It was checked very carefully that this effect was real. We showed that it was not caused by noise generated in the end contacts of the filament, nor by a fault in the amplifier. We also showed that it was not caused by the input circuit of the amplifier nor by the presence of barriers in the Ge-filament; the input circuit incorporating the filament behaved as a simple *RC* circuit with frequency-independent values of *R* and *C* for the whole frequency range.

According to the theory[3] the shot effect in semiconductors resulting from carriers of charge $\pm e$, having an average lifetime τ_0 and a drift time τ and giving a contribution I_c to the dc current, is

$$\langle i^2\rangle_{Av}=2eI_d(\tau_0/\tau)\Delta f/[1+\tfrac{1}{2}(\omega\tau_0)^2] \qquad (3)$$

if $\tau_0\ll\tau$. As $1/\tau$ is proportional to I_c, $\langle i^2\rangle_{Av}$ is actually proportional to I_c^2.

The third term in (2) can thus be interpreted as a shot effect term. The value $f_0=1.5\times10^5$ cycles/sec corresponds to a lifetime τ_0 of the carriers of 2×10^{-6} sec. As this is comparable to the lifetime of the holes in the filament reported by Montgomery and Shockley,[2] the third term in (2) can be interpreted as resulting from the shot effect of the holes.

N-type Ge-filaments should also show a shot effect of the electrons; this requires the addition of a term of the type

$$CI^2/[1+(f/f_1)^2] \qquad (4)$$

to (2). $f_1\gg f_0$, as the time constant τ_1 involved in this process (representing the average time between the liberation of an electron from a donor atom and its subsequent temporary capture by an ionized donor) is much smaller than τ_0. Our measurements above 500 kc seem to indicate that such an effect exists but they do not extend to sufficiently high frequencies to establish this with certainty.

The relative importance of the terms $BI^2/[1+(f/f_0)^2]$, $CI^2/[1+(f/f_1)^2]$ and AI^2/f depends upon many factors such as the time constants τ_0 and τ_1, the conductivity of the material, the treatment of the surface of the filament, etc. For that reason it should not be expected that the noise of all Ge-filaments will show the same pronounced deviations from the $1/f$-law as reported here. In fact we found for another filament that the measurements were not accurate enough to detect deviations from the $1/f$-law.

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1 By excess noise we mean the noise generated by the flow of dc current which is over and above the thermal noise. The noise ratio n of a device is defined as: n = total available noise power of the device/available noise power of equivalent circuit at room temperature. $n=1$ if there is no excess noise; $(n-1)$ is a good measure for the amount of excess noise generated.

2 H. C. Montgomery and W. Shockley, Phys. Rev. 78, 646 (1950).
3 A. van der Ziel, Physica 16, 359 (1950).

Scattering of 30-Mev Alpha-Particles by Helium*

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THE angular distribution of elastic scattering of 30-Mev alpha-particles by helium has been measured using the emergent beam of the MIT cyclotron. The results are shown in Fig. 1 on a semilogarithmic plot, together with the results of Mather[1] for the elastic scattering of 20-Mev alpha-particles by helium and a theoretical curve fitted to the experimental results at 30-Mev. It should be noted that the results plotted for this single region in the center-of-mass system were assembled from three regions in the laboratory system: 0° to 45°, 45° to 90°, and 270° to 360°.

Scattered alpha-particles were detected with a double proportional counter, which could be rotated within a 2-foot-diameter scattering chamber filled with helium at 1 or ½ atmosphere.[2] The outputs of the two shallow counters, located back to back, were placed in time coincidence to reduce background.

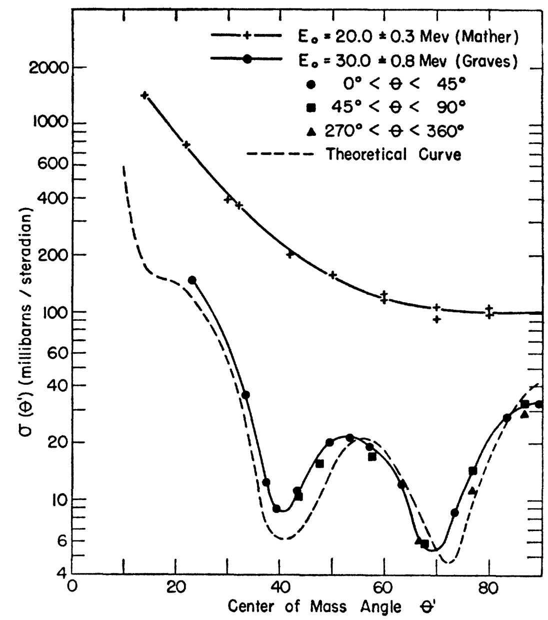

FIG. 1. The angular distribution of alpha-particles elastically scattered from helium, shown in the center-of-mass system on a semilogarithmic plot: at 20 Mev, according to the earlier work of K. B. Mather, and at 30 Mev, according to the present work, with a theoretical curve for scattering at 30 Mev based on three phase shifts: $\kappa_0=-85.5°$, $\kappa_2=+45.5°$, and $\kappa_4=+35.5°$

