very promising solution to the problem of generation and amplification of energy at millimeter wave-lengths. This feature also makes it easy to understand how electromagnetic radiation over limited frequency bands is produced in nature whenever there exist inhomogeneous streams of charged particles. For example, streams of charged corpuscles emerging from sun spots during solar flares present just such conditions where enormous amplification of space charge fluctuations can occur over a limited frequency range determined by the composition of the streams. The associated space-charge fields radiate the electromagnetic energy in this frequency band, and it is usually observed in radio telescopes as intense bursts of solar noise. Application[2] of the above theory made it possible to estimate the expected spectral energy distribution of radio noise associated with solar flares which agrees well with measurements such as those of Appleton and Hey.[3]

The excess noise in electron-beam tubes and in magnetrons can also be explained in terms of the new theory. The inhomogeneity of the electron stream in beam tubes is caused by d.c. space-charge field and the excess noise is then the result of amplification of the original shot noise due to interaction of the different velocity components of the stream. In magnetrons the original fluctuations of cathode current create fluctuations of space-charge field. These fluctuating fields or waves interact with electrons in such a manner that original fluctuations increase in amplitude and some electrons gain and some lose energy. Since at cut-off fields many electrons return to the cathode, the space-charge waves also travel in both directions and the amplification proceeds to a saturation level determined by the anode potential, the magnetic field, and the density of the electron cloud. Some electrons can thus attain high excess energy proportional to anode potential so that the final energy distribution of the electron cloud may correspond to an apparent temperature of millions of degrees.[4] The flow of current to the anode at magnetic fields exceeding cut-off value can thus be understood.

[1] The author's paper on "The electron wave tube—A novel method of generation and amplification of microwave energy" has been submitted to the Proc. I. R. E.

[2] A fuller account of the theory of generation of abnormal solar radio noise is the subject of a paper now in preparation.

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Disintegration of Deuterium by Gamma-Rays from ^{24}Na

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ACCORDING to theory, the angular distribution of protons created by the process ${}^2_1D+h\nu\rightarrow{}^1_1H+{}^1_0n$ can be described by the formula $n_\theta=a+b\sin^2\theta$, where n_θ is the number of protons emitted per unit solid angle in a direction making an angle θ with the direction of the incident γ-rays, and a and b are constants. The first constant term is caused by the so-called photomagnetic effect, the second term to the photoelectric effect. The ratio σ_m/σ_e between the cross sections for the two processes can be derived when the ratio $n_{0°}/n_{90°}=a/(a+b)$ is measured, and such measurements have been performed by several investigators.[1–5] However, since the various results do not agree with each other and, furthermore, since mainly the angles $\theta=0°$ and $\theta=90°$ have been examined, measurements of the angular distribution were undertaken by means of a new method.

The instrument used was a battery of proportional counters arranged in parallel and filled with pure deuterium. Each counter was cylindrical, having a length ten times the diameter. The photo-protons created in the gas inside the tubes were recorded by means of a proportional amplifier and a cathode-ray oscillograph which was photographed on a moving film. The magnitude of the pressure inside the counters was such that the range of the protons was about $\frac{3}{4}$ the counter diameter. Hence, protons traveling perpendicularly to the axis of the counters will hit the

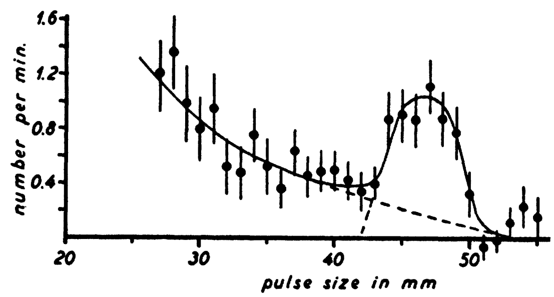

FIG. 1. Pulse-size distribution curve obtained for $\theta=90°$.

walls and only a small part of their tracks will lie inside the counters; consequently, these protons will give rise to much smaller pulses on the oscillograph than those moving parallel to the counter axis. Only protons moving in directions deviating from the axis by less than a certain small angle, the magnitude of which is determined by the range and the counter diameter, will end their paths inside the counters and produce pulses of maximum size. A simple calculation shows that the pulse-size distribution curve falls off with increasing pulse sizes, except in the very end where a peak occurs, the height of which is determined by the accuracy of the pulse-size measurements. In order to get reasonably good statistics it was necessary to use a rather strong γ-irradiation ($\sim$500 millicuries at a distance of 30 cm), which caused a high background ionization in the counters and consequently a background noise on the oscillograph, which involved a rather high spread in the pulse size measurements. Nevertheless, a pulse size distribution curve with a peak was actually obtained, as shown in Fig. 1. The protons corresponding to this peak will have tracks deviating but little from the counter axis, and hence the angular distribution of the protons can be obtained by measuring the number corresponding to the peak for varying values of the angle θ between the γ-rays and the counter axis. For small values of θ two peaks corresponding

