

Physics. — Penetrating radiation. II. By J. CLAY.

(Communicated at the meeting of December 22, 1928).

For the determination of the intensity of the penetrating radiation which was reported in these Proceedings Vol. 30, 1927, p. 1115, two electrometers, constructed according to KOLHÖRSTER by GÜNTHER and TEGETMEYER at Brunswick, were used.

When computing the results, we adopted the values of the capacity as given by the firm. At the time we lacked in Bandoeng the opportunity to measure this particular small capacity (the given values being 0.51 cm and 0.61 cm). In order to get a control on the value of this capacity, EVE's constant was determined with the help of the ionisation due to 1 m.gram Ra at 2 m distance. The values found were 6.4×10^9 I (ions cm^{-1} $\text{gr}^{-1} \text{ sec}^{-1}$) and 6.6×10^9 . These values were rather large, but the agreement got with the two apparatuses, made one trust the given capacity.

On a visit at Brunswick the value of the capacity was again determined; it then appeared that the method applied viz. with a condensator to HARMS, was not at all sufficiently accurate for the determination of these small capacities.

Through the kind permission of Dr. HOLST, director of the physical laboratory of the Philips' Works, I was allowed to make a capacity measurement in his laboratory with the apparatus especially built by Dr. V. D. POLL and Ir. GROENEVELD, for accurate measurement of small capacities. The method was founded on the adjusting of two circuits; the frequency of one of them was kept constant, while the frequency of the other, which held the capacity of the apparatus, was brought by means of a standard, parallel mounted condensator to such a value, that the difference in frequency of this one with the first was equal to another constant frequency. After disconnecting the capacity of the electrometer, the parallel capacity was varied, so that again the result was the same difference in frequency.

By this determination it appeared that an accuracy of 0.001 cm could be attained. As the electric system of the electrometer is mounted insulated in the middle of the ionisationchamber, the capacity is found by measuring the difference which arises when the charging connection first is brought into contact with the system and then is taken away by turning. The position which was adopted as the most accurate value, was the one in which the capacity of the charging connection did not change anymore by turning it further. In this position we may assume that the capacitive working of the system is no longer influenced by the charging-connection.

With three independent observations the values 0.287, 0.288 and 0.289 cm were obtained. An entirely different measurement was carried through at the Reichsanstalt in Berlin with the aid of Dr. ZICKNER and Dr. KOLHÖRSTER. There the capacity was measured with the help of a bridge with an alternating current of high frequency and telephone. The result of this measurement was 0.297 cm. The accuracy amounted to about 2 %. From now we adopted 0.288 as value of the capacity. Probably also other investigators, who used KOLHÖRSTER's electrometer and who had no opportunity to make accurate capacity measurements will also have found some uncertainty in the absolute value of the measured intensities. From this may be partly explained the difference of the values found.

The capacity of the electrometer *B*, which remained in Bandoeng, was after our return determined by comparing it with *A*, while both were mounted at a distance of 2 m from 1 m.gr. radium. In this way the capacity of *B* was found to be 0.315 cm, so that important corrections had to be applied to the absolute values of the intensities published in a previous paper. The values of *A* have to be multiplied with 0.57 and those of *B* with 0.50. After a series of measurements during a few weeks at Leyden, instrument *A* was filled there with argon from the Philips' Works, the latter having been kept there for about ten years and being of a sufficient purity.

It was proved before that the apparatus showed no leakage when an overpressure of 20 cm mercury was applied.

The proportion of the ionisation values with argon and with air was determined from some series of measurements and appeared to be at Leyden without armour 1.15 and with an armour of 8 cm iron 1.06. The same proportion was for a second time determined in Bandoeng in July and under the influence of *Ra*-radiation there was successively found 1.18 with armour and 1.17 without armour.

For the mean value of the ionisation proportion filled with argon and with air, we obtained in this way 1.15. Supposing that the ionisation is simply dependent on the number of electrons per unit of volume, we could expect to find for this proportion the number 1.14.

A calibration of the electrometer *A* with a quantity *Ra* of 9.17 m.gr. *Ra*-element of the physical laboratory at Leyden gave for the EVE's constant a value of $3.81 \times 10^9 I$, which therefore proved, that the found value of the capacity could now be trusted. After having the instrument in an armour of 8 cm iron, it appeared that only 3.8 % of the rays penetrated into the electrometer. From now the measurements were made with this armour in order to exclude the radio-activity of the surroundings.

