



XXXIII. On the motion of radium in the electric field

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“ \aleph_0 -exponential numbers.” That, however, these two classes are coincident is now easily seen; and, further, all the propositions proved by Whitehead* for either class of exponential numbers hold equally for the whole class of transfinite cardinal numbers. In fact that equations (7) and (8) have been already proved, and it is also evident that, if

$$1 < \mathfrak{d} \leq 2^{\mathfrak{a}}, \mathfrak{b} \geq \mathfrak{a}, \mathfrak{c} = \mathfrak{d}^{\mathfrak{b}},$$

then

$$\mathfrak{c}^{\mathfrak{a}} = \mathfrak{c}.$$

The exponential numbers have not, then, shown a behaviour different in any respect to the other transfinite cardinal numbers; and consequently no indication is to be found in addition, multiplication, or in at least many cases of exponentiation, of a characteristic of these numbers. In particular, no contradiction has been found in supposing

$$2^{\aleph_0} = \aleph_1; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

because

$$2 \cdot \aleph_1 = \aleph_1, \aleph_1^2 = \aleph_1, \aleph_1^{\aleph_0} = \aleph_1, \aleph_1^{\aleph_1} > \aleph_1;$$

we cannot, however, yet assert the equation (9). Some investigations on this important question will be given subsequently.

Little Close, Yateley, Hants.
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XXXIII. *On the Motion of Radium in the Electric Field.*

By J. JOLY, D.Sc., F.R.S.†

A LIGHT disk, delicately suspended, and coated upon the one side with a few milligrammes of radium bromide of high activity, exhibits, when an electrified body is brought near to it, motions very different from what would be observed in the case of an inactive substance. The usual sequence of attraction, electrification, and repulsion are replaced by the following effects. The electrified body, whether positive or negative in sign, *repels* the suspended body if brought up to it *on the side coated with radium*, but attracts it if presented at the naked side.

Before attempting an explanation I will describe the experiment which first gave rise to this observation.

Two thin microscope cover-glasses about 12 mms. in diameter, are attached at the extremities of a glass fibre

* *Amer. Journ. of Math.* vol. xxiv. (1902) pp. 393, 394.

† Communicated by the Author.

about 6 cms. long, their surfaces lying in the same plane. A short piece of a fine needle is fixed by cement at the middle of the fibre, perpendicularly to it and in the plane of the vanes, so that when the needle-point is poised upon a smooth surface a radiometer-like instrument with vanes in a vertical plane is provided. A drop of alcohol is placed upon a face of one of the cover-glasses and about half the contents of a 5-milligramme tube of radium bromide poured over it. The alcohol and radium are carefully spread over the surface and warmed over a lamp till the radium is alone left adherent to the glass. The second vane is treated in the same manner, but upon the alternative or opposite face—the, rotationally, similar face.

A glass receiver is turned over the little mill, some calcium chloride being placed beneath. If now an electrified body, such as a rod of ebonite rubbed on cat's skin or glass rubbed on silk, is brought up close to the receiver, there is a rotational motion imparted to the vanes, which becomes much more marked and decisive as to its direction if the pressure of the air under the receiver is reduced to about 5 or 6 centimetres; and may then become so violent as to cause the vanes to refuse to remain upon the support. It matters not what the sign of the electrification, the rotation is always in the one direction, and in such a sense that the radium-covered surface is repelled from the electrified body. A steady rotation is best obtained by placing the mill between metal plates (contained under the receiver), which can be connected with a small Wimshurst machine. A little consideration will show that this unidirectional rotation is a result of the effects described above.

The rotation persists at pressures of a couple of millimetres, but, I think, more feebly. I have not extended the observation to high vacua.

In order to examine the effect more closely a radium-coated cover-glass was attached to the beam of a Coulomb's balance, which was modified in such a way that the fixed metal sphere could be charged from without. It was then found that sharp repulsion was produced when the sphere was opposite the radium-coated surface and charged with positive or negative electricity, and that there was equally definite attraction when the sphere was upon the naked side of the glass, whatever the sign of the charge. If, however, the charge given is very intense and the radium is very close to the sphere, there may be attraction in every case.

It is possible to frame more than one explanation of this peculiar behaviour of a radium-coated body in an electric

field. Thus (a) we might ascribe it to the presence of electrified particles or ions of *both* signs in the region between the radium and the fixed electrified body. We may suppose these ions are not strongly attracted to the vane carrying the radium, and more abundant in front than at the rear of the vane. Then if a plus charge is presented opposite the radium the positive particles are repelled against it, the negative withdrawn. The first effect produces mechanical repulsion of the vanes, the second a relatively small force in the opposite sense. A minus charge acts in the same manner, the repulsive force being now caused by the negative ions. If the charged body is behind the disk, a mechanical force acting in the same sense as before is occasioned by the *attractions*, the repulsions being now ineffective.

(b) The presence of the charged body induces a charge of opposite sign upon the radium, and repels a charge of like sign to the remote side of the disk. The first (attractive) charge rapidly dissipates in virtue, chiefly, of the ionizing influence of the α -rays, the second (repellent) charge remains to exert a mechanical effect upon the vane. Too intense a charge may cause the attractive effect to predominate.

