[7] Allen, Frank, 1920, Persistence of vision and the primary color sensations. *Amer. J. Physiol. Optics*, **1**, 94–134.

[8] Steindler, 1906, Der Farbenempfindlichkeit des normalen und farbenblinden Auges. *Sitz. Weiner Akad.*, **105**, 11a, 115–6.

** One of these instruments belongs to this Laboratory, while the other was loaned to us by the kindness of Professor G. H. Parker, Harvard University.

CHARACTERISTICS OF A SHORT WAVE OSCILLATOR AT VERY LOW PRESSURES

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Various investigators have experimented with three element vacuum tubes oscillating at a wave-length of the order of one meter. All of them have used commerical tubes, having a cylindrical arrangement of filament, grid, and plate.

Barkhausen and Kurz[1] discovered a type of oscillation which was apparently due to the motion of electrons in the tube itself, and was independent of the inductance and capacity of the external circuit. The computed time for an electron to travel across the tube, from filament to plate and back, under the potentials applied, agreed fairly well with the period of the waves as measured by means of Lecher wires coupled to the tube.

Whiddington[2] experimented with a similar type of oscillation, but he observed much lower frequencies and attributed the observed effects to the motion of ions instead of electrons. An explanation was given which involved a discontinuous emission from the filament.

Gill and Morrell[3] have experimented extensively with the Barkhausen type of oscillation, using commercial tubes made by the Marconi company, and have given an explanation of the effect which involves a natural mode of oscillation of the electrical system connected to the tube.

The work of Barkhausen and Kurz and that of Gill and Morrell was done with so-called "hard" tubes, which in the process of manufacture have been thoroughly heated to remove occluded gas and then sealed off from the vacuum pump. These men have assumed that they were dealing with a purely electronic phenomenon, and that no gaseous ionization was concerned.

The essential departure in the experimental arrangement in the present investigation was the use of a tube which was left permanently connected to the vacuum pumps, and was made with a ground joint to make the inside parts accessible for modification, replacement of burned out filaments, etc. Also, more power was used than by other investigators, electron currents as high as 300 milamperes and at voltages up to 700 being used at times.

The electrical connections were made as indicated in figure 1, except that the filament heating circuit is not shown. The Lecher wires, LL, were closely coupled to, but not in metallic contact with, the grid and plate leads, which were brought straight in through the sides of the tube. A sliding bridge, B, across the Lecher wires, carried a crossed wire thermocouple which was connected to a sensitive galvanometer by long, twisted leads. This thermocouple served to measure the strength of oscillations, and by

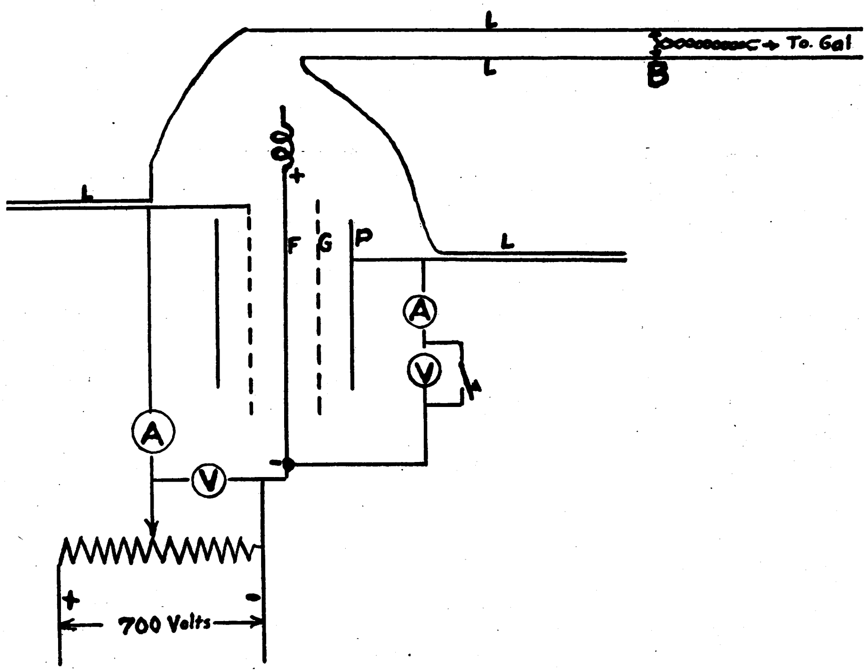

FIGURE 1

sliding the bridge along the wires, the points of maximum deflection gave the loops of the standing waves, and the distance between these points gave the half wave-length of the oscillations. In the discussion which follows, by strength of oscillations is meant the deflection of the thermocouple galvanometer when the bridge position is adjusted so that this deflection is a maximum.

