formulas. The consensus of the plane grating results of Bearden has tended toward values of Λ 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 Λ 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 Λ 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 Λ, 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	α	Λ	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 Λ would (1) bring the directly observed results on Λ of Tyrén and Bearden into much better agreement; (2) produce much better agreement[5] between input and least squares adjusted output values of Λ (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.

* Work performed under contract with the U. S. Atomic Energy Commission.

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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.

On the high-field "reverse" half-cycle, ionization of the luminescent centers occurs; the electrons are transported sufficiently far by the field that no luminescence can occur until the field is removed or reversed, permitting them to return to and recombine with their parent centers. The typical waveform of light output from many-particle lamps, showing two major peaks per cycle, occurs because these rectifying junctions can be oriented in either direction. Excitation will occur in some on one half-cycle and in others on the other half-cycle.

We quite agree with Thornton's computation of 10^{14} ionized luminescent centers per cubic centimeter as an average concentration which would correspond to about one-half lumen radiated per cubic centimeter. However, in view of item (A) we believe these to be localized in approximately one percent of the volume, making the local concentration 10^{16} per cubic centimeter. This is about the same as the 10^{16} thermally-ionized coactivators Thornton assumes to determine the potential distribution.

In view of items (B) and (C), we cannot believe that an assumption such as Thornton's second, which ignores the transport of free electrons by the field away from and back to the ionized luminescent centers, can be correct. We cannot explain our observations on the application and removal of dc fields without considering this transport.

In addition, in setting up boundary conditions, Thornton assumes that the response of the phosphor to both half-cycles of the ac electric field is the same. Figure 16 of our paper[2] shows that the response of the ultimate radiating spot to both half-cycles of the ac field is most certainly not the same.

While we agree completely that trapping of electrons does occur and that it has effects upon the shape of the brightness waveform, we do not agree that the entire dependence of light output on time during the cycle can be accounted for on this basis alone. Our observation (C) above indicates that the removal of the electric field shortly after its application suffices to release electrons and produce light, whereas the original application of the field produced no detrapping and no light.

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[2] J. F. Waymouth and F. Bitter, Phys. Rev. **95**, 941 (1954).

Electroluminescence in Zinc Sulfide

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OF the considerations objected to by Waymouth and Bitter,[1] the first is not a basic assumption but an incidental remark at the end of a section of paper I[2]; the second is not at all inconsistent with the experimental observations (A) through (C) pointed out in the preceding Letter.

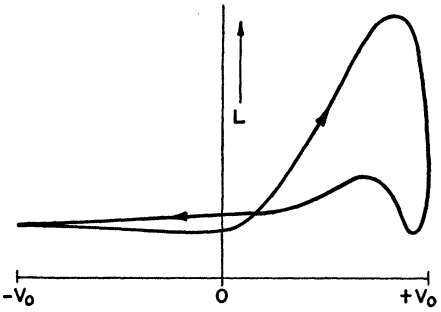

FIG. 1. Expected light output wave form of electroluminescence from a single crystallite or small crystal volume.

The point concerning localization of light emission is feasible. It is also likely, however, that all of the trapping states or donors, at depths near 0.2–0.3 ev, become ionized at least in the localized region of maximum field. Since neither the density of the ionized luminescence centers nor that of the ionized traps or donors is apparently known within a factor of 100, it seems of little value to compare them. What is more to the point is that the theory of paper I considers an average (not constant) field proportional to applied voltage; the distribution of this field, and whether it is dominated by ionized luminescence centers or traps, is irrelevant.

The following remarks refer to the second question: (a) The dependence on field of effective trap depth is considered to govern only the shape and phase of the primary peak. Processes contributing to the secondary peak are not considered, and the dc light level upon which the peaks are superposed is considered due to thermal release and recombination in crystal regions not dominated by the field. (b) The importance of potential barriers in electroluminescence is assumed in paper I; their presence, plus the assumed strong field dependence of the ionization process, leads to strongly localized regions of light emission. Electron transport is implicit in these ideas, also, both in setting up the potential barriers and in motion back and forth between traps and luminescence centers. This latter transport is very likely involved also in observation (C); there being initially no ionized centers, the sequence must be: ionization, trapping, thermal release, and recombination. This sequence is identical to that considered in paper I except that the rate of the third process is enhanced and controlled by the onset of the applied sinusoidal voltage. (c) It can be noted that the theoretical curves on wave form, in paper I, cover a range of the argument from zero to π radians; that is, light output is considered from zero voltage through the primary peak until it falls toward zero due to depletion, and this occurs within the first half-cycle of voltage. It is not suggested that the same crystal region responds to both half-cycles; rather it is believed that this is not