700 „	570
4600 „	560
4500 „	610
4400 „	540

TABLE B

Wavelength 5600 Å	
Time	Intensity
10.10	400
10.12	1200
10.15	410
10.18	280
10.20	800
10.22	730
10.25	1100
10.30	570

The intensity of the light incident on the horizontal white surface varies very considerably in the course of a year. The fact that values of 3000 and 120000 Lux at 12 o'clock occur, may serve as an example. This means that if throughout the year the total amount of daylight were used for illuminating the rooms, intensities would occur differing on various days by a factor 40. To admit such tremendous differences is out of the question and the necessity, therefore, arises for an arrangement by which the illumination in a picture-room can be regulated. *A regulating system was therefore indeed plan ned and subsequently applied in every room.* This will be discussed more in detail when we come to deal with the actual construction of the building.

The question now arises: to what value of the intensity of the daylight must the construction of the rooms be adapted? Not to the average value, because in that case on a great number of days either artificial illumination will be necessary or the light will not be sufficient. Since, however, as already stated, a regulating system for the intensity must be applied in any case there is no fear for excessive illumination. The most efficient way will therefore be to adapt the construction to that daylight intensity, for which the number of days with insufficient light inside is a minimum.

The intensity of daylight once being known we have to decide which material is the most appropriate for the skylight. This material is subject to the condition that it shall be colourless and that it shall mix the diffuse light from the sky and the directed sunlight so completely that in the emerging light no trace of a direction of preference is left. Moreover, its transparancy must be such as to allow the daylight after passing through it to possess the illumination required for the walls of the picture-room.

Materials or substances likely to satisfy these conditions are:

a. Cloth:

This has the great advantage of being inbreakable and light, easy to handle and, owing to its texture, pleasant to look at. Its very serious disadvantages are its great inflammability and liability to decay.

b. Bakelite:

This, too, is unbreakable and light but the kinds introduced on the market up to now are liable to warp quickly and to change colour in course of time, and, besides they are not quite fireproof, so that, for the time being at least, they can be left out of consideration.

c. Glass:

This has the disadvantages of being heavy and breakable but as it is absolutely fireproof, not subject to decay and constant as regards colour and shape, it is to be preferred above the others for use in a picture-gallery.

§ 2. *Investigation of the optical properties of samples of glass*

Since glass, as already stated, is the most suitable material for the construction of skylights there remains to find out the right kind of glass. To this end we examined sampels of *opaline glass, opal-sheet glass*, and *frosted glass*. We measured more in particular:

1) the dependence of the vertically emerging light on the wavelength in the case of vertically incident light. This enables us to check the colour of the glass.

2) At one and the same wavelength the intensity of the light emerging at various angles in the case of incident light in a few definite directions (analogous to the position of the sun).

For a detailed account of the measuring method and of the results obtained we refer the reader to appendix § 2.

It may suffice here to observe that practically speaking all kinds of opaline glass and a few kinds of opal-sheet-glass act as completely diffusing media (see fig. 1); only, opaline glass transmits a much smaller amount of light than opal-sheet-glass.

In figure 1. we plotted for a few samples of glass the power of transmission against the angle of refraction in the case of vertical incidence. The value of the angle between the emerging light and the normal are read along the abscis, the ordinate gives the corresponding intensities incident on 1 cm^2 of a surface at 1 m distance from the glass, on the understanding that 1 cm^2 of the glass radiates on to the surface and that the intensity of the light incident on the glass is put arbitrarily equal to 1.

The curves a, b and c refer to samples of opaline glass, completely diffusing opal-sheet-glass and non-completely diffusing opal-sheet-glass respectively. In the case of frosted glass the dependence of the transmission power on the angle of refraction is strongly onfluenced by the method of frosting applied. It turned out, however, that the direction of the incident light is always more or less prominent in the emerging light, whatever the method of frosting.

In order to decide between the possible kinds of opal-sheet- or opaline glass the dimensions of the rooms or galleries must be taken into account. Usually these dimensions from an illuminating engineering point of view they are of necessity rather vague.

Now, there are two ways of proceeding under these conditions, namely either by computation or by making a reduced model of the room to be constructed. The latter method may only be applied, however, when one has ascertained that the principle of similarity holds for the case in question. Since we have to deal here with completely diffusing media, the method may be applied without hesitation.

In our case the length and breadth of the rooms were given as

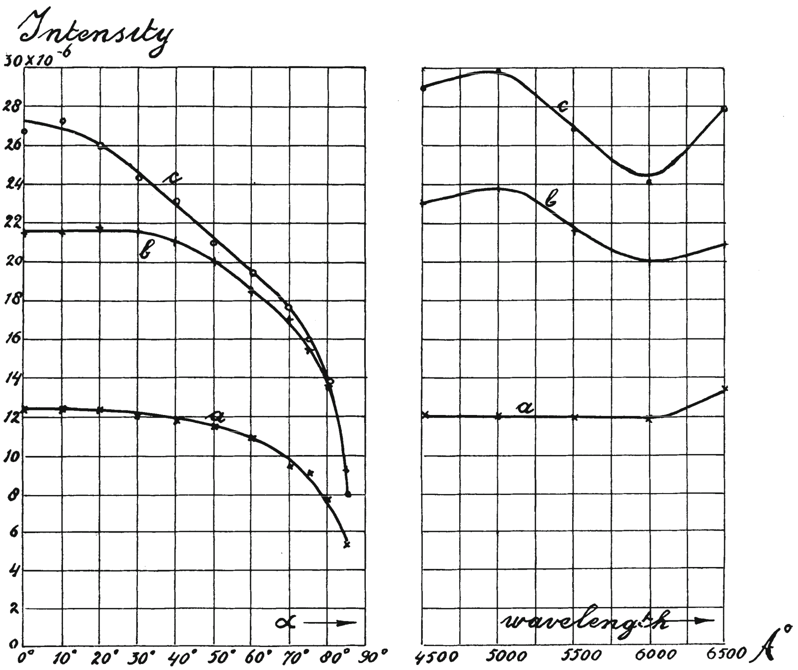

Fig. 1.

was also the height of the glass roof. The height of the skylight was still left more or less indeterminate. For this reason lighting-engineering computations were carried out for a number of these heights and widths and from the results the most suitable values could be chosen.

If, however, as is here the case, reduced models may be used, this way of proceeding is to be preferred.

Let us for example construct a model of the room in question in the proportion, say, of 1 to 10. We can do this by simply taking a box of which the horizontal cross section is somewhat larger than or equal 1/100 of the one of the room to be built. The box is covered with diffusing glass illuminated from underneath. With the help of easily adjustable strips of black paper or card board certain dimensions are then readily given to the model. Finally, the distribution of the light over the walls is measured, for example by means of a rectifier-cell in connection with a galvanometer. By moving the paper strips and by taking in turn for the glass layer the different kinds of glass likely to prove suitable it is possible to measure rapidly a number of cases. The advantage of working with reduced models as compared with the computing method as a quick means of obtaining final results is greater according as fewer dimensions are fixed definitely beforehand or according as one has to deal with more unknown quantities.

Now in the case of our model a simple measuring gives the ratio between the intensity of the light on the glass, (this, of course, must be illuminated homogeneously) and on the „walls". The actual intensity of the light to be expected on the walls inside the building is then obtained from the intensity of the light which will in reality fall on the glass roof by reducing the latter in the same ratio.

The following example may serve to illustrate the use of reduced models, but it is in this connection, necessary first to explain the meaning of the „coping". From computations it appeared that when the opal-sheet-glass occupies the whole of the ceiling the lighting is uniform at the same height all round the room, but that the toppart of the walls receives, in this case, much more light than the lower part. It is, therefore, impossible to use this construction, but it must be altered so as to reduce the excessive illumination at the top. This is achieved by making the border of the ceiling up to a certain width of an opaque material. This opaque border is called the „coping". Computations showed that the optimum effect of this contrivance is obtained when it is applied somewhat lower than the opal glass itself .

As regards the most suitable width of the coping, this might have been determined also by computation, but it is here that our reduced model comes in. It represented a room of the following dimensions: length 11 m., breadth 8 m., height of the opal glass 6 m., height of the coping 4,80 m. (The effective distance between opal-sheet-glass and coping was therefore 1,20 m.) By means of this model we could readily measure the distribution of the light in such a room, first without a coping, then with a coping of $\frac{1}{2}$ m width and finally with one of 1 m width. The results are given in fig. 2*a, b* and *c* respectively. Since the distribution appeared to be symmetrical with respect to the middle of the walls only one quarter of the room is represented in the figures and the walls are drawn flattened out into the plane of the floor. The illumination was measured for every 1,50 m round the room, at heights of 1, 2, 3 and 4 m and the numbers give the relative values, obtained at the corresponding parts of the walls.

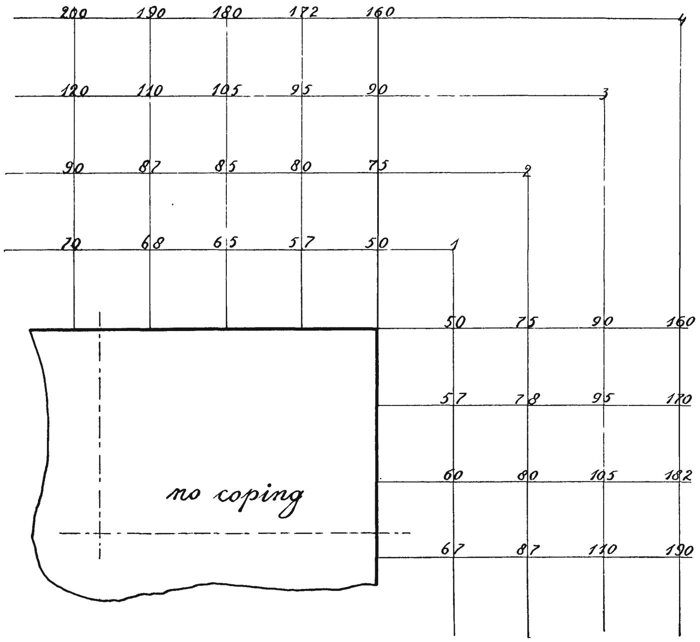

Fig. 2*a*.

From the results here given, it will be particularly clear, that a coping is necessary. Without one, the illumination at the height of 4 m is three times stronger than at the height of 1 m; with a coping of $\frac{1}{2}$ m width, the former is reduced already appreciably and finally with a coping of 1 m width the intensity at the height of 2 and 3 m is even stronger than at a height of 4 m. As was shown when the uniformity of the intensity over the walls was discussed it is the latter distribution that contributes to the right effect of the pictures.

The arrangement must be such that an intensity of 100 Lux

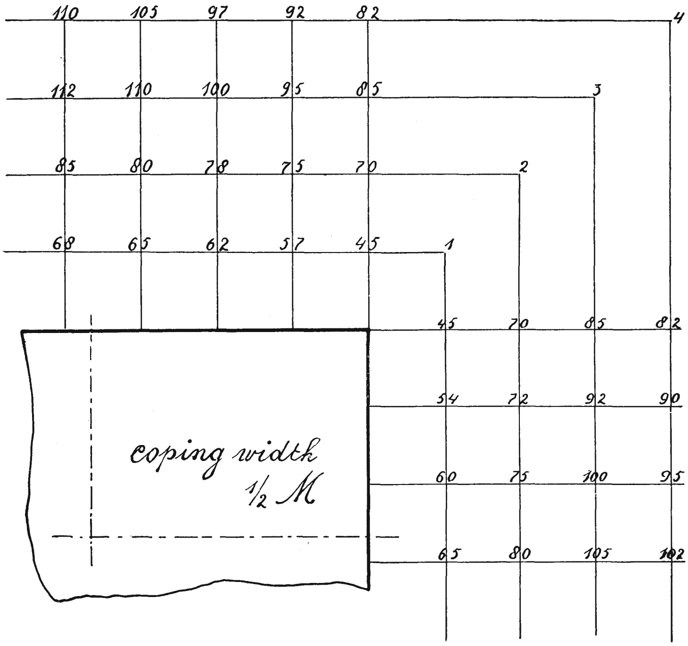
110 105 97 92 82 4
112 110 100 95 85 3
85 80 78 75 70 2
68 65 62 57 45 1
45 70 85 82
54 72 92 90
60 75 100 95
65 80 105 102
coping width
½ M

Fig. 2*b*.

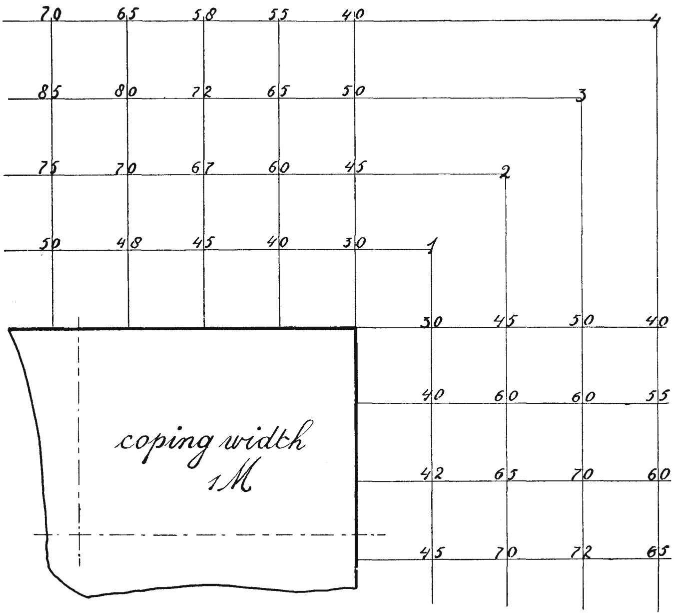
70 65 58 55 40 4
85 80 72 65 50 3
75 70 67 60 45 2
50 48 45 40 30 1
30 45 50 40
40 60 60 55
42 65 70 60
45 70 72 65
coping width
1 M

Fig. 2*c*.

shall fall on the walls of the room. This condition led us by the following considerations to choose a special opal-sheet-glass for the material in question. In the first place it diffuses the incident light completely and in the second place its power of transmission is such that for the inside intensity just mentioned an outside illumination of 4000 Lux is necessary. As matters stand, however, it appears from statistical data that in our country on about 10% of the days in the course of a year the daylight intensity falls short of 4000 Lux. In the case of opal-sheet-glass, therefore, the light on the central parts of the walls will be insufficient on such days and one will have to make use of, if at all feasible, artificial illumination. Since, however, the power of transmission of opal-sheet-glass is the highest of all (see fig. 1b) any other material would require a stronger outside illumination, and consequently there would be a greater number of days on which artificial illumination would be necessary. This is the reason for our choice of that opal -sheet-glass.

Later on, in the chapter on artificial illumination we shall treat the question in further detail.

THIRD CHAPTER

A FURTHER SPECIFICATION OF THE CONDITIONS NECESSARY FOR THE ILLUMINATION OF A PICTURE-ROOM

In order to specify the illuminating system in further detail, we must carefully consider which factors, depending on the illumination influence the impression of a picture exhibited in a picture-room.

These factors were:

1. The purely physical ones, i.e. those referring to the illumination of the picture itself and

2. the physiological-psychological ones, i.e. those referring to the illumination of the surroundings of the picture and of the spectator himself, required by him, so as to provide the best conditions for looking at the picture.

Now, the physical factors could be specified (see page 1) as colour, illumination, and direction of incident light, and as reflexions on the picture. The three first of these factors were already discussed in detail in the above so that we can now pass on to the remaining question concerning the reflexions.

Every picture has a more or less reflecting surface, glass or veneer, so that one might ask what it is that the spectator actually sees; the images formed by the surface of parts of the room or of objects in the room are, so far as this reflected light enters his eyes, superposed, as it were, on the picture itself. These reflexions are not necessarily disagreeable as is proved by the fact that many painters even prefer to cover their pictures by glass. One may say that these reflexions may never strike the spectator by their colour nor by their intensity; neither may they possess any considerable intensity- or colour-gradients. They must be whitish, and the combined effect of these grey reflexions which, as it were, cover the picture, is that all the colours in it will be slightly less saturated and give the impression of flowing more harmoniously into each other. But if this grey image is not to be felt as an annoyance, its brightness may not be more than a certain fraction of the brightness of the picture itself. An immediate consequence of this fact is, that direct light from the light source (window or skylight) may not by any means reach the eye of the spectator after being reflected in the picturesurface, because the intensity of such a reflected image would be far too strong [1]).

Since it is impossible to avoid these reflexions when the room is illuminated by windows at the same height as the pictures, this is one of the arguments against this fenestration.

In order to prevent any possible reflexion from the skylight windows in the upper part of the walls the pictures are sometimes given a slightly overhanging position. In the case of very large pieces however, this is apt to give rise to difficulties and it is with these pieces more than with the others, that the chance of reflexions in the top part, which can still catch the eye, is the greatest.

