apparatus would detect efficiently only neutrons with energies between about 0.5 and 15 Mev, the results refer to the knock-on and evaporation neutrons lying in this range and exclude neutrons of higher energies which may be produced in the absorption mechanism.

The π-mesons were produced by the 315-Mev bremsstrahlung beam of the Cornell synchrotron incident on a Be target. Negative mesons, with energies between about 30 and 75 Mev, were selected by a double-focusing magnet system.[2] After the magnets, the mesons passed through three trays of GM counters, A, B, and C in Fig. 1, and were brought to rest in the absorber Σ, which was

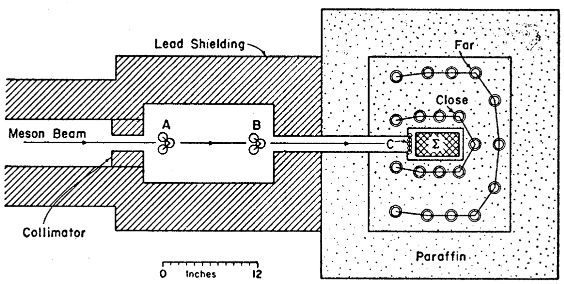

FIG. 1. Side view of the experimental arrangement. A, B, and C are GM counters; Close and Far are groups of BF_3 proportional counters connected in parallel. Σ is the absorber in which π-mesons stop.

thick enough to stop 90-Mev mesons. Neutrons emitted from Σ following the absorption of the meson by a nucleus were thermalized by the surrounding paraffin (total volume about 3 ft$\times$3 ft $\times$2.5 ft) in which were embedded 20 BF_3 proportional counters. The counters were divided into two groups, designated as "Close" and "Far," and the counters of each group were connected in parallel. About 2 Mev and 10 Mev were needed for neutrons to reach counters "Close" and "Far," respectively.

Coincidences $A+B+C$ triggered the sweep of a cathode-ray tube gated to have a length of 600 μsec, spread over a path of 60 cm. The amplified pulses of the neutron counters were applied to the deflecting plates of the CRT in such a fashion that counters "Close" and "Far" produced pulses of opposite sign. A camera, triggered by $A+B+C$, took pictures of the sweep.

The experiment was run at a beam intensity sufficiently low for the neutron background to be smaller than 5 percent. The background was estimated by analyzing the distribution in time of the neutrons appearing on the 600-μsec sweep, using the experimental information that the neutron lifetime in the detector was (150$\pm$5) μsec. The estimate of the background was found in agreement with the results obtained in 500 pictures taken with the magnets set to select positive mesons.

The contamination of the π-meson beam by μ-meson, resulting from the decay in flight of the π's, was estimated to be not larger than 4 percent; our results have been corrected accordingly, using the results of Widgoff for neutrons produced by μ-meson absorption.[3]

The results are listed in Table I. The first five rows give the corrected numbers of pictures in which n neutrons were observed. The efficiencies ϵ of the apparatus for detecting each neutron were determined with a RaαBe source placed at various points in the absorbers Σ. The largest uncertainty in these determinations arises from the fact that the energy spectra of the neutrons emitted by the various absorbers will in general differ from the spectrum of the RaαBe source. The values of the ratios of the recorded rates "Close" and "Far" are given as an indication of the relative hardness of the neutron spectra in the various absorbers. With the RaαBe source located in the absorbers, such ratios were between 4.5 and 5. Therefore, the efficiencies listed for Pb and Sn are underestimates, and those for Al and C overestimates. In row 8 are given the average numbers $\langle\nu\rangle$ of neutrons with $E<\sim 15$ Mev emitted per π-meson absorbed; i.e., $\langle\nu\rangle=\langle n\rangle/\epsilon$. The errors given are statistical only. The spread in the distribution of the ν's around $\langle\nu\rangle$ is given by the standard deviation σ computed according to

$$\sigma^2=\langle\nu^2\rangle-\langle\nu\rangle^2=[\langle n^2\rangle-\langle n\rangle^2-\langle n\rangle(1-\epsilon)]/\epsilon^2.$$

For comparison, in row 10 are given the average numbers of neutrons $\langle\nu_\mu\rangle$ produced by absorption of a negative μ-meson.[3]

The present data support the interpretation that the starless meson tracks observed in plates (about 30 percent of all meson tracks ending in the emulsion) are associated with emission of neutrons only. By interpolating our data to $A=100$, one gets $\langle\nu\rangle=5.2\pm0.4$ and $\sigma\approx2$, which is not inconsistent with the data obtained from plates and with calculations of LeCouteur[4] ($\langle\nu\rangle=4.5$ and $\sigma=1.9$) and with recent detailed calculations of Puppi *et al.*[5] ($\langle\nu\rangle\approx5$). The energy spectrum of the neutrons as calculated in reference 5 is also not inconsistent with the recorded ratio Close/Far.