Intensities were measured using both differential and integral energy spectra, which were obtained by range analysis with a remotely controlled aluminum foil changer mounted in front of the counters. Differential spectra were obtained by "peaking" with a low level discriminator in the circuitry for the output of the second counter. The intensity was taken as proportional to the height of the integral "step" or to the area under the differential curve, with a correction for background when present. Alternate measurements at a normalization angle permitted correction for drifts in over-all counting efficiency. The measured intensity was multiplied by the factor $\sin\theta$ to correct for the change in scattering volume in the gaseous target with detector angle θ and by the factor $g(\theta)=\frac{1}{4}\cos\theta$ to convert laboratory intensity to center-of-mass intensity.

The estimated root-mean-square probable error for the relative intensity at each angle of measurement, except $\theta=11.6°$, is ±15 percent. This error includes contributions from statistical fluctuations, from changes in over-all counting efficiency, from an inaccuracy of ±0.5° in detector angle for each measurement, from fluctuations in incident energy, and from the effects of multiple small-angle scattering. No attempt has been made to correct the distribution for the effect of the angular width of the detector slit system, which permitted a maximum deviation of ±2° from the mean counter angle. At 11.6° the average of seven measurements with the target gas at 1 atmosphere exceeded by 40 percent the average of four measurements at ½ atmosphere. This difference is attributed to a greater contribution from multiple small-angle scattering at the higher pressure. In the absence of an adequate correction for this effect, the average value for ½ atmosphere is given as an upper limit.

The absolute differential cross section was measured by comparison with the elastic scattering from a 6.6 mg/cm² gold foil target to be $(2.8\pm0.7)\times10^{-26}$ cm²/steradian at $\theta'=83.2°$. The gold cross section was assumed to equal the Rutherford cross section, since earlier work by H. E. Gove at MIT revealed that the elastic scattering of 28-Mev alpha-particles from gold obeys the inverse $\sin^4(\theta/2)$ relationship back to $\theta=50°$.

A brief investigation revealed no evidence of an excited state in He^4 up to 14 Mev.

An expansion in partial waves, involving the 0th-, 2nd-, and 4th-order phase shifts due to nuclear scattering, has been fitted to the experimental data by the method of Wheeler.[3] We computed the ratio R of the experimental cross section to the Mott cross section[4] (center-of-mass system):

$$\sigma_{\mathrm{Mott}}=(z^2e^2/mv^2)^2(\csc^4\theta+\sec^4\theta+2\Phi\csc^2\theta\sec^2\theta),$$

where $\Phi=\cos[(z^2e^2/\hbar v)\tan^2\theta]$. The partial wave expansion for this ratio is[4]

$$R(\theta)=|1+(i\hbar v/z^2e^2)\sin^2\theta\exp[i(\hbar v/z^2e^2)\ln\sin^2\theta]$$
$$\Sigma_l\exp[2i(\zeta_l-\zeta_0)][\exp(2i\kappa_l)-1](2l+1)P_l(\cos 2\theta)|^2$$

in which the Coulomb component of the phase shift is

$$\zeta_l=\arg\Gamma[l+1+i(\hbar v/z^2e^2)],$$

and the nuclear components κ_l of the phase shifts are to be determined. $P_2(\cos 2\theta)$ and $P_4(\cos 2\theta)$ have zeros at three angles between 0° and 45°. A graphical solution in the complex plane yielded eight sets of values of κ_0, κ_2, and κ_4 consistent with the experimental values of R at these three angles. Only one of these sets gave substantial agreement with the experimental values of R at 20° and 45°:

$$\kappa_0=-85.5°,\quad \kappa_2=+45.5°,\quad \kappa_4=+35.5°.$$

The theoretical curve in Fig. 1 has been computed using this set of κ values and the expressions above for σ_{Mott} and R.

