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given by Milne of usually from 2 to 6 minutes* between the shock and its echo is exactly that between the beats. On the 15 sec. diagram the interval is about three minutes for a boom period 16·5. With a nearer approach to isochronism the interval would be longer until, if the periods are sufficiently near, the free vibration will have been damped out before opposition in phase can occur. This is evident in the 16 sec., 17 sec., and 18 sec. diagrams.

The object of this paper is to point out that on ordinary elementary theory it is erroneous to derive information regarding the movement of the earth from the measurement of the boom of a Milne seismograph as at present constructed, as we have no knowledge to what extent synchronism may affect the result. To obtain the necessary knowledge the tape must be driven at a higher speed, or it might be obtained in some cases from the interference effects. In cases where there is a near approach to isochronism between the boom period and the wave period, the amplitude of swing depends largely on the damping effect of friction (equation 1), which is entirely ignored at present in this connexion.

LIII. *A Penetrating Radiation from the Earth's Surface.*
By H. LESTER COOKE, M.A., *Demonstrator of Physics,*
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C. T. R. WILSON‡ has examined the rate of discharge of an insulated charged conductor placed inside a closed vessel, the inclosed gas not being exposed to any known ionizing agent. The effect of different gases and varying pressures was studied. He found that the rate of discharge was approximately proportional to the pressure and also to the density of the gas employed. This discharge takes place through the gas, and must be ascribed to a production of ions proportional to the pressure and density of the gas; in other words, to the amount of gaseous matter present.

To account for this there are several explanations possible. The ionization may be due to:—

(1) a radiation or active emanation from the walls of the inclosing vessel;

* British Association Reports, p. 72 (1900).

† Communicated by Prof. Rutherford, F.R.S. A preliminary account of these experiments was given before the American Physical Society, Washington, Dec. 1902. An abstract of the paper was published in the 'Physical Review.' See Rutherford and Cooke, *Phys. Rev.* lxxxiv. p. 183.

‡ C. T. R. Wilson, *Proc. Roy. Soc.* lxviii. p. 151 lxix. p. 277.

(2) an external radiation capable of penetrating the walls of the inclosing vessel ;

(3) a spontaneous ionization of the gas itself ; or

(4) a combination of any two, or of all three, of the foregoing.

In order to explain the facts by (3) it must be assumed that the spontaneous ionization is due to the action of the particles of gas on themselves, and not due to any form of radiation or collision between adjacent particles. If this latter were the case the amount of ionization, instead of being simply proportional to the number of particles present, would vary as the square of this number. It would therefore seem advisable, before accepting this "Spontaneous" theory, to examine the other possible explanations of the phenomena. It was on this account that the following research was undertaken.

It was decided to employ an electroscope in these experiments. The observations could be made either with an electrometer and large testing-vessel (or small vessel in which the gas is under high pressure), or by means of an electroscope, which could be made small and portable. As the effects are somewhat small to come within the range of an ordinary electrometer, and as the method of experimentation required the use of heavy metal screens, and necessitated observations being taken at different places and under varying conditions, it was decided that the electroscope most nearly fulfilled the experimental requirements.

The form of instrument used, which is very similar to that employed by Wilson, is shown diagrammatically in the accompanying figure (fig. 1). The case of this electroscope is of brass, about 2 millimetres thick, and the volume of gas inclosed measures 1100 c.c. A metal rod, A, passes through an ebonite cork in the centre of the top plate, and is terminated by a sulphur bead B. In the lower end of this bead a strip of rolled copper wire is secured, and to this the gold leaf, which acts as a potential indicator, is fastened. Another wire, C, bent as shown in the diagram, passes through the ebonite cork, and is capable of being turned so as to be brought into electrical contact with the gold leaf system, and thus serves as a charging device. In the bottom of the vessel is placed a small glass dish, covered with perforated tinfoil, and containing calcium chloride; this serves the purpose of removing the moisture from the inclosed gas without causing any electrostatic disturbance. The divergence of the leaves was read with a microscope having a 100 division scale in the eyepiece.

In beginning these experiments it was found that the effect of care in the preparation of the instrument was to greatly decrease the ordinary rate of collapse of the leaves.

