

## Hall Coefficients of Alkali Metals

Studer and Williams<sup>1</sup> have recently determined the Hall coefficients of potassium and caesium. The purpose of this letter is to point out the interesting theoretical implications of their experimental values.

The classical formula for the Hall coefficient is

$$R = c/ne, \quad (1)$$

where  $n$  is the density of free electrons, and  $e$  is their charge. This formula is unaltered<sup>2</sup> when the classical statistics is replaced by the Fermi statistics.

When account is taken of the fact that the electrons move in a periodic lattice, the expression for  $R$  becomes rather formidable.<sup>3</sup> However, when the energy of a conduction electron, expressed as a function of its wave numbers  $k_x, k_y, k_z$ , is

$$E(k_x, k_y, k_z) = \epsilon(k_x^2 + k_y^2 + k_z^2), \quad (2)$$

where  $\epsilon$  is an arbitrary constant, the Hall coefficient is again given by (1).  $n$  is now the density of conduction electrons (or of atoms for monovalent metals). Thus the validity of (1) is an indication of the validity of (2).

From Table I we see that the agreement for Li is com-

TABLE I. Hall coefficients.

	Li	Na	K	Rb	Cs
$R_{\text{exp}}$	-0.00175 <sup>5</sup>	-0.0025 <sup>5</sup>	-0.0042 <sup>1</sup>		-0.0078 <sup>1</sup>
$R_{\text{calc}}$	-0.00137	-0.00245	-0.00476	-0.0058	-0.0073

paratively poor. This is a confirmation of the calculations of Millman<sup>3</sup> which show that  $E(k_x, k_y, k_z)$  is dependent upon the *direction* of the vector  $(k_x, k_y, k_z)$ . The excellent agreement for Na is a confirmation of the calculations of Slater<sup>4</sup> which show that for this element the energy of the conduction electrons is quite exactly given by (2). The relatively good agreement for potassium and caesium indicate that for these elements (2) is a very good approximation.

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<sup>1</sup> Studer and Williams, Phys. Rev. **47**, 291 (1935).

<sup>2</sup> Sommerfeld and Frank, Rev. Mod. Phys. **3**, 11 (1931).

<sup>3</sup> H. Jones, Proc. Roy. Soc. **A144**, 233 (1934).

<sup>4</sup> Jones and Zener, Proc. Roy. Soc. **A145**, 271 (1934).

<sup>5</sup> J. C. Slater, Phys. Rev. **45**, 794 (1934).

<sup>6</sup> Int. Crit. Tables.

## The Energies of X-Ray Photoelectrons

In recent papers, Ruark<sup>1</sup> has directed attention to the possibility of deciding between the crystal and ruled grating scales of x-ray wavelength, in the light of the Kretschmar<sup>2</sup> and Robinson<sup>3</sup> experiments on photoelectron energies. In his first paper, he showed that the measured energies were 0.36 percent higher than those computed

from crystal values of wavelength, and 0.61 percent higher than those from grating measurements. He pointed out, however, that changes in the most probable values of the physical constants might easily make the data favor the grating wavelengths, instead. In his second paper, using the Bearden-Bäcklin value of  $e$ , and the Shane-Spedding value of  $e/m$ , he found that the measured value of the photoelectron energies is now 0.09 percent lower than those from ruled gratings, and consequently 0.34 percent lower than the crystal values.

Kirkpatrick suggested to Ruark that the 0.09 percent discrepancy was in the correct direction to be explained by a retardation of the electrons in passing through the thin metallic foils from which they are ejected. When that suggestion was published, I was in correspondence with Kretschmar about the same point, and through his courtesy, was supplied with one of the platinum films which had been used in his work. Measurements of the absorption of light in the film enabled its thickness to be fixed<sup>4</sup> as somewhere between 3 and  $6 \times 10^{-7}$  cm. The passage of electrons through matter follows the Thompson-Whiddington law:  $V_0^4 - V_x^4 = \alpha x$ , where  $V_0$  is the velocity of approach to a thin foil of thickness  $x$ ,  $V_x$  is the most probable value of the velocity after passing through, and  $\alpha$  is a constant for a given metal. Several experimenters have verified this law for small velocity ranges, but have shown that  $\alpha$  depends on the velocity. Terrill<sup>5</sup> determined  $\alpha$ (Au) for the range  $\beta = 0.3 - 0.4$ , and Klemperer<sup>6</sup> measured  $\alpha$ (Al) and  $\alpha$ (Ni) in the range  $\beta = 0.15 - 0.22$ . From the experimentally determined law that  $\alpha$  is directly proportional to the density of the absorber, it is possible to calculate  $\alpha$ (Pt) for the two ranges. The values are  $123 \times 10^{42}$  and  $49 \times 10^{42}$ , respectively. Kretschmar used electrons of  $\beta = 0.24$ , so the value of  $\alpha$ (Pt) in his case should be close to the mean of the two given above, or  $86 \times 10^{42}$ . If  $x$  is small, the Thomson-Whiddington law may be written in the form  $V_0 = V_x(1 + \alpha x/4V_x^4)$ , or  $\Delta V/V = \alpha x/4V^4$ . Since  $\Delta V/V$  varies directly with  $x$ , and since electrons come from all depths of the film in equal numbers, it is permissible to use  $x/2$  as the effective thickness of the film.  $\Delta E/E = 2\Delta V/V$ , so that  $\Delta E/E = \alpha x/4V^4$ , where  $E$  is the energy of the electrons, and  $x$  is now the thickness of the foil in which the electrons originate. A small correction (+0.09 percent) is also needed to take account of the finite width of the slit in the  $\beta$ -ray spectrograph.<sup>7</sup> For the two extremes of  $x$ , it is found that the energies of the photoelectrons (in Kretschmar's experiment) should be increased by 0.32 or 0.56 percent. These new values of the energies, therefore, favor the crystal rather than the grating scale, since their mean is 0.04 percent higher than the former, and 0.29 percent higher than the latter.

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<sup>1</sup> Ruark, Phys. Rev. **45**, 827 (1934); **47**, 316 (1935).

<sup>2</sup> Kretschmar, Phys. Rev. **43**, 417 (1933).

<sup>3</sup> Robinson, Phil. Mag. **14**, 605 (1932).

<sup>4</sup> Int. Crit. Tab. **5**, 256 (1929).

<sup>5</sup> Terrill, Phys. Rev. **22**, 101 (1923).

<sup>6</sup> Klemperer, Zeits. f. Physik **34**, 532 (1925).

<sup>7</sup> Wooster, Proc. Roy. Soc. **A114**, 729 (1927).