where χ is the ordinary thermionic work function. The second argument is an attempt at a more exact theory in which Fowler introduces a factor to represent the quantum mechanical probability of emergence of electrons. This argument yields

$$I \backsim \frac{T^{3/2}}{(\chi_0 - h\nu)^{1/2}} f_2\left(\frac{h\nu - \chi}{kT}\right).$$

Both of these expressions represent the experimental data almost equally well.

We believe that (adopting Fowler's hypotheses) we should introduce, not Fowler's probability of escape $(\frac{1}{2}mu^2 + h\nu - \chi_0)^{-1/2}$ but a factor proportional to

$$\frac{(\frac{1}{2}mu^2 + h\nu)^{1/2} \ (\frac{1}{2}mu^2 + h\nu - \chi_0)^{1/2}}{[(\frac{1}{2}mu^2 + h\nu)^{1/2} + (\frac{1}{2}mu^2 + h\nu - \chi_0)^{1/2}]^2}$$

(see e.g. Frank and Young, Phys. Rev. **38**, 82, 1931, formula 10). This leads to

$$I \backsim \frac{T^{5/2}}{(\chi_0 - h\nu)^{1/2}} f_3\left(\frac{h\nu - \chi}{kT}\right)$$

where

$$f_3(\mu) = \int_0^\infty y^{1/2} \log (1 + e^{\mu - y}) dy.$$

It should be interesting for those working in this field to compare this formulation with experimental data.

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Massachusetts Institute of Technology,
July 23, 1931.

A New *K*-Series X-Ray Line due to Fermi-Sommerfeld Electrons

Duane[1] has recently reported the observation of a new *K*-series line or band situated between the familiar gamma line and the critical limit of the *K*-series (position of the *K* absorption discontinuity.) This band is of great interest because in all probability it can be ascribed to transitions to the *K* level of electrons which in their initial state are dissociated from particular atoms and form a group resembling that predicted by Sommerfeld based on the Fermi statistics. To obtain this line Duane used a single crystal photographic spectrometer, the distance from crystal to plate and from crystal to tube being 475 cm, and the exposure time 90 hr, with the crystal rocking over a very small range. Long vacuum cells were used to reduce the absorption and scattering over the long air path. We are much indebted to Dr. Duane and to Dr. Lanza for their kindness in sending us some of their beautiful original spectra to examine and analyze.

We have succeeded with our double crystal spectrometer in confirming the existence of this line or band which, following Duane, we will call the delta radiation. The double crystal spectrometer whose construction we have described in a recent article[2] permits of high resolution without the use of fine slits or large distances. It is also feasible to use a very large focal spot with such an instrument. The accompanying figure shows an ionization curve obtained with the double spectrometer with two calcite crystals each in the first order. The molybdenum tube used was run at 58 kv and only 6.6 milliamperes. The glancing angles on the scale of abscissae of this plot should be corrected by a small additive constant to give the true glancing angle. The position of the molybdenum *K* absorption edge has been plotted from data given by Siegbahn.

The delta band between the gamma line and the *K* absorption edge is plainly distinguishable. The resolution here obtained is not as good as the resolution of Duane's photographs made with his Bragg-Moseley high resolution spectrometer. This may in part be due to the superiority of his crystal over ours. We have tried to observe this line in the third order on both crystals in which case we believe the resolution would be excellent, but unfortunately the natural fluctuations in the background here become of the same order of magnitude as the ordinates of the delta line. It is our plan to continue the study of this interesting new radiation with much more intense sources of x-radiation using tubes provided with means for vibrating the focal spot so as to permit of at least ten times the energy input at present available.

The best estimate we can make of the breadth of the delta band from molybdenum, both from our own and Duane's observations, is about 0.5 X.U., which corresponds to an energy breadth of 16 volts. This estimate is necessarily very rough as it is difficult to correct for the resolving power of the spectrometers used. Such a correction can however be

[1] W. Duane, Phys. Rev. **37**, 1017 (1931).

[2] Jesse DuMond and Archer Hoyt, Phys. Rev. **36**, 1702 (1930).

