the beaker would rise if there were no film flow at all, and the line $b$ indicates the rate at which the bath and beaker levels would rise together due to displacement of liquid by the plunger if at every instant the transfer rate was exactly that necessary to keep both levels equal.

The following features of the curve are regarded as the most significant:

(a) Initially, for $0<t<20$ sec the level rises very rapidly almost along the line $a$, indicating that during this time the flow rate is very close to zero. The duration of this initial rapid rise appears to increase as the height, $H$, of the beaker top above the bath is increased at a given temperature, and also as the temperature is increased at a given height $H$. Attempts are now being made to measure these dependences more precisely.

(b) At approximately $t=20$ sec a sharp break in the curve occurs, and from 50 sec to 100 sec the level moves downward in a stepwise fashion, indicating that the helium may be transferred in pulses rather than uniformly. If an average transfer rate is calculated from the slope of a straight line drawn through the points on this portion of the curve, the value obtained agrees with that measured at large level differences ($\sigma_0=8.81\times10^{-5}$ cc cm$^{-1}$ sec$^{-1}$).

(c) From $t=100$ sec onwards, the curve levels off and then eventually rises gradually in a stepwise fashion, remaining on the average parallel to, but approximately 0.02 mm above, line $b$. The value of $\sigma$ calculated for this portion of the curve is less than $\sigma_0$ and varies with the rate of plunger motion.

(d) When the plunger is stopped at $t=471$ sec, the level does not simply drop to zero, but executes what appears to be a damped oscillatory motion. The period of these oscillations is roughly linearly proportional to the film height $H$ and is somewhat less than that calculated for our conditions from equations derived by Atkins.[3] From the fact that the eventual equilibrium position of the level in the beaker is lower than the level position when the plunger is stopped, and from the results in (c), we infer that a finite but small level difference is always necessary to sustain film flow, even at rates less than the critical value.

Investigations of these phenomena at different temperatures and film heights, $H$, are now being carried out in order to distinguish whether the initial sharp rise noted in (a) above is due to a critical level difference necessary to initiate film flow or to a critical time for transmission of the initial information of the changed conditions produced by the plunger motion. We also hope to determine the level differences necessary to maintain flow at less than the critical rate. A detailed paper will be published soon.

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# Scattering of $1.3^3$ Mev Gamma-Rays by an Electric Field*

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A SEARCH has been made to detect the elastic scattering of gamma-rays by the electric field of the nucleus, an effect sometimes called Delbruck or potential scattering.[1] In the experimental arrangement shown in Fig. 1, 1.3-Mev gamma-rays from a 2.5-curie Co$^{60}$ source are collimated by the conical opening in a lead block and are then incident on the scattering material. The scattered gamma-rays pass through a lead absorber of variable thickness and fall on an energy-sensitive detector comprised of a NaI(Tl) crystal (4 cm o.d. by 3 cm long) and an RCA 5819 electron multiplier tube, the energy resolution of the whole system being about ten percent. The large inelastic Compton scattering (about $10^4$ times larger than that which might be reasonably expected for potential scattering) is discriminated against by biasing the detector above the energy of such scattered photons. Further energy discrimination is provided by the lead absorber.

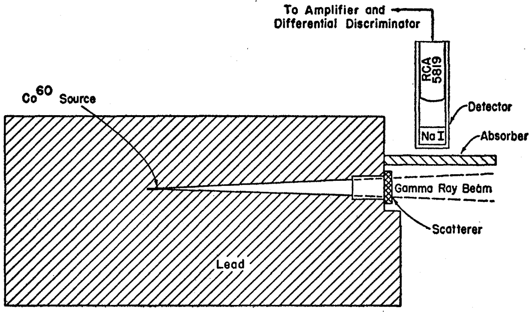

FIG. 1. Experimental arrangement.