Fig. 1.

After repeated trials the following method was adopted as giving the most satisfactory and consistent results. The three brass sections were first carefully polished with metal-polish, then washed with soap and hot water, and thoroughly dried with a clean towel. The glass dish containing the drying agent was similarly washed and dried, fresh calcium chloride placed in it, and then covered with perforated tin-foil, previously cleaned with ammonia. The sulphur bead was made larger than required, and then pared down with a sharp clean knife, the utmost care being taken during this operation not to touch the bead with the fingers. All the joints and the edges of the mica windows were then carefully waxed over, and the instrument set aside for a day to give the calcium chloride time to dry the inclosed air, and render the insulation of the sulphur bead as perfect as possible.

The leakage of electricity across the sulphur bead could

be determined by observing the rate of collapse of the leaves when the rod which supported the bead was earthed, and then repeating the observation with this rod at a potential of 300 volts. The difference gave the leakage across the bead for a P.D. of 300 volts. This was generally found to be about $\cdot 02$ division per hour, and was negligible in comparison with the leakage due to the ionized air. After charging the leaves the rod C was always earthed. This had the effect of slightly reducing the potential of the insulated system. This lowering of the potential, which could be accurately measured, did not in any way interfere with the results, as it was constant throughout the experiments.

The voltages employed ensured the removal of practically all the ions, the potential gradient across the gas, according to the measurements of the instrument, never falling below 20 volts per cm.

The primary object of this research was to ascertain whether there was any penetrating radiation coming from some external source, and responsible for the ionization of the air inclosed in the electroscope. For this purpose slabs of lead were cast, an inch in thickness, which could be built in the form of a cage for the insertion of the instrument. Lead was chosen as the material for these screens on account of its high absorptive power for ionizing radiations, as compared with its density ; this ratio in the case of lead being nearly double the value of the same ratio in the case of most other materials.

The instrument was charged, then placed in a definite position on an earthed support, which was carefully levelled, and the deflexion of the leaf observed. The instrument was then placed inside the lead cage and allowed to remain for about twelve hours, then removed, set up as before, and the deflexion again read. Great care was taken during these operations not to jar the instrument in any way. It was found that moving the instrument in this way did not introduce an error of more than $\cdot 2$ of a division ; and as the observed collapse of the leaves was usually between 20 and 40 divisions this did not introduce any serious source of inaccuracy.

The effect of surrounding the electroscope with lead screens was always to reduce the rate of discharge of the leaves. The inch slabs of lead used in the first experiments diminished the ionization as much as 25 per cent. This result was arrived at by a continued series of observations extending over more than a month, the readings being taken and the instrument recharged night and morning.

Measurements were then made of the relation between the thickness of the lead screen and the decrease in the ionization, screens ranging in thickness from 1 mm. to about 40 cms. being employed. The results of repeated experiments indicated that this radiation was subject to the ordinary law of absorption, and that it was cut down to half value by a thickness of lead somewhere between .25 and .5 of an inch, being almost completely absorbed by 2 inches of lead. The greatest quantity of lead employed in the construction of a cage was about 10,500 lbs., the value thus obtained being practically the same as with a cage 2 inches thick. The individual observations were not as consistent as one could wish, sometimes showing a variation of as much as 10 per cent., but the averages obtained from a very extended series of experiments clearly indicated the above results. As will be shown further on, the current measured in these experiments was almost inconceivably minute, and thus any slight disturbing influence, which would be incapable of being detected by ordinary methods, was apt to become a serious factor of disturbance, and had to be guarded against with the utmost care. Altering the distribution of the lead slabs revealed the fact that the radiation was of practically uniform intensity in all directions, coming equally from the floor, walls, and ceiling of the laboratory.

It was thought possible that this radiation might be due in some way to the fact that radium and other radioactive substances had been used in the laboratories, and might in some way have affected the walls of the room. To test this point a series of experiments was carried out in the basement of the University Library, where no radioactive materials had been used. From observations extending over a period of more than two weeks it was definitely shown that this effect was present in the library as well as in the Physics building, and therefore could not in any way be due to contamination with radioactive substances.