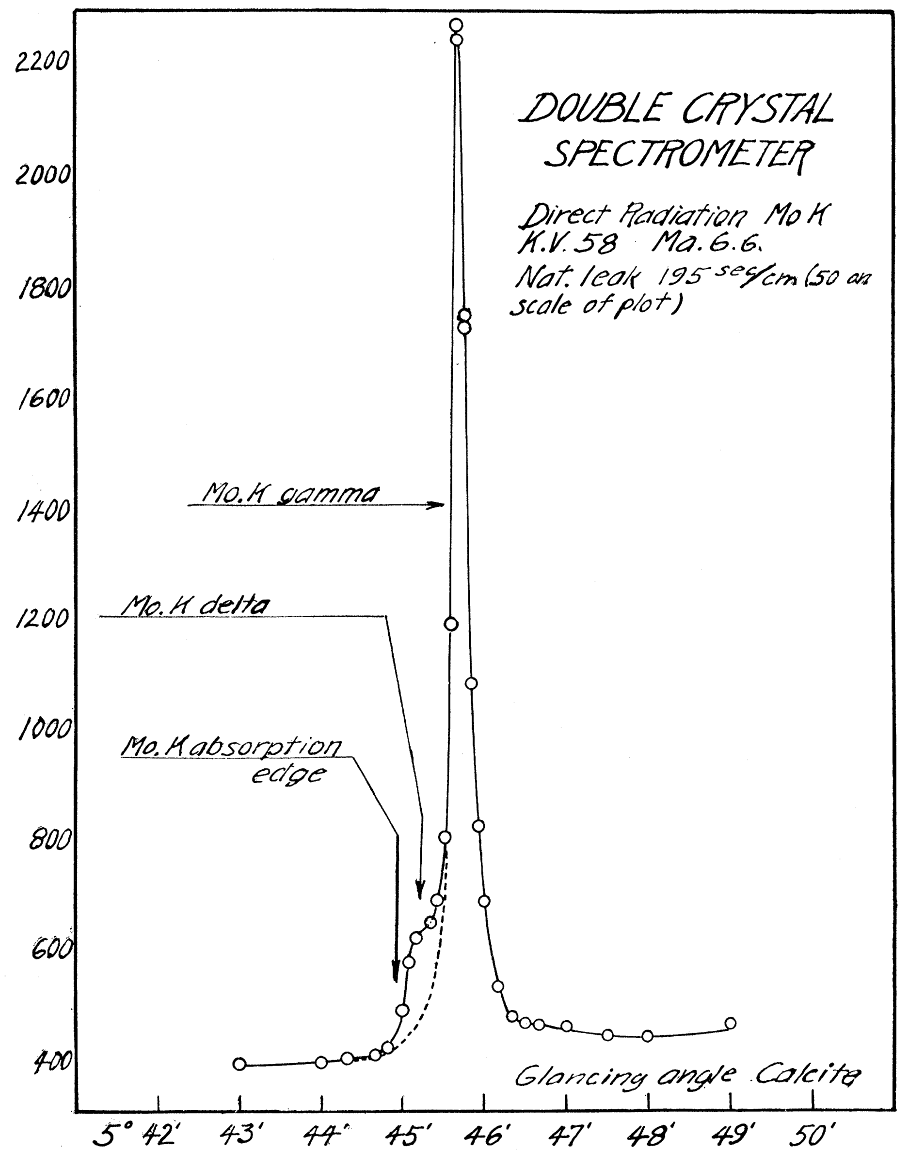
DOUBLE CRYSTAL SPECTROMETER
Direct Radiation Mo K
K.V. 58 Ma. 6.6.
Nat. leak 195 sec/cm (50 on scale of plot)
Mo. K gamma
Mo. K delta
Mo. K absorption edge
Glancing angle Calcite
2200
2000
1800
1600
1400
1200
1000
800
600
400
5° 42'
43'
44'
45'
46'
47'
48'
49'
50'

Fig. 1.

made after a fashion from the observed width of the gamma line, a large part of which is probably instrumental.

If we substitute the energy breadth of 16 volts into the equation derived by Sommerfeld[3] relating the energy breadth of the Fermi ensemble of electrons to the number density of such electrons

$$W = \frac{h^2}{2m}\left(\frac{3}{8}\,\frac{\rho}{\pi}\right)^{2/3}$$

in which h is Planck's constant, m the mass of electron, ρ the number of Fermi electrons per cc, we obtain for the density ρ 0.57×10^{23} electrons per cc or about five electrons per molybdenum atom. This estimate might be in error by one unit either way on account of the uncertainty in the breadth estimates.

The Sommerfeld theory applying the Fermi statistics to conduction or "free" electrons in metals is of course only a first approximation. Bloch[4] has approached the problem differently by considering the perturbing effect of neighboring atoms on any given atom in a solid. W. V. Houston has computed the line shapes that should result from an energy distribution of the conduction electrons such as would result from Bloch's theory. It turns out that while the line has a quite different shape from what would be expected on the simpler Sommerfeld theory the energy breadths in the two cases are about the same.

An estimate of the intensity of the delta radiation relative to the gamma line can easily be made from the ionization curve we have obtained by comparing the areas under the two lines. Our results indicate that the gamma line is 7.2 times as intense as the delta radiation. A similar value obtained from a microphotometric analysis of one of Duane's photographic spectra gives the gamma line five times as intense as the delta radiation. The value 7.2 is probably the more nearly correct of the two. The gamma line on Duane's negative is very strongly blackened and the microphotometer therefor probably gives the ordinates of the gamma line too low.

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ARCHER HOYT

Norman Bridge Laboratory of Physics,
Pasadena, Calif.,
July 18, 1931.

[3] A. Sommerfeld, Zeits. f. Physik **47,** 1 (1928).

[4] F. Bloch, Zeits. f. Physik **52,** 555 (1928).