The effect of Compton scattering from electrons was shown to be small by the use of a copper target containing the same number of electrons as the Pb target; the elastic scattering from copper should be negligible compared to that from heavy elements such as lead. When a sufficiently thick lead absorber was placed between target and detector, the scattering from copper was less than 20 percent of that from lead. The cross sections measured were not dependent on knowing the absolute calibration of the source nor on knowing the efficiency of the detector, over-all calibration being made by exposing the source directly to the detector placed at a large distance.

Gamma-rays can be scattered elastically by atoms in several ways: (a) by Thomson scattering through the motion of the whole nuclear charge; (b) by Rayleigh scattering from the tightly bound electrons; (c) by nuclear resonance scattering; and (d) by potential scattering through virtual pair production.

The Rayleigh scattering will be in phase with the Thomson scattering which is given by $R_0^2(1+\cos\theta)/2$, where $R_0=Z^2e^2/Mc^2$, $Z$ and $M$ being the charge and mass of the scattering nucleus. Using a Fermi-Thomas model, Franz[2] has made calculations of Rayleigh scattering which have been confirmed at 0.43 Mev by

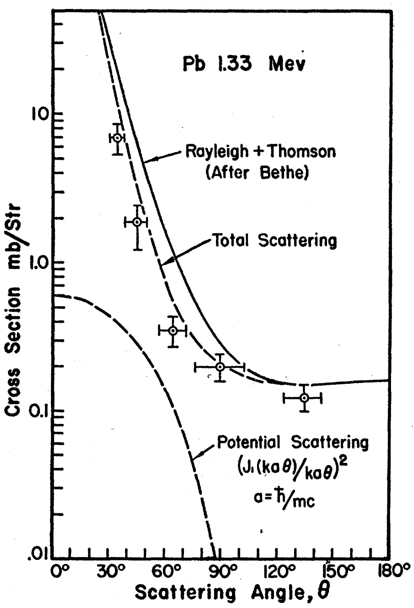

FIG. 2. The cross section in millibarns per steradian for the elastic scattering of 1.33-Mev gamma-rays by lead. The curve marked total scattering is a very rough estimate of Rayleigh, Thomson, and potential scattering combined.

Moon[3] and Storruste.[4] Bethe[5] has made similar calculations but using relativistic wave functions for the $K$ electrons instead of the Thomas-Fermi distribution assumed by Franz. The compound effect of Rayleigh and Thomson scattering as calculated by Bethe is shown in Fig. 2.

Nuclear resonance scattering[6] should be very small except at resonance; the resonances should be less than $10^{-3}$ ev wide and spaced by at least several kev, hence one would be unlucky indeed to land near such a resonance. Measurements have also been made on Bi, Au, Pt which give very similar results to Pb. Thus nuclear resonance scattering is unlikely to contribute in any way to the measured results.

The experimental results for lead are plotted in Fig. 2, the horizontal bars indicating the angular resolution and the vertical bars, the standard statistical counting error. The measured cross sections agree with Bethe's calculation of Rayleigh-Thomson scattering at large angles, but are considerably lower at angles less than 90°.

Because the experimental difficulties all tend to make the measured cross sections come out too high, one is inclined to conclude (a) that the calculations of Rayleigh scattering at small angles are incorrect, or (b) that another scattering process is occurring which interferes destructively with the Rayleigh scattering to give the small cross sections actually observed. It does not seem likely that Bethe's calculation is wrong by a factor of five; hence the more probable conclusion is that potential scattering is responsible for the reduction of the cross section. Potential scattering would interfere destructively.

Now Rohrlich and Gluckstern[7] have calculated the potential scattering cross section in the forward direction and find it to be 0.6 millibarn per steradian at this energy. No calculation has been made as yet of the angular distribution. The curve plotted in Fig. 2 is on the assumption that the distribution is the same as that obtaining for a wave scattered by a black disk of radius $\hbar/mc$, i.e., diffraction scattering, and normalized to the theoretical result at zero degrees. The dashed curve marked "total scattering" is the result of compounding the amplitudes of the potential scattering and of the Rayleigh and Thomson scattering, assuming that they are exactly of opposite phase. That the measurements are in much better agreement with this curve can be taken as evidence for the occurrence of potential scattering, but this conclusion is subject to a refined calculation of the angular distribution of potential scattering and of the Rayleigh scattering at small angles.

