the conclusion that errors from this source were negligible for his experiments in mercury vapor. However, since the electron affinity of the halogens is large it is possible that an appreciable space charge might be built up through the formation of negative ions by electron capture.

Assuming a simplified form for the molecular field, Fisk[14] extended the quantum mechanical method of Allis and Morse[15] to the calculation of the total cross section for elastic scattering of slow electrons from diatomic molecules. He has completed calculations for nitrogen, oxygen, hydrogen and chlorine. Excellent agreement between experiment and theory was obtained for the first three gases, but wide deviations were found for chlorine, for which the total cross section for scattering (elastic and inelastic) was measured. The discrepancy was interpreted as meaning that considerable inelastic scattering was present.

It would be instructive to apply Fisk's method to bromine, for which Arnot has made measurements for *elastic* scattering. The agreement for low energies would probably not be very good in view of the strong effect of atomic polarization, which in Fisk's theory is ignored. The agreement, however, should be considerably better than that for chlorine because of the absence of inelastically scattered electrons in the experimental work.

[14] J. B. Fisk, Phys. Rev. **49**, 167 (1936); **51**, 25 (1937).

[15] W. P. Allis and P. M. Morse, Zeits. f. Physik **70**, 567 (1931).

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Scattering of Fast Electrons in Helium

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Failure of the quantum mechanical theory of elastic scattering to account for experimental results of Kuper on scattering of 50- to 80-kilovolt electrons in helium has been explained by neglect of the inelastic scattering. Computation of the cross sections including inelastic as well as elastic collisions by an approximate method yields satisfactory agreement without requiring any modification of the theory.

MEASUREMENTS by Kuper[1] on the scattering of fast electrons (50 to 80 kilovolts) in rare gases were in satisfactory accord with the quantum mechanical theory for elastic scattering in the cases of argon and neon. In helium, however, the observed scattering cross sections were much larger and increased more rapidly at the smaller angles than the elastic scattering theory predicted.

In spite of the fact that the resolving power of the electrostatic energy analyzer was such as to permit passage of electrons which had lost as much as 100 electron volts it was assumed that inelastic scattering was absent for two reasons. First it was thought that at these energies the losses would be large compared to 100 electron volts, and second that if only elastic scattering was found in neon and argon the same would be true in helium. Both of these assumptions seem to be wrong. The first would be true if we were dealing with larger angles but at angles smaller than 2° the predominant energy losses will be well under 100 electron volts. This can readily be seen by considering the momentum changes involved. The second assumption neglects the fact that while the inelastic cross section (for losses not exceeding 100 ev) will vary approxi-

[1] J. B. H. Kuper, Phys. Rev. **53**, 993 (1938).

mately as the number of electrons in the outer shell, the elastic cross sections increase very roughly as the square of the effective atomic number. For example the elastic cross sections[2] for 80-kilovolt electrons near 1° are in the ratio 1 : 25 : 119 for He, Ne, and A, respectively. Thus we can see that the inelastic scattering contribution in the case of argon would scarcely affect the shape of the curve at all. In neon we could expect the inelastic scattering to become appreciable at the smallest angles and this was in fact observed.

An exact calculation of the cross sections for inelastic scattering in helium would be extremely laborious as it would be necessary to sum the contributions of the various excitations and ionization. Fortunately, the expression for the total inelastic scattering in hydrogen given by Bethe[3] and Mott and Massey[4] can readily be modified to apply to the case of helium. This involves an approximation in using excited hydrogen wave functions for helium, but this procedure has been well justified by experiments at lower energies.

The modified expression used for the total inelastic cross section is

$$I_{\text{in}} = 2\cdot\frac{4m^2\epsilon^4}{h^4k^4}\cdot\frac{\cos\theta}{\sin^4\theta}\left[1-\frac{1}{(1+\frac{1}{4}k^2(a_0^2/Z^2)\sin^2\theta)^4}\right],$$

I_{in} being the effective cross section for inelastic scattering through the angle θ into unit solid angle. Here m, e, and $\hbar$ have their usual meanings, k is the momentum of the incident electrons divided by $\hbar$, a_0 is the radius of the first Bohr orbit in hydrogen, and Z the effective atomic number, taken as 1.69. The factor 2 was introduced to allow for the extra electron in helium. For the energies considered here the term in brackets has a value of 0.05 at 0.3° and rises nearly to 1 at about 3°. Thus it exerts a strong influence on the cosec[4] distribution in the angular range covered by the experiments (the cosine term may be set equal to 1).

In Fig. 1 we have plotted Kuper's data on scattering of 49.5, 63.3 and 78 kilovolt electrons in helium. Also we show the elastic cross sections

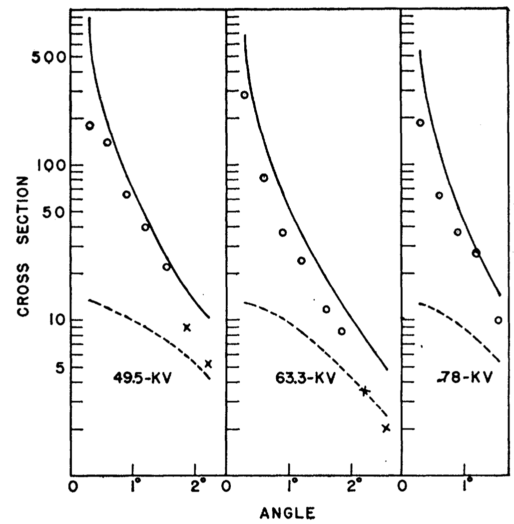

FIG. 1. Scattering of 49.5-, 63.3- and 78-kilovolt electrons in helium. Dashed curves, elastic cross sections; solid lines, total cross sections, elastic plus inelastic, in units of 10^{-18} cm². The experimental points were not adjusted to fit the curves but are located by the effective scattering volume of the apparatus found for neon and argon. Those points shown as crosses represent currents less than 1000 electrons per second and therefore the error may be expected to be high.

for scattering into unit solid angle from Mott and Massey[5] and the total cross sections obtained by adding to the elastic the inelastic scattering computed from the formula above. The agreement can be considered quite satisfactory, especially when it is realized that this calculation gives an upper limit to the cross sections, losses greater than about 100 electron volts being excluded by the analyzer. Also the experimental cross sections involve a determination of the effective scattering volume of the apparatus. This was obtained from the results of the measurements in neon and argon. Correction of the latter to account for the inelastic scattering would tend to raise the experimental points. No significance need be attached to the experimental points shown as crosses. In these cases the observed currents were less than 1000 electrons per second and the error is probably high.

We feel that these considerations make unnecessary the treatment suggested by Hughes[6] to account for the experiments. We wish to thank Professor J. Howard McMillen for discussion of this problem.

[2] N. F. Mott and H. S. W. Massey, *The Theory of Atomic Collisions* (Oxford, 1933), p. 120 and 124.
[3] H. A. Bethe, *Handbuch der Physik*, second edition, Vol. 24, No. 1 (1933), p. 505.
[4] N. F. Mott and H. S. W. Massey, reference 2, p. 174.
[5] N. F. Mott and H. S. W. Massey, reference 2, p. 120.
[6] A. L. Hughes, Phys. Rev. **55**, 350 (1939).