Oscillations of the Barkhausen type, at wave-lengths of from 50 to 200 cm., were obtained. The unusual characteristic of a tube when oscillating in this way is that there is a negative current to the plate, which may flow against a negative potential of 100 volts or more with respect to the filament, the grid being at a positive potential of several hundred volts. If the plate is simply connected to the filament through a voltmeter, this voltmeter may read as high as 150 volts, or if connected through an ammeter, the negative current to the plate may be as much as 25% of the total electron current from the filament. The magnitude of this negative current or voltage varies greatly with the temperature of the filament, grid voltage, and gas pressure. There is never oscillation in the Lecher wires without a negative current or potential on the plate, but this negative current may be present and yet the Lecher wires show very feeble or no oscillations. The characteristics of this negative current and the associated oscillations have been studied as affected by changes of grid voltage, of electron current, and of gas pressure.

It was found, very unexpectedly, that both the negative plate current and any sign of oscillation, as indicated by the Lecher wires, ceased abruptly

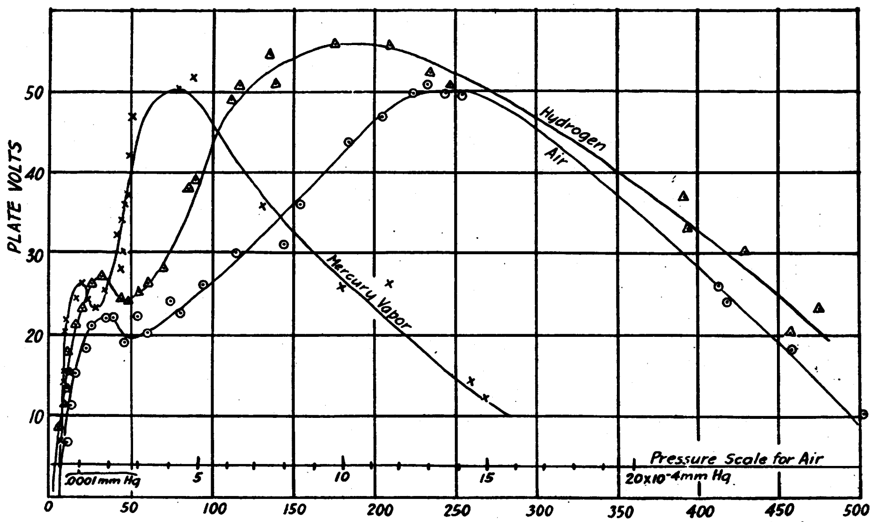

FIGURE 2

at very low pressures. This is shown in the curves of figure 2 for plate voltages, and in figure 3 for the strength of oscillation in the Lecher wires. These observations were all made with the grid at 250 volts and the filament heating currents such that the electron current was 200 milamperes. The pressure of the residual gas in the tube was measured with an ionization manometer. The pressures of hydrogen and air were controlled by adjusting the flame under the mercury vapor pump, with liquid air on the trap to keep out mercury vapor. The mercury vapor pressure was controlled by keeping the liquid air trap (with a pool of mercury at the bottom) at different temperatures, the mercury vapor pump operating at its maximum rate to reduce the pressure of any gas to the minimum. The curves are plotted with the readings of the ionization manometer as abscissae. This was done because it is probable that the essential thing is not the presence of the gas itself, but of gaseous ions. Since different gases at the same pressure give different amounts of ionization when under the same ionizing agent, it seemed better to plot their ionization instead of pressure. The pressure corresponding to a given ionization current is

