from a scintillation or from photomultiplier noise, indicates that the satellites originate in the photomultiplier rather than in the counter solution.

The time distribution of the satellites was measured in another group of pictures of scintillation pulses. The results are given in Fig. 1. The variation of the rate of occurrence of satellites with photomultiplier voltage is shown in Fig. 2.

The time delays of the satellites are consistent with their being due to single positive ions, produced by the electrons of the main pulse, drifting back and striking an electrode.

In an experiment in which one records more than one pulse from the same scintillation counter—for instance, in the measurement of the π^+ meson lifetime—it will be necessary to take into account the multiple pulses due to satellites, which will give a background much greater than that calculated from the random noise rate.

* Supported by the joint program of the ONR and AEC.
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An Energy Level in Li^6

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PRIOR to the work reported herein and the concomitant investigation of Gove and Harvey,[1] there had been no conclusive evidence for the position of an energy level in Li^6.[2] Bjerge and Broström proposed a level at 3.7 Mev from the beta-decay of He^6,[3] and Pollard and Margenau deduced a level at 2.4 Mev from the resonance yield in the recoil deuterons when 2.6-Mev alpha-particles were scattered in deuterium.[4,5]

A level has been determined at 2.12±0.05 Mev (Fig. 1) by using a single-focusing 180° magnetic spectrograph in conjunction with the 7-Mev proton beam of the Rochester 26″ cyclotron to measure the energy spectrum of protons scattered from an enriched target. The target was prepared from a sample of LiF, enriched in Li^6,[6] by evaporating the LiF onto a thin film of polystyrene. By bombarding through such a target (i.e., so that the spectrograph slit accepts scattered particles which have emerged from the "back" face of the target), the angles between the target plane, incident beam, and emergent beam can be so chosen as to permit a first-order correction for energy loss in the target.

The low mass of the Li^6 target nucleus created a difficult problem: In a given scattering experiment the energy carried away by the recoiling target nucleus is a function of the scattering angle, and the variation of the scattering angle over the aperture of the spectrograph introduces, for light nuclei, so large a change in the recoil energy as to interfere seriously with the conditions of 180° focusing. It was found, however, that the position of a line on which focus is restored can be computed in terms of the parameters of the experiment.

Eastman NTA plates were used for detection. Background was materially reduced by having the microscopist accept only those tracks whose orientation in the emulsion satisfied stringent criteria.

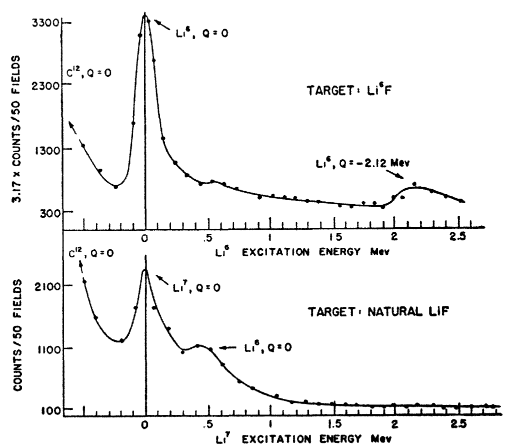

FIG. 1. Comparison of excitation curves obtained by proton scattering in which the targets were lithium fluoride enriched in Li^6, and natural lithium fluoride. The intensities have been normalized to correspond to the same bombarding flux per atom of lithium.

* Assisted in part by a grant from the Research Corporation of America. Now at Brookhaven National Laboratory, Upton, New York.
[1] H. E. Gove and J. A. Harvey, Phys. Rev. 82, 658 (1951).
[2] Browne, *et al.* [Phys. Rev. 83, 179 (1951)] announce a level at 2.19 Mev from the reaction $Be^9(p, \alpha)Li^{6*}$.
[3] T. Bjerge and K. J. Broström, Nature 135, 400 (1936).
[4] E. Pollard and H. Margenau, Phys. Rev. 47, 571 (1935).
[5] E. Pollard and H. Margenau, Phys. Rev. 47, 833 (1935).
[6] Obtained from the Stable Isotopes Division of Oak Ridge.