The next thing to be ascertained was whether this radiation would be reduced on passing through other metals besides lead. For this purpose small slabs of polished iron were obtained which could be built up in the form of a cage as in the case of the lead. In this way iron was found to also cut down the radiation. The relation between the thickness of iron and the absorption was not determined, the object being merely to show that this screening effect was not a property peculiar to lead.

The effect of water was also tried. A brass cylinder was obtained with a top which could be bolted down and rendered

water-tight by means of a rubber washer. The electroscope was placed inside this vessel and the rate of discharge obtained with the apparatus resting exposed on the slate in the laboratory. The run was then repeated with the cylinder containing the electroscope immersed in a large tank, so as to be surrounded on all sides by a thickness of water of at least $2\frac{1}{2}$ ft. Under these conditions it was found that the rate of discharge was reduced as in the experiments where lead and iron were used. The tank used in these experiments was of iron, about an inch in thickness; it is thus doubtful how much of the radiation was cut off by the iron, and how much by the water. The only two conclusions which can be drawn with certainty from these experiments are that the iron and water combined reduced the amount of penetrating radiation, and that the water did not supply any such radiation to an appreciable extent.

Radioactivity of Ordinary Materials.

The walls of the laboratory in which the experiments were carried on were of brick. It was therefore thought advisable to ascertain what would be the effect of surrounding the electroscope with a brick cage. New bricks were obtained and two cages built, the sides of one being one brick in thickness and the sides of the other four bricks thick. Placing the electroscope inside these cages caused the rate of collapse of the leaves to *increase* 40 and 50 per cent. for the small and large cage respectively. This increase, however, was not due to a penetrating form of radiation, for when a casing of lead a millimetre thick was interposed between the electroscope and the bricks the leakage was immediately reduced to its normal value. This also precludes the idea of the leakage being due to an emanation from the bricks, which was suggested as an explanation of the effect. The rays from the bricks were evidently of a comparatively low penetrating power, probably being very similar in character to the β rays given off by radium. Experiments were tried to detect the presence of very easily absorbed rays from bricks, the base of the electroscope being removed, and the instrument placed on a brick support. Bricks covered with gold leaf, bare bricks, and powdered bricks, were successively tried in this way. The removal of the base of the electroscope slightly increased the ionization of the inclosed air, but not to an extent sufficient to indicate the presence of an appreciable amount of easily absorbed rays. Since the ionization was the same when the electroscope surrounded by lead one millimetre in thickness was placed inside the brick cage, as

when it was left exposed in the laboratory, it follows that the bricks must have supplied an amount of penetrating radiation equal to the amount they cut off. This result might have been anticipated, as the walls of the laboratory were of brick.

The activity of lead slabs which had been exposed for over two weeks on the roof of the building was tested, and also the activity of the copper roof itself. Both exhibited greater activity than materials which had been kept in the laboratory, but the radiation was not of a penetrating character. Experiment showed that the amount of penetrating radiation was approximately the same in the laboratories, on the roof, and on the bare ground outside the building; in fact this radiation seems to be present everywhere with practically uniform intensity.

The effect of placing metal sheaths as linings inside the electroscope was observed in an attempt to reduce the ionization as much as possible, and also the instrument with its base removed was placed on other non-metallic substances. In this way dried earth, polished tin, writing-paper, a stone window-ledge, pine wood, brick, lead, zinc, and iron were tried; the results showing that they were all, with the exception of iron, more active than polished brass. Iron exhibited about the same effect as brass, but it is probably more active, for the iron used was a slab about $\cdot 75$ of an inch in thickness, which must necessarily have absorbed a considerable amount of the penetrating rays. Great care was not taken in this part of the work to secure numerical values for the activity of the various substances, as the object was merely to determine if any material showed a lower ionizing effect than brass. The results would, however, indicate that the above list represents the materials arranged according to their activity, beginning with the most active. The quantitative aspect of this branch of the subject has been carefully investigated by McLennan and Burton*, and by R. J. Strutt†.

In order to calculate the number of ions produced per c.e. per sec. it was necessary to reduce the readings on the micrometer scale to volts, to estimate the electrical capacity of the insulated gold-leaf system, and to calculate the volume of the inclosed air.