I am grateful to H. A. Bethe, F. Rohrlich, and J. S. Levinger for many stimulating discussions.

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[*] The measurements here reported were all made in 1951. Publication has been held up until now in the hope that the Rayleigh scattering could be calculated more accurately.

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## Inner Bremsstrahlung and the Magnetic Moment of the Neutrino

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RECENT measurements on the beta-spectrum of $H^3$ establish an upper limit of 250 ev for the neutrino rest mass.[1] It is of some interest to point out that the question of the magnitude of the neutrino rest mass is intimately related to the question of the magnitude of its magnetic moment.

During beta-decay, the neutrino is ejected from the neighborhood of the parent nucleus with a velocity very nearly equal to light velocity. Assuming the particle possesses a finite Pauli magnetic moment, one can calculate the intensity of inner bremsstrahlung.[2] The result shows that the total intensity is directly proportional to the square of the moment and inversely proportional to the square of the neutrino rest mass. Confirmation of this relation can be obtained also by a purely classical calculation in the manner outlined by Chang and Falkoff.[3]

A polar vector interaction in an allowed transition yields the following result for the intensity of neutrino inner bremsstrahlung (integrated over all directions):

$$I(k)dk \approx \frac{2\alpha}{\pi}\left(\frac{m}{\mu}\right)^2 g^2 k^2 (W_\nu - k)^2 dk, \quad \mu \to 0 \tag{1}$$

where $\alpha$ is the fine structure constant, $m$ the electron rest mass, $\mu$ the neutrino rest mass, $k$ the photon energy, $W_\nu$ the initial neutrino energy measured in units of $mc^2$, and $g$ is the neutrino moment in Bohr magnetons.

The expression must be integrated over the neutrino spectrum corresponding to the probability for emission with energy $W_\nu$. As superimposed on the normal $\beta$ inner bremsstrahlung, the neutrino spectrum would appear as a spurious "line." Adopting the value 1/5000 Bohr magneton allowed by ionization measurements,[4] and Langer's upper bound for $\mu$, the peak of this line would be about three times as great as the corresponding $\beta$ inner bremsstrahlung for kinetic energies for both particles of 1 Mev. Identification of the entire inner bremsstrahlung by actual experimental observation as $\beta$-radiation[5] clearly necessitates the adoption of a smaller value for the upper limit of the neutrino moment, consistent with the limits of experimental error. Detection of the anomalous line would constitute direct observation of the neutrino.

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## Possible Breakdown of Isotopic Spin and Charge Parity Selection Rules

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IT is of interest to determine the purity of isotopic spin[1] and charge parity[2] states. In nuclei of moderate excitation it appears that the contamination of such states may amount to a few percent in *amplitude* from the two probable violations of the selection rules so far reported;[3] the many examples of the success of the rules are consistent with such a purity. A contamination of this order is expected even under perfect charge independence or charge symmetry of the specifically nuclear forces in view of the Coulomb perturbation.[4] It must be anticipated that at higher excitations these concepts of isotopic spin and charge parity will cease to have much significance, and effectively complete breakdown of the rules must be expected. This note indicates one probable and two possible breakdowns.

The reaction $N^{15}(p, \alpha)C^{12}$ (ground state) is strongly resonant, for a particular angle of observation, at a proton energy of 1020 kev; the total width of the resonance is about 160 kev.[5] The reaction $N^{15}(p, \gamma)O^{16}$ (ground state) is strongly resonant at a proton energy of 1050 kev with a total width of about 150 kev.[5] It seems reasonable to identify these resonances and to ascribe their small separation in energy to effects of neighboring levels. The first observation permits the spin of the compound state to be (0+)(1−)(2+), etc.; the second observation eliminates (0+). If we take (1−), we have $E1$ radiation with $(2J+1)\Gamma_\gamma = 450$ ev and $(2J+1)|M|^2 = 0.29$ in excellent accord with other $E1$ transitions