It was stated in a former communication that it was impossible to obtain a reliable value of the residual ionisation of the electrometer in the Stasz-fürter saltmines. So it was of great importance to determine it in another way. To do this there was in Bandoeng an opportunity viz. to bring the

electrometer in a deserted tunnel of some waterpowerworks, where we could mount the instruments under a layer of 84 m rock. In the middle of the tunnel which was 124 m long, was a niche, in which we could place the electrometers. The electrometers were alternately armoured for an hour in iron, then left unprotected and finally an observation was made, in which the electrometer *A* was kept in armour for 16 hours. In the armour we found the mean value during several single hours to be 1.63 *I* with a deviation of 0.07 *I*, while for the value during those 16 hours we found 1.63 also. Out of the armour the ionisation was 4.01 *I*. As 3.8 % of the radioactive rays penetrates the armour, 1.52 could be considered as residual ionisation, and for the radioactive rays 2.49 *I*. With the instrument *B*, 1.69 *I* was found as residual ionisation with a radioactive radiation of 2.43 *I*.

From these results it appeared, that the value of the residual ionisation was very much lower than the previous one, which was obtained with an armour of 48 cm lead, the latter being 1.96 *I*.

With a view to the obtained results a new series of absorption-determinations were performed in order to determine a more accurate value for the absorption coefficient of lead. The electrometer was put into the iron-armour of which the absorption corresponds to that of 6.5 cm lead, (when we suppose the absorption to depend on the number of electrons per cm^3 only).

The following values were obtained

cm. lead	<i>A</i>	<i>B</i>
0	1,01	0,99
6,5	0,70	—
11,0	0,63	0,62
15,5	0,59	—
22,5	0,54	0,52
28,5	0,46	—
34,7	0,42	—

All these values were obtained from the mean of the measurements during at least two days and with an observation-time between 6 and 8 hours.

While at present for the above mentioned radiation the values 1.01 *I* from *A* and 0.99 *I* from *B* are found, the corresponding values obtained in March 1927 were respectively 1.16 *I* from *A* and 1.12 *I* from *B*. The latter values have been computed both with the corrected value of the capacity and the corrected value of the residual ionisation.

The side armouring of the instrument however was somewhat higher now than in March 1927. Therefore no conclusions can be drawn from this

difference. The only thing that is apparent is that the electrometers during this period of more than a year didn't change appreciably.

An important question, which has to be solved first, is whether the radiation is homogenous or composite.

According to the theory of COMPTON and others on the scattering of the Röntgen- and gamma-rays, the primary rays on the earth will certainly cause a secondary radiation of less penetration and of smaller absorption-coefficient. Assuming that this secondary radiation, that is called by STEINKE¹⁾ „Umgebungsstrahlung“ is completely absorbed by 11 cm lead, and that the primary radiation is homogeneous, we may write

$$I_1 = I_0 e^{-\mu d_1} \text{ and } I_2 = I_0 e^{-\mu d_2}$$

if we take d_1 at least 11 cm.

$$\text{Then } y = \log \frac{I_1}{I_2} = \mu (d_2 - d_1).$$

From our observations appears, that this is approximately correct. In fig. 1, we took $d_1 = 11$ cm. Our observed values for $d_2 > d_1$ lay nearly on a straight line, for which we find $\mu = 0.17$ per cm lead. This corresponds to a wave length²⁾

$$\lambda = \frac{\mu}{60} = 0.00028 \text{ A.E.} = 0.28 \text{ } X.$$

At the same time we can now determine the value of the intensity which we ought to find for the primary radiation when not absorbed by lead. When the straight line in the figure is extrapolated till $d_2 = 0$ we find 0.76 I while for $d_2 = 6.5$ cm lead we obtain 0.68 I . The observed values are 1.01 I and 0.70 I respectively. From this it appears that 0.25 I is caused by the secondary radiation or "Umgebungsstrahlung". From EINSTEIN's equation $h \frac{c}{\lambda} = eV$ and from the wavelength determined before, we may compute which are, the transformations of energy that may cause a radiation of the same wave-length. In this formula h is PLANCK's universal constant, c is the lightvelocity, e the elementary charge of the electron and finally, V the potential difference which the electron needs to acquire this energy. The question arises, which are the physical causes corresponding to those transformations. In the first place we think of the destruction of the atoms, as occurs in the radioactive processes. These quantities however are too small. In the second place there is the formation of atoms from protons and electrons, a.o. the formation of helium from hydrogen. During this process a destruction of mass occurs, the amount of which is very well

¹⁾ E. STEINKE. Neue Untersuchungen über die durchdringende Hess'sche Strahlung. Z. f. Physik, Bd. 48, p. 655 en 656.