Besides, notwithstanding all the measures taken to prevent it, the chance will always remain that the surface of the picture under consideration will show reflexions of pictures hanging on the other walls or of the wall-covering. This is one of the reasons for choosing white or light grey for the colour of the wall-covering; another reason is that thanks that colour the walls will add a weak general side-illumination to the illumination of the pictures. The chief reason, however, will be mentioned later on.

The great influence of the homogeniousness has been discussed in Chapter I.

Let us now pass on to the physiological-psychological factors.

1. The influence of the brightness and colour of the surroundings (the walls) on the appreciation of a picture.

As is well-known, this influence is very strong, and may easily spoil the impression of a picture. The primary condition, which the surroundings must satisfy, for the right impression is that they shall intensify to the utmost our power for receiving colour-differences and intensity-differences.

---

1) The power of reflection of glass amounts to about 8%, that of veneer to about 7% in the chief direction of the reflection. For the determination of this value and also for the determination of the power of reflexion in the case of various directions of incidence and for the age and treatment of veneer see appendix § 3.

As regards colour-differences, our power of perception is greatest in white or grey surroundings [1]).

As regards the intensity, the lighting is obviously the same on a picture and on the wall next to it. Now the wall may not divert our attention from the picture; or, what comes to the same, the brightness of the former must be such as to make our power of perception an optimum.

This will be the case here when the brightness of the surroundings is equal to that of the picture. Now the power of reflexion of light paints is as high as 60%, but of the dark hues, frequently present in older pictures, it often amounts to only a few percentages. If, therefore, the wallcovering were white (power of reflexion 60% to 80%) our power of perception in the case of dark-toned pictures would be considerably reduced by the large difference in brightness; light-toned (many modern) pictures, on the other hand, can stand white surroundings very well. As it happens, however, grey wall-covering, which, as is clear from the above, is the most appropriate for dark-toned pictures, has a favourable influence on the appreciation of light-toned pictures also.

2. The influence of the illumination of the spectator himself, on his appreciation of a picture.

Here we are concerned with the question: What illumination does the spectator require for himself so as to acquire the best conditions for looking at the picture.

In order to answer this question, one must bear in mind that our power of discrimination is not only dependent on the colour and brightness of the immediate surroundings of the object under consideration. It is also, and very strongly, influenced by any extra light, for example the light from „the lightsource", that may eventually enter out eye. In this connection it is not only the pupil of the eye that comes into play, but the greater part of the eyeball. It has turned out(3), namely, that the transmission power of the sclerotic is so great, that the light which enters our eye through it, can play an important part in our way of perceiving.

The questions confronting us are, therefore: may the skylight, which illuminates the pictures, be seen by the visitor? If so, what

1) This is the reason why a greay wall-covering is chosen for sortingrooms, where the eye must be able to register small colour-differences, as, for example, in the case of the sorting of tobacco, corn etc.

must be the brightness of the skylight as seen from the average position [1]) of the visitor? If not, to what extent is it advisable to screen it from his view by special arrangements?

As will appear from experiments, presently to be mentioned, it is impossible to answer these questions unambiguously. One has simply to admit the fact that some persons like to have an illuminated surface overhead, while others dislike it strongly. The experiments in question, were carried out also with a view to throwing light on this difference. (We realise quite well, that they can not claim to be more than a rough approximation to what is required by our problem; they were, indeed, only meant as a first orientation) They were carried out as follows: fifteen persons were examined as regards their power of discrimination between spectral (saturated) and non-saturated colours, first, while light entered their eyes in a slanting direction from overhead, (for the illuminated surface a plate of opaline glass was used) and secondly, while this surface was screened from their eyes.

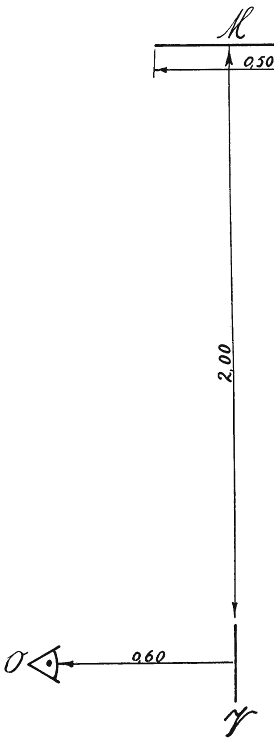

Fig. 3.

They were also checked as to a possible difference in colour-perception for both cases.

In order to secure the necessary data, the following arrangement was used (see fig. 3). The person to be examined fixed his eye which in the fig. 3 is at 0 on a small white surface V at the same level as the eye. On this surface two fields were projected one above the other, which could be made to differ in colour; the coloured fields were surrounded by a grey boder-field. Over this arrangement

1) By „average position" is here meant the whole of the room, reckened from a small distance from the walls. When one enters a room, namely, one is at that moment oneself part of the wall and receives then the same illumination as the pictures; one is, therefore, bound to see the illuminating surface, unless some special lighting-engineering measures are taken at the place of the doors, a sloping roof, for example, over the door-opening or ome appliance in the skylight.

a opaline glass plate M was applied. In the case of pure spectral colours the surface V was screened from the light radiated by M; in the case of non-saturated colours the screen was removed. The whole of the arrangement was mounted in a small room with white walls; by the illumination applied above M the room was at the same time dimly-lighted by diffuse light.

By means of a shade the light from M could be screened at will from the eye of the observer. The numbers given in the fig. represent the distances (in meters) in the actual experiments. The brightness of M amounted to about 0,01 K/cm^2.

The result obtained from these observations can be stated as follows: there appeared to be chiefly two groups of persons; for the first group the power of perception of colour-differences is less when the plate of opalineglass is visible than when it is not; i.e. a larger wavelength difference is necessary in the former case than in the latter to make them aware of a colour-difference. For the second group the power of perceiving colour-differences is greater in the case of a visible illuminating surface, than without it; especially in the green and the orange parts of the spectrum, whereas it is less in the red and the blue-green parts. For both types of persons the colour-perception changes also slightly. In the case of saturated colours, the red and green made a slightly more yellow impression when the skylight was visible than when it was not.

The persons examined were also asked whether they thought the visible skylight trying or disageable.

We investigated also the value, for various persons, of the angle between the horizontal line joining the eye with the point at its own level, on which the eye is fixed, and the line joining the eye and a lightsource, overhead, when it is first seen entering the field of view. As could be expected this angle turned out to depend on the depth of the eyesockets of the various persons examined, but in our applications we can safely use the average value, which aws 77°. Besides, we have in reality to deal not with a lightsource of very limited extent, but with a luminous *surface* of which the effect of its visibility is much less disturbing than that of the lightsource. We can therefore, take 77° as a safe upper limit of the angle with the horizontal direction, at which the luminous opalglass surface will first become visible, when we look at pictures hanging at the level of our eyes. We can conclude from this the value for example, that, when the opal-sheet-glass is at a height of 4,80 M. above the floor and the coping has a width of 1 M., we can stand away from the walls at a distance of 1,70 M. before the luminous surface can have any disturbing effect.

It results also impossible to draw general conclusions regarding this matter and one can but ascribe equal importance to the observed facts. The result, already referred to above, was that there are two groups of persons; one that prefers a visible skylight, provided there are no parts in it possessing a too strong brightness, and another that strongly prefers a screened skylight. Since the number of persons of the two groups was about equal, our problem is how to meet the demands of both of them. This is obviously only possible by constructing two types of rooms with skylight illumination:

1°. rooms where the visitors can see the skylight directly. The visibility is dependent on the dimensions of the room. We shall enter into further detail as regards this point, when we come to the discussion of the construction of the rooms.

2°. velum rooms, i.e. rooms in which the skylight is screened from the eye of the visitor.

As regards sub. 1, a skylight of opal-sheet-glass looks rather severe and cold; besides, it scatters the light evenly in all directions, whereas the visitor would prefer a stronger illumination on the walls than on the floor or himself. In order to obtain this, it is advisable to apply under the diffusing glasslayer a second layer, thereby bringing about the most favourable distribution of the light and at the same time improving the aspect of the roof.

As regards sub. 2. For reasons of a lighting engineering nature, the dimensions of the velum and the level it may be applied are subject to conditions, arising from the construction of the room. For, in order to illuminate the pictures by means of light-pencils of maximum opening, and also to obtain the required evenness, the wall must receive on a level with the lower part of the pictures (i.e. about 1 M. above the floor) as much light from the glass skylight as on a level with the toppart.

It follows from this that a velum, if it is not to spoil the lighting, may nowhere be higher than the lines AS and SB (see fig. 4). In planning the part so demarcated, the architect must, besides, satisfy certain aesthetic and psychological conditions. A velum may not be too low, for example, because that gives an oppressive feeling; it must not be too dark either, for the same reason. The material for such a velum must, therefore, be more or less transparent, and this leads, once more, to the choice of glass for the same reasons as were

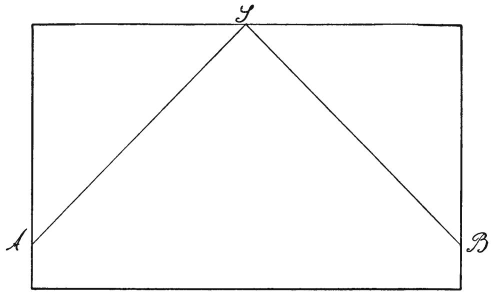

Fig. 4.

mentioned in the beginning. It remains only to decide upon the kind of glass possessing the right transparency.

For the second glasslayer in the skylightrooms various kinds of figured glass are likely to serve the purpose. Since, however, the glass-dealers could not provide the data necessary for a decision, we had to set about furnishing them on our own account.

FOURTH CHAPTER

THE VARIOUS TYPES OF THE CONSTRUCTED ROOMS

In the preceding chapters we deduced from physical and psychological data the conditions, which the rooms of a picturegallery must satisfy. It was found that the application of an opal-sheet-glass skylight to rooms lighted from above, meets the various demands to a great extent, that, however, a further improvement of the lighting can only be obtained by either applying a second skylight or a velum. It was also made clear that for this second skylight figured glass must be used. Before entering into a discussion about the construction of the rooms, it will, therefore, be advisable to deal with the relevant properties of figured glass a little longer. Since this kind of glass will always be used underneath the opal-sheet-glass, its colour and the angular distribution of the emergent light, only in the case of diffuse incident light, were investigated. A detailed description of the experiments and their results is given in Appendix § 2. Here the following statements will be sufficient.

It appears to make a difference for this kind of glass whether the smooth or the uneven side is turned towards the opal-sheet-glass. In the latter case the distribution of the light suits our purpose better; indeed the proportion of the amount of light, emerging at great angles to the normal to that in the direction of the normal is then greater, than when the glass is placed the other way round and this proportion governs the amount of light on the walls, compared with that on the floor or the visitor. This difference is particularly pronounced for the various types of prismatic glass; this glass must therefore in the majority of cases, be applied with the prism's turned upwards. Since, however, in this position, any dust entering from outside, is apt to gather in the furrows of the glass, it must be protected by an extra glass-layer. For the common types of figured glass the difference, mentioned above, is much less pronounced.

They can therefore, in all cases be applied with the smooth side up, which greatly facilitates the cleaning.

By way of illustration, fig. 5A and B show a few transmission-curves of the various types of figured glass. Along the abscis the angle is measured between the direction of the emerging light, and the normal, along the ordinate the intensity of the emerging light is expressed in percentages of the incident light. The curves a and b in fig. 5A give the result for a drop-glass with the smooth side (0) respectively the figured side (+) turned towards the opal-sheet-glass. In fig. 5B the results for a symmetrical prismatic glass are given in both situations (see 0 and +) while the curve c in the same

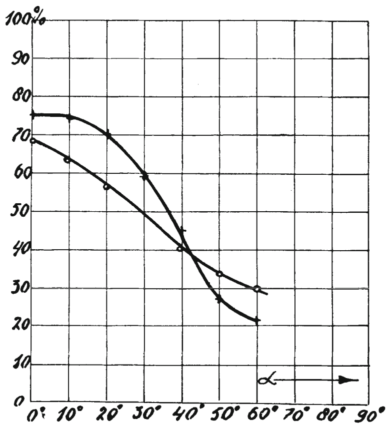

Fig. 5A.

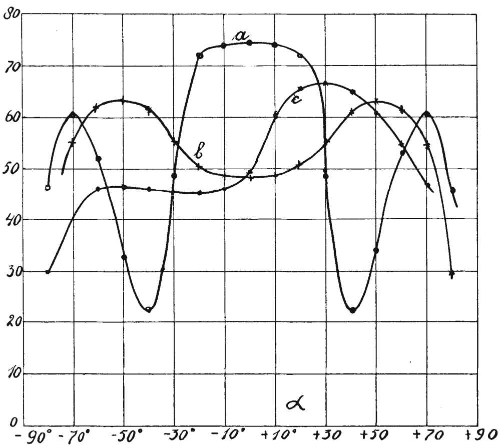

Fig. 5B.

figure represents the result for an asymmetrical prismatic glass with the prism' sturned towards the opal-sheet-glass. The results, given in fig. 5B were obtained by measuring at right angles to the direction of the ridges.

From a closer inspection of these figures it will be seen that the proportion of the amount of light emerging at an angle of say 45° to the normal, to that in the direction of the normal in the case of drop-glass, differs essentially from that proportion in the case of prismatic glass. For the latter it is greater than one, that is to say, the walls of the room receive more light than the central part. For drop-glass, however, this proportion is smaller than one, so that in this case, the central part of the room is more strongly lighted than the walls.

To a visitor, a prismatic glass syklight will consequently appear less bright than one of drop-glass. It would seem, therefore, that by the application of the former kind of glass the same lighting-engineering effect could be obtained as one tries to realise by a velum-construction. As a matter of fact however, the ways these two constructions affect the visitor, is not nearly the same, owing to the low position of the velum as the outstanding difference.

Fig. 6 shows by way of illustration photographs of a few kinds of glass used by us. These were obtained as follows: the sample was put on a background half of which was white and the other half black. It was then photographed from above and sideways in a slanting direction (in the latter case the cross section of the glass was made black, so as to make it stand out clearly). The scale is 1: 2, so that one can form an opinion about the real size of the figuring. The specific action of the various kinds of glass can be seen from the reproductions, more in particular the action of the prismatic glass is strikingly reproduced.

Now that the lighting properties of the various kinds of glass are known, we shall proceed to consider the constructional details of the rooms. These were studied for the greater part (as already mentioned in Chapter II) with the aid of reduced models (scale 1 : 10), which afford the quickest way to determine for each type of room separately the kind of glass required and also the copingwidth, the height and dimension of the velum etc. By these models we were led to the following constructions:

a. skylight rooms.

b. rooms with high fenestration,

while the skylight rooms are further subdivided into

1°. rooms with a secondary skylight of drop-glass

2°. „ „ „ „ „ „ prismatic glass

3°. velum rooms

Fig. 7 shows a cross section of part of the first floor of the Municipal Museum at The Hague. Three types of rooms are here represented, namely (from left to right) a skylightroom, a velumroom and a cabinet, lighted by windows in the upper part of the wall. (Next to this there is still a passage with glasscupboards, receiving its light from an inner court.)

We shall discus the various types of rooms one by one, and point out their specific advantages and disadvantages.

