NOTE ON THE ELECTROMAGNETIC FORCE BETWEEN TWO ATOMS.

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SYNOPSIS.

Making use of results obtained in a previous paper giving the average radial repulsion exerted by a charge e on a charge e' when both charges are revolving in circular orbits at a great distance, the author obtains a formula for the force between atoms. He concludes, in reply to a criticism by A. C. Crehore,—

In a passive neutral atom the radial force vanishes completely.

When both atoms are ionized there is a residual force, negligible in comparison with an electrostatic force which may be taken to represent the chemical force between the ions.

When one atom is neutral and the other ionized, the electrostatic force vanishes, leaving a residual force, which is estimated to be too small to play anything but a very small part in chemical actions.

1. Crehore's preliminary reply[1] to my criticism[2] of his first paper[3] has just come to my notice. Previously I purposely confined my attention as far as possible to the supposed gravitational attraction between two revolving *electrons*, but now Crehore has raised the question of the force between *neutral atoms*, so I will consider it briefly.

The problem is to calculate the average radial force, to the order of the inverse square of the distance, exerted by an atom of type 2 on an atom of type 1, both being supposed symmetrical about an axis, and the axes distributed uniformly in all directions on the average for a large number of atoms. My formula (50), p. 37, gives the average radial repulsion, F, exerted by a charge e, revolving in a circle with β times the speed of light, on another charge e' at a great distance r in the form

$$F = ee'\{1 + f(\beta)\}r^{-2}, \qquad f(\beta) = \beta^2\left(\frac{1}{1-\beta^2} - \frac{1}{2\beta}\log\frac{1+\beta}{1-\beta}\right). \quad (1)$$

The formula (54), p. 456 of Crehore's earlier paper, when averaged for all directions of the axes of the orbits, is of the same form, but

$$f(\beta) = -\tfrac{1}{3}\beta^2. \quad (2)$$

The speed of the second charge e' does not occur at all, so that the law of action and reaction is violated, as Crehore objects. But this violation

[1] A. C. Crehore, PHYS. REV., Vol. XIII., p. 89.

[2] G. A. Schott, PHYS. REV., Vol. XII., p. 23.

[3] A. C. Crehore, PHYS. REV., Vol. IX., p. 445.

follows directly from the use of retarded potentials, which express the fact that electromagnetic force, momentum and energy require time for their propagation. Without it we could not even account for electromagnetic mass, which is a result of the unbalanced internal electromagnetic forces between the parts of the electron.

2. In applying (1) to the problem of the atoms we replace e, β, e' by $-e_2$, β_2, $-e_1$, or by E_2, O, E_1, according as we seek the actions between the electrons, or the positive nuclei, of the atoms. The average radial repulsion is the sum of these four terms:

$$\left.\begin{array}{lll} (a) & \text{Electrons 2 acting on electrons 1:} & \Sigma e_1 \Sigma e_2 \{1 + f(\beta_2)\} r^{-2}, \\ (b) & \text{Electrons 2 acting on nucleus 1:} & -E_1 \Sigma e_2 \{1 + f(\beta_2)\} r^{-2}, \\ (c) & \text{Nucleus 2 acting on electrons 1:} & -\Sigma e_1 E_2 r^{-2}, \\ (d) & \text{Nucleus 2 acting on nucleus 1:} & E_1 E_2 r^{-2}, \end{array}\right\} \quad (3)$$

Hence we find

$$F = \{(\Sigma e_1 - E_1)(\Sigma e_2 - E_2) + (\Sigma e_1 - E_1)\Sigma e_2 f(\beta_2)\} r^{-2}, \quad (4)$$

where the summations are for all the electrons of the two atoms. The first term represents the electrostatic repulsion, the second a comparatively small residual force, which for low speeds is of the order β_2^2 with (2), but only of order β_2^4 with (1). There are three cases:

(1) *Passive atom neutral*; $\Sigma e_1 = E_1$.

The radial force F vanishes altogether.

In my opinion this disproves Crehore's objection to (1). He himself obtains a different result, because he retains the term $f(\beta_2)$ in (3*a*), but omits it in (3*b*); in other words he treats a passive nucleus differently from a passive electron, although the velocity of neither one nor the other occurs in (1) or (2). I cannot see any reason for this different treatment of passive negative and positive charges. It is different with Crehore's modified formula, which differs from (2) by the presence of an additional factor, viz., the square of β for the passive charge multiplied by a positive constant, chosen so as to account for ordinary gravitational attraction. Since (2) ought to be replaced by (1), the chief reason for this change disappears; besides, as it makes the formula agree with the law of action and reaction, it is difficult to reconcile it with the explanation of electromagnetic mass.

(2) *Both atoms ionized*; $\Sigma e_1 \neq E_1$, $\Sigma e_2 \neq E_2$.

The residual force may be neglected in comparison with the electrostatic force, which may be taken to represent the chemical force between the ions according to the usual interpretation.

(3) *Active atom neutral, passive atom ionized*; $\Sigma e_1 \neq E_1$, $\Sigma e_2 = E_2$.

The electrostatic force vanishes, and we are left with the residual force

$$F = (\Sigma e_1 - E_1)E_2 f(\beta_2) r^{-2}.$$

Since $f(\beta_2)$ is essentially positive according to (1), this force is a repulsion, or an attraction, according as the passive ion is negative, or positive. Taking β_2 to be of the order 0.01 we see that the force is only of the order of one hundred-millionth of ordinary chemical forces. Thus it is not likely to play anything but a very small part in chemical actions, though it might conceivably be influential in solution phenomena and others of like nature. I think that I was quite justified in my former paper in expressing a doubt as to the possibility of detecting its existence by experiment.