Some experiments were made to decide among these possible sources of unidirectional motion. Five milligrammes of radium bromide were divided between two thin metal disks, 12 mms. in diameter, which were then attached in a vertical plane at the extremities of the beam of the Coulomb's balance and in the plane of the beam. Fine aluminium wires were brought from the vanes nearly to the centre of the beam. The beam was a drawn glass tube, and the suspension was a fine quartz fibre. A U-shaped rider with two hooks, suspended from the beam at its centre, served to place the disks in metallic connexion. Removal of the rider disconnected them. A second fixed metal sphere was added to the balance diametrically opposite the usual one, and all was adjusted so that when the torsion-head was turned the disks could be brought up to the spheres, each presenting its radium-coated surface to one of the spheres. The spheres could be charged from without either singly or connected together. Drying material was placed in the balance.

If explanation (a) is correct, *i. e.* that the effect is due to the pressure of electrified particles, then whether the vanes are electrically connected one with another or not should make no difference in the repulsion of the vanes. It was found, however, that when one of the spheres is electrified and the vanes are connected there was no repulsion, but, on the contrary, a brisk attraction, whatever the sign of the

charge. Breaking the connexion restores the repulsive effect. If the spheres are connected with each other and the vanes are also connected one with another, then when a charge is given to the spheres there is repulsion.

Now evidently this behaviour is in favour of assuming that the repulsive effect is due to the preponderating influence of a charge given to the vane by induction, for such a charge would, when the vanes are connected, be repelled to the remote end of the beam. When the charged body is presented at both ends of the beam and the vanes are connected, the repulsive charge must remain in the vanes, and accordingly there is repulsion.

Rather unintentionally a further experiment was made supporting these results. Vanes of very thin mica had been mounted radiometer-fashion at the extremities of an aluminium wire beam. The wire was stitched through the mica, and was therefore in good contact with both sides of the vane. When those vanes were coated on alternate faces with radium bromide the mill refused to rotate decisively in any one direction, but showed, if anything, a tendency to rotate in the "attractive" direction. I at first ascribed this to the use of vanes too thin in substance, but subsequently, in accordance with the view that electrical connexion between the vanes must destroy the rotation, I substituted a glass fibre for the wire. The mill now rotated freely and in the "repulsive" direction in the electric field. The experiment suggests that the mica itself must have acted as a conductor under the influence of the radium.

On the question as to how far it is an induced or a conducted charge which leads to the repulsion of the radium-coated vane when the radium is presented towards the charged body, it is to be observed that not only some of the preceding experiments but also the rapidity with which the repulsion succeeds the charging of the sphere are in favour of ascribing the effect to induction. Quantitative measurements would be required to fully elucidate the matter. Possibly there is some direct ionic conduction of the charge as well as the inductive effect, and, of course, the experiments do not exclude the existence also of some mechanical effect from the transport of electrified particles, but they serve to show that the latter effect must, at best, constitute but a small part of the force acting upon the vanes.

Another source of rotation is to be sought for in the reactionary force attending the discharge of α -radiation. It is improbable that any intensification of this discharge in the electric field, sufficient to give rise to the effects observed,

could hitherto have passed unnoticed. Normally the effect is too small to be considered. This force might, however, be successfully looked for with larger quantities of radium. According to Rutherford (Phil. Mag. May 1903, p. 588) the kinetic energy of each α -ray is 10^{-5} ergs and their velocity 2.5×10^9 cms.; hence $MV = 8 \times 10^{-15}$ dynes, and this is the force for one ray projected. If 2×10^5 rays per second are projected from each milligramme of radium having an activity one million times that of uranium, the reactionary force of 100 milligrammes is 1.6×10^{-6} dynes. This should be observable, but complications would arise from motions due to thermal convection-currents in the surrounding gas arising from the spontaneous evolution of heat in the radium. The latter source of energy would, indeed, probably be sufficient to alone determine a rotation with suitably disposed vanes.

XXXIV. *Notices respecting New Books.*

Traité de Chimie Physique. Les Principes. Par JEAN PERRIN, Chargé du Cours de Chimie Physique à la Faculté des Sciences de Paris. Paris: Gauthier-Villars. 1903. Pp. xxvi + 299.

ONE of the indications of the rapid strides which are being made in physical chemistry, and of the increasing interest which is being taken in this highly important but difficult branch of science, is the appearance within recent times of several important textbooks on the subject. Of these, the book now under review must be regarded as one of the most important.

Modern theories of chemical equilibrium are based on thermodynamical methods; and in the whole range of science there is probably no subject which presents greater difficulties to the beginner or is more full of pitfalls than thermodynamics. That such is the case has been abundantly proved by the somewhat heated controversy regarding entropy carried on recently in a number of leading technical journals. Students of this subject will therefore feel grateful to M. Perrin for the fearless manner in which he handles real difficulties, and for the searching criticism which he brings to bear on slovenly or superficial methods of exposition. He may, at times, be hypercritical and somewhat too fastidious, but the reader can only be the gainer by such scrupulous care in the handling of a difficult subject.

The present volume is the introductory one of a comprehensive treatise, and a brief outline of its contents will give some idea of its scope. Chapter I. deals with the notion of generalized forces, Chapter II. with the factors of energy, Chapter III. with the principle of equivalence of the various forms of energy, Chapter IV. with the part played by the various factors of energy in producing changes in a system, Chapter V. with the principle of evolution, according to which the physical universe never returns to a previous state of existence, Chapter VI. with the characteristics of