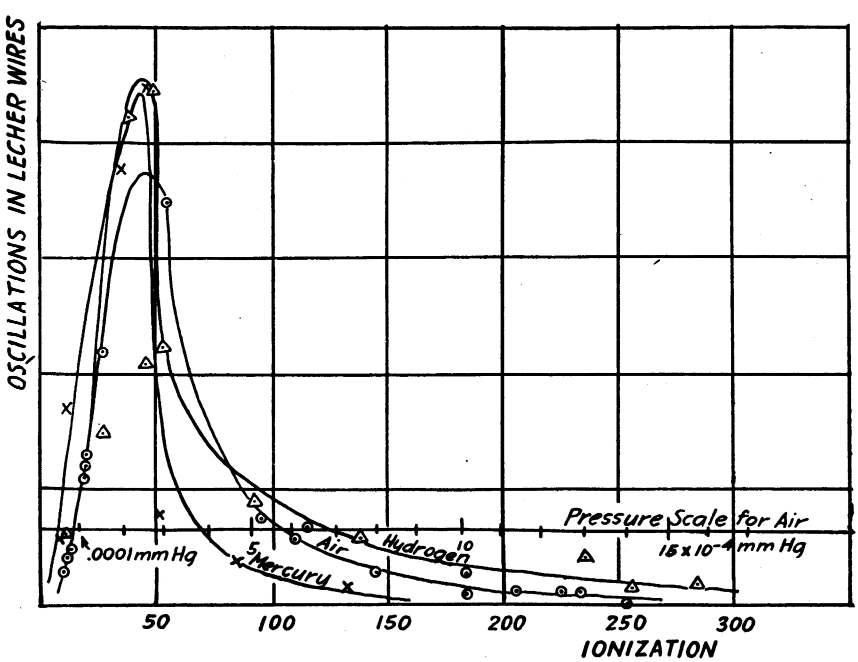

FIGURE 3

for mercury about half, and for hydrogen about twice that for air. The pressure scale for air is given on the curves, so by multiplying and dividing by 2 the approximate pressures of hydrogen and mercury, respectively, will be obtained.

These curves apparently indicate that a small amount of ionization is necessary for this type of oscillation. The kind of gas does not seem important. Since the gas pressure at which the oscillation stops is so low, being less than .00005 mm. there can be no connection with the mean free path of the ions, for at these pressures the path is many times longer than the dimensions of the tube. It is not likely that the commercial tubes used by other investigators are sufficiently exhausted to give any indication of the dropping off of the curves at the low pressure side. So far, no staisfactory explanation has been found for the profound effect of such a small amount of gas or the behavior of the tube.

The investigation is being continued and a more detailed account will be published in the near future.

[1] Barkhausen and Kurz, *Phys. Zs., Leipzig*, **21**, No. 1, Jan. 1920, p. 1.

[2] Whiddington, *Radio Review*, Nov. 1919, p. 53.

[3] Gill and Morrell, *Phil. Mag.*, **44**, No. 259, July 1922, p. 161.

THE REFRACTION OF X-RAYS IN CALCITE

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The effect of refraction in X-ray spectra has been discussed by Stenström,[1] who made some determinations of the index of refraction from the relative displacement of the several orders. In most cases the effect was too small to admit of measurement, but for sugar and gypsum crystals he obtained some values for wave-lengths greater than 2.5 Å.

The present paper applies a modification of the same method to the reflection from calcite of the $K\alpha_1$ line of Molybedenum, 70783 Å.

Since we measure the angle from the crystal face, and not the normal, the customary equation for the index of refraction becomes

$$\nu = \frac{\cos\theta}{\cos\theta'}, \tag{1}$$

where θ is the glancing angle outside the crystal and θ' the angle of the beam inside. We will use a subscript to indicate orders higher than the first. Placing $\nu = 1 - \delta$, Stenström computes the values of δ from the equation

$$\delta = \frac{\left(\frac{\sin\theta_m}{m}\right)^2 - \left(\frac{\sin\theta_n}{n}\right)^2}{2\left(\frac{\cos\theta_m}{m}\right)^2 - 2\left(\frac{\cos\theta_n}{n}\right)}$$

where m and n are any two orders.

As the shift is small in any case, it seemed desirable to express the value of δ directly in terms of angle, in order to more readily determine the effect of errors of observation which are liable to be of the same order of magnitude as δ itself. Now from (1) we have

$$\sin^2\theta' = 1 - \nu^{-2}\cos^2\theta$$