[1] Armstrong, A. H., Duane, W., and Stifler, W. W., *Proc. Nat. Acad. Sci.*, **10**, 374 (1924).

Allison, S. K., Clark, G. L., and Duane, W., *Ibid.*, p. 379 (1924).

[2] Woo, Y. H., this number of these PROCEEDINGS.

THE SIGNIFICANCE OF THE DISCOVERY OF X-RAY LAWS IN THE FIELD OF OPTICS

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I. *The Extension of Moseley's Law to the Field of Optics.*—Through our recent stripping of all the valence electrons from one up through seven from the whole group of atoms, sodium, magnesium, aluminum, silicon phosphorus, sulphur and chlorine, and from one up through five from the group, lithium, beryllium, boron, carbon and nitrogen, we have obtained for the first time a long series of light atoms having an identical electronic structure, but a linearly increasing nuclear charge. It is precisely this combination of identity of internal electronic structure among heavy atoms with linearly increasing nuclear charge which is responsible for the existence of the Moseley Law in the X-ray field, and the so-called irregular-doublet law, which flows from it.

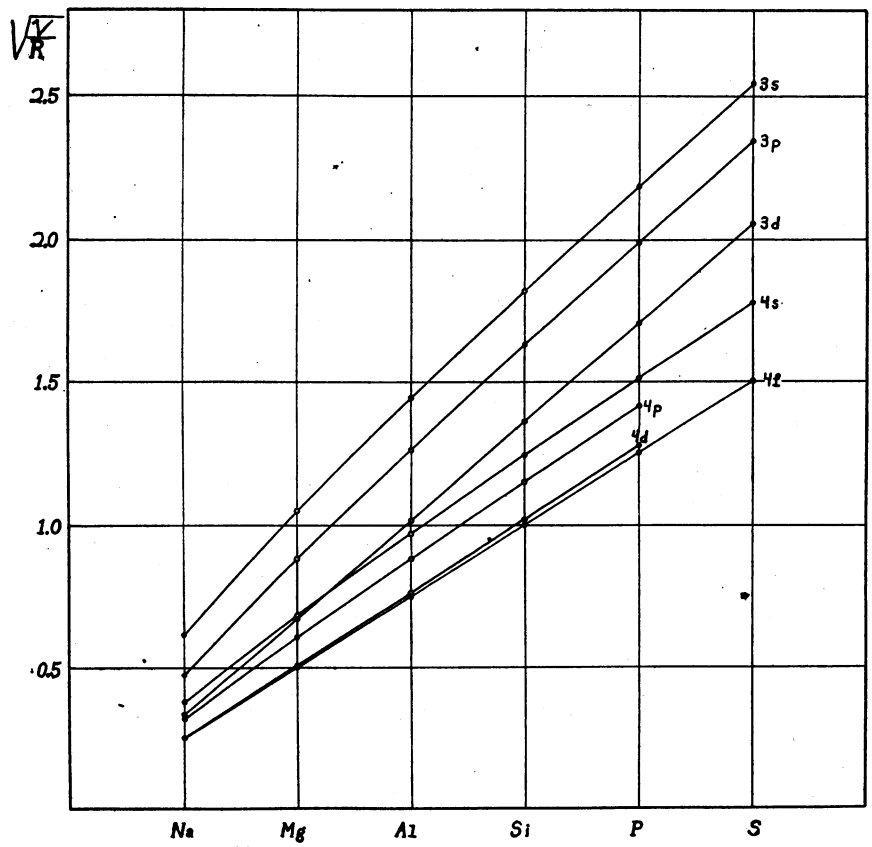
Through the recent working out[1] of all the important energy levels (term-values) of the spectra of the stripped atoms of phosphorus (*P V*) and sulphur (*S VI*) and the locating of the first term of the principal series of the stripped atom of chlorine (*Cl VII*) we have been able to complete the experimental proof *that the Moseley Law, with its corollary the irregular-doublet law, holds in the field of optics just as beautifully as in the field of X-rays.*

This work is soon to be reported in detail in the *Physical Review*, but figure 1, gives a very illuminating graphical proof of the foregoing statement. The Moseley Law is shown everywhere in this diagram in the linear progression of our measured term-values with atomic number. The irregular-doublet law is seen in the parallelism between the lines joining the 3*s* terms, the 3*p* terms and the 3*d* terms, or the 4*s*, the 4*p*, the 4*d* and the 4*f* terms.

When it is remembered that these terms are all in the visible or the ultra-violet region explored by ordinary grating methods, it will be seen that the proof is complete that the Moseley Law is quite as much an optical as an X-ray law.

II. *A Possible Interpretation of the Relativity Doublet Law.*—Our fur-

ther recent discovery,[2] that the regular or relativity doublet law also holds throughout the field of optics, instead of fitting in beautifully with theory as does the extension to the field of optics of the Moseley and Hertz laws, is extremely difficult to reconcile with the present status of physical theory. Indeed, we have recently shown[3] that the exact validity of this law in optics, if granted, forces us to choose between one or the other of two horns of a dilemma which may be stated thus;



The Moseley Law in the Field of Optics.
FIGURE 1

(1) The abandonment of relativity causes and effects altogether in electronic orbits or

(2) The abandonment of Bohr's interpenetration ideas and with them the practice of assigning azimuthal quantum numbers 1, 2, 3, 4, etc., to s, p, d, f terms, respectively.

