using Chambers'[9] values of the effective number of free electrons per atom in tin and copper.

The variation with the magnetic field $H$ of the resistance, expressed as a percentage $r$ of its value in zero field, for an electropolished single crystal of tin is shown in Fig. 1. The angles $\theta$ and $\phi$ describing the orientations of the tetrad and dyad axes of the crystal with respect to the normal to its surface are defined in reference 8. The upper and lower curves correspond to current flow $J$ in the $X$ direction parallel to the projection of the tetrad axis in the surface and the perpendicular $Y$ direction, respectively. For both orientations and for both the transverse case ($H\perp J$) and the longitudinal case ($H\|J$), the behavior is characterized by an initial rapid decrease of resistance, followed by a "resonance peak" and a linear decrease at a rather slower rate in high fields. If the field at the turning point is identified with the cyclotron resonance field $H_c$ in the expression $eH_c/m^*c=\omega$, the values of the effective mass $m^*$ range from 0.23 $m_0$ to 0.43 $m_0$. For a second tin specimen of a different orientation having $\omega\tau=20$, there was some evidence of an additional peak at a lower field, possibly a subharmonic resonance. For both specimens the resistance at high fields decreases much less rapidly than is implied by the expression $r=(2/3\omega\tau)\{2\pi H_c/H\}^{\frac{1}{2}}$ to which Azbel's[6] Eq. (7) reduces when $\omega\tau\gg1$ and $H\gg H_c$. This may be due to the complex geometry of the Fermi surface of tin[8] or to a pronounced anisotropy of the relaxation time, either of which might considerably modify the behavior.

Figure 2 shows the results for an electropolished single crystal of copper. Here the $X$ direction is the intersection with the metal surface of a plane containing the normal and two of the tetrad axes, one of which makes an angle of 28° with the normal. The absence of a resonance peak is to be expected when $\omega\tau\sim1$ (see Fig. 1 of reference 5). The decrease at high fields is not inconsistent with Azbel's formulation for this value of $\omega\tau$ if we take $m^*\sim1.5\ m_0$,[10] but the anisotropy of the effect is surprisingly marked for a cubic monovalent metal such as copper.

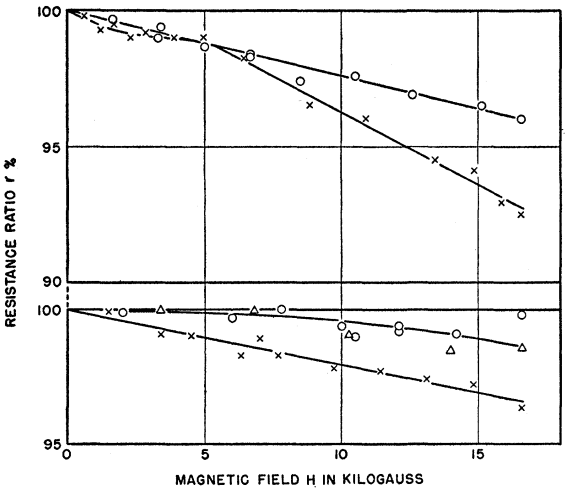


FIG. 2. Cyclotron resonance absorption in copper at 4.2°K for plane polarized radiation near 24 kMc/sec and magnetic field parallel to the metal surface. Specimen orientation—see text; upper curves—$J\|X$, lower curves—$J\|Y$; O—$H\|J$, ×—$H\perp J$; $\omega\tau=1.05$.

