Letters to the Editor

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Elastic Scattering of 1-Mev Electrons from Aluminum and Gold

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KINZINGER and Bothe[1] have reported significant deviations from Mott theory in the large-angle scattering of 245-kev electrons from heavy nuclei. For gold at 150° they found that the scattering is more than 35 percent low. Subsequent measurements by Kinzinger[2] at 120° show a consistent deviation which is 25 percent low and is independent of energy between 150 and 400 kev. Paul and Reich[3] report similar behavior for 2.2-Mev electrons, the deviation being about 15 percent for platinum at 90° and 120°.

A preliminary measurement of the scattering of 1-Mev electrons by aluminum and gold has been made. Electrons from a Van de Graaff generator are focused on Parlodion (0.006 mg/cm²) backed foils of aluminum (0.22 mg/cm²) and gold (0.02 mg/cm²), and the relative number of electrons scattered at 30°, 60°, 90°, 120°, and 150° is measured. The two detectors are photomultipliers with anthracene crystals mounted at the end of collimators. An integral pulse-height discriminator is biased to minimize the x-ray and low-energy electron background so that the electrons elastically scattered from the foil nuclei are counted. The ratios of scattering at 30°, 60°, 120°, and 150° to that at 90° are measured and compared with the theoretically predicted values. Account has been taken of background counting rate, counting losses due to finite resolving time of the scaling circuits, multiple scattering, plural scattering (transmission-reflection asymmetry), and scattering in the Parlodion foil support. The maximum contribution for each of these was of the order of one percent and was in most cases less than this.

The results for aluminum and gold are given in Table I. The uncertainties shown are the standard deviations associated with counting. The results for aluminum are compared with the α^4 approximation to the Mott series given by McKinley and Feshbach[4] rather than the α^2 approximation formula, since the latter does not fit the experimental values as well as the more accurate α^4 approximation. For gold, the α^4 approximation is not sufficiently accurate, since $\alpha=Z/137=0.58$ and the series does not converge rapidly enough. The theoretical values given in Table I for gold were obtained by interpolating the calculations of Bartlett and Watson[5] for mercury and multiplying the result by the ratio of gold to mercury scattering given by the α^4 approximation. This procedure should give results accurate to about 1 percent.[4] As may be seen in Table I, the experimental results do not differ from these theoretical values by more than 1.5 percent and the differences exhibit no systematic trend. Thus, there is no evidence for deviation from the Mott theory of electron scattering at 1 Mev. Work is continuing on the measurement of relative scattering at other energies as well as of the absolute scattering.

TABLE I. Relative scattering with respect to 90°.

Angle	Aluminum Experimental	Theoretical	Deviation (%)
30°	89.06 ±0.27	89.08	−0.0
60°	5.504 ±0.011	5.496	+0.2
120°	0.2654 ±0.0007	0.2665	−0.4
150°	0.08572 ±0.00029	0.08544	+0.3
Angle	**Gold Experimental**	**Theoretical**	**Deviation (%)**
30°	39.50 ±0.12	39.87	−0.9
60°	3.898 ±0.009	3.840	+1.5
120°	0.3204 ±0.0008	0.3178	+0.8
150°	0.09610 ±0.00039	0.09693	−0.9

[1] E. Kinzinger and W. Bothe, Z. Naturforsch. **7a**, 390 (1952).
[2] E. Kinzinger, Z. Naturforsch. **8a**, 312 (1953).
[3] W. Paul and H. Reich, Z. Physik **131**, 326 (1952).
[4] W. A. McKinley, Jr., and H. Feshbach, Phys. Rev. **74**, 1759 (1948).
[5] J. H. Bartlett and R. E. Watson, Proc. Am. Acad. Arts Sci. **74**, 53 (1940).

Feynman's Theory of Liquid Helium

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RECENTLY, Feynman[1] has developed a new theory of liquid helium. In the present note we wish to show how the approximations that Feynman has to make to evaluate the partition function may be related to well-known approximations in statistical mechanics. We should also like to point out that Matsubara[2] has developed a theory of liquid helium using almost the same mathematical approximations as Feynman. It appears to us that the relationships that exist between Feynman's approximations and the standard approximations of statistical mechanics throw new light on the nature of Feynman's work.

We shall confine ourselves in this note to the first of Feynman's papers—hereafter referred to as I— in which he discusses the origin of the lambda transition of liquid helium. In I, three approximations are made in order to evaluate the partition function for the system. Feynman first argues that it is very reasonable to assume that the helium atoms move about as if they were practically free, and therefore that to a high degree of accuracy the distribution function in configuration space will be essentially the same as that for an ideal Bose-Einstein gas. This distribution function is proportional to

$$\Sigma_P \exp\Big[-(\pi/\lambda^2)\sum_{i=1}^{N}|\mathbf{z}_i-P\mathbf{z}_i|^2\Big],$$

where $\mathbf{z}_i$ is the coordinate of the ith atom, P is any permutation of the N indices, $\lambda^2=h^2/2\pi mkT$, and Σ_P stands for a summation over all permutations P. In order to take into account the effects of the interactions between the atoms Feynman proposes to modify this distribution function by replacing the true mass m by an effective mass m' and by multiplying it by an additional distribution function $K_\beta\cdot\rho_N(\mathbf{z}_1\cdots\mathbf{z}_N)$, where K_β is a normalization constant. The function ρ_N is stated to be "$\cdots$ qualitatively very similar to the distribution function for a classical gas." We can therefore write it in the form $\exp[-\beta V'(\beta)]$, where $V'(\beta)$ is a quasi-interaction potential, with properties similar to that for a classical system except that it depends slightly on the temperature. With these approximations the partition function reduces to

$$Q'=\lambda'^{3N}\frac{K_\beta}{N!}\int_{\mathbf{z}}\exp[-\beta V'(\beta)]\times\sum_P\exp\Big[-(\pi/\lambda'^2)\sum_{i=1}^{N}|\mathbf{z}_i-P\mathbf{z}_i|^2\Big]d\mathbf{z}, \quad (1)$$

where $\lambda'^2=h^2/2\pi m'kT$ and $\mathbf{z}$ stands for the set of all coordinates $(\mathbf{z}_i)$. We now wish to compare this approximate partition function with another that can be obtained from the semiclassical expansion due to Wigner[3] and Kirkwood.[4] These authors showed that the