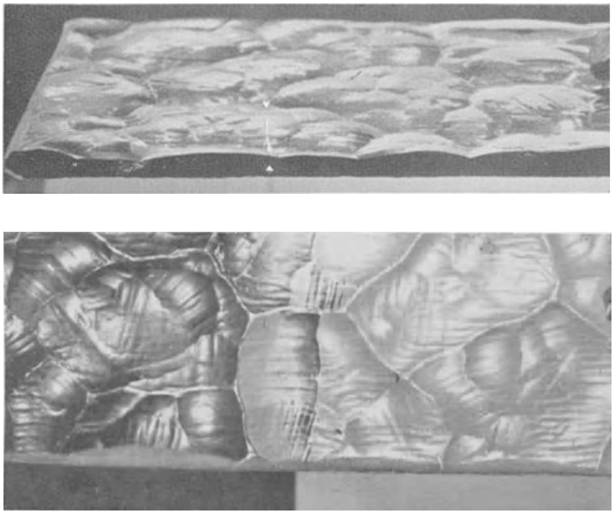

Fig. 6 *a*

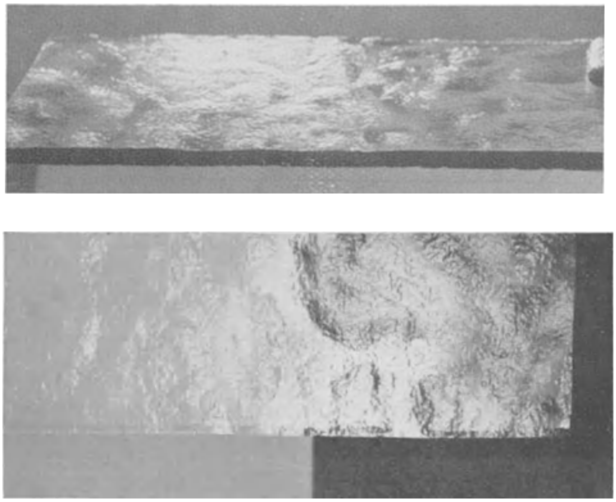

Fig. 6 *b*

Pl. II

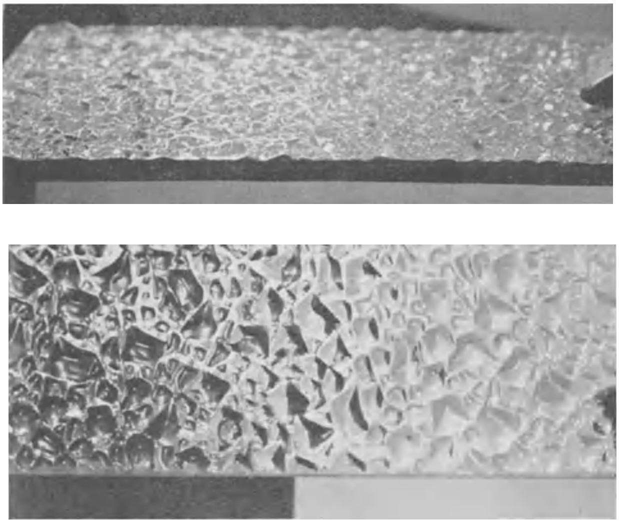

Fig. 6*c*

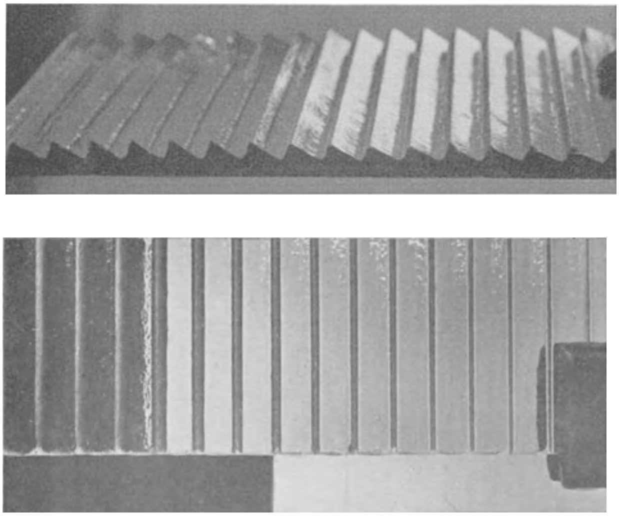

Fig. 6*d*

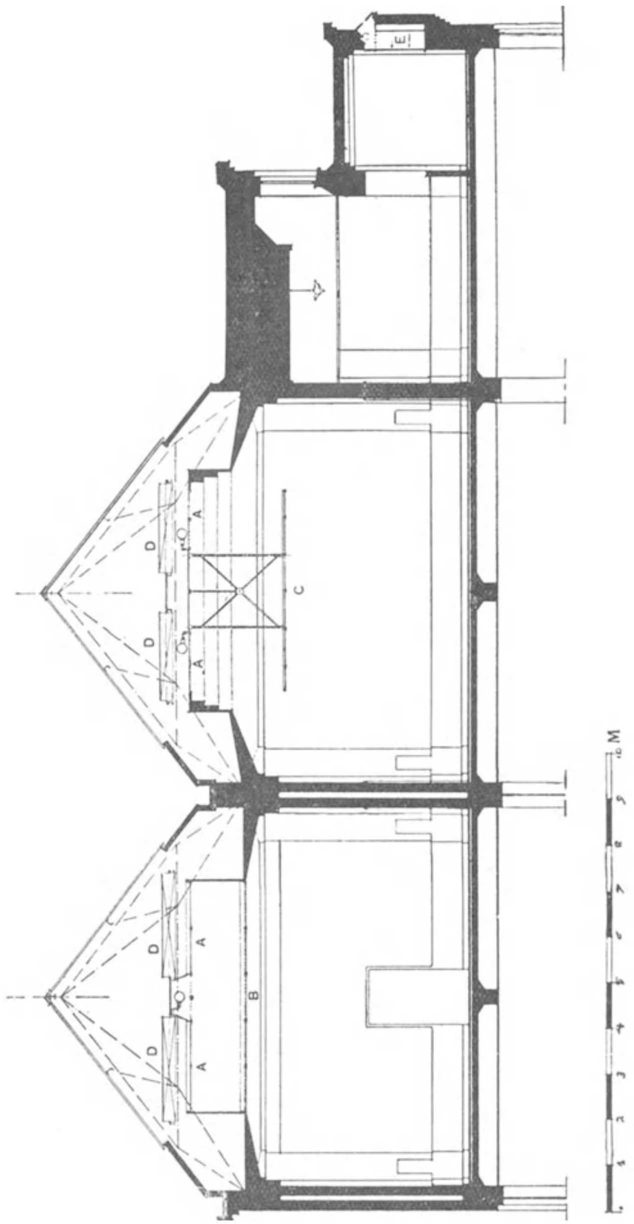

Fig. 7.

A. Opal.-sheet-glass. B. Figured glass. C. Velum. D. Screens.

a. *Skylight-rooms*

Our starting point for the lighting construction of the various rooms was the ∧ shaped roof of transparant wire netting glass, originally planned by the architect of the building [1]). From a lighting engineering point of view this shape of the roof is of no importance, as the roof itself is not a constructional part of the lighting system as such. It has, however the quality that, owing to its transparency, the iron construction of the building can be seen through it; which reminds some people unpleasantly of a factory. This difficulty can be removed by simply making the horizontal opal-sheet-glass layer i.e. the first essential feature of the lighting construction, play the part of the roof. On account of the rainwater, however, it may in that case, not be accurately horizontal; one can either give it a ∧ shape with very slight inclinations, or make it incline as a whole at a very small angle [2]). Seen from the street, both constructions will give the impression of a flatt roof, so that thereby, the drawback of the visibility of the iron construction is overcome.

In all skylight rooms opal-sheet-glass is used for the diffusing toplayer. A gangway is applied in this layer from which every part of the roof-construction is accessible and to which besides the appliances for artificial illumination can be fastened. All over the opal-sheet-glass layer movable screens are applied (see fig. 8) which serve to regulate the illumination in the room. The necessity of this screens has been commented upon in Chapter II. They are operated from the rooms so that:

1°. in the course of the day the illumination can be kept constant.

2°. if a visitor would prefer — for a short time — a different illumination, the attendant can adjust the screens accordingly.

3°. so long as the rooms are not used, the light can be kept screened completely, thereby protecting the pictures from its damaging influence. It is advisable to do this daily after closingtime for rooms in which pictures are exhibited, so that the latter need not be exposed to the light before 10 o'clock in the morning, and

1) When the building was nearly finished the effect of the construction of the roof which could be seen through the glass, was thought ugly and objectionable; in finishing the building the transparant glass was therefore made white. This entailed an appreciable loss of light. This might have been avoided if the white roof had been planned from the beginning.

2) The diffusing properties of the used opal-sheet-glass exclude slopes of any appreciable steepness.

also for longer periods at a stretch for rooms in which the pictures are stored away.

What has been said of the skylight rooms so far, refers equally to the three kinds of rooms, mentioned sub. 1°, 2° and 3°, because they have the opal-sheet-glass layer in common. We shall now deal with the types separately.

1°. rooms with the lower skylight of drop-glass [1])

Owing to the fact that the scattering for these kinds of glass is symmetrical with respect to the normal and that their transmission in the direction of the latter is a maximum, *the illumination in the central part of the room is greater than on the walls* (about three times as much) and seen from anywhere in the room, the glasslayer will have a considerable brightness. All walls are in this case lighted by the whole of the skylight.

The distance of the two layers is in the construction about 1,20 M. This rather large space is also chosen to allow a person to move about when necessary for repairing or cleaning and besides to contain the appliances for artificial lighting. For safety the lower layer must consist of wire-netting glass.

The coping width is fixed for the majority of the rooms at 1 M. the value for which the illumination at the level of the pictures is greatest, while at heights of 1 M. and 4 M. it is reduced to 60% à 70% of it. The attention is therefore, drawn automatically to the right part of the walls, moreover the distribution of the illumination is such that the upper part of the walls is not yet so dark as to cause the room to make a gloomy impression. Some kinds of dropp-glass possess at greater angles to the normal a higher transmission than other types of these glasses; in rooms therefore where the lower skylight consists of the former, the topparts of the walls are lighted nearly as strongly as the central parts. In the corners of a room, measuring 8 × 10,5 M. the illumination is about the half that at the centre of the longer wall. This difference does not affect the visitor unpleasantly, so long as the central illumination amount to about 100 Lux. For apprecially lower values, however, these differences

1) One type of this kind of glass is called: Large Morocco.

would begin to be disagreable. These darker corners are not an essential feature of this construction, for by either making the coping narrower at the corners or by applying there a slightly different kind of glass, this complication is easely overcome. Besides there are even people who think it an advantage when the illumination is not perfectly uniform round the whole room. Applied to long and narrow rooms, however, this construction would entail a very marked decrease ot the illumination in the lenghtdirection and the longer and shorter walls of the room would show a strong difference between their illumination. It is therefore not advisable to apply it in such a case, without special arrangements. For smaller, more or less square rooms however, it is the right construction which, moreover, recommands itself by its simplicity.

2°. rooms with the lower skylight of prismatic glass

With the prism's turned upwards the maximum transmission of glass of this description is not in the direction of the normal and the various kinds have each their own value for the angle of maximum transmission which differs from the others. By a suitable combination of a few of these glasses one can therefore arrange that the diffuse light, emerging from the opal-sheet-glass, is directed any way one likes, i.e. in our case towards the walls. The kinds of glass to be used and the way to apply it in the skylight, must, of course be wholly adapted to the size and the destination of the room in question. In the Municipal Museum at The Hague the lighting system of two rooms is constructed in this way, the one room long and narrow (8 × 15 M.) the other nearly square (11,5 × 14,5 M.). The lower skylight in the long-narrow room is constructed as follows (see fig 9): division A consists of symmetrical prismatic glass, which therefore directs the light towards the two long walls .For the other divisions a certain kind of asymmetrical prismatic glass is used, placed in such a way that the projection of the maximum transmission on the plane of the glass is in the direction of the arrows, while the ridges are at right angles to them. As shown in the figure, the glass in the corners had to be cut slanting to the ridges, which can be done without any difficulty. The second, nearly square room, (see fig. 10) contains very special and very large pictures. Here, asymmetrical prismatic glass is used throughout and the way it is

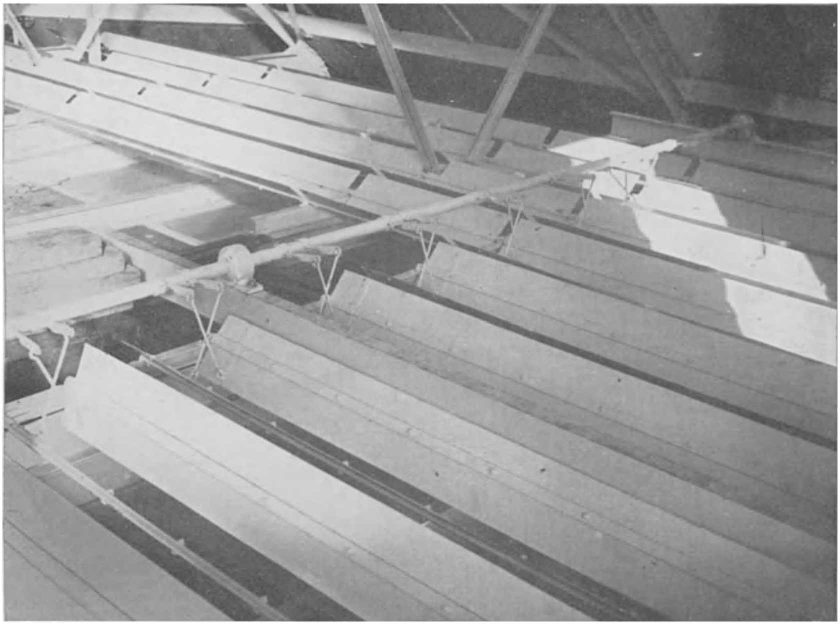

Fig. 8. The sereens, half opened

Pl. IV

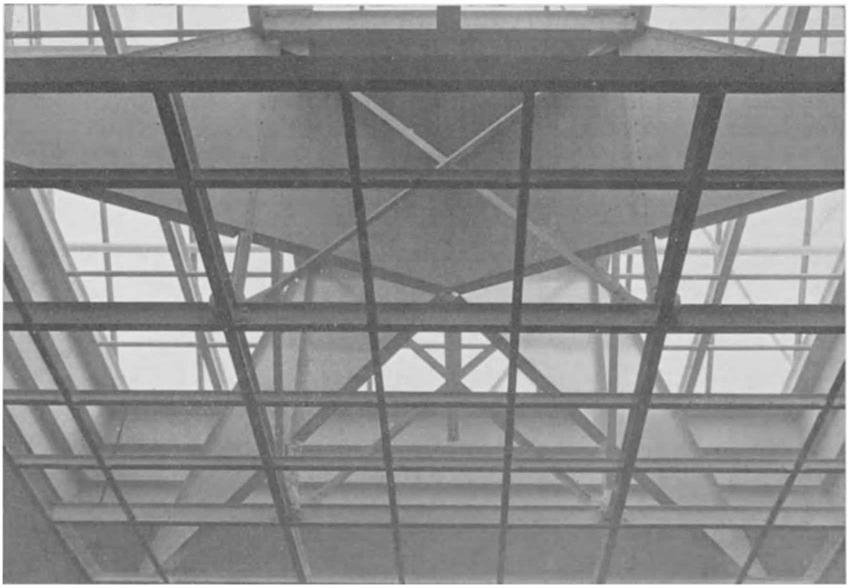

Fig. 11

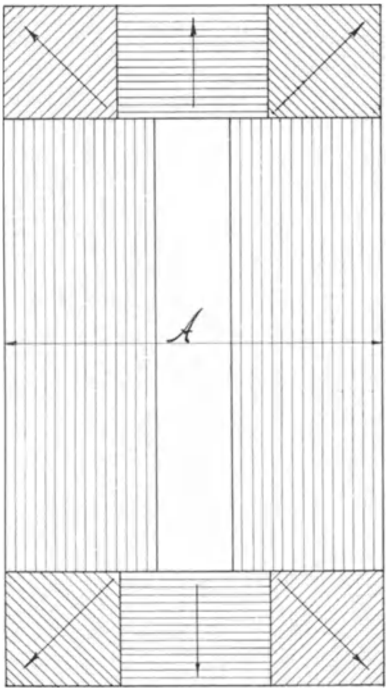

Fig. 9.

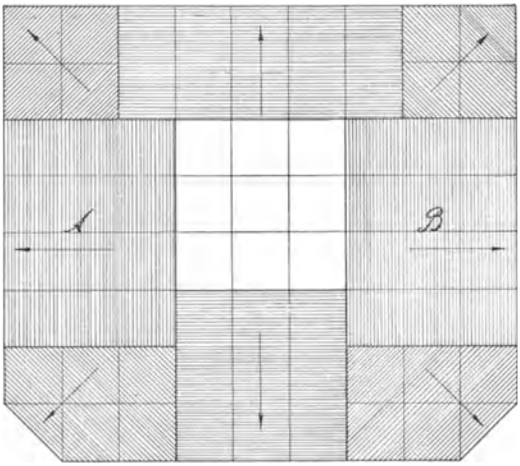

Fig. 10.

placed in the skylight is shown in the figure. The central part of the ceiling was not necessary for the illumination of the pictures. The choice of its material was, therefore, entirely a matter of personal taste; in this case opaline glass was applied.

The differences between the rooms with prismatic glass and those with other figured glass in the lower skylight can best be summarized in the following points:

owing to the fact that prismatic glass shows a certain direction of preference for its transmission, a wall will receive its light chiefly from a definite part of the skylight and the light incident on a picture will, therefore, be more directed.

it follows from that same property that the brightness of the glass seen from other directions than that of maximum transmission, will be comparatively small; seen from the room the skylight will therefore appear less bright. (The illumination in the central part of the room is nearly equal to that on the walls).

since the light, emerging from the topskylight is not cast for the greater part towards the central part of the room, but is used to a much higher percentage for the illumination of the pictures, one can, relatively speaking, suffice with less light. This means that on dark days, the pictures can still be illuminated adequately, while with the other skylights the intensity would already be insufficient.

by the choise of the pattern according to which the glass is laid in the skylight and of the kind of glass itself, rooms of all sizes and shapes can be lighted satisfactorily.

since the only way this kind of glass can here be used is with the prism's upwards, it must be covered with an extra layer of glass, fitting hermetically on all sides. This makes the whole of the construction heavier and more expensive.

prismatic glass ist not to be had reinforced by wirenetting; this must therefore be applied to the covering glasslayer just mentioned, so that the chance of breakage for the prismatic glass itself is greater.

finally, in the direction of maximum transmission this glass is, practically speaking, transparant; consequently, from a place close to the wall (and therefore also on entering the room) one can see the constructional parts between the upper and lower skylight, whereas in the other cases these parts are invisible.