The author is indebted to Dr. R. G. Chambers for a stimulating correspondence and for drawing his attention to the work of Azbel, and Kaner.[5]

[1] See, for example, Dresselhaus, Kip, and Kittel, Phys. Rev. **98**, 368 (1955); Lax, Zeiger, and Dexter, Physica **20**, 818 (1954).
[2] Galt, Yager, Merritt, Cetlin, and Dail, Phys. Rev. **100**, 748 (1955); P. W. Anderson, Phys. Rev. **100**, 749 (1956); R. N. Dexter and B. Lax, Phys. Rev. **100**, 1216 (1955); see also reference 3.
[3] R. G. Chambers, Phil. Mag. (to be published).
[4] M. Ya. Azbel' and M. I. Kaganov, Doklady Akad. Nauk S. S. S. R. **95**, 41 (1954).
[5] M. Ya. Azbel' and E. A. Kaner, J. Exptl. Theoret. Phys. U. S. S. R. **30**, 811 (1956). It should be noted that, although these authors emphasize a distinction between the oscillatory behavior they predict and the phenomenon of cyclotron resonance in semiconductors, their expression for the fundamental resonance frequency when $\omega\tau\gg1$ is identical to that for cyclotron resonance even in the case of a Fermi surface of quite general geometry [W. Shockley, Phys. Rev. **79**, 191 (1950)]. They point out that the occurrence of subharmonics is simply a consequence of the restriction of the high-frequency field to a thin surface layer of the metal under extreme anomalous conditions; thus an electron moving in a helical orbit about the magnetic field direction need be in phase only when it returns to the surface.
[6] M. Ya. Azbel', Doklady Akad. Nauk S. S. S. R. **100**, 437 (1955).
[7] E. Fawcett, Bull. Am. Phys. Soc., Ser. II, **1**, 217 (1956).
[8] E. Fawcett, Proc. Roy. Soc. (London) **A232**, 519 (1955).
[9] R. G. Chambers, Proc. Roy. Soc. (London) **A215**, 481 (1952).
[10] Corak, Garfunkel, Satterthwaite, and Wexler, Phys. Rev. **98**, 1699 (1955).

## Need for Upward Revision of $\lambda_g/\lambda_s$ and its Consequences*

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THE conversion constant, $\Lambda(=\lambda_g/\lambda_s)$, from the Siegbahn nominal scale of x-units to milliangstroms has been extensively measured in Sweden by comparing, with a concave ruled grating spectrograph, certain x-ray lines with certain standard reference lines obtained from hydrogen-like spark spectra whose wavelengths were computed by means of a theoretical formula for the Lyman series. The work of Tyrén[1] is an outstanding example. Bearden[2] and others, on the other hand, have determined $\Lambda$ by absolute measurements of the diffraction angles of certain x-ray lines in grazing incidence on plane gratings. The grating constants were either measured directly (by comparator measurements of a counted number of lines) or calibrated directly with optical spectra whose wavelengths in angstroms were known without resort to theoretical

formulas. The consensus of the plane grating results of Bearden has tended toward values of $\Lambda$ some 30 or 40 parts per million higher than those of Tyrén.

The Sommerfeld-Dirac formula,[3] used by Tyrén for calculating the wavelengths of hydrogen-like reference lines in light atoms up to O VIII can no longer be considered correct in view of our present knowledge of quantum electrodynamics (the Lamb shift). This effect chiefly involves the ground state in the hydrogen-like transitions and according to the work of Bethe, Brown, and Stehn[4] the relative shift should be given by the formula for $np-1s$ transitions:

$$\Delta E/E=\{8n^2/[3\pi(n^2-1)]\} \times(7.723-2\ln Z-0.0439/n^3). \quad (1)$$

For the Lyman series transitions used by Tyrén, the ground state shift in parts per million is given in the following table:

| | Be IV | B V | C VI | N VII | O VIII |
|---|---|---|---|---|---|
| Shift of alpha line | 34.6 | 49.0 | 64.5 | 81.5 | 98.5 |
| Shift of delta line | 26.8 | 38.3 | 50.5 | 63.5 | 77.5 |

Tyrén's dissertation does not specify exactly how his calibration lines were associated with his x-ray lines. A preliminary rough estimate of the corrected value for Tyrén's $\Lambda$ based on the assumption that most nearly adjacent calibration and x-ray lines were always associated yields $\Lambda=1.002026\pm0.000016$ as compared to Tyrén's originally inferred value, $\Lambda=1.00199$.