Shot Noise in Germanium Single Crystals*

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THE excess noise of thin single-crystal Germanium filaments has been measured over the frequency range 1–1600 kc by connecting the filaments to the input of a sensitive selective amplifier and measuring the noise ratio n of the filament.[1] The filaments were of the type used by Montgomery and Shockley in their noise measurements at lower frequencies.[2] They consisted of N-type material, but the excess noise was found to be caused by the generation of holes at the surface of the filament. The lifetime of the holes was of the order of 10^{-6} sec. At lower frequencies the noise ratio could be represented by a formula:[2]

$$n = 1 + AI^2/f, \tag{1}$$

where I is the dc current and A a constant.

The noise of one of the filaments measured by us showed important deviations from (1) at higher frequencies; we found that the experimental values of n could be very well represented over a wide frequency range by a formula of the type (Fig. 1):

$$n = 1 + AI^2/f + BI^2/[1 + (f/f_0)^2]. \tag{2}$$

At a filament current of 3 ma we found

$$AI^2 = 9.3 \times 10^5; \quad BI^2 = 54 \quad \text{and} \quad f_0 = 1.5 \times 10^5 \text{ cycles/sec};$$

f_0 was practically independent of the dc current.

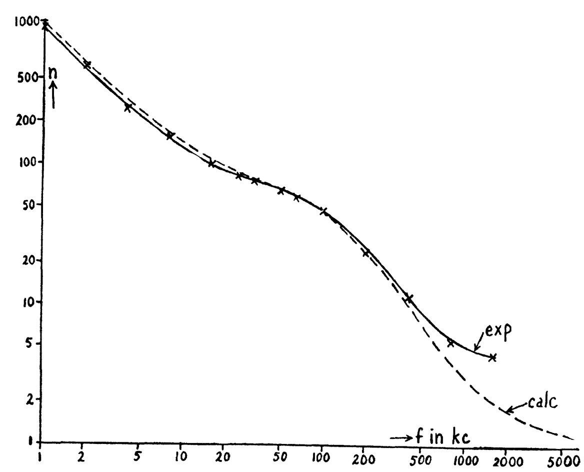

FIG. 1. Noise ratio n as a function of frequency for a current I of 3 ma. Crosses and full-drawn line: experimental results; dotted line: formula (2) with $AI^2 = 9.3 \times 10^5$; $BI^2 = 54$; $f_0 = 1.5 \times 10^5$ cycles/sec.

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

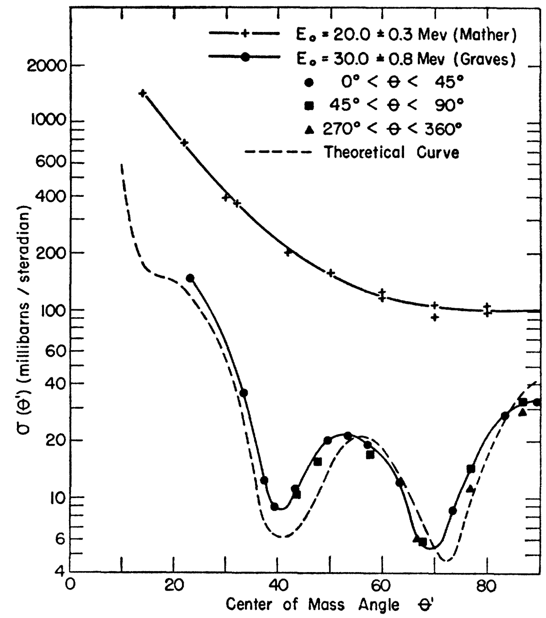

FIG. 1. The angular distribution of alpha-particles elastically scattered from helium, shown in the center-of-mass system on a semilogarithmic plot: at 20 Mev, according to the earlier work of K. B. Mather, and at 30 Mev, according to the present work, with a theoretical curve for scattering at 30 Mev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

outputs of the two shallow counters, located back to back, were placed in time coincidence to reduce background.

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 $\pm0.5°$ 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 $\pm2°$ 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 $\theta=50°$.