[2] Blakeslee, A. F., 1921, *Amer. Nat.*, **55**, 254–267.
[3] Blakeslee, A. F., and John Belling, 1924, *Jour. Hered.*, **15**, 194–206.
[4] Dwarf, Wedge, Mutilated, Sugarloaf, Polycarpic, Scalloped, Elongate, Nubbin, Pinched and Hedge belonged to line 1, not line 1A. Maple arose in an extract from the related lines 1 and 2 and has been several times back-crossed to line 1A. Wiry and Undulate arose in extracts from lines 1 and 4 and have been back-crossed to line 1A.
[5] Exceptions: Maple, derived from lines 1 and 2; Wiry, Elongate and Undulate derived from lines 1 and 4.
[6] Blakeslee, A. F., 1924, these PROCEEDINGS, **10**, 109–116.
[7] Belling, John, and A. F. Blakeslee, 1924; *Ibid.*, **10**, 116–120.
[8] Belling, John, and A. F. Blakeslee, 1926, *Ibid.*, **12**, 7–11.
[9] Blakeslee, A. F., 1922, *Amer. Nat.*, **56**, 16–31.
[10] Belling, John, and A. F. Blakeslee, 1924, *Amer. Nat.*, **58**, 60–70.
[11] Blakeslee, Belling, Farnham and Bergner, 1922, *Science*, **55**, 646–647.
[12] Blakeslee, A. F., and John Belling, 1924, *Ibid.*, **60**, 19–20.
[13] Belling, John, and A. F. Blakeslee, 1922, *Amer. Nat.*, **56**, 339–346.

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# *REMARKS ON PENETRATING RADIATION*

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The recent measurement by Millikan[1] and by Myssowsky and Tuwim[2] of the coefficient of absorption of the penetrating radiation which is the source of the small residual ionization always found in closed vessels,[3,4] has stimulated thought,[5,6] on the origin of this penetrating radiation. The extreme shortness of the estimated wave-length, 0.00038 Å makes it apparent that the source of this radiation must lie in a radiative process involving the very smallest units of matter—the electron and the proton. In this brief note I desire to record a calculation whose result is in surprising agreement with the measurements, a result which because of the difficulties involved I can scarcely regard as more than coincidence. But perhaps it is not.

Let it be supposed that an electron is a sphere of negative electricity of uniform density $\rho$ and radius $r_0$. Suppose also that relative to $r_0$ the proton can be regarded as a point charge. A proton can thus have an equilibrium position inside the electron just as an electron was supposed to be in equilibrium inside a sphere of positive electricity in the atom of three decades ago which served for Lorentz classical theory of the Zeeman effect. Given such a "neutron" the work required to take the proton to the surface of the electron is easily seen to be $e^2/2r_0$ and the work to take it to infinity against the Coulomb force is $e^2/r_0$. Suppose one assumes that this energy of separation of the neutron into its parts is equal to the relativistic equivalent of the mass of the electron; then one has

$$\frac{3}{2}\frac{e^2}{r_0} = mc^2 \quad \text{or} \quad r_0 = \frac{3}{2}\frac{e^2}{mc^2}.$$

These assumptions therefore yield an electron whose radius is $^9/_4$ that of the usual theory which supposes the charge to have a surface distribution on a sphere.

When the proton is displaced from its equilibrium position it is acted on by a Hooke's law restoring force of amount $e^2x/r_0^3$ if $x$ is the displacement. If $\mu$ is defined by $1/\mu = 1/m + 1/M$, $M$ being the mass of the proton, the "neutron" can thus execute simple harmonic oscillations of frequency (in spectroscopic $cm.^{-1}$ units):

$$\nu = \frac{1}{2\pi}\sqrt{\frac{2}{3}\frac{m}{\mu}}\cdot\frac{1}{r_0}.$$

Since $\mu$ and $m$ are almost equal, this becomes, in terms of $r'$ the radius of the electron on the surface distribution theory

$$\nu = \frac{1}{2\pi}\sqrt{\frac{2}{3}}\cdot\frac{4}{9}\cdot\frac{1}{r'}.$$

The value of $r'$ is known to be $1.87 \times 10^{-13}$ cm. so that one has

$$\nu = 3.09 \times 10^{11} \text{ cm.}^{-1}.$$

Turning to experiment one finds that Millikan's estimated wave-length gives an observed frequency

$$\nu = 2.63 \times 10^{11} \text{ cm.}^{-1}.$$

As a second part of this paper, I desire to point out a geometrical consideration which enters into the determination of the absorption coefficient $\mu$ in $I = I_0e^{-\mu x}$ from the observed data. As it is supposed that the radiation comes from all directions in space, the law of decrease of intensity of the radiation with depth in a lake will not be a simple exponential absorption of the rays from different directions and hence of different lengths of path in the absorbing medium.