If in fact an upward revision for the directly measured value of $\Lambda$ of 30 or 40 parts per million is indeed required, this would have exceedingly far reaching effects on all of the fundamental atomic constants and on all of the constants and conversion factors of physics and chemistry derivable therefrom. For each part per million change in $\Lambda$, the number of parts per million change in seven other important quantities can easily be estimated from Table X of one of our recent papers[5] with the following results:

| $e$ | $m$ | $h$ | $\alpha$ | $\Lambda$ | $N$ | $F$ | $hc^2/(e\Lambda)$ |
|---|---|---|---|---|---|---|---|
| 0.686 | 1.108 | 1.285 | 0.087 | 1.000 | −1.035 | −0.348 | −0.401 |

The last item is the voltage-wavelength conversion factor whose direct measurement by means of the short-wavelength limit of the continuous x-ray spectrum has been the subject of several recent experiments.[5,6]

An upward revision of 30 or 40 ppm in $\Lambda$ would (1) bring the directly observed results on $\Lambda$ of Tyrén and Bearden into much better agreement; (2) produce much better agreement[5] between input and least squares adjusted output values of $\Lambda$ (the output value is affected by other influences beside the direct input measurements); (3) go far toward resolving the discrepancy[5] between input and output values of $h/e$ or of the voltage-wavelength conversion constant. We believe that a careful recalculation of Tyrén's results in the light of the Lamb shift is emphatically in order. We are much indebted to Professor M. Gell-Mann for a helpful discussion regarding the Lamb shift.

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[1] Folke Tyrén, dissertation, Uppsala, 1940 (unpublished); Z. Physik **109**, 722 (1938).
[2] J. A. Bearden, Phys. Rev. **37**, 1210 (1931); **38**, 2089 (1931); **48**, 385 (1935).
[3] W. G. Penney, Phil. Mag. **9**, 661 (1930).
[4] Bethe, Brown, and Stehn, Phys. Rev. **77**, 370 (1950).
[5] Cohen, DuMond, Layton, and Rollett, Revs. Modern Phys. **27**, 363 (1955).
[6] Bearden, Johnson, and Watts, Phys. Rev. **81**, 70 (1951); J. A. Bearden and G. Schwarz, Phys. Rev. **79**, 674 (1950); Felt, Harris, and DuMond, Phys. Rev. **92**, 1160 (1953).

## Electroluminescence in Zinc Sulfide

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THE purpose of this letter is to take exception to two of the basic assumptions adopted by Thornton in a recent article[1] on electroluminescence in zinc sulfide. These assumptions are (1) that the density of ionized luminescent centers ($10^{14}$cm$^{-3}$) is too small to disturb the potential distribution established by thermally ionized co-activators ($10^{16}$cm$^{-3}$), and (2) that the effect of the applied electric field on the shape of the brightness wave is due to the variation of the effective trap depths with field strength. The entire dependence of light output upon time during the cycle is then to be thought of as arising from periodic detrapping of electrons by the alternating electric field.

We believe that these assumptions ignore certain experimental facts about electroluminescent zinc sulfide which we have already published.[2]

(A) The light output from the individual particles is far from uniform. Particularly at the low average field strengths employed by Thornton (20 000 volts per cm), the light is emitted almost entirely from small discrete "spots." The dimensions of these spots are difficult to estimate, but a conservative guess indicates that about one percent or less of the phosphor volume emits all of the light.

(B) The light output from these individual spots, in most phosphors, displays not two but *one* major peak per cycle.

(C) When a dc electric field is applied to a lamp composed of many particles, little or no light is observed; when the field is removed, a large light flash is observed. Certain yellow phosphors show a light flash upon application of the field.

We have interpreted these observations to mean that the spots themselves are miniature rectifying junctions.