²⁾ These Proc. Vol. 30, 1927, p. 1123.

known nowadays from ASTON's determination of the atomic-weights. When we put the mass of an atom of oxygen equal to 16, that of one atom

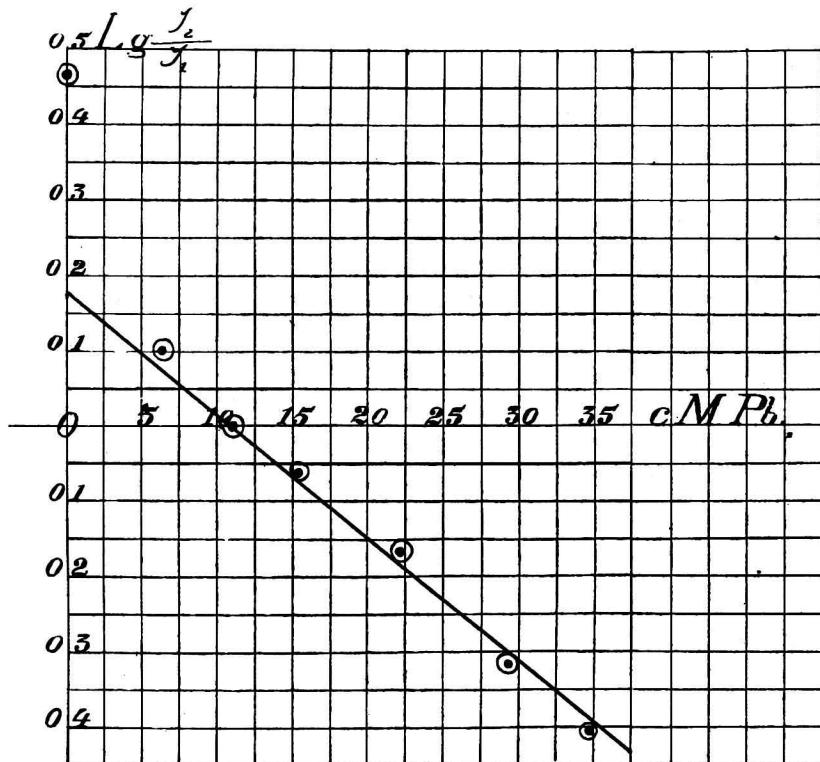


Fig. 1.

of hydrogen is 1.00778 while four atoms have a mass of 4.0311. The mass of an atom of helium is 4.00216. The real mass of an atom of hydrogen is 1.6×10^{-24} gr. Therefore the loss of mass by the formation of one helium-atom is equal to $0.0290 \cdot 1.6 \cdot 10^{-24}$ gr. According to the theory of relativity this loss of mass corresponds to a loss of energy $dE = c^2 dm$.

If this is transformed into radiation, then we have

$$dE = hV = h \frac{c}{\lambda} = c^2 dm.$$

or

$$\lambda = \frac{h}{cdm} = \frac{6.6 \cdot 10^{-27}}{3 \cdot 10^{10} \cdot 0.0290 \cdot 1.6 \cdot 10^{-24}} = 5 \cdot 10^{-12} \text{ cm.}$$

The corresponding coefficient of absorption is 0.03. This value is of the same order as the observed one. It is apparent that also other formation-processes may cause this radiation. MILLIKAN and CAMERON¹⁾ who from their measurement of the absorption in water conclude that the radiation

¹⁾ R. A. MILLIKAN and G. H. CAMERON. Scientific American. Aug. 1928, p. 136.

consists of three different components with values of the absorption-coefficients, resp. 0.028, 0.0064 and 0.0032, finally arrived at the conclusion that probably there are three different causes of radiation, which in some way are related to the formation of helium, oxygen and silicium from hydrogen.