It is easy to see that if $x$ is the vertical depth into an absorbing medium of infinite extent measured from its plane surface then the intensity at this depth is given by

$$I = I_0\int_0^{\pi/2} e^{-\mu x \sec.\theta} \sin\theta\, d\theta$$

where $I_0$ is the intensity at zero depth. Carrying out the integration one has $I = I_0[e^{-\mu x} + \mu x \Sigma i(-\mu x)]$, in which $\Sigma i(-\mu x)$ is the exponential integral $\Sigma i(z) = \int_{\infty}^{-z} \frac{e^{-\mu}}{u} du$, tables of which are in the collection of Jahnke-Emde (Teubner, 1923). (Compare this problem with that of Rutherford, "Radioactive Substances and Their Radiations," p. 262. There is an error on this page in that the factor $\mu d$ is lacking from the integral term.)

If one plots the simple exponential law, and this corrected absorption law, it is readily seen that in reducing experimental data for which $I/I_0$ observed is from 0.2 to 0.8 one would overestimate the value of $\mu$, *i.e., one would understate the penetrating power by a factor of 2 or 3 in the absorption coefficient.* The ratio varies according to the following table:

| $I/I_0$ | 0.8 | 0.6 | 0.4 | 0.2 |
|---|---|---|---|---|
| Ratio = $R$ | 3.66 | 2.78 | 2.42 | 2.00 |

These considerations at once point to an alternative explanation of a fact observed by Millikan, namely that the rays appear to have a spectrum. That is, he finds that his observations show a systematic deviation from the exponential law in the sense that $\mu$ appears to decrease with increasing depth. That is, at greater depths the average penetrating power of the rays is greater as though the rays consist of a spectrum of radiations having different absorbing powers.

It is, however, clear that *the observed behavior is exactly that of the behavior of a beam of truly homogeneous radiation under the conditions of the experiment.* For if $\mu$ is the absorbing power where the intensity ratio is $I/I_0$ as computed from an exponential law, then $\mu_c$ the true absorption coefficient is given by $\mu_c = \mu/R$, where $R$ is the appropriate value taken from the table. As $R$ decreases with increasing depth it is evident that $\mu$ must also decrease with increasing depth to preserve the true constancy of $\mu_c$. Thus it appears that the rays may be homogeneous in wave-length and that *the observed deviations from the exponential law find their explanation in the geometrical conditions of the experiment.*

The effect of dividing Millikan's observed $\mu$ by 2 is, roughly, to multiply the corresponding frequency of radiation by $\sqrt[3]{2}$ as the extrapolation assumes, in the main, a variation of $\mu \propto \nu^{-3}$. This would make the observed frequency be

$$\nu = 3.31 \times 10^{11} \text{ cm.}^{-1}.$$

The full effect of this geometrical correction does not make itself felt, however, since the $I_0$ of Millikan is not measured at the surface of the absorbing medium but at the bottom of the earth's atmosphere which represents a considerable penetration into the absorbing medium. It is easily seen that the effect of such penetration is to work toward making the residual radiation a parallel beam to which the exponential law applies.

Therefore one may say that the agreement of the radiation frequency of the "neutron" here proposed and the experimental frequencies is perfect. However, this neutron faces two serious difficulties. In the first place, the classical radiation reaction, roughly estimated, indicates that such an oscillator would be overdamped and hence would not oscillate. Secondly, it is not big enough to oscillate with one quantum of energy without going to pieces so that a quantum picture cannot be invoked in its support. The discussion given indicates, however, that the geometrical conditions of the experiment have an important effect on the value of $\mu$ inferred from the observations and this should not be neglected.

[1] Millikan, *Proc. Nat. Acad. Sci.*, **12**, 48 (1926).

[2] Myssowsky and Tuwim, *Zeits. Physik*, **35**, 299 (1925).

[3] McLennan and Burton, *Physic. Rev.*, **16**, 184 (1903).

[4] Rutherford and Cooke, *Ibid.*, **16**, 183 (1903).

[5] Jauncey and Hughes, *Proc. Nat. Acad. Sci.*, **12**, 169 (1926).

[6] Jeans, *Nature*, Dec. 12, 1925.

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## *NEW EVIDENCE IN FAVOR OF A DUAL THEORY OF METALLIC CONDUCTION*

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In these PROCEEDINGS for October, 1925, Professor Bridgman, after stating that he has discovered a Peltier development of heat where an electric current changes direction within a metal crystal, remarks, "The mere existence of an internal Peltier heat would seem to have important bearings on our views of the nature of electrical conduction. I cannot see that any of our ordinary pictures of electrical conduction would lead us to expect a reversible absorption of heat on changing the direction of current flow." Shortly after reading this passage I called Professor Bridgman's attention to the fact that a formula which I had published some years ago,[1] as the dual-theory expression for Peltier heat, gives a ready explanation of the newly observed phenomenon. This he at once saw, though he had overlooked it before.

The formula is this,

$$\Pi_{\alpha\beta} = \left(\frac{k_f}{k}\right)_\beta \lambda_\beta - \left(\frac{k_f}{k}\right)_\alpha \lambda_\alpha, \qquad (1)$$

where $\Pi_{\alpha\beta}$ is the amount of heat, in ergs, absorbed by the unit quantity of electricity, $(1 \div e)$ electrons, in going from metal $\alpha$ to metal $\beta$, $(k_f \div k)$