The prismatic glass skylights are, properly speaking, an intermediate form between skylightrooms with drop-glass and velumrooms. Indeed with the former they have the constructional features in common, with the latter (at least in the way they are applied here) the distribution of the light.

3°. velumrooms

The object of their construction is to screen the skylight from the visitors eye. When he lookes at the pictures, at the same time it must be possible that the visitor can, without strain, read his catalogue. For that reason the velum may not be quite opaque, apart from the fact that such a velum would give a strongly oppressive feeling. It is therefore made of a slightly translucent material, namely of a certain kind of opalineglass. Our leading idea in fixing the dimensions of the velum was that over the whole height of the pictures the wall should receive the light from half the breadth of the opal-sheet-glass skylight. The velumconstruction was actually carried out in two types of rooms, one of 10 × 11 M. and the other of 8 × 14,5 M. In the nearly square rooms, its application does not meet with particular difficulties. In our case, we fixed the height of the velum at 3,90 M. and its dimensions at 6,10 × 7,20 M. (the skylight was at the usual height of 6 M. above the floor). But the application of the velum would entail that the corners of the room receive light from a much greater part of the skylight than the middle of the walls. The illumination in the corners would accordingly be much too strong. To prevent this complication, we applied a few screens on top of the velum (see fig. 11). With the rooms, equipped with lower skylights of prismatic glass, the velum rooms have in common that the light incident on the pictures is more directed than in rooms with drop-glass. Besides in velum rooms, the illumination at the top of the walls is slightly higher than at the level of the pictures.

The application of the velum in the oblong rooms was less simple. As already mentioned, the rooms measured 8 × 14,5 M.; now, if the velum were to hang again at a height of 3,90 M. this would mean (due to the comparatively narrow room) that its width should not be more than 3,50 M. From an aesthetic point of view, however, this width is inadmissible. A smaller height of the velum (which would make a greater width possible) is not possible, because it would then make the room look gloomy. We have therefore applied the velum at the height of 3,90 M. and fixed its width at 4.30 M. This means that the lower part of the walls, up to about two meters from the floor, are lighted by less than half the width of the skylight, in other words: the distribution of the light over the height of the walls is not homogeneous. In order to put this right again, we once more applied prismatic glass. This time, however, the object was to diminish the light at the top and to increase it, as much as possible, at the bottom of the walls, while the velum itself may also be illuminated. This involves the condition that the maximum transmission of the prismatic glass shall make only a small angle with the normal and that the transmission in directions at larger angles to the normal shall be considerably less. This condition is satisfied when the prismatic glass is laid with the prism's downwards, which we did accordingly. The opal-sheet-glass layer is this time immediately on the prismatic glass.

In the nearly square rooms, only the outer border of the glass velum will contribute to a certain extent to the lighting of the walls; in the oblong rooms, on the contrary, the part of the velum contributing to the lighting, will not be restructed to the outer border only. In the latter rooms, therefore, the velum must consist entirely of white glass, whereas, in the former, it may, except for the outer border, consist of coloured glass.

b. *rooms with high fenestration*

This type of lighting is applied to all small cabinets round the inner court. The windows are made of opal-sheet-glass, thereby obtaining again an illumination on the walls, which is uniform as regards colour and intensity. The windows of the rooms not facing north, must be provided with shutters by means of which the intensity of the lighting can be regulated. The high fenestrating lighting has, of course, the serious disadvantage that one of the walls can not be used for hanging pictures on it, but apart from this it is (at least according to the tast of the present writer) the most gratifying way of lighting a picture-gallery.

FIFTH CHAPTER

ARTIFICIAL ILLUMINATION

Before we can proceed to a more detailed specification of an adequate construction for artificial illumination, we must first inquire (as in the case of daylight illumination) into the factors that are relevant to this matter. For the greatest part these factors are the same as in our former case. We meet again with the intensity and the direction of the incident light, the possibility of reflections, the colour and brightness of the walls, the homogeniousness of the illumination, and in particular the question whether or not a „visible'' source of illumination is advisable, must be answered again. Since these factors lead to the same conditions as were found for daylight illumination, it follows that the method of artificial illumination must resemble, as closely as possible, the one of daylight illumination:

The specifically new problems in this connection are:

a. what must be the spectral composition of the artificial light?

b. how must it be applied, in order to resemble in its effects, as nearly as possible, the daylight illumination and to work out at the same time as economically as possible?

a. To begin with, let us confine ourselves to the colour of the artificial light. In order to decide this matter, we must first answer the questions how the colour of the incident light influences the impression, made by a picture, and what we do ourselves wish this impression to be like?

To answer these questions we must bear in mind, that, apart from the influence of the surroundings, our impression of a colour in a picture is dependent on the way in which the power of reflection of the paint in question is connected with the wavelength, the spectral composition of the incident light and the sensitivity of the eye. In order to form an opinion as to what a picture will look like, when a given artificial illumination is applied, one must, therefore, know first:

1°. the energy distribution of the various artificial sources of light,

2°. the selectivity of the power of reflection of the paints, used in pictures,

3°. the changes in colour that are realised as colourdistortion.

1°. What is the spectral energydistribution of artificial sources in comparison with that of the daylight?

As already stated in Chapter II, one can take the spectral composition of daylight to be that of an aequienergyspectrum. As artificial sources of light, suitable to replace daylight, we must mention in the first place, tungsten lamps. The continuous spectrum of the light, emitted by these lamps, depends on the colourtemperature of the particular lamps used. The colourtemperature is in its turn a function of the power (in Watts). The higher the latter, the higher also the former. Table C (4) gives a few connected values for these (and other) quantities for a gas-filled lamp.

TABLE C

Power	Colourtemp.	Hue	Saturation
50 Watt	2690° K	5840 Å	55,7%
100 „	2765° „	5840 „	53,4%
200 „	2845° „	5840 „	51,1%
500 „	2935° „	5830 „	47,6%
1000 „	2995° „	5830 „	45,7%
2000 „	3025° „	5830 „	45,1%

By way of illustration, fig. 12 shows the relative intensitydistributions over the wavelengths for a 50 Watt- (×) and a 1000 Wattlamp (.), the energy at 5600 Å being in both cases put equal to 100. It will be clear from this figure that with the higher powers the spectral constitution does indeed approach the one required for our purpose, but that it still differs strongly from an equienergyspectrum. Expressed in terms of the colourpoint (see table C under „hue" and „saturation") this means that whereas, practically speaking, the hue does not change, the saturation does change considerable with the power of the lamp; with increasing power the colour becomes to an appreciable degree white. Fig. 12 shows also the energycurve for a Philips daylight lamp. (0)

Besides these lightsources with continuous spectra, there are also lightsources producing discontinuous spectra, which, nevertheless, make an impression on the eye of being white. We mention for example, the mercurylamp with cadmium, further ordinary mercurylight, combined with mercurylight in yellow glass (which absorbs the blue line, so that the light makes an impression of green) and with neonlight and finally, the light from CO_2-dischargetubes. The spectra of all this lightsources (at least of the specimina brought on the market up to 1934) show more or less numerous lines, in the

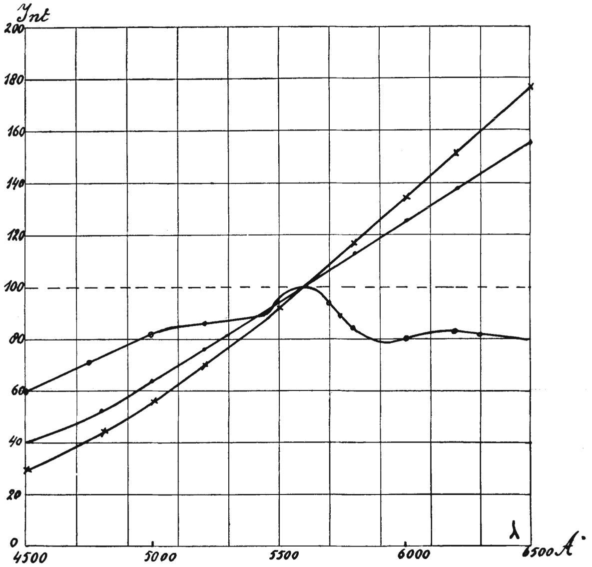

Fig. 12.

majority of cases, widened, between which lie more or less deep minima.

2°. The selectivity of the power of reflection of the paints in pictures. This power was measured, for a number of cases (for which we refer the reader to Appendix § 3). For some of the paints in ancient as well as in modern pictures, it turned out to show maxima and minima, restricted to very narrow ranges of wavelength. An example of this very pronounced selectivity is given in fig. 13, which shows het reflectioncurve of a flesh coloured paint, used by Jan Sluyters in one of his pictures.

3°. What changes in the colourimpression are realised as colour-

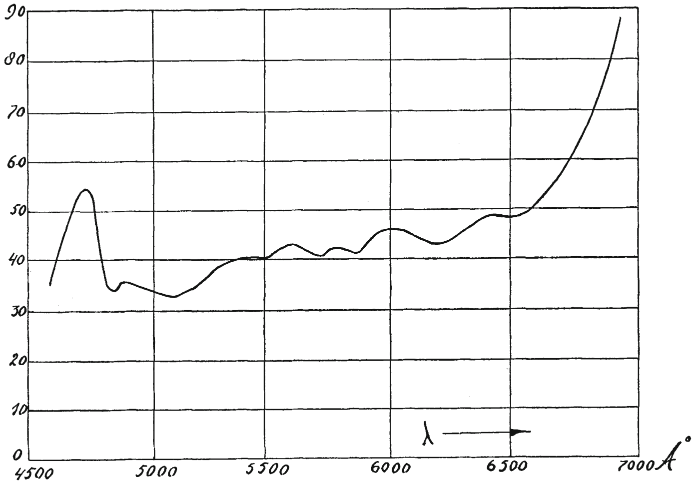

Fig. 13.

distortion? Before answering, let us put the preliminary question as to how much the differences in wavelength must at least amount to, so as to be observed as a colour difference. It is only natural to think, in this connection, of the numerous investigations, carried

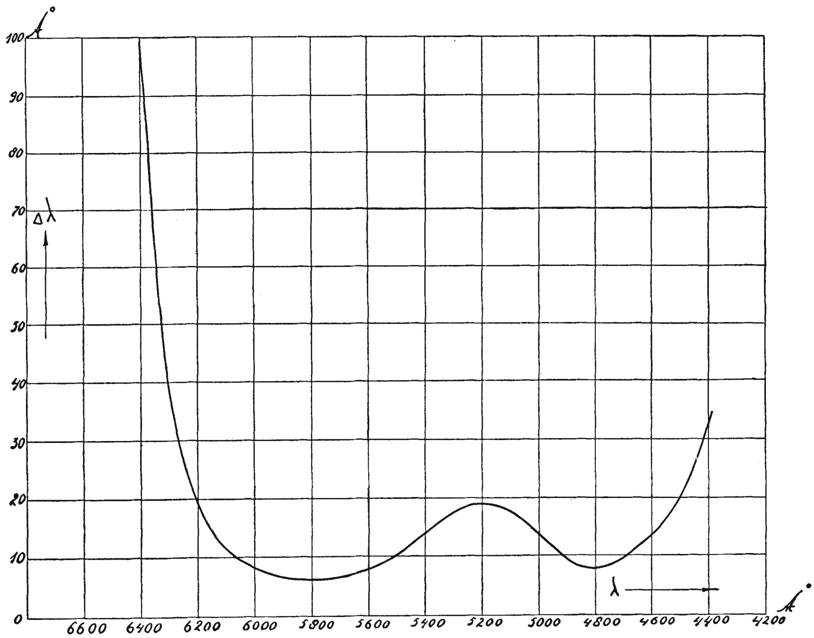

Fig. 14.

out with a view to answering this question. We mention, for example the doctor's thesis of P. M. Ladekarl (5), containing an account of his own observations and, besides, an important survey of the literature. Most investigators have confined themselves to the determination for various wavelengths, of the value to which for a given wavelength λ the difference $\Delta\lambda$ can increase, before the colour belonging to $\lambda + \Delta\lambda$ is realised as different from the colour belonging to λ. For normal trichromates, Ladekarl gives the curve, shown in fig. 14. The results of earlier investigation showed also minima, lying at 5800 and 4900 Å, occasionally a third maximum was found lying at 4500 Å. We must also mention another investigation, dealing with the same question, namely the one by G. Haase (6). He determined the $\Delta\lambda$ — λ connection for widely different illuminations and also for various degrees of saturation of the colours. His results show several minima, which proved rather strongly variable with the intensity; he found further that for degrees of whiteness from 0% up to 50% the $\Delta\lambda$—λ connection remains the same, but that for still lower saturations $\Delta\lambda$ must be larger, before colourdistortion is observed; Fig. 15 shows for λ = 5700 Å, $\Delta\lambda$ as a function of the degree of whiteness. The majority of the paints used for pictures contains an appreciable percentage of white. In connection with Haase's results just mentioned, one would be inclined to think that the risk of colourdistortion cannot be very great. But one must bear in mind that Haase's results do not apply directly to our case. Indeed, our problem is not such that we have simply to compare the colour of a paint, illuminated by daylight with that colour of the same paint, illuminated by artificial light, but it must be stated as follows: when do we realise the effects of colourchanges, which artificial illumination can bring about in a picture as a distortion to the effects which we take it that the painter wished to convey to us? It is clear from this formulation that it would be more to our point to show to a great many persons various paints in daylight surround-

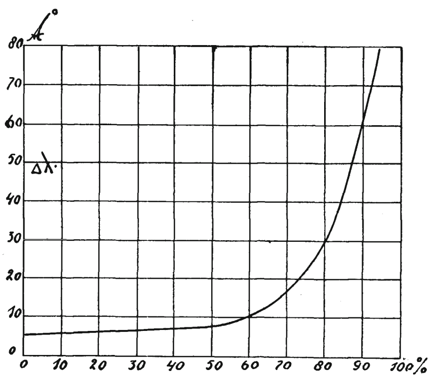

Fig. 15.

ings as well as in artificial lighted surroundings and then to investigate the differences in colourimpression between the two cases. But even that would not meet completely the demands of our problem. Indeed our point is not to find out when a given paint, illuminated by light of a certain spectral composition makes a different impression from that of the same paint, illuminated by light of a different spectral composition, but when this difference is realised as a distortion. When, for example, in daylight the colour of an artificial of dress makes a different impression from that in artificial light, this difference does not necessary falsify the impression; when, however, a picture, representing a sunlit snow-landscape looks in artificial light like a moonlit snowlandscape, the difference does indeed falsify the impression. The paints of some special details in pictures are particularly liable to this colourdistortion; the paint used for rendering the colour of the skin, for example, is very striking in this respect. Now, those paints turn out, in the majority of cases, to possess the type of a reflectioncurve with many maxima and minima as for example is shown in fig. 13. They make it therefore necessary to illuminate the pictures at night exclusively by light producing a continuous spectrum. As soon as a minimum in the energy curve of a lighting source with a discontinuous spectrum covers the same range of wavelength as a maximum or minimum in the reflectioncurve of the paint in question, an appreciable colourdistortion will be realised in these specially sensitive hues. For that reason not one of the daylightlamps, brought on the market up to now, suits our purpose, owing to a pronounced maximum in the green (see fig. 12). We are, therefore reduced to the use of tungsten lamps, and to correct the spectrum of their light with the aid of special filters, in order to obtain, as nearly as possible, an aequienergyspectrum. Since, compared with the latter, the tungsten spectrum contains towards the longer wavelengths an increasing surplus of light, these filters should transmit the blue part unreduced, but should possess an increasing power of absorption towards the red part; strickly speaking, the transmissioncurve of the filter should be the reciprocal of the emissioncurve of the lamp.

It will be clear from fig. 12 that the higher the number of Watts of the lamp used, the more economical the lighting will be, for the amount of blue in the spectrum is then relatively greater so that a lower percentage of the energy towards the red must be absorbed.