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[1] K. B. Mather, Phys. Rev. 82, 126 (1951).
[2] See Boyer, Gove, Harvey, Deutsch, and Livingston, Rev. Sci. Instr. 22, 310 (1951) for a thorough description of the instrumentation of the emergent beam of the MIT cyclotron.
[3] J. A. Wheeler, Phys. Rev. 59, 16 (1941).
[4] N. F. Mott and H. S. W. Massey, *The Theory of Atomic Collisions* (Oxford University Press, London, 1949), second edition.

Removal of Space Charge in Cadmium Sulfide Crystals and Their Conduction Properties under Electron Bombardment

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SINGLE crystals of cadmium sulfide were grown here by the method used by Frerichs.[1] These crystals were 2.5 cm long and 0.2 cm wide, with a thickness between 0.002 cm and 0.008 cm.

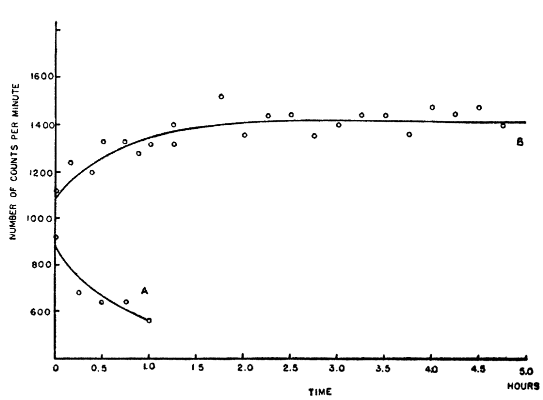

Fig. 1. Counting rate *versus* time. A. Crystal before heating. B. Crystal after heating for one minute.

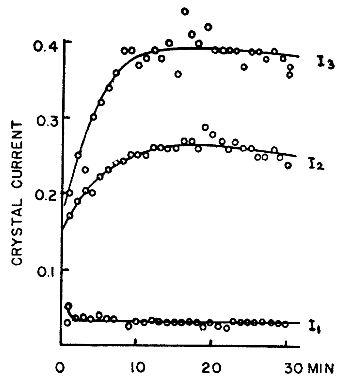

Fig. 2. Crystal current *versus* time. Electron energy 20 kev. Voltage across crystal 306 v. Incident current $I_3>I_2>I_1$.

A conventional arrangement was used for the detection of Po−α-particles by these crystals. The amplifier was similar to that described by Jordan and Bell.[2]

The space-charge formation in these crystals was studied, and it was found that the counting rate decreased rapidly with time, the effect being greater at lower fields across the crystal. In order to eliminate this effect the crystal was heated for one minute by means of a hot wire. It was found that for the first half hour the counting rate increased and then remained constant for about five hours. This method was tried for several crystals and found reliable. Figure 1 shows the counting rate before and after heating. This method of eliminating space charge by heating the crystal seems very successful in CdS because of its strong absorption in the infrared region. Corresponding effects have been observed in diamond when irradiated by violet and red light by Willardson and Danielson[3] and by heat by Pearlstein and Sutton.[4]

The conduction properties of CdS crystals under electron bombardment were also studied. The electrons were produced from an electron-gun and accelerated by a dc generator producing 100 kv. The amplification factor (current through the crystal/incident current) was found to be of the order of 10^3, and this remained constant for several hours. It seems that an equilibrium is reached between the electrons trapped and the reemission of these electrons resulting from the heating effect of the bombarding electrons. As shown in Fig. 2, the crystal current is steadier at smaller values of the incident current. The crystal currents for various energies of the incident electrons are shown in Fig. 3. The increase in the current is not linear, and this may possibly be because of the fact that at lower incident energies the surface effects play an important part.

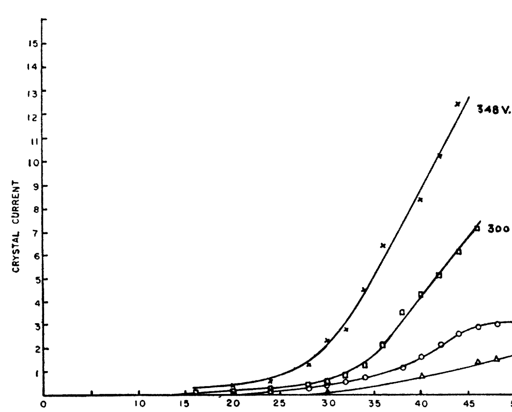

Fig. 3. Crystal current *versus* electron energy at various voltages across crystal.