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 twentieth of the preceding month; for the second issue, the fifth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

Experimental Determination of the Distribution of Conduction Electrons in Metals

The most direct method of finding experimentally the distribution with energy of the filled conduction electron levels in a metal is to observe the intensity distribution in the x-ray bands which are emitted when electrons from the conduction group make transitions to replace the electrons which have been ejected from the relatively sharp atomic K or L-levels of the lattice. It is best to work with long wave-lengths; and the region of the extreme ultraviolet (40 to 500A), which contains the K-radiation of metals of the first row of the periodic table and the L-radiation of those of the second row, appears to be the most profitable field. A comparison between the beryllium K-band at 111A as observed by Söderman[1] and the predictions of theories of the Sommerfeld and Bloch types was made by Houston.[2] He concluded that the observed curve approximated more closely to what would be expected on the latter theory. But our experiments (with a tangential concave-grating spectrograph of 2 meters radius) have shown that the short wave-length edge of the beryllium band is very much sharper than Söderman, and later Prins[3] (who used plane gratings) had found. The difference in the results seems to be due mainly to the care we have taken in the preparation and treatment of the metal surfaces, which were evaporated and bombarded by electrons in a vacuum of the order of 10^{-6} mm. The result is that Houston's conclusion is reversed. As can be seen from Figs. 1 and 2, the beryllium band shows a quite close agreement with the prediction of the elementary Sommerfeld theory. In Fig. 1, Söderman's curve is dotted in for comparison. The agreement will certainly be improved on the long wave-length side of the band when the actual photometer curve of Fig. 1 is translated to intensities.

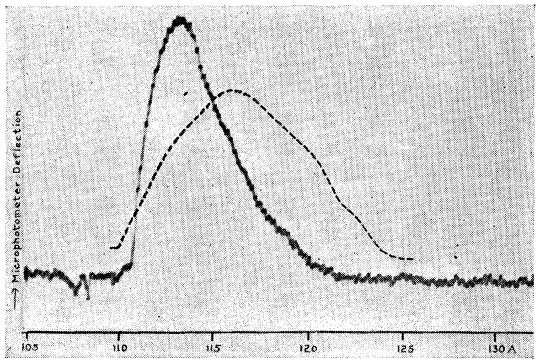

FIG. 1.

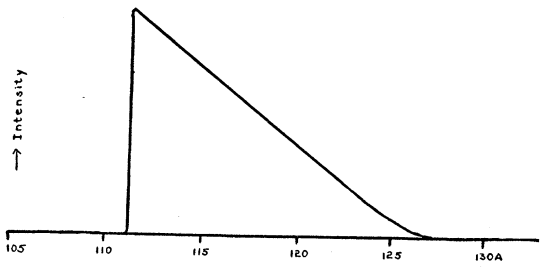

FIG. 2.

On the Sommerfeld theory, the conduction levels are filled up to an energy $E_0=(h^2/2m)(3n/8\pi)^{\frac{2}{3}}$, where n is the free-electron density. The intensity in a band would rise approximately as $E^{\frac{1}{2}}$ from the tail, until the value E_0 is reached; then, by neglecting small temperature effects, it would drop suddenly to zero. The drop for beryllium actually occupies about 2 volts; in most of the other metals tried, it is even more sudden. On the other hand, among the semiconductors, neither carbon nor silicon show this characteristic; their x-ray bands resemble very diffuse lines

TABLE I. *Observed and calculated widths of the x-ray bands from several elements.*

Element	Number of conduction electrons per atom	*Edge of Band* A	*Edge of Band* volts	Breadth observed (volts)	Breadth calculated (volts)
Li	1	225.3	54.9	4.2±0.6	4.6
Be	2	110.9	110.3	13.5±2	13.8
C	4(?)	45.4*	272.0*	<5	20.8
Na	1	405†	30.5†	3.5±1	3.2
Mg	2	251	49.2	8.9±1	7.2
Al	3	169.8	72.8	16.8±2	12.0
Si	4	120	102.5	20.0±3	13.0

* Center of band.
† Approximate.

[1] Söderman, Zeits. f. Physik **65**, 656 (1930).
[2] Houston, Phys. Rev. **38**, 1797 (1931).
[3] Prins, Zeits. f. Physik **69**, 618 (1931).

rather than the "triangular" shape which is characteristic of the genuine metals. A comparison between the Sommerfeld and the observed breadths for various elements is given in Table I. It will be observed that the breadth is given approximately even for the semi-metal silicon; only for carbon is there a marked disagreement.