Filters possessing the required curve are not to be had on the market, we were therefore forced to prepare them ourselves. Once coated on their base, they should possess of course the right transmissionpower, but, besides, their colours should be fast, preferable (if at all possible) also at high temperatures. In that case namely, the colouring matter might be applied directly on the bulb of the lamps. It turned out, however, to be impossible to meet these various demands at the same time. After many experiments Mr. J. J. Zaalberg van Zelst succeeded in preparing two coloured filter-substances for us, which, however, when mixed,appeared not to suit our purpose. Therefore the two coats must be applied separately, either each on a plate or on the two sides of one plate. By altering the

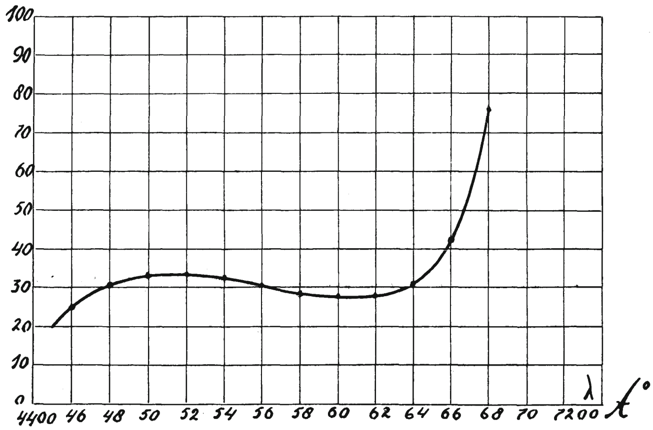

Fig. 16.

concentration of the coloured liquids or by choosing a suitable thickness for the coloured layer, one can prepare filters adapted to lamps of various powers. In this connection one must not forget however that the economy of the filters decreases continually with decreasing power. The filters actually prepared by us for lamps of 500 Watt, have an efficiency of about 50%. Fig. 16 shows the spectral composition of the light radiated by such a lamp, with the filter-combination applied. The colours of the filters are, however, not fast at high temperatures; the plates must therefore, be used at a safe distance from the lamp.

b. *The lighting system*

Here we must try to meet the two demands mentioned above, namely that the method of lighting shall be as closely as possible similar to that used for daylight and that it shall be as economical as possible. We may aid here as a matter of course, that the appliances for the artificial lighting is on no account to intercept the daylight.

If one confines oneself strictly to the first of these conditions, the right solution is to mount the lamps above the opal-sheet-glass. This is accordingly put into practice in the velumrooms. The lamps might, in this case, have been provided with reflectors secured in the roof over the revolving screens, but the efficiency of the best reflectors is not more than 60%. Besides, the purchase and the upkeep of the armatures is expensive. For this reason we decided on a different construction. The lamps are now mounted in a horizontal position between the opal-sheet-glas layer and the screens, as is also shown in fig.7.

The screens which as we know are painted white, are in this system simply closed at night and so are made to play the part of reflectors. The gangway is painted white underneath, so that any light reflected by the opal-sheet-glass is also sent back for the greater part. By this solution the screens in the velumrooms are made therefore to serve a *double* purpose. Owing to, the fact that only the bare lamps are mounted between the opal glass and the screens, no daylight worth mentioning is intercepted. The lamps develop an appreciable amount of heat, but since the construction in this system is left open at the sides a sufficient ventilation can be kept going on. The white paint on the screens turns out to keep very well at these temperatures.

As already observed above, high power lamps offer some advantages over those of low power. In the first place, the light emitted by the former lamps contains more white and in the second place the efficiency (i.e. the number of Lumens per Watt) increases with increasing power. This appears also from the following table, which gives the various values for gasfilled lamps of 110 Volt.

Power	Flux of light	Number of Lumens/Watt
150 Watt	2250 Lumen	15,0
200 „	3200 „	16,0
500 „	9300 „	18,6
1000 „	20500 „	20,5

When very strong lamps are used one can suffice with only a few of them, but then the brightness of the opal-sheet-glass close to the lamps will be very high, and since the few lamps are naturely wide apart, this will entail an inhomogeneous illumination of the glasslayer, which may make itself felt in an unpleasant way. But in this connection we must also bear in mind that the artificial lighting is not only meant to be used at night, but also as an *auxiliary lighting in the daytime,* whenever the daylight alone proves unsufficient. For this purpose however only part of the number of lamps available, will always be enough. For that reason the connections are made in such a way that either all the lamps or a certain part of them can be switched on at a time. In the velumrooms in question this fraction is $\frac{1}{2}$. Now, if only a few very strong lamps were used for artificial lighting in these rooms, the number of lamps providing the auxiliary daytime lighting would be so small that a very inconvenient inhomogeneousness would be the result. This complication therefore, limits the power of the lamps to be used. The necessary compromise between efficiency and homogeneousness led in our case for example to the choice of 500 Watt lamps.

Generally speaking, however, this method of lighting is not the most economical; there is indeed still a rather appreciable loss of light. In the majority of the skylightrooms, where a different method can be readily applied, the space underneath the gangway is therefore used for the lighting appliances, as is also shown in fig. 7. But it is not feasible simply to mount there the bare lamps, because the illumination of the figured glass underneath would in that case give rise to difficulties. Indeed under these conditions the glass would show little „stars", that is to say one would have to deal, as it were, with a great many pointsources of light of great brightness in the illuminating layer and these would have a dazzling effect. To prevent this it would seem advisable to apply a very slight matting to the glass: as it happens however this process gives at once a very dull appearance to it, especially in daylight, so, that we must look in another direction for the solution. Apart from this complication, this lighting system would involve the inconsistency that the central parts of the figured skylight would receive the strongest illumination, though these parts do not contribute the greatest amount of light to the lighting of the walls, whereas the light of the lamps should obviously be directed towards those parts that do. Now in most skylight rooms the division of the lower skylight is as shown in fig. 17, the gangway is above the shaded track. Now the glasssheets of rows 2 and 4 lie nearest the direction from the lamps towards the walls; the lighting will therefore be the most economical when the light of the lamps is principally directed towards these panes. This is achieved by closing off the space underneath the lamps by symmetrical prismatic glass which indeed directs the light in the two above mentioned directions. Moreover, the space underneath the gangway is painted entirely white, to increase the efficiency as much as possible. Here again, one must take proper care to secure a sufficient ventilation and also the construction does not interfere in the least with the daylight.

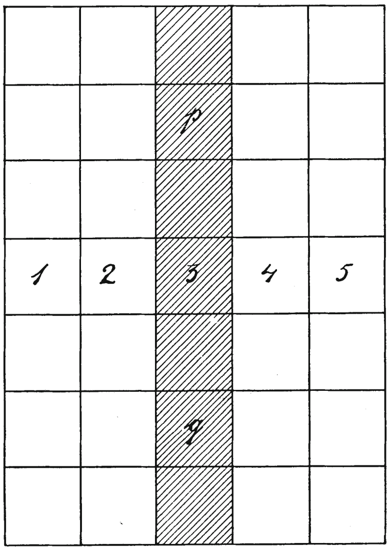

Fig. 17.

In order to obtain a uniform illumination along the longer walls, the lamps must of course not be placed at equal distances from each other, because then the intensity in the central parts would be underly high. One must therefore proceed as follows: to begin with, one lamp is mounted in the space underneath the gangway and the illumination is then measured at various spots along the walls. From these data one can readily compute where the other lamps must be mounted to secure the required uniformity. As for the shorter walls, these must chiefly be lighted from the divisions p and q. Here, therefore, more lamps must be mounted of which the flux of light is then led in the right direction by means of prismatic glass. Underneath this glass the filters for the colour of the light can be applied.

With a view to an eventual auxiliary lighting, the lamps are in this case also electrically connected in groups in such a way that either 1/3 or 2/3 or all of the lamps can be switched on at the same time. In order to obtain some idea of the powers, actually used we mention here for example that in a skylightroom of 8 × 11 M. the power is $3\frac{1}{2}$ K.W. and in a velumroom of 10 × 11 M. it is 12 K.W.

In rooms with high fenestration in one of the walls it is impracticable to make the artificial illumination enter the room in a way imitating that of the daylight. Indeed when the artificial light should at night fall from outside through the windows, this would probably affect the visitor as most unnatural. For that reason special armatures have been designed for the small cabinets. The principal of their construction is the following (fig. 18 shows a cross section in the direction of its length): the lamp is surrounded by the opal-sheet-glass walls A and right against this opal-sheet-glass the prismatic glass B is applied. The lamp is finished off at the bottom by the opaline glass plate C. The dimensions and the outward appearance of the lamp follow more or less from aesthetical considerations which in their turn are related to the size of the room for which the lamp is constructed. The prismatic glass B serves here to direct the light towards the walls; the prism's must therefore be turned once more towards the opal-sheet-glass. The glasslayers A and B are here kept together by the same dustproof-frame; this offers the advantage that the prismatic glass ist at the same time efficiently protected from dust. The kind of prismatic glass must, of course, be chosen in accordance with the demensions of the room. As regards the transmissionpower of the bottomplate C, one is quite free. The most pleasant effect is obtained by making the brightness of C equal to that of the ceiling.

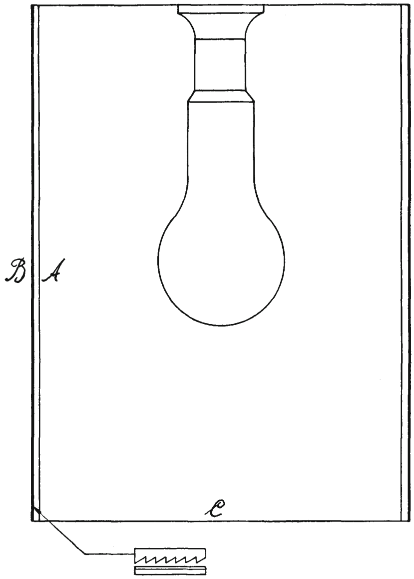

Fig. 18.

The same type of lamp was used for the small skylightrooms without a gangway. A few of these lamps of very sober make were in this case mounted between the upper and the lower skylight preferably along the sides in order to interfere as little as possible with the daylight illumination. Here also, as for the cabinets, the dimensions and shape of the lamps must be adapted to the dimensions of the room.

Now as regards the colour of the artificial illumination!

This remains for the time being an open question. As we have seen above, the colour and the intensity of the illumination at night must be the same as of daylight, if we make it a condition that the picture shall make the same impression on us at night as in daytime. For the present, however, an illumination complying with this condition will certainly not be applied throughout a picturegallery. For, in the halls, passages and other parts of the building, this equality of colour at night and in daytime is not really necessary, so that one shall for economy not apply to these parts an illumination which on account of the filters is twice as expensive as without them. This means that one will continually pass from parts with a „yellow" illumination into picturerooms illuminated by „white" light. The latter will perhaps produce under these conditions a very unnatural and cold effect .Even if the whole building were illuminated by the same white light, we should at first, almost certainly get the same impression of unnaturalness, since we are used in our own surroundings to a different colour of the light at night. But this impression will very soon wear out during a prolonged visit as we ourselves have experienced. Indeed after a certain lapse of time one is no longer aware of any unnatural effect of this white illumination at all, provided the illumination be not too low! It is just the other way round! Now on passing from the „white" rooms into the „yellow" ones, it is the latter illumination which is apt to affect one as being unnatural.

At present, this white illumination is applied at night to only *one* room in the Municipal Museum at the Hague. It therefore remains to be seen how long it will, in general, take the visitors to adapt themselves to the two different colours of the artificial illumination. In any case, it is very much to be regretted that this experiment has not been started on a larger scale, because it will now be much more difficult to form a definite opinion about this matter. But to the present writer it would seem to be a safe supposition that if a picturegallery were lighted throughout by „white" light, it would not only not interfere with the visitors from a psychological point of view, but that, generally speaking, it would have even a beneficial influence on the appreciation of the pictures.

APPENDIX

§ 1. *Investigation of the special constitution of daylight*

a. Method of measuring

In order to find out the constitution of daylight, in the visible part of the spectrum, we measured for about two years daily at fixed hours the brightness of a horizontal white surface as a function of the wavelength. To be in accordance with the conditions of our problem, the surface must be illuminated by the whole of the hemisphere of the sky; this was achieved by placing the measuring arrangement on the roof of the Physical Laboratory at Utrecht, from which the view is indeed, practically speaking, free on all sides. The white surface is that of a sufficiently thick layer of magnesium oxide, precipitated on a flatt brass plate. When there was no measuring going on, a cover was laid over it, to keep it clean. In case of rain during the measuring, it was protected by a bell glass, because it was desirable not to let the rain interfere with the measuring. The magnesium oxide layer was renewed at regular intervals. The measurings are carried out with the aid of a spectralpyrometer (7), inside which is applied as the spectral apparatus, a Fuess-spectroscope of constant deviation. As the white surface is horizontal, it is necessary to adjust the pyrometer at a certain inclination with respect to it. By its presence, however, the pyrometer is bound to screen part of the sky from the surface, but this part is reduced as much as possible by making the inclination a minimum and by placing the pyrometer at a large distance from the surface. In our case the angle between the axis of the pyrometer and the normal to the white surface was, therefore, made as high as 80°, and the distance about 3 M. A wooden shed was built round the whole of the arrangement to protect it against atmospheric influences.

The standardising of the apparatus is carried out partly on the roof in its working condition and partly in a room of the laboratory. In the latter is performed, firstly, the standardising of the spectroscope as to wavelengths, and secondly the connection is there determined, for a number of wavelengths, between the relative intensity and the strength of the pyrometer current. This is done with the aid of a tungsten bandlamp of which the true temperature is a known function of the strength of the current. The intensity-range over which this relative standardising is carried out, is made as wide as possible; on the side of the high intensities, however, it is limited by the maximum strength of the current, on which the pyrometerlamp may be run. Now, as it is, the intensity of the white surface appears frequently to be still higher than this upper limit. In order to be able to measure in these cases also and to avoid, at the same time, an overrunning of the pyrometerlamp, a support is applied in front of the first lens of the pyrometer, in which various photographic reducers can be inserted. These reducers are standardised beforehand.

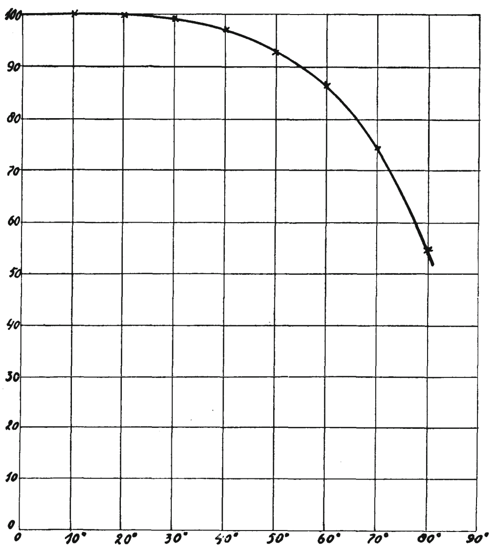

Fig. 19.

As regards the absolute standardising, one must bear in mind that for large values of the angle of reflection, the reflection-power of MgO has turned out to be a function of that angle (see fig. 19), a function, which is not necessarily the same for all wavelengths. Now, owing to the conditions of observation on the roof, the spectralpyrometer is only used for a large value of this angle. It will be clear therefore, that the absolute standardising of the pyrometerlamp may not be carried out in the room in the laboratory; it was therefore performed on the roof on a dark night. To this end a projectinglamp was placed perpendicularly over the white surface at a known distance from it, the amount of energy in ergs, radiated per sec., per unit of solid angle and per Å being known. The brightness of the white surface was then determined with the aid of the pyrometer for the same wavelengths as the daylight, namely: 6800, 6600, 6400, 6200, 6000, 5800, 5600, 5400, 5200, 5000, 4900, 4800, 4700, 4600 and 4500 Å. At regular intervals the standardising was subject to a complete checking.

The measuring took place as nearly as possible at 9, 12, 14 and 17 o'clock, because these times cover the visiting hours of a museum. At the same time, the degree of cloudiness and the type of clouds were observed when the sun was shining, the brightness caused by sky + sun, as well as the one due to the scattered light of the sky only, was measured. The latter measurements were obtained by intercepting the direct rays from the sun by a small screen, taking care that this should cover as little as possible of the sky, as seen from the white surface.

b. Results

As already mentioned, the complete list of the observations together with a discussion of their arrangement, with a view to drawing conclusions from them are published in (2). In table I are given, by way of illustration, the observations made on 3 bright days of constant cloudiness and on 4 days with a completely overcast sky, for various times of the year. The intensities are expressed in erg/Å, sec. cm².