For reasons which will be discussed more fully in a forthcoming article,[4] *both of these horns seem to us completely inadmissible.*

The only possible escape then was to discredit the completeness of our proof of the *exact* applicability of the relativity doublet law to the explanation of fine structure generally. This is what we have recently endeavored to do, both by further analysis and by further experimental work. The results of this study may be briefly summarized thus:

(1) The relativity doublet law does indeed account for fine structure in optics quite as well as in the field of X-rays. Combined with the Moseley law, it also has provided us with one of the most powerful tools thus far discovered for identifying the origins of spectral lines and working out spectral series.

(2) In neither the field of optics nor the field of X-rays, save in the case of atomic hydrogen and ionized helium (H and He^+) does the theoretical relativity doublet law, numerical constants and all, predict the observed fine-structure-separation within quite the limits of observational error. There must always be introduced a so-called screening constant s, which is essentially an arbitrary parameter with the aid of which the experimental and theoretical results are made to agree.

(3) It is a very remarkable fact, however, that in the three or four limiting cases in which we know what this screening constant ought to be, the relativity law applied to measured doublet separations yields *nearly* the correct value of s, but not quite so within the limits of observational error.

(4) This last fact furnishes some little justification for finding a break in the continuity of our proof of the quantitative applicability of the relativity formula to the fine structure of the spectra of all atoms from hydrogen to uranium. This break we make between ionized helium and lithium and hence consider the cause of the fine structure of atomic hydrogen and ionized helium to be the relativity cause as has been customary heretofore; for this cause predicts quantitatively within the very narrow limits of observational error the observed separations.

(5) All other so-called relativity doublets, both the familiar ones in X-rays and our own newly discovered ones in the field of optics, we assume to be, in fact, not relativity doublets at all, despite their general following of the relativity law. We assign them instead to some new cause, of magnetic origin, or a combination of magnetic and electrostatic origin, which operates between the nucleus and two orbits of the same shape but different orientations with respect to the nucleus, and which not only follows very closely the same law of variation with atomic number (a fourth power law), with total quantum number (a third power law) and with azimuthal quantum number as does the relativity cause, but which has also nearly the same numerical constants as has that law.

The chief advantage in this apparently strange and difficult assumption of a fairly close accidental agreement between the effect of this new hy-

pothetical cause and the relativity cause is that, if we have no alternative between throwing overboard relativity as a cause altogether and postulating some other cause which, quite accidentally, leads to a formula in *exact quantitative* agreement with the relativity formula—such a postulate is necessary if the behavior of atomic hydrogen and ionized helium are to be placed within the scope of the new cause—or, on the other hand, postulating a new cause upon which the demands are a little less rigidly quantitative, even though still quite severe, we must of course make the second and less extreme choice; *for precise quantitative agreement between theory and observation constitutes by far the best evidence which we can have at all for the correctness of any of our physical conceptions.*

A crucial test of this assumed fundamental difference between the nature of the fine structure of the lines of hydrogen and ionized helium and those of all other atoms, ought to be found by comparing the behavior of these two different types of substances in magnetic fields. *In weak fields this sharp difference is actually manifested.* For hydrogen and ionized helium show the normal Zeeman effect, while lithium and the like show the anomalous Zeeman effect. In strong magnetic fields, on the other hand, the Paschen-Back effect, exhibited by lithium and the like as it should be, should not be exhibited by hydrogen and helium at all. This last crucial point has not yet been decided to a certainty, we think, by the experimentalist, though the evidence up to date is in favor of the existence of the Paschen-Back effect in the spectra of hydrogen and helium.[5]

Nevertheless, the evidence for a difference in kind between the fine structure of the lines of the two lightest elements, atomic hydrogen and ionized helium and that of lithium and all the elements beyond it is so good, despite their apparent similarity in behavior in strong magnetic fields, that we propose to attribute the doublets of atomic hydrogen and ionized helium to a true relativity cause, and to introduce a new non-relativistic cause, which, however, obeys an equation almost exactly like the relativity equation, to account for the behavior of lithium and the elements of higher atomic number. This is the only possible way to retain both Bohr's interpenetration ideas and Sommerfeld's relativistic treatment of electron orbits, and both of them seem at present to demand retention. To find a new cause for the relativity-doublet formula with only a little leeway in the value of the numerical constants is a problem worthy of the efforts of the theoretical physicist.

[1] Bowen and Millikan, *Physic Rev.* (in Press).

[2] Bowen and Millikan, *Ibid.*, Sept. 24, 1924, p. 209.

[3] Millikan and Bowen, *Ibid.*, Sept. 24, 1924, p. 228.

[4] Millikan and Bowen, "A Possible Reconciliation of Bohr's Interpretation Ideas with Sommerfeld's Relativistic Treatment of Electron Orbits."

[5] Oldenburg, *Ann. Physik* **67**, 253 (1922); Försterling and Hansen, *Zeit. Physik*, **18**, 26 (1923).