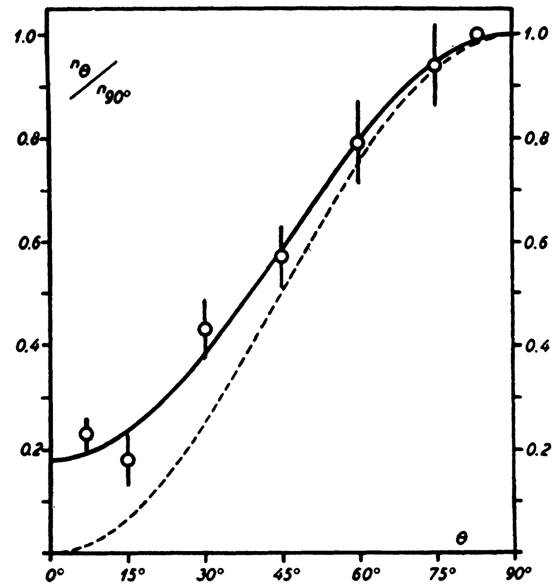

FIG. 2. Angular distribution of photo-protons.

to the different energies of forward and backward directed protons could have been expected, but the limited statistical material and the mentioned spread in pulse sizes did not allow their separation. In fact, for small values of θ the position of the peak was not very well defined, and therefore the number n_θ of pulses higher than 40 mm (see Fig. 1) was counted for the various values of θ. The result of the measurements, in which ^{24}Na was used as a γ-ray source, is given in Fig. 2, where the full-drawn curve corresponds to the formula

$$n_\theta/n_{90°}=a+b\sin^2\theta=0.18+0.82\sin^2\theta.$$

The ratio $a/(a+b)$ is found to be 0.18 ± 0.03, the ratio a/b to be 0.22 ± 0.04, in good agreement with the value 0.26 ± 0.08 given by Graham and Halban.[5] The present experiments give $\sigma_m/\sigma_e=0.33$ and $\sigma_m/\sigma_{\text{total}}=0.25$. The dotted curve in Fig. 2 corresponds to $\sigma_m=0$, and the figure clearly shows that there can be no doubt that both the photomagnetic and the photoelectric effect exist for the γ-energy concerned.

When determining the absolute cross section it is necessary to know the absolute strength of the γ-source and the range ρ of the protons. The author is indebted to Mr. Koefoed-Hansen for measuring the absolute strength of a weak sample of ^{24}Na by means of a special counting arrangement. Unfortunately, ρ is not known very accurately and, hence, the result may be given as follows, where a correction of $+20$ percent resulting from the absorption of the γ-rays and a correction of -20 percent resulting from the foot on the pulse-size distribution curve are included:

$$\sigma_{\text{total}}=0.8\cdot10^{-27}\cdot\frac{9\rho^2}{11-3\rho}\ \text{cm}^2\pm20\ \text{percent},$$

where ρ is the range in cm deuterium. Putting $\rho=1.5$ cm we get $\sigma_{\text{total}}=2.5\cdot10^{-27}$ cm^2 but, as we have seen, the result depends strongly on the value of ρ chosen.

A more detailed account of the work will soon be published in the Communications of the Danish Academy of Science.

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Multiple Scattering with Energy Loss

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FERMI[1] has found the distribution function for the lateral and angular displacements of charged particles which undergo multiple elastic scattering in passing through a layer of matter. In his treatment the energy loss which the particles suffer due to ionizing collisions is neglected. In this note we show that energy loss can be taken into account to a good approximation, and that this leads to a simple generalization of Fermi's distribution function.

The diffusion equation for the distribution function $F(t, y, \theta)$ is, in Rossi and Greisen's[1] notation and units,

$$\frac{\partial F}{\partial t}=-\theta\frac{\partial F}{\partial y}+\frac{1}{W^2}\frac{\partial^2 F}{\partial\theta^2},\tag{1}$$

where $W=2p\beta/E_s$. *We assume that p and β are functions of t*, i.e., we neglect the fact that a particle at t has traveled a somewhat greater distance than t due to the deviations caused by scattering. For the multiple scattering of high energy particles these deviations will be small and the approximation will be a good one. In (1) then we assume that W^2 is some known function of t, although not necessarily one for which there is an analytic expression. If we apply the Fourier transforms

$$F(t, y, \theta)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}G(t, x, \zeta)\exp(i(xy+\zeta\theta))dxd\zeta,\tag{2}$$

$$G(t, x, \zeta)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}F(t, y, \theta)\exp[-i(xy+\zeta\theta)]dyd\theta,\tag{3}$$

to (1) we are led to the equation for $G(t, x, \zeta)$,

$$\frac{\partial G}{\partial t}=x\frac{\partial G}{\partial\zeta}-\frac{\zeta^2}{W^2(t)}G.\tag{4}$$

After introducing the two new variables

$$\xi=t+\zeta/x,\quad t'=t,\tag{5}$$

Eq. (4) becomes:

$$\frac{\partial G}{\partial t'}=-\frac{x^2(\xi-t')^2}{W^2(t')}G.\tag{6}$$

The solution of (6) is

$$G=H(\xi)\exp\left[-x^2\int_k^{t'}\frac{(\xi-\eta)^2}{W^2(\eta)}d\eta\right],\tag{7}$$