TABLE I

Date	29th November 1932							
Time	10.00	12.10	13.50	15.00	10.30	12.20	14.00	15.05
Sun's altitude	15	20	15		17	20	14	
Degree of cloudiness	0,1	0,1	0,1	0,2	0,1	0,1	0,1	0,3
Type of clouds	ci	ast	ast	st	ci	ast	ast	st
Total or indirect	tot.	tot.	tot.	tot.	ind.	ind.	ind.	ind.
wavelength								
6800 Å	36,4	49,8	27,7	11,2	15,0	15,0	13,8	9,2
6600 „	40,5	46,3	24,6	9,4	14,8	13,4	11,1	7,4
6400 „	39,1	47,5	26,7	9,4	15,7	13,5	12,6	7,0
6200 „	43,2	44,0	24,7	8,9	15,4	13,8	12,0	7,0
6000 „	43,4	49,3	23,9	8,9	16,7	15,8	12,8	6,8
5800 „	43,7	54,3	26,9	9,2	18,9	17,9	14,3	7,2
5600 „	44,0	54,3	27,9	10,0	19,6	18,6	15,8	7,2
5400 „	47,2	57,7	31,2	10,8	22,1	21,5	17,9	8,1
5200 „	50,0	58,3	31,8	11,2	25,9	23,9	19,2	9,0
5000 „	48,2	57,5	32,0	11,9	28,0	26,0	20,8	9,5
4900 „	45,6	57,0	32,0	12,2	29,7	26,8	21,4	9,9
4800 „	44,7	55,2	30,6	12,5	29,4	27,8	21,3	9,9
4700 „	47,9	55,6	30,3	12,5	30,4	29,2	21,6	8,9
4600 „	45,8	57,0	30,5	22,1	34,7	30,7	22,3	11,0
4500 „	40,3	51,3	27,8	11,1	34,2	29,5	21,0	9,0
Illumination in Lux	28300	34200	17700	6350	14100	14500	10000	4850

Date	13th March 1933							
Time	10.00	12.30	14.00	16.00	10.20	12.15	14.10	16.20
Sun's altitude	30	35	30	15	31	36	29	11
Degree of cloudiness	0	0	0	0	0	0	0	0
Type of clouds								
Total or indirect	tot.	tot.	tot.	tot.	ind.	ind.	ind.	ind.
Wavelength								
6800 Å	110	115	89,5	58,5	25,3	28,4	21,7	22,5
6600 „	121	120	106	57,0	32,7	33,7	22,6	21,0
6400 „	115	120	108	55,0	29,5	35,3	24,1	21,9
6200 „	121	128	110	55,6	36,8	37,0	26,1	21,2
6000 „	124	129	112	53,5	36,2	39,0	27,8	22,5
5800 „	134	134	117	57,0	37,0	42,5	30,6	23,9
5600 „	136	142	126	56,3	40,5	44,5	33,0	25,2
5400 „	124	131	120	55,6	46,5	48,6	38,0	28,4
5200 „	135	136	120	57,8	49,4	53,0	44,7	29,2
5000 „	138	129	125	57,0	51,4	56,1	43,7	32,0
4900 „	129	121	119	54,2	50,0	53,0	42,4	31,8
4800 „	129	115	106	52,2	56,3	53,0	43,7	32,7
4700 „	131	104	108	50,0	54,2	54,2	47,3	31,8
4600 „	129	101	99	51,5	55,8	52,2	46,0	34,5
4500 „	132	101	99	—	57,7	43,0	38,4	30,5
Illumination in Lux	81000	83000	74000	35000	26300	28400	21300	16200

Date	22nd May 1933							
Time	9.00	10.30	12.30	14.35	8.45	10.10	12.15	14.20
Sun's altitude	42	52	57	46	40	51	57	47
Degree of cloudiness	0	0	0,1	0,2	0	0	0,1	0,2
Type of clouds			acu	sten			acu	sten
Total or indirect	tot.	tot.	tot.	tot.	ind.	ind.	ind.	ind.
Wavelength								
6800 Å	150	137	140	120	29,5	25,8	33,5	41,7
6600 „	146	155	136	111	30,0	27,5	28,8	40,4
6400 „	150	157	138	118	31,5	29,0	31,5	43,1
6200 „	156	172	152	132	38,7	34,0	37,5	48,7
6000 „	156	166	156	134	38,7	34,0	36,0	47,3
5800 „	171	180	166	148	42,5	37,0	41,7	54,2
5600 „	178	182	168	149	42,5	40,0	43,8	57,0
5400 „	172	177	157	149	51,4	46,5	49,4	62,0
5200 „	163	177	164	152	55,0	48,6	51,4	64,7
5000 „	170	209	166	150	58,3	53,0	57,8	64,0
4900 „	169	172	157	152	57,8	52,0	55,7	64,0
4800 „	165	176	156	148	60,0	53,0	57,0	68,0
4700 „	164	178	152	153	58,0	57,0	55,6	71,7
4600 „	172	193	164	129	66,0	62,0	58,4	82,0
4500 „	151	186	157	120	66,0	62,0	53,0	79,0
Illumination in Lux	109500	112000	101000	90700	28600	25700	28000	35400

Date	13th December 1932				30th March 1933			
Time	10.00	12.05	14.20	15.10	10.00	12.00	14.00	16.00
Sun's altitude	11	16	9	4	36	42	36	21
Degree of cloudiness	0,9	1	1	1	1	1	1	1
Type of clouds								
Total or indirect	tot.	tot.	tot.	tot.	tot.	tot.	tot.	tot.
Wavelength								
6800 Å	8,2	24,0	—	—	29,5	26,8	15,3	22,0
6600 „	7,8	21,7	3,8	1,5	33,3	26,3	15,3	22,4
6400 „	7,9	23,1	3,8	1,1	26,9	25,3	15,7	22,0
6200 „	7,8	20,4	3,8	0,8	22,6	27,8	15,3	23,3
6000 „	9,3	20,7	2,8	0,9	22,2	27,0	15,2	23,5
5800 „	10,2	22,2	2,7	0,8	25,7	30,1	15,2	25,0
5600 „	10,0	21,8	2,7	0,9	27,7	30,6	14,2	27,4
5400 „	11,6	23,8	2,7	1,0	31,8	37,7	14,8	29,7
5200 „	11,7	26,4	2,8	1,0	29,2	35,0	14,8	30,1
5000 „	12,7	28,5	2,9	0,9	29,2	36,3	13,9	32,0
4900 „	13,1	30,0	3,0	1,5	26,8	33,5	12,5	32,0
4800 „	14,4	30,6	2,9	1,0	22,7	30,5	13,1	29,7
4700 „	15,2	29,5	3,6	1,1	24,9	29,5	13,1	30,0
4600 „	16,3	29,5	3,8	—	26,1	27,7	13,4	28,6
4500 „	15,2	25,6	3,6	—	27,8	26,0	11,7	26,5
Illumination in Lux	6540	14500	1780	580	16900	19900	9200	16900

Date	4th April 1933				23rd June 1933		
Time	10.00	12.00	14.00	16.00	10.00	12.00	14.10
Sun's altitude	38	44	38	23	55	62	54
Degree of cloudiness	1	1	1	1	1	1	1
Type of clouds	st	st	st	st	st	st	st
Total or indirect	tot.	tot.	tot.	tot.	tot.	tot.	tot.
Wavelength							
6800 Å	19,8	25,8	65,2	29,0	62,0	92,5	62,5
6600 „	23,8	23,9	62,0	30,3	64,8	94,0	56,2
6400 „	23,2	23,7	62,6	32,2	64,8	93,0	59,0
6200 „	22,5	25,0	64,7	32,7	73,8	100,0	58,3
6000 „	23,2	24,6	63,2	31,3	69,0	94,5	59,8
5800 „	23,7	27,4	62,7	34,0	78,0	104	63,2
5600 „	22,3	28,6	71,5	31,2	82,0	100	62,5
5400 „	22,6	28,8	73,7	29,5	78,5	103,5	61,2
5200 „	25,1	30,0	73,7	—	80,0	106,5	61,2
5000 „	28,8	33,4	78,0	32,0	78,0	110	64,0
4900 „	22,7	32,0	79,0	24,8	71,5	106	55,0
4800 „	18,1	33,0	79,0	25,2	68,0	103	58,3
4700 „	23,1	33,5	82,0	24,0	69,5	103	57,0
4600 „	24,1	35,8	78,0	28,1	70,2	107	59,8
4500 „	31,6	32,3	76,5	28,1	66,0	98,0	54,0
Illumination in Lux	14600	17500	43200	19100	47900	63500	40600

The observations are the material from which the colour- and the intensity-fluctuations of the daylight must be studied. As regards the former, one must bear in mind that the measurements given under a definite hour of the day are in reality obtained one after the other, over an interval of about ten minutes (at each wavelength two or three pyrometeradjustments were performed). The fluctuations occuring is such a series, will therefore partly be due to changes in the cloudiness during the time covered by the measuring. This involves that if one subtrates the observed values, belonging to a bright hour, due to the scattered light from the sky only, from those, due to the total light, the results will show fluctuations, which are certainly influenced by the changes in cloudiness during the times, covered by the two series. Now observations, for one and the same wavelength, on a bright day of constant cloudiness have shown that the intensity-fluctuations on such a day need not amount to more than a few percentages in the course of half an hour. It will therefore be permitted in our case to calculate the intensity, due to the direct solarradiation only, by simple subtracting from the observed intensity, due to sun + sky the value due to the scattered light from the sky only. This is what we did for the bright days, quoted in table I, and the results are given in Table II.

TABLE II

Date	29th November 1933				13th March 1933				22nd May 1933			
Time	10 h.	12 h.	14 h.	15 h.	10 h.	12 h.	14 h.	16 h.	9 h.	10 h.	12 h.	14 h.
wavelength												
6800 Å	21,0	34,8	13,9	2,0	85	87	68	36	120	111	106	78
6600 „	25,7	33,0	13,5	2,0	88	87	83	36	116	127	107	71
6400 „	23,4	34,0	14,1	2,4	86	85	84	33	118	128	106	75
6200 „	27,8	30,2	12,7	1,9	84	91	84	34	120	140	116	85
6000 „	26,7	33,5	11,1	2,1	88	90	84	31	117	132	118	85
5800 „	24,8	36,4	12,6	2,0	97	92	86	33	128	143	124	94
5600 „	24,4	35,7	13,3	2,6	96	97	93	31	135	142	124	92
5400 „	25,1	36,2	13,3	2,7	88	82	82	27	121	130	108	87
5200 „	24,1	34,4	12,6	2,2	85	83	78	29	108	128	113	87
5000 „	20,2	31,5	11,2	2,4	86	73	81	25	112	156	108	89
4900 „	15,9	30,2	10,6	2,3	79	68	77	22	111	120	101	88
4800 „	15,3	27,4	9,3	2,6	73	62	62	20	105	123	99	80
4700 „	17,5	26,4	8,7	3,6	77	50	61	18	106	121	96	81
4600 „	11,1	27,7	8,2	1,1	73	49	53	17	106	131	106	47
4500 „	6,1	21,8	6,8	2,1	74	58	61	—	85	124	104	41

Now taking into account the time-factor mentioned above, our conclusion is that the intensity due to the sun only, changes rather smoothly in the visible spectrum, showing a slight depression at about 5600 Å and a gradual decrease towards the blue part of the spectrum. The scattered light from the sky on a bright day shows on the other hand an increase towards the shorter wavelenghts, this increase beeing strongly influenced by the cloudiness. (Compare for example the observations on the 29th of Nov. '32 at 15.05 with the one on the 13th of March '33 at 10.20 or the one on the 22th of May '33). Since the intensity, due to the sun only fluctuates strongly with respect to the one, due to the scattered light from the sky, the colour will also be subject to rather strong variations. In order to demonstrate this also in another way, we computed for a few cases the colourpoints (For an explanation of this computation

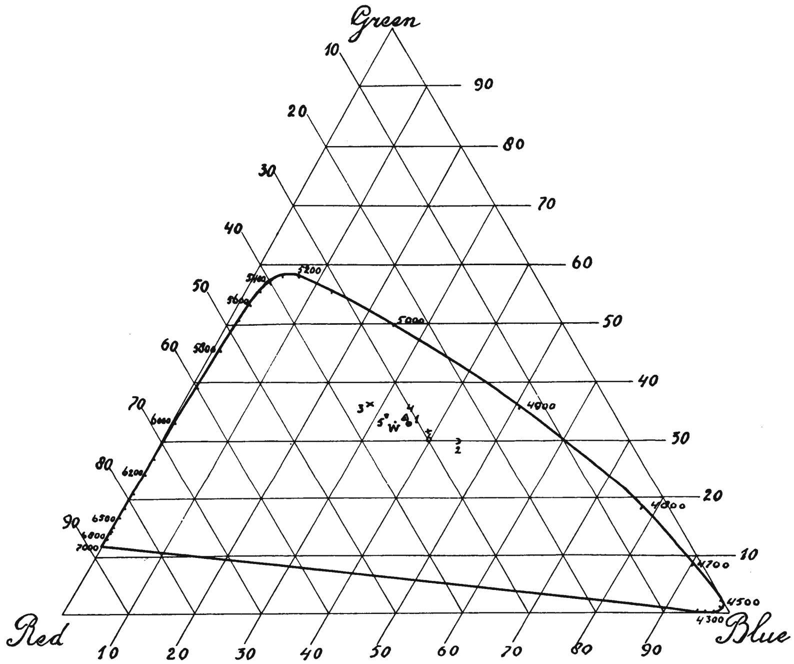

Fig. 20.

see for example C.I.E. 1928, page 822). They are shown in fig. 20 in a colour triangle after Maxwell-Helmholtz; the spectral colour-curve is also drawn in this figure. The point (1) represents the radiation on 29 Nov. '32 at 12 o'clock of sun + sky, (2) of the sky only, (3) of the sun only; (6) shows the radiation on 4 April '33 at 12 o'clock, (4) on 30 March '33 at 10 o'clock and (5) at 14 o'clock. The points 4,5 and 6 refer therefore to the light on dull days. They represent three extrem cases in this respect, namely a sky with bluish cloudiness (6), an evenly grey sky (4) and a cloudiness with relative weak blue radiation. The colourshade of the daylightmoves therefore in these case from 5650 Å to 4770 Å, and the saturation between 5,4$^0/_0$ (5) and 23,8$^0/_0$ (2).

Beside the study of the colourvariations and the construction of colourpoints as a mea as to forming an opinion about them, we wished also to make a closer study of the intensityfluctuations. To this end the illumination, expressed in Lux, was computed for each series of observations, with the aid of the sensitivity-curve of the eye, internationally agreed upon. The values, thus obtained, are given at the bottom of each series in Table I.

The above examples, taken at random from the whole of the material, are sufficient to show that the brightness of daylight is subject to very large fluctuations. Indeed there occur such widely different values as 112000 Lux and 1780 Lux! In this connection, we mention also the example given in Chapter II, page 9, showing the considerable intensityfluctuations which can occur within a very short time, on a day of strongly variable cloudiness.

As already mentioned however, the daylight intensity can be expressed in terms of the sun's altitude and the degree of cloudiness. Since, besides, the average number of days with a given degree of cloudiness in the various months of the year is know in our country from statistical data of the Royal Dutch Met. Inst. at de Bilt, one can compute the average illumination, to be expected at fixed hours of the day in the various parts of the year. We have performed these computations for total as well as for indirect daylight-intensity and their results are given in Table III.

TABLE III*a*

Month	Hour	Probability (in %) for a certain total illumination																	Average value
Jan. . . .	8	1	2	3	13	16	14	8	12	9	5	16	2						850 Lux.
	10						1	1	3	12	15	18	17	26	5	2			8500 „
	12									1	3	12	19	26	29	6	2		17000 „
	14							1	3	11	14	19	18	27	6	2			8500 „
Febr.. . .	8					1	3	10	13	11	9	17	28	5	2				5800 „
	10									1	3	10	17	23	16	24	5		21000 „
	12										1	3	9	17	26	16	22	4	32000 „
	14									1	3	10	17	24	17	23	5		21000 „
March . .	8								1	2	6	11	18	17	35	6	1		17000 „
	10											1	4	6	10	28	43	8	54000 „
	12												2	5	12	25	19	36	60000 „
	14										1	1	5	7	13	22	41	8	54000 „
April . . .	8										1	3	11	20	30	27	6	2	27000 „
	10											1	3	9	18	28	19	21	43000 „
	12											1	2	8	16	24	16	31	52000 „
	14											1	2	9	18	31	20	19	45000 „
	18½			1	2	7	9	9	9	19	17	24	4	1					3900 „
May . . .	8										1	2	7	9	15	22	32	10	43000 „
	10											1	2	8	16	25	15	30	54000 „
	12												2	3	13	24	19	37	68000 „
	14											1	2	8	15	24	15	35	54000 „
	18½						1	1	5	7	12	19	20	31	5	1			9000 „
June . . .	8											1	2	9	17	26	17	27	38000 „
	10											1	2	8	16	25	15	36	54000 „
	12												1	3	14	25	20	38	60000 „
	14											1	2	6	14	24	16	38	56000 „
	18½								1	4	6	12	22	44	9	2			14000 „
July . . .	8											1	2	8	18	30	33	10	50000 „
	10											1	2	7	13	22	15	41	60000 „
	12												2	3	15	26	20	35	60000 „
	14											1	2	8	15	25	16	33	54000 „
	18½						1	1	6	8	13	20	19	25	5	1			8500 „
Aug. . . .	8										1	1	5	7	14	24	36	11	52000 „
	10											1	2	7	13	22	15	40	60000 „
	12												2	6	13	25	17	36	58000 „
	14												2	6	13	23	16	38	59000 „
	18½					1	2	2	4	9	21	21	33	5	1				6500 „
Sept. . . .	8									1	2	6	13	21	16	32	6		27000 „
	10											1	2	6	13	24	41	12	57000 „
	12											1	2	6	12	20	16	45	72000 „
	14												1	5	13	25	40	15	55000 „
Oct. . . .	8						1	2	8	10	16	22	16	20	4				6800 „
	10									1	1	7	9	15	24	32	10		29000 „
	12										1	2	8	11	17	23	36		42000 „
	14									1	1	7	9	15	23	32	10		29000 „
Nov. . . .	8			1	3	11	14	13	9	15	11	19	3						2150 „
	10								1	2	11	15	19	22	23	5			13500 „
	12									1	3	12	20	28	18	15	4		17000 „
	14								1	2	10	14	20	27	21	5			13500 „
Dec. . . .	10						1	3	11	14	17	17	14	20	3				7500 „
	12							1	2	10	13	17	18	13	21	3			11000 „
	14						1	3	12	15	17	16	13	20	3				5600 „
Illumination		54—85 Lux.	85—135 „	135—215 „	215—340 „	340—540 „	540—850 „	850—1350 „	1350—2150 „	2150—3400 „	3400—5400 „	5400—8500 „	8500—13500 „	13500—21500 „	21500—34000 „	34000—54000 „	54000—85000 „	85000—135000 „	

