CIX. On a balance method of measuring X-rays

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Better agreement is scarcely to be anticipated, since the values of P for any liquid are not known to any degree of accuracy; P for benzene, for example, varying from 1300 to 3810 atmospheres, according to the method employed for its evaluation (Hildebrand, J. A. C. S. xli. p. 1072 (1919)). The parallelism between the two sets of determinations and the decrease in the molecular relaxation period or increase in molecular "sensibilité" with increasing polarity is, however, clearly marked.

Summary.

The rate of penetration of a liquid into a fine capillary under its own forces is shown to be expressed by the relationship $t = \frac{2\eta}{\gamma r} x^2 - \frac{\delta r^2}{8\eta} \log x$. For relatively large capillaries the penetration coefficient is $\sqrt{\frac{\gamma r}{2\eta}}$.

The experimental determination of the coefficient is shown to agree with the calculated values. In the case of mixed solvents the dynamic surface tensions and not the static values are probably the governing factors.

The reciprocal of the penetration coefficient is proportional to the square root of the period of molecular relaxation as defined by Maxwell, and on analogy with reactions in the solid state is probably important in reactions taking place in liquid media.

The writer is indebted to Mr. R. L. Huntingdon for assistance in the experiments detailed in this paper.

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CIX. *On a Balance Method of measuring X-Rays.* By Professor S. RUSS, D.Sc., and L. H. CLARK, M.Sc., Physics Department, Middlesex Hospital*.

THE frequent and prolonged running of X-ray tubes calls for some convenient method of recording continuously the intensity of the X-radiation emitted during the period of excitation. The balance method described below indicates at any instant this intensity and is capable of giving a continuous record of it. It is suitable for the measurement of the ionization produced by a powerful beam of X-rays.

* Communicated by the Authors.

In principle, this balance method is similar to that devised by Rutherford and described by Bronson (Phil. Mag. vol. xi. p. 143, 1906). Electrical communication is made between two ionization chambers by joining the insulated electrode which each contains. Initially these electrodes are earthed, but the chambers are maintained throughout at a constant potential difference by connecting them to the terminals of a battery of cells. One chamber is exposed to a beam of X-rays and the other simultaneously to the radiation from a very small mass of radium. Under the action of the two consequent ionization currents, the potential of the insulated electrodes rises to a steady value when a balance is set up. The potential of the electrode is indicated by attaching to it a gold leaf, the deflexion of which is then used to indicate the intensity of the X-radiation.

Fig. 1 represents a working model on the lines indicated.

Fig. 1.

Vessel A supports within it a small ionization chamber C, measuring $0.4 \times 1.0 \times 1.5$ cubic cm., the two small opposite ends of which are closed by windows of aluminium foil. This chamber carries along its long axis an insulated brass electrode, connected by a fine wire to the gold-leaf support in vessel B. One wall of this vessel is made of very thin aluminium leaf to allow entry of α radiation from a small mass of radium.

Fig. 2.

Another form of the apparatus is shown in fig. 2. In this case the ionization chamber C consists of a lead cylinder 1.2 cm. long and 0.8 cm. in diameter fitted with an axial

electrode. Each end of the chamber is closed by a very thin mica window coated with aluminium leaf. A lead diaphragm 0.5 cm. in diameter carrying a minute lead disk at its centre allows an annulus of radiation to enter the chamber C, and pursue a direct air path to the further window, without impinging upon either the interior of the chamber or the axial electrode.

Under working conditions 200 volts are applied to the chamber C, the connecting tube and the vessel B are earthed, the central electrode and gold leaf being initially earthed—then left insulated. The deflexion of the gold leaf is observed through a tele-microscope or the image of the leaf is projected on a screen.

From a practical point of view it is important to know how small a quantity of radium can serve to balance the ionization current due to a powerful beam of X-rays. In the two types of apparatus shown diagrammatically in figs. 1 and 2, 0.08 mgm. of radium bromide served to balance currents set up in the given ionization chambers C, when the latter were approximately 30 cm. from the anticathode of a Coolidge tube. The radium was spread over a circular area of 2 cm. diameter, the preparation being covered by a thin layer of mica, which allowed the α rays to pass through.