The bands of the elements sodium to silicon show a type of structural complication which does not correspond to the multiplicity of the L-levels, and therefore must probably be interpreted as a structure effect of the conduction electron levels. It may perhaps represent a departure from the simple electron-gas theory of a type to be expected for a periodic lattice (Kronig zones). We shall defer discussion of this point, since the object of this note is to stress the fact that the bands of the metals are much more naturally represented by a theory of the Sommerfeld type than by one based on perturbed atomic levels. This remark holds even in the least favorable case, namely that of the alkali metals with their small electron densities.

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September 1, 1933.

Hyperfine Structure of the Rare Earths

In my recent publications on *The Dependence of Nuclear Moments on Atomic Number*,[1] through an oversight I failed to mention some of the earliest important work on the subject published by Dr. A. S. King.[2] He has shown that in general the spectra of the rare earths of odd atomic number possess rather wide hyperfine structure patterns, while the spectra of the even numbered rare earths are comparatively quite sharp. This indicates, among other things, that in general the rare earths of odd atomic number possess decidedly larger nuclear magnetic moments than those rare earths with Z even. This result is in complete agreement with the observation[1] that nuclei of Class II (Z odd, M odd) in general possess larger magnetic moments than those nuclei of either Classes III or I (Z even).

King[3] has since noted certain exceptions to this generalization, for the lines of thulium ($Z=69$) are apparently rather sharp while structure has been found in the spectrum of one of the even numbered rare earths. These exceptions may however be apparent only, for few thulium lines have been examined under high resolving power, and the structure observed in the spectrum of an even numbered rare earth may very possibly be due to isotope displacement. It is also to be expected that the even numbered rare earths will possess some isotopes with odd mass number (nuclei of Class III) which will in general have half integral nuclear mechanical moments, and magnetic moments different from zero by virtue of which their spectra might show hyperfine structure.

King[2] lists the probable numbers of components for many lines in the spectra of Eu, Tb, Ho and Lu. Since his spectrograms were taken under conditions of moderate resolving power, only a few of the hyperfine patterns are completely resolved. The numbers of components which he quotes are often therefore little more than an estimate, however, they are probably low, rather than high. It is possible therefore to set a lower limit to the value of I for the nucleus which gives rise to the observed structure.

In Table I King's results on the hyperfine structure of Eu, Tb, Ho and Lu are summarized and some conclusions are drawn regarding their nuclear mechanical moments. Unfortunately the isotopic constitution of these elements is unknown. From the atomic weights (assuming these to be fairly accurate) one can say something about their probable isotopic constitution—a tentative assignment is given in column 4. Previously interpreted results on Pr[4, 5] are included in the table for the sake of completeness. This table must not be taken too seriously for its main purpose is to show how little is really known about the nuclear properties of the rare earths. It is hoped that further study of the hyperfine structure of the rare earths will not only permit the accurate determination of their nuclear moments but may also furnish information regarding their isotopic constitution.

TABLE I. *Nuclear mechanical moments of some of the rare earths.*

Element	Z	Atomic Wt.	Probable isotopes	Greatest No. of h.f.s. components observed in flag pattern	Mechanical moment I
Pr	59	140.9	141	6	5/2
Eu	63	152.0	151 153	probably 4	probably $\geq 3/2$
Tb	65	159.2	159 161 (?)	6	$\geq 5/2$
Ho	67	163.5	163 165 (?)	6 (possibly 8)	$\geq 5/2$ (possibly $\geq 7/2$)
Tm	69	169.4	169 171 (?)	no h.f.s. observed	
Lu	71	175.0	175	4	$\geq 3/2$

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September 7, 1933.

[1] Grace, Phys. Rev. **44**, 58 and 361 (1933).

[2] King, Astrophys. J. **68**, 194 (1928), **72**, 373 (1930) and **74**, 299 (1931).

[3] King, private communication.

[4] Gibbs, White and Ruedy, Proc. Nat. Acad. Sci. **15**, 642 (1929).

[5] White, Phys. Rev. **34**, 1397 (1929).

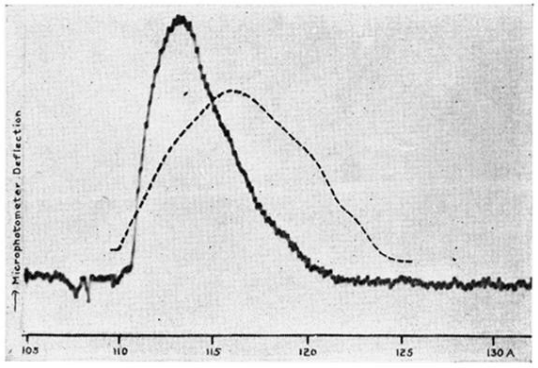

FIG. 1.