LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twenty-eighth of the preceding month; for the second issue, the thirteenth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

An Unusual Spectral Series

The recent measurement by Selwyn (Proc. Phys. Soc. London **41,** 361, (1929)) of certain copper arc lines in the Schumann region have led to the identification of the following terms (mostly known as levels previously) of the ordinary $d^{10}np\ ^2P$ series of Cu I.

Designation	*Level*	*Interval*	*Ryd. denominator*
$4p^2P$	31772.8	248.4	1.858
	31524.4		1.865
$5p$	21925.0	−0.3	2.913
$6p$	7523.9	−243.6	3.818
	7280.3		3.881
$7p$	4889.4	+530.6	4.737
	4358.8		5.016
$8p$	3031.9	− 47.0	6.015
	2984.9		6.063

It is not surprising that such an array was not previously considered to form a series, but the evidence is now quite conclusive. The appearance of intervals of both signs from a configuration in which only one electron is not in a closed group is at variance with our ordinary ideas of the production of spectral terms. The explanation will probably be found when the wave mechanics is able to account for the occurrence of inverted ^2D and ^2F terms in the simple doublet spectra of the alkali metals. Such an explanation has not as yet been given.

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On the Possibilities of a Gravitational Drag of Light

I suggested in a recent paper[1] that the well known velocity distance relation for extra-galactic nebulae might possibly be accounted for by a gravitational drag of light. In this paper I discussed the momentum which a particle m moving in a straight line with the velocity v transfers to a mass M initially at rest. The velocity c was assumed for the gravitational waves. For the change of momentum of m along its path an expression of the following type was obtained:

$$\Delta G=(fmM/v)\left[g_0+g_1v/c+g_2(v/c)^2+\cdots\right] \quad (1)$$

where g_0 is due to the static gravitational potential and the rest of the terms represent the retardation, g_1 not being equal to zero. Now Professor Eddington kindly informs me in a letter that g_1 should be zero on account of the following consideration. The retarded potential can be represented as this series[2]

$$\Phi(r,t)=\left.\frac{\text{const.}}{r(1-v_r/c)}\right|_{t'=t-r/c}=\left.\frac{\text{const.}}{r}\right|_{t'=t}+ \quad (2)$$

terms of second and higher order in v/c. As the forces are derived from Φ they do not contain any terms in v/c and ΔG should therefore not contain any such terms either. This is actually so provided that the particle m is moving along the straight line without being started or stopped. But if it is started from rest at P_1 and stopped at P_2 a term in v/c appears as given in my paper. This is due to the fact that at the time t_0 at which the signal from the start at P_1 has reached M, the mutual distance of the two particles

[1] F. Zwicky, Proc. of the Nat. Acad., Oct. 1929.

[2] A. S. Eddington, Phil. Mag. **46** 1112 (1923).

differs from P_1M in terms v/c. It may very well be that the way in which I have introduced the time limits for the interaction between M and m is not justified. The problem is indeed quite complex because of the fact that the expulsion of a particle (light quantum) is accompanied by a direct recoil (atom) which would have to be considered.

It seems to me however that the question whether g_1 is zero or not has no direct bearing on the question of the existence of a gravitational drag of light. Indeed for $v=c$ all the terms in (1) become of equal importance. The above consideration for a moving particle of matter was given in my paper for the sole purpose of illustrating the effect of the retardation on the transfer of momentum. Any relation of the type (1) holds of course only for $v<c$. Only dimensional extrapolations can be made for $v=c$. It was therefore always my opinion that the existence of a gravitational drag of light must be derived or disproved from the general theory of relativity.

An approximate relativistic solution of the problem might possibly be obtained in this way. Suppose that a quantum $h\nu$ is passing by a mass M (star, etc.). If we hold M fixed, then the path of the quantum is given by Einstein's solution. Let now M recoil, but retain as a first approximation Einstein's path for the light. Then four unknowns have to be determined; namely, the three velocity components of M and the resulting shift in frequency from ν to ν'. The four generalized equations for the conservation of "momentum" and "energy" should yield the necessary relations for the unknowns.

Finally I wish to mention some observational tests related to the velocity of recession of nebulae which might decide between a "geometrical" theory (de Sitter) and a physical explanation. In the latter case, the red-shift should essentially depend on the distribution of matter in space, which might result in some of the following phenomena.

(a) A dependency of the red-shift on direction should be expected, especially within our own galactic system.

(b) For very dense clusters of extragalactic nebulae (like the Coma cluster for instance) its different nebulae might show differences in apparent radial velocities larger than those due to peculiar motions.

(c) If a nebula appears inclined to the line of sight, the light from the far edge might show a larger red-shift then the light from the near edge. The possibility of such an effect has also been mentioned by Dr. I. S. Bowen in conversation. Some observations of this type have been made by F. G. Pease[3] on the Andromeda nebula. His data indicate a slight difference in red-shift (20 km/sec) from the near edge to the far edge which is of the order of magnitude one should expect from the theory. The observational uncertainties involved are, however, too large to justify any definite conclusions.

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December 4, 1929.

[3] F. G. Pease, Proc. of the Nat. Acad. **4,** 21 (1918).

The Early Stages of Electric Spark Discharges

The broadening of spectrum lines in condensed spark discharges has been attributed to the Stark effect of inter-ionic fields. It occurred to us that probably the current density, and therefore the ionic density, in a spark is much greater immediately after breakdown than later and therefore that spectra at the beginning of spark discharges should be relatively more diffuse. By a slight modification, we have adapted the electro-optical shutter of Abraham-Lemoine and Beams to the observation of the width of spectrum lines at successive intervals of time after the beginning of sparks, and the results have led to interesting information on the density of the ions. We find, for example, that the spark doublets of Mg, Cd, and Zn are diffuse bands over 40A wide during 2 (10^{-7}) sec after breakdown. Assuming that the broadening of the lines is a second order Stark effect due to the ions in the discharge and with the aid of experimental data on the Stark effect of Mg we have calculated from our observations that *about 31 percent of the atoms and molecules in the path of the discharge are ionized.*

The electro-optical shutter has enabled us as well to measure the velocity of migration of the luminosity of the metallic spark lines from the anode. In the case of Zn the lumi-