TABLE III*b*

Month	Hour	Probability (in %) for a certain indirect illumination																Average value
Jan. . . .	8	2	3	14	16	14	3	7	21	9	9	3						850 Lux.
	10						1	3	12	14	22	35	11					8300 „
	12								1	3	11	20	39	21	5			18000 „
	14						1	3	11	13	21	38	12					8500 „
Febr. . . .	8					1	3	11	13	19	34	18	3					5500 „
	10								1	2	10	14	28	35	10			20000 „
	12									1	2	10	26	46	13			23500 „
	14								1	2	9	13	26	39	11			21500 „
March . .	8							1	1	5	6	20	51	16				16000 „
	10										1	4	11	33	41	10		34000 „
	12											1	9	32	46	11		41000 „
	14									1	1	4	11	32	41	10		34000 „
April . . .	8									1	2	11	27	46	12			23500 „
	10										1	2	9	26	49	14		37000 „
	12										1	2	8	23	52	15		39000 „
	14										1	2	8	24	52	14		39000 „
	18½		1	2	7	8	7	13	40	13	7	2						2450 „
May . . .	8										1	2	9	27	48	13		38000 „
	10										1	2	9	26	49	13		38000 „
	12											1	4	25	49	18	2	41000 „
	14										1	1	8	26	50	14		39000 „
	18½					1	1	4	5	16	44	13	3	10	3			6200 „
June . . .	8										1	2	11	28	46	13		36000 „
	10											1	5	26	49	17	2	40000 „
	12											1	4	25	53	15	2	41000 „
	14											1	3	24	53	17	2	41000 „
	18½								1	4	20	57	17					10500 „
July . . .	8										1	1	9	27	50	14		38000 „
	10										1	1	8	28	50	14		38000 „
	12											1	3	24	52	18	2	41000 „
	14										1	1	8	25	51	14		39000 „
	18½					1	1	6	6	6	16	50	14					10000 „
Aug.	8									1	1	5	9	27	45	12		36000 „
	10										1	1	9	28	49	13		37000 „
	12											1	6	24	54	15		40000 „
	14											1	6	25	52	16		40000 „
	18½				1	2	2	2	13	50	26	5						4500 „
Sept. . . .	8								1	1	5	10	27	42	14			22000 „
	10										1	9	28	48	13			38000 „
	12										1	1	8	27	50	14		40000 „
	14											3	7	27	50	13		38000 „
Oct. . . .	8						1	2	7	8	20	47	14					9300 „
	10									1	1	8	25	49	14			24500 „
	12									1	2	8	11	24	41	11		34500 „
	14									1	1	8	24	51	14			24500 „
Nov. . . .	8			1	3	12	13	20	33	11	4	1						2150 „
	10								1	2	11	23	48	15				15000 „
	12									1	2	11	25	48	14			24000 „
	14								1	2	9	22	50	15				15500 „
Dec. . . .	10						1	3	11	13	22	39	12					8500 „
	12							1	2	10	15	28	34	9				12500 „
	14						1	3	12	14	22	37	11					8100 „
Illumination		85—135 Lux.	135—215 „	215—340 „	340—540 „	540—850 „	850—1350 „	1350—2150 „	2150—3400 „	3400—5400 „	5400—8500 „	8500—13500 „	13500—21500 „	21500—34000 „	34000—54000 „	54000—85000 „	85000—135000 „	

§ 2. *Investigation of the diffusing properties of specimen of glass*

A. Diffusing glasses

In connection with our problem, it turned out to be of great importance that there should be available kinds of glass, satisfying the condition that the distribution of the light after its passage through the glass shall be entirely independent of the way the light falls on it. Another very important point is the ratio between the intensity of the incident light and of the light emerging from the glass, because this has a direct bearing on the adequate lighting of the rooms in connection with the available amount of daylight. A third point, finally demanding a careful control, is the colour of the glass. In order to measure a great number of sambles in a short time, the investigation is performed in successive steps, as follows:

first, of all samples of opal-sheet- and opaline glass, the angular dependence of the intensity of the light, emerging from the glass after perpendicular incidence, was measured (expressed in an arbitrary unit); secondly, to control the colour, the spectral constitution of the light emerging in the normal direction was determined. This way of proceeding provided the first and very effective sifting, by which many samples fell out already, because they proved to be deficient, either as regards their colour- or their angulardependence. A second sifting was furnished by determining the absoluts amount of the transmitted light, of the samples which still remained after this test, the angular dependence of the emergent light was again

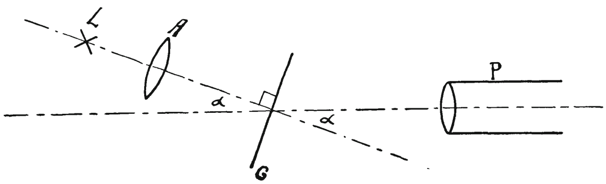

Fig. 21.

measured, but in this final test, for various slanting directions of the incident light. Fig. 21 shows the arrangement used:

A beam of light from lamp L is made parellel by the lens A and falls on the glassplate G, to be investigated. The light, emerging from G is measured by means of a spectralpyrometer P of which for various wavelengths, the connection between the relative intensity and the strength of the pyrometercurrent is known. Since it was essential to measure the emerging for various values of the angle α and since the pyrometer could not very well be mounted so that it could revolve, the lamp, lens and glass were mounted together on a plank, which could revolve round the center of G. The revolving part of the arrangement was contained in a box, blackened inside, thereby preventing, for large values of α any possible entering of scattered light into the pyrometer. For $\alpha = 0°$, the relative intensity of the emerging light was measured at the wavelengths 4500, 5000,

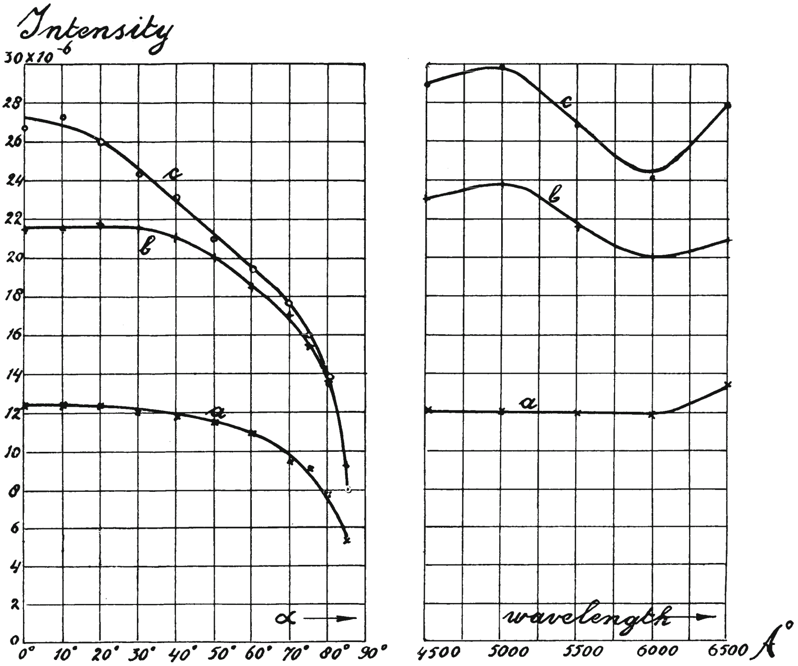

Fig. 22.

5500, 6000 and 6500 Å. For the various values $\alpha = 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 75°, 80°$ and $85°$ the intensity was only measured for light of the wavelength 5500 Å. In this way the proporties, bearing on our problem, of about 30 samples of glass were investigated. A few of the results, so obtained, are shown in fig. 22.

For all samples of opaline glass and for a few of opal-sheet-glass, the intensity of the emerging light appeared to be constant for values of α up to 60°. For our problem still greater values of α are hardly of any practical importance, so that the angular dependence for these higher values need not be considered here. As mentioned above, many samples fell out already after this first test, on account of a too pronounced angualar- or wavelength dependence.

The second test, namely the determination for the remaining samples of the emerging light in absolute measure, was carried out as follows: (see fig. 23).

The lamp L is again in the focus of lens A, so that the light incident on the plate G, to be investigated, is parallel. G has been adjusted with the utmost care, at right angles to the axis of the arrangement. S is a screen in front of G, perforated with a hole of O cm^2 area. At a known distance of say b cm. from G, a white surface W is put at right angles to the prolonged axis of the arrangement. Let the brightness of the centre of W, measured with the pyrometer, be H_1.

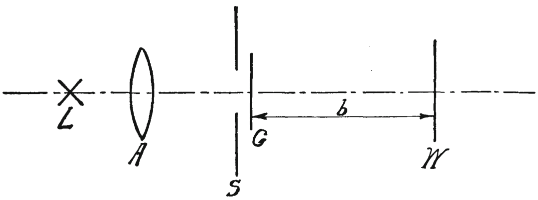

Fig. 23.

Now, remove G, put W in its stead and measure again its brightness. Let the result be H_2. If the angle between the normal to W and the axis of the pyrometer is the same in both cases, one can ignore completely the scattering properties of W. If now, the intensity of the light incident on G is 1, the intensity due to 1 cm^2 of the glass-surface at a distance of 1 M. is given by:

$$\frac{H_1}{H_2} \cdot \frac{b^2}{O \times 10^4}.$$

This absolute standardising was performed for one colour only.

As a result of our computation, the transmission power of the opaline glass samples came out too small to be suitable for the purpose in view, so that only the opal-sheet-glass samples remained to chose from. Those of them, likely to serve our purpose, were then finally tested by measuring the angular dependence of the emerging light for incident light in various directions. Fig. 24 shows the result for one of these samples (the same as (b) in fig. 22). The result of this last was that the diffusingaction of these kinds of glass proved sufficiently even to make them suitable for the illumination of a museum.

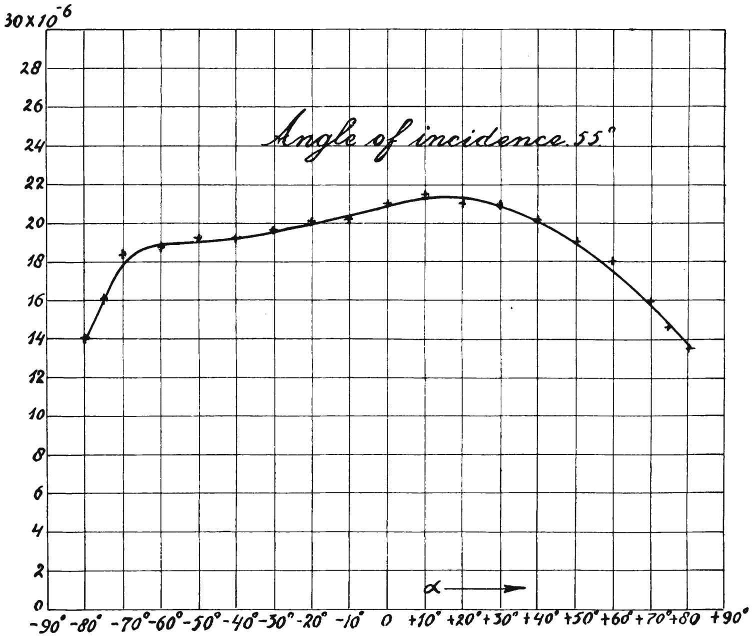

Fig. 24.

B. F i g u r e d g l a s s e s

Since glasses of this description were meant to be applied, in all cases, underneath the opal-sheet-glass, the angular dependence of the emergent light was only investigated for diffuse incident light. The measuring arrangement is shown in fig. 25. The lamp L. il-

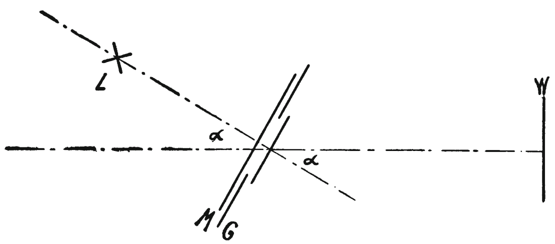

Fig. 25.

luminates the opal-sheet-glass M; the light emerging from M is therefore homogeneously diffuse. This light falls on a glass plate

G, to be investigated. The latter is held by a support, provided with an aperture of fixed area, O cm². The illuminated area of each sample is, therefore, the same. The light, emerging from G, falls on the white surface W of which the brightness is again measured by means of a spectralpyrometer. L, M and G were mounted together inside a box with blackened inner walls and the whole of this arrangement could revolve round a vertical axis through the centre of G. The brightness was measured only for light of wavelength 5500 Å, since a checking as to colour appeared in these cases to be superfluous. The brightness was measured first without glass at G and, for $\alpha = 0°$; afterwards with glass at G and for $\alpha = 0°, 10°, 20°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°$ and $70°$. Since for values of α, differing from 0°, the surface W is illuminated by an area of $O \times \cos\alpha$ cm² the measuring results must be divided by $\cos\alpha$, in order to obtain the true distribution of the intensity behind the glass. These values are expressed in percentages of the brightness of W in the case that there is no glass in G. All glasses of this description were measured with the even side as well as with the uneven side turned towards the opalglass. For a few samples, this turned out, namely, to influence very considerably the curve of lightdistribution.

The true amount of light, transmitted by these kinds of glass, is somewhat less than one would conclude from the measurements: because the opal-sheet-glass reflects part of the light emerging from the sample under investigation on its side-back again, so that the light, incident on the glass at G is slightly stronger than measured. But it is just this combination of both kinds of glass, which is essential in the lighting of a gallery, and which we, therefore, wished to investigate.

A few of the results are shown in fig. 26-32. Fig. 26, 27, 28 and 29 refer to the more usual types of figured glass, fig. 30, 31 and 32 to a few kinds of prismaglass. It is clear from fig. 26 that for the sample in question, the curve of the light distribution is the same, wether the glass turns its flatt (+) or its uneven side (0) towards the opalglass. But this is an exceptional case. For most glasses, it is by no means a matter of indifference, whether their flat or uneven surfaces are turned towards the opalglass.

In the former case, the amount of light, transmitted in the direction of the normal, and in directions making small angles with it, is nearly always less — and the amount of light, transmitted at great angles to the normal, more than when the uneven surfaces are turned towards the opal glass. So, what is shown in fig. 27 is just an exception to this rule too.

As regards the powers of transmission in the direction of the normal, their differences for the various kinds of glass amount to not more than a few tens of percentages, whereas for angles of 60°

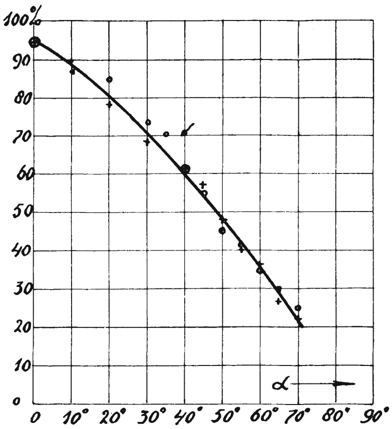

Fig. 26,

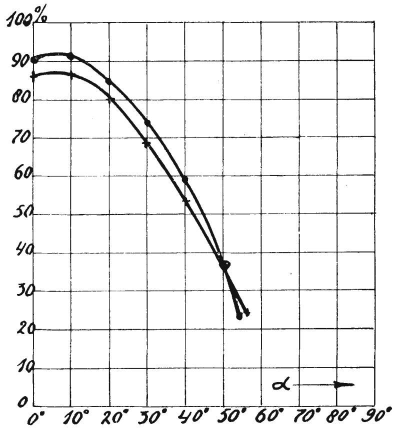

Fig. 27.

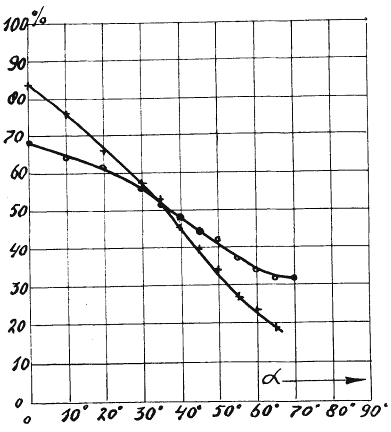

Fig. 28.

