

physical interest, it does have a purely mathematical interest, and I shall therefore determine also these orbits.

The expression which must be integrated is ⁴

$$\frac{d\mathbf{v}}{dt} \cdot \frac{d\mathbf{v}}{dt} = \left(\mathbf{v} \times \frac{d\mathbf{v}}{dt} \right) \cdot \left(\mathbf{v} \times \frac{d\mathbf{v}}{dt} \right), \quad (8)$$

provided the units are so chosen that the velocity of light is 1. Let R be the radius of curvature of the orbit (in ordinary space). The tangential and normal resolution of acceleration throws (8) into

$$\left(\frac{dv}{dt} \right)^2 + \frac{v^4}{R^2} = \frac{v^6}{R^2} \quad \text{or} \quad \left(\frac{dv}{ds} \right)^2 = \frac{v^4 - v^2}{R^2}.$$

Hence

$$v = \sec \int \frac{ds}{R}. \quad (9)$$

If then any space curve be given intrinsically by the equation $R = f(s)$, equation (9) determines the velocity at which the curve must be traced if there is to be no radiation as estimated by the usual electro-magnetic formula.

¹ See H. A. Lorentz, *Theory of Electrons*, Art. 37, B. G. Teubner, Leipzig, 1916.

² See M. Planck, *Theorie der Wärmestrahlung*, p. 110, J. A. Barth, Leipzig, 1906.

³ Wilson, E. B., *Boston, Proc. Amer. Acad. Arts Sci.*, 50, 1914, (105-128).

⁴ See Wilson and Lewis, *Ibid.*, 48, 1912, (387-507), especially p. 481.

THE EFFECT UPON THE ATOM OF THE PASSAGE OF AN ALPHA RAY THROUGH IT¹

BY R. A. MILLIKAN, V. H. GOTTSCHALK AND M. J. KELLY

RYERSON PHYSICAL LABORATORY, UNIVERSITY OF CHICAGO

Read before the Academy, November 11, 1919

In 1910, by catching at the instant of ionization the positive residues of atoms ionized by X-rays, and by beta and gamma rays of radium, it was conclusively shown² that the act of ionization by these agencies uniformly consists in the detachment of a single negative electron from a neutral atom.

The method consisted in balancing the force of gravity acting upon a minute oil-drop by a strong vertical electrical field, holding the oil-drop under observation in a telescope with the aid of a powerful beam of light,

passing a sharply limited beam of X-rays, beta rays or γ rays immediately underneath the drop, catching upon the drop the positive ion, formed by the ionization of a neutral molecule by the rays under investigation, and finally measuring the charge communicated to the drop by the advent of the ion upon it through observing the speed imparted to the drop by its new increment in charge.

Just before the war, Millikan attacked the more difficult and the more interesting problem of catching by the same general method, the ions formed by the passage of an alpha particle through an atom, expecting in this case to find that this relatively huge and powerful ionizing agent would often detach more than one negative electron from a single atom. When he was called to other duties by the war, the experimental work already begun was continued and completed by Gottschalk and Kelly. The results are as follows:

1. Alpha rays have been shot through atoms of the most diverse sorts (H, C, O, N, Cl, I, Hg) and of atomic weights from 1 to 200, without bringing to light in any case evidence of the formation of multiply-valent ions.

2. Twenty-nine hundred ions formed by the passage of α rays through neutral molecules have been caught on oil drops at the instant of ionization and the charges carried by each of these ions individually measured. Of these 2900 captures, 5 might possibly have corresponded to double charges, though even these were in all probability due to the nearly simultaneous advent upon the drop of two singly charged ions.

3. In no single case has an α particle been observed to form an ion carrying three or more charges, even though mercury, from which octivalent ions had been expected, was one of the substances tested.

4. *Alpha ray ionization consists, then at least 99 times out of a 100, in the case of all the gases and vapors studied, in the detachment of a single negative electron from a neutral molecule.*

¹ A detailed report of these experiments will shortly be published in the *Physical Review*.

² Millikan, R. A., and Fletcher, H., *London Phil. Mag.*, (Ser. 6) 21, 1911, (753).