With the ionization chamber C set up at a definite distance from the anticathode of a Coolidge tube, a series of observations was made to determine the way in which the deflexion of the gold leaf varied with the intensity of the X-radiation from the bulb. Keeping the spark-gap constant, the filament current to the tube was varied over wide limits and the intensity of the X-radiation was measured by a distant electroscope. Simultaneously with these readings the balance deflexion was observed.

The curve of fig. 3 was obtained with the apparatus shown in fig. 2. It indicates a simple relationship between the balance deflexion and the intensity of the X-radiation entering the chamber C. The conditions of the experiment were as follows:—180 volts on chamber C, distance of C from anticathode 27 cm., alternative spark about 4 inches: the distance of the radium from the aluminium window in B, 2.2 cm.

The time taken for a state of balance to be set up was found to be independent of the intensity of the X-ray beam. If the leaf be started from its zero position it moves more slowly to its position of balance with a weak than with a strong intensity, but the smaller actual displacement practically

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compensates this so that the time for a balance does not vary appreciably over a considerable range of intensity. This is

Fig. 3.

well shown by the curves of fig. 4, which were obtained with the model of fig. 1. The position of the gold leaf was read at 3-second intervals from the moment the excitation of the Coolidge bulb was begun. The ultimate steady deflexions were 21.2, 29.2, and 47.5 respectively, yet the time taken to reach these values was approximately 30 seconds in each case.

Saturation of the ionized air in C is of course essential if the method is to be used for the quantitative measurement of the intensity of the beam of X-rays. With 200 volts on C, it was found that saturation was obtained provided that the radium was in such a position that the leaf balanced at a deflexion corresponding to a voltage on the leaf of about 120; this left 80 volts for the ionization current. If the radium is removed to a greater distance the leaf deflects more, but the corresponding rise in voltage now leaves insufficient for saturation. One result of this is that a spurious steadiness obtains in the balance; when saturation

occurs in C oscillations are easily observed, vide fig. 4. The oscillations under our experimental conditions were not due to fluctuations in the radiating power of the radium, for, if the ionization in C is produced by a radium source giving beta and gamma rays, a very steady balance is obtained. The oscillations which may be produced when an alpha ray

Fig. 4.

source is used has been studied by Geiger (Phil. Mag. vol. xv. p. 539, 1908), who showed that they were due to actual variation with time in the number of alpha particles emitted. He showed that for similar ionization by beta radiation, oscillations still occurred, though their significance was minimized owing to the greater numbers involved. It might be possible to detect oscillations in the X-ray case, considering their origin in the cathode stream, but under the usual experimental conditions it seems certain that the lack

of steadiness of the balance is mainly due to the instrumental side of the high tension apparatus.

How far the ionization produced by X-rays in the air of a vessel may serve as a reliable indicator of the intensity of the former is for experiment to decide. With any change of wave-length the issue becomes complicated by the selective production of characteristic and scattered radiation at any surface struck by the incident rays. The effect can hardly completely be got rid of because of the necessity for windows to the vessel. The apparatus shown in fig. 2 was constructed so as to reduce the above effect to a minimum.

Necessity for an International Unit of X-ray intensity.

The need has long been felt for a unit of X-ray intensity which shall receive International sanction. Investigators who wish to compare their results have of necessity recourse to various indicators, over the performance of which there is, however, not too much confidence. Attempts have from time to time been made to express the output of X-ray tubes in terms of the gamma rays from radium; more, however, with a view to comparing their relative output of energy than to standardize X-ray intensity in terms of the constant source of radiation which a sealed preparation of radium affords.

The need mentioned above is also an urgent one in the practice of medical radiology at the present time. The radiologist who is dispensing X-rays wields a highly complicated collection of apparatus; he is provided with X-ray tubes, the dimensions and output of which increase almost yearly, but so far he has not been given the security he needs, namely, a unit of intensity of the rays he is using. It seems that this can hardly be done without action of some sort by physicists, and the suggestion is made here, as it has been made elsewhere as well as by others, that steps be taken to fix upon some International Unit of X-ray intensity which will serve at one and the same time the interests and requirements of physical and medical investigators.