The deflexions of the gold leaf in micrometer divisions could be reduced to readings in volts by observing the deflexions when the leaves were charged to different known

* McLennan and Burton, *Phys. Rev.* lxxxiv, p. 184.

† R. J. Strutt, '*Nature*,' Feb. 19, 1903, p. 369; see also '*Nature*,' 1903, pp. 391, 414, 439.

voltages, the curve thus obtained being practically linear between 100 and 340 volts, these being the extreme limits of potential for the observations. For different gold-leaf systems this calibration gave between 2.5 and 3 volts per division.

To determine the capacity of the gold leaves the electro-scope was set on an insulating block of paraffin, and the outside cylinder connected to the quadrants of a very delicate Dolezalek electrometer, which was connected in parallel with a standard capacity of .002 microfarad. The leaves of the electro-scope were charged, and the reading observed. The leaves were then discharged, and the charge which had been attracted to the case of the instrument thus released and allowed to charge up the electrometer and standard capacity. The deflexion of the electrometer was then read, and was a measure of the charge which had been on the leaves of the electro-scope. The observations were taken five successive times, using 200 and 300 volts, and showed an agreement of better than four parts in a hundred. The sensitiveness of the electrometer was 543 divisions per volt. From the data thus obtained the capacity of the system was calculated, and came to .85 and .91 cms., for 200 and 300 volts respectively. As the observations generally ranged between 325 and 175 volts the average capacity of the system was taken as .88 cm.

The volume of the air inclosed in the electro-scope was 1100 c.c.

With a gold-leaf system giving 2.6 divisions deflexion for a volt, the rates of collapse of the leaves for the electro-scope exposed in the laboratory, and then surrounded with a very thick lead screen, were 2.4 and 1.7 divisions per hour. This gives as the number of ions 7.5 and 5 respectively. The number given by Wilson, 14, is for conditions similar to those under which the value 7.5, above, was obtained. The lower number here obtained may be accounted for by the fact that Wilson used silvered glass in the construction of his electro-scope, whereas an instrument of brass 2 mms. thick was used in these experiments.

To sum up, the results of this investigation are :—

(1) The proof of the existence of a very penetrating radiation, present everywhere under ordinary conditions. This radiation is similar in properties to the radiation from radium, and is comparable to it in penetrating power. This radiation is accountable for between 30 and 33 per cent. of the natural ionization observed in ordinary testing-vessels, 33 per cent. being the greatest reduction obtained by the use of massive

lead screens. This penetrating radiation may have its origin in the radioactive matter which is distributed throughout the earth and atmosphere. It was not found possible to obtain sufficient excited activity on a wire charged negatively in the open air to show the presence of a very penetrating radiation due to it. The effect observed is too large to be accounted for by the excited activity distributed on the walls of the laboratory.

(2) That all the substances examined give forth a radiation of a not very penetrating character; that this is probably the cause of all the residual ionization in the electroscope when surrounded by heavy metal screens; and that this activity varies with different substances, being very low in the case of brass.

(3) The reduction by the experimental arrangements of the number of ions produced per c.c. per second in air under atmospheric pressure from 14 to 5.

In conclusion, I wish to thank Prof. Rutherford, at whose suggestion and under whose very kind supervision this research was undertaken and carried out.

McGill University, June 23, 1903.

LIV. *On the Law of the Condenser in the Induction-Coil.*
By JAMES E. IVES, *Ph.D.*, *Instructor in Physics in the University of Cincinnati**.

[Plate XVII.]

THE optimum capacity, in an induction-coil, is defined as that capacity of condenser which, when placed around the break, will give the longest spark in the secondary. It has also been found by experiment to be the least capacity that causes the sparking at the break to disappear, or if not entirely to disappear to become very small.

In the July number of the *Physical Review* I proposed a formula for it, based upon theoretical considerations, viz.:—

$$K = \frac{I_0}{av_0}$$

where K is the optimum capacity; I_0 the steady current in the primary at the instant of breaking the circuit; v_0 the velocity with which the circuit is broken; and a some constant which depends upon the medium in which the break is made. Unfortunately for this theory, experiments made

* Communicated by the Author.