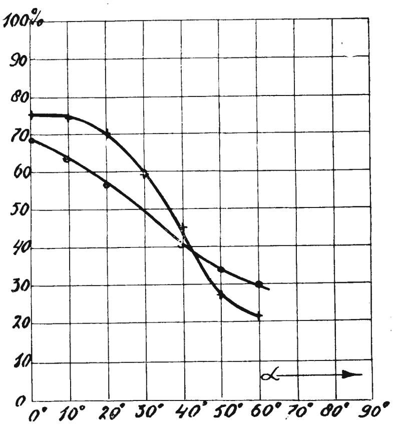

Fig. 29.

upwards, these differences become very much greater, and may even amount to a factor 3!

Now, in a picturegallery, the light which falls on the walls, has emerged from the glass ceiling at angles of 45° and more. The distribution of the light, in the neighbourhood of such angles, is therefore especially important, not only as regards the intensity itself, but also as regards its homogeneousness over the height of the walls. For that reason we are, more in particular, concerned with the transmission power of the various kinds of glass at large angles with the normal. Now as already mentioned, these powers differ widely and this is also true for those kinds of glass, which, to all appearances, are very much alike.

All glasses of this description have this in common, that the amount of light emerging perpendicularly, is greater than that emerging in slanting directions. When these glasses are applied to the lighting of rooms, the distribution of the light will therefore be necessarily such that the floor (or any horizontal surface) receives more light than the walls (or any vertical surface).

These lighting-engineering conditions alter completely with the use of prismaticglass (see fig 30-32). The shape of the transmission-

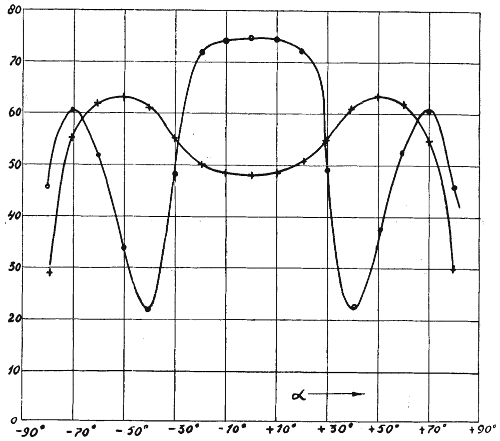

Fig. 30.

curve, when its flat side is turned towards the opalglass differs now in an essential feature from the shape when the prism's are turned towards the opalglass. For in the latter case, the maximum transmission is *never* in the direction of the normal, whereas for the reversed position of the glass, this maximum at $\alpha = 0°$ does indeed occur in a few cases.

Let us look more closely at fig. 30, which refers to a sample of symmetrical primatic glass. When the flat side is turned towards the opal glass(o), the transmissionpower is high from $\alpha = -20°$ to $\alpha =$

$+20°$, but also at $\alpha = -70°$ and $+70°$. When the glass is turned the other way round, the maximum transmissionpower lies, on the contrary, at $-50°$ and $+50°$. This means that, when the glass is

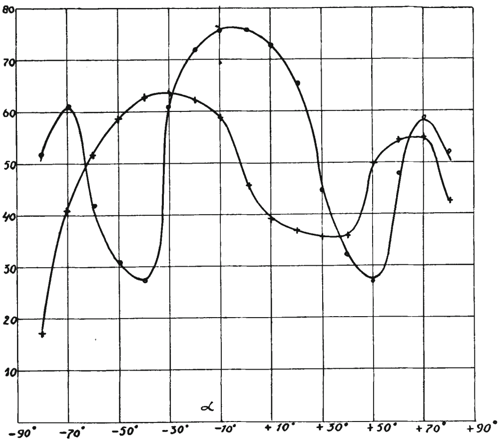

Fig. 31.

used in its latter position, for lighting a gallery, the walls receive more light than the central parts of the rooms; *a velum-effect,* as it were, only obtained, this time, by the application of a certain type

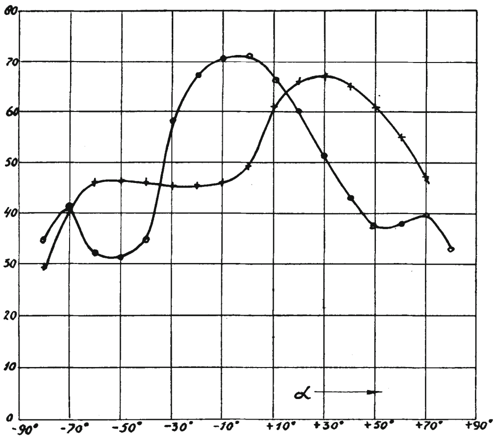

Fig. 32.

of glass and *not* by actual construction of a velum. As the figs. 31 and 32 show, simular effects can be attained by the use of asymmetrical kinds of prismatic glass. The action of the combination opal-sheet-glass — prismaticglass, results, therefore, in what we may call, directed diffuse light.

For prismatic glasses also, the transmissioncurves may differ widely for kinds of glass which at first sight, are very much alike. This dissimilarity concerns more in particular the angle of maximum transmission. Comparing in this connection, for example, the transmission curves in fig. 31 and 32, when the glass turns its prism's towards the opal-sheet-glass, it is seen that both curves show a maximum transmission at $\alpha = 0\text{-}3°$, but in fig. 31, there is, besides, another maximum at $\alpha = 70°$. Such a secondary maximum is apt to give rise to the most unexpected and surprising effects!

Since for other kinds of prismatic glass the maximumtransmission has now this direction and then that, one can by a suitable combination of various kinds, give to the diffuse light any direction, that may be advisable in connection with the dimensions and the destination of the rooms, to which it is applied.

This is the reason why, as mentioned in the description of the rooms of the Municipal Museum at the Hague, prismatic glass is in some rooms applied with either the one or the other side turned towards the opalglass, according to the particular ends in view.

§ 3. *Inquiring into the reflective power of the surfaces of pictures*

a. Investigation of the angular dependence of the reflecting power of varnish

In connection with our general problem it was also necessary to know the angular dependence of the reflective power of varnish, because it governs the extent to which pictures, not covered by glass, will show reflections. In order to determine it, for variously directed incident light the angular dependence of light, reflected by black paint with and without varnish, is measured. The black paint used was Talens oil paint Rembrandt, Ivory black, diluted with turpentine which was coated on a glass plate. If the coat appeared to be opaque when inserted in a light path, it was accepted as a covering paint. In this way 26 small plates were prepared. An hour after the paint was applied, the measuring was carrired out by means of the arrangement, shown in fig. 15.

The lamp L is in the focus of lens A, so that the light, incident on the small plate P is parallel. P is placed on a little revolving table, provided with a graduated circle, which allows the adjustment of

P at various angles. L, A and the revolving table with P are mounted together om a rail, which can pivot round a vertical axis through the centre of P. By means of this arrangement the brightness of P is then measured for various angles β (while α remains constant). The reflecting power obtained, is expressed in percentages of that of a white surface, placed at P and for which $\alpha = 0°$ and β a small angle. (for small angles, as we know, the reflection of the white surface shows no angular dependence) Our measuring was done only: for $\lambda = 6000$ Å. The relative power if the black paint as well as of the varnish applied later on, turned out to be independent of the wavelength; for our present purpose however, this is not to the point.

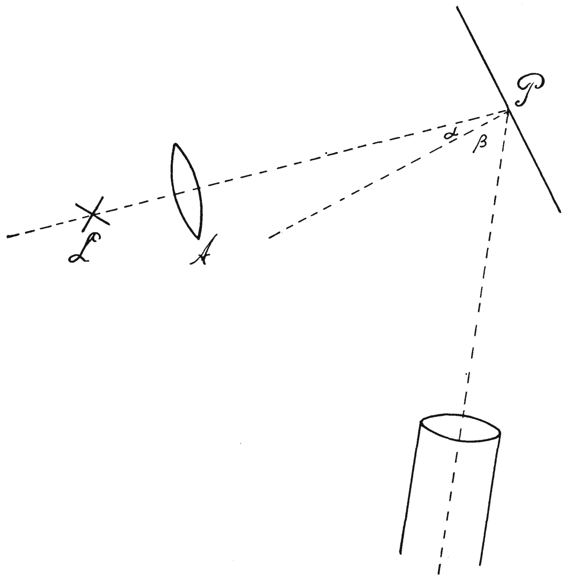

Fig. 33.

After all of the 26 plates were measured in this way, with the paint still wet; they were put away for four weeks to dry, whereupon the reflecting power was again measured. They were coated then with a varnish from a shop. After 6 days drying, the varnished plates were measured again; 13 of them were then varnished for the second time and measured a new after another 6 days' drying, finally six of them were varnished for the third time and likewise measured after 6 days. In order to smooth out during the measuring effects of unevennesses in the layer of the paint or the varnish, P was put on a dise, revolving round a horizontal axis through the centre of P.

Of the same set of plates the reflecting power was also measured for diffusely incident light, for which we used the same arrangement as Hamaker (8), so that in this case the sum of the diffuse and the directly mirrored reflection was measured. Table IV gives the average values of the results for the various plates. Since the reflecting power turned out to be symmetrical with respect to the direction for which $\beta = \alpha$, only the values towards one side are given.

TABLE IV

$\alpha = 0°$		$\alpha = 30°$		$\alpha = 45°$	
β	Int. refl. light	β	Int. refl. light	β	Int. refl. light
		dry point (dried for four weeks)			
15°	11,0	0°	1,9	15°	1,9
20°	4,3	5°	3,4	30°	15,8
25°	2,4	10°	6,6	45°	167,0
30°	1,5	15°	15,2		
45°	0,8	30°	120.		
60°	0,7				
		Varnished once			
15°	11,6	0°	0,4	15°	0,4
30°	0,4	15°	2,7	30°	2,0
45°	0,3	30°	263.	45°	292.
		Varnished twice			
15°	7,4	0°	0,4	15°	0,4
30°	0,5	15°	3,7	30°	2,9
45°	0,4	30°	355.	45°	418.
		Varnished three times			
15°	2,2	0°	0,5	15°	0,4
30°	0,4	15°	1,3	30°	1,4
45°	0,3	30°	390.	45°	480.

Older varnishes showed analoguous results.

It appeared that in the case of diffuse illumination the reflecting power of the variously varnished plates was practically the same; it amounted to about 7%.

The main result from the above is that varnished surfaces show a strong reflection for $\beta = \alpha$, while the diffuse scattering decreases very rapidly with increasing differences of β from α. The effect of this chiefly mirrored reflection of the varnish is judged unadvisable by the painters. The varnishes, at present to be had on the market, are all of them artificially prepared and very shiny. The ideal would be a varnishing substance of smaller refractive index [1]). As an attempt on that direction wax is occasionally applied on the pictures, but this requires regular polishing and is therefore not satisfactory in practice. The right solution has not been found yet.

b. Inquiry to the dependence on wavelength of the reflecting power of paints on pictures

In chapter V we made it clear that, in order to be able to state the conditions, which the spectral composition of artificial lighting must satisfy one cannot dispense with (among other things) data concerning the selective reflecting power of paints on pictures. With these data at one's disposal, one can find out how the colourimpression of

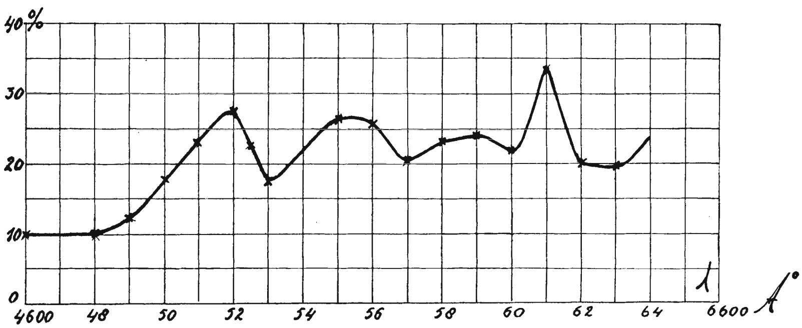

Fig. 34.

a given paint changes with artificial lighting of a spectral composition, different from that of daylight.

To obtain the necessary data [2]), pictures were illuminated at an angle of 45°, by a projecting lamp and the spectral composition of the light, reflected in the direction of the normal was measured and compared with the light, reflected by a small white surface (MgO), put in the place of the plate under investigation. For the greater

1) Wavelength Refractive index of varnish used

Wavelength	Refractive index of varnish used
6678 Å	1,4912
5876 „	1,4946
5016 „	1,4998
4472 „	1,5065

2) Nearly all these measurements have been obtained in the Centraal Museum at Utrecht. I desire to express my sincere thanks to the director, Dr. W. C. Schuylenburg, for his great kindness in giving me the opportunity to avail myself of many of the pictures there for the measurements.

part the measuring was carried out by means of a spectralpyrometer (7), later on a number of measurements were obtained with a colorimeter, (9) which works in many respects much more simply for our purpose. Indeed, with the spectralpyrometer, the light from the paint of the picture and that from the white surface are measured one after the other, requiring a double set of adjustments and readings, and on the understanding that the voltage of the lightsource shall remain constant in the meantime. Since, however, our lamp was connected with the main, fluctuations are sure to have occurred in the time covered by our measurements. With the colorimeter

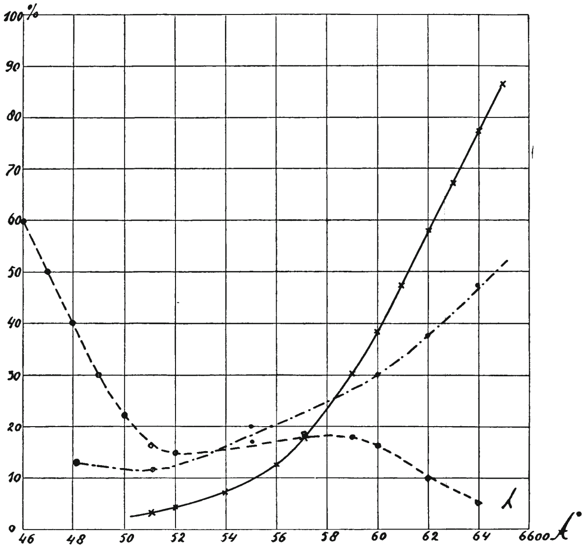

Fig 35.

however (which was constructed only much later), the light of each wavelength reflected by the paint, is compared directly with the corresponding light of the white surface; the fluctuations of the lightsource have no longer any influence. On the other hand, the pyrometer allows the measuring of the reflective power of a very small surface, whereas the colorimeter always measures the light reflected by a surface of some odd cm², so that it always averages out the colourfluctuations over that surface.

We measured a number of paints on a few modern pictures and a single ancient one. We mention here for example:

Clown with mandoline	by	Severini
Beggars	„	v. d. Leck
Study of the nude	„	Jan Sluyters
Boxer	„	Isaac Israels
Cows in meadow	„	W. Maris

and a picture by Jan van Scorel.

The outcome of this investigation is that the majority of the paints show smooth reflecting curves; a few examples are given in fig. 35. There are however also paints of which the reflectioncurve shows many minima and maxima; one of these is shown in fig. 13 and another in fig. 34.

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STELLINGEN

I

Voor de berekening van de dagverlichting van gebouwen is de kennis van de oppervlaktehelderheid van de hemel onder verschillende omstandigheden als zonshoogte en bewolking noodzakelijk.

II

Bij het onderzoek naar de echtheid van oude schilderijen is naast de chemische en Röntgenografische methode een physisch onderzoek van groot belang.

III

Onder kleurennormalisatie zal men alleen moeten verstaan het standaardiseren van de meetmethoden tot en van het aangeven van de kleuren en nimmer het vastleggen van de toelaatbare kleuren zelf.

IV

Het kleuronderscheidingsvermogen wordt sterk beinvloed door de helderheid en de helderheidsverhouding van de te vergelijken vlakken.

G. Haase, Ann. Physik **20**, 75, 1934.
P. M. Ladekarl, thesis Kopenhagen, 1934.

V

Ten onrechte beweert Osthoff dat zijn schattingen van de kleur der sterren wel met de theorie van Hering en niet met die van Helmholtz te verklaren zijn.

Specola Vaticana **8**, 1916.
Hevelius, blz. 158 e.v.

VI

De voorschriften van de doorlating van lasglazen in het zichtbare gebied moeten berusten op lichttechnisch-physiologische grondslagen, waarbij rekening gehouden moet worden met het gemiddelde helderheidsniveau van de werkplaats.

VII

Door de meting van de relative waarschijnlijkheden der trillingsovergangen in één bandensysteem kan in vele gevallen de vorm der potentiaalkrommen van het molecule nauwkeuriger vastgesteld worden.

VIII

Bij de studie der bioluminescentie is een gelijktijdige studie der chemoluminescentie zeer gewenst.

IX

De opvatting dat er geen verband bestaat tussen de ademhaling der lichtbacteriën en de intensiteit van het door hen uitgestraalde licht is onjuist.

C. S. SHOUP and A. KIMLER, J. Cell. and Comp. Phys. **5**, 269, 1934.
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