A very remarkable fact is, that the third source of energy which is amply discussed by the astronomers, viz. the destruction of protons, corresponds to a wave-length which is considerably smaller than the one found up till now, viz. $0.014 \text{ } X$ with a coefficient of absorption in lead amounting to 0.00084. Untill now no radiation of this absorption has been observed. Moreover, as MILLIKAN remarks, if this radiation really exists, its intensity cannot be large as the value of the residual ionisation only leaves a small value for the ionisation, which may be ascribed to this radiation.

The important question remains to be solved however, where this radiation comes from. KOLHÖRSTER and BÜTTNER have advocated the opinion, that the radiation should originate in the Milky way. If it is true, that it originates in a definite part of the universe, we should expect a dayly variation systematically depending on sidereal time. According to the above mentioned investigators this actually did occur. From observations made in Bandoeng in May 1927, I qualified in my previous communication this opinion as being improbable ¹⁾. The investigations of MILLIKAN and CAMERON ²⁾ near lake Miguilla in Bolivia, of E. STEINKE ³⁾ in Davos and of HOFFMANN and LINDHOLM ⁴⁾ in Muottas Muragl lead to the same negative conclusion. I think it more probable that the radiation originates nearer by, perhaps even in the upper layers of our atmosphere. This view is for instance confirmed by the decrease of intensity with decreasing latitude of the place of observation. During the voyage from Europe to Java on board of s.s. „Prins der Nederlanden“ frequent observations were made while the instrument was 14 meter above sealevel. The observations were made without any armour and with an armour of 8 cm iron. The following consecutive values were obtained (see table following page).

From these data it is apparent that the intensity of the radiation decreases towards the equator. In the armour the gamma radiation of Ra was reduced to 3.8 %. On board of the steamer this radiation proves to be very small, as appears from the observations which from time to time were made without armour. By the armour, when protected at the bottom and at the side by a thick layer of lead, also the secondary penetrating radiation

¹⁾ These Proc. Vol. **30**, 1927, p. 1119.

²⁾ R. A. MILLIKAN and G. H. CAMERON. Nature. Jan. 1928 p. 19.

³⁾ E. STEINKE. Neue Untersuchungen über die durchdringende Hess'sche Strahlung. Z. f. Physik Bd. **48**, p. 655 and 656.

⁴⁾ G. HOFFMANN und F. LINDHOLM. Registrierbeobachtungen der Hess'schen Ultra- γ -Strahlung. Gerlands Beiträge zur Geophysik Bd. **20**, 1928, p. 12.

	I with armour	II without armour
Leiden	1,49	—
From Genua till Messina	—	1,49
Strait of Messina	1,25	—
Messina till Port Said	0,97	—
Port Said	0,99	—
Canal of Suez	0,82	1,30
Read Sea Northern part	0,92	1,25
Read Sea Southern part	0,92	—
Indian Ocean	0,86	1,04
Colombo till Sabang	0,88	—
Port of Sabang	0,87	—
Sabang till Singapore	0,85	—
Singapore till Batavia	0,82	—
Port of Batavia	0,88	—
Bandoeng (760 m above sealevel)	0,99	1,01 protected at the bottom and at the side.

is for the greater part absorbed, as is seen from the measurement in Bandoeng. On land the gammaradiation causes a larger ionisation of course, while probably the amount of secondary radiation will be larger also.

If the proportion between primary and secondary radiation may be assumed to be the same in Leyden and in Bandoeng, we find the value of the primary radiation in Leyden to be $\frac{0.76}{0.99} \cdot 1.49 I = 1.1 I$. This agrees with the data given by STEINKE¹⁾ in Konigsberg who also gives a value of $1.1 I$. On the other hand the value of the primary radiation in Bandoeng is $0.76 I$ with $0.25 I$ „Umgebungsstrahlung“ (see before). According to MILLIKAN and CAMERON²⁾ the total amount of radiation at sealevel is $1.4 I$, while in Bandoeng it is found to be $1.01 I$.

Bandoeng, Nov. 1928.

¹⁾ E. STEINKE. Z. f. Physik Bd. 48, p. 647.

²⁾ R. A. MILLIKAN and G. H. CAMERON. Nature, Jan. 1928, p. 19.