TABLE I. Data on neutrons produced by various nuclei in the absorption of negative mesons at rest.

		Pb	Sn	Al	C
1.	$n=0$	484	425	950	1128
2.	$n=1$	234	159	125	128
3.	$n=2$	78	36	6	4
4.	$n=3$	21	3	1	1
5.	$n=4$	5	0	0	0
6.	ϵ(%)	6.2	6.3	6.5	7.0
7.	Close/Far	7.8$\pm$1.1	6.0$\pm$1.1	3.5$\pm$0.7	3.2$\pm$0.6
8.	$\langle\nu\rangle$	9.3$\pm$0.5	6.1$\pm$0.4	2.0$\pm$0.2	1.6$\pm$0.2
9.	σ	5.5$\pm$0.8	2.3$\pm$1.0	1.4$\pm$0.5	1.2$\pm$0.5
10.	$\langle\nu_\mu\rangle$	2.1$\pm$0.2	1.5$\pm$0.2	0.9$\pm$0.2	...

* Work supported by the ONR.

[1] E.g., see bibliography quoted in: R. E. Marshak, *Meson Physics* (McGraw-Hill Book Company, Inc. New York, to be published).
[2] M. Carmac, Rev. Sci. Instr. 22, 197 (1951).
[3] M. Widgoff, Ph.D. thesis, Cornell University, 1952 (unpublished).
[4] K. J. LeCouteur (private communication).
[5] Puppi, De Sabbata, and Manaresi (private communication).

Magnetic Double Refraction at Microwave Frequencies

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(Received August 12, 1952)

WE have recently observed a magnetic double refraction effect at microwave frequencies similar to the well-known Voigt and Cotton-Mouton effects at optical frequencies. This magnetic double refraction was evidenced by a conversion from linear to elliptical polarization of a dominant TE wave in a section of circular wave guide filled with ferrite and subjected to a dc magnetic field H_0 transverse to the direction of propagation and at 45° to the input polarization.

This double refraction is to be explained by the difference between the rf permeabilities of the medium along the dc field $\mu_{\parallel}$ and at right angles to the dc field $\mu_{\perp}$. In order to compute these permeabilities we shall make the simplifying assumption that we are dealing with a uniform TEM wave in an infinite medium of ferrite. It is believed that the results should apply rather closely for the wave-guide case, just as the analysis for the infinite plane wave Faraday effect applies fairly closely to wave guides, as found by Hogan.[1] Furthermore, it is assumed that the ferrite is saturated and has no magnetic losses.

For the above conditions, the wave whose magnetic vector is parallel to H_0 sees a relative permeability of one, independent of the magnitude of H_0. However, an rf magnetic vector $H_\perp$ perpendicular to H_0 sees a permeability $\mu_\perp$, which depends on the magnitude of H_0 as shown in the ferromagnetic resonance papers of Kittel.[2] This dependence is caused by the uncompensated electron spins in the ferrite, which are oriented by H_0 and have a natural precession frequency given by $\omega_0=\gamma H_0$, where γ is the spectroscopic splitting factor.

In order to calculate the permeability for the rf $H_\perp$, we decompose the $H_\perp$ into two circularly polarized components whose permeabilities are shown by Polder[3] to be, (in rationalized units)

$$\mu_+/\mu_0=1+\gamma M/(\omega_0-\omega),\quad \mu_-/\mu_0=1+\gamma M/(\omega_0+\omega), \tag{1}$$

where M is the saturation magnetization of the sample and ω is the operating frequency. Knowing μ_+ and μ_-, it can be shown that the effective $\mu_\perp$ is given by[3]

$$\mu_\perp=\frac{2\mu_+\mu_-}{\mu_++\mu_-}=\left[1+\frac{\gamma M\omega_0+\gamma^2M^2}{(\omega_0^2-\omega^2)+\gamma M\omega_0}\right]\mu_0. \tag{2}$$

It is interesting to note that $\mu_\perp$ becomes infinite, not when $\omega=\omega_0=\gamma H_0$ as for an infinite medium magnetized in the direction of propagation, but when $\omega=\omega_0(1+\gamma M/\omega_0)^{\frac{1}{2}}$. Thus, the maximum magnetic displacement in the medium will occur at different frequencies depending upon the direction of the dc magnetic field relative to the field vectors of the wave.[3] This is due to the fact that for a uniform plane wave there is no rf B in the direction of propagation as can be seen from Maxwell's curl equation. The electrons therefore experience a restraint from turning their spin axes in a longitudinal direction, since there will be an rf H along the z axis opposing their alignment in this direction. This restraint is equivalent to a demagnetizing force which raises the resonant frequency. No such restraint to electron precession exists when the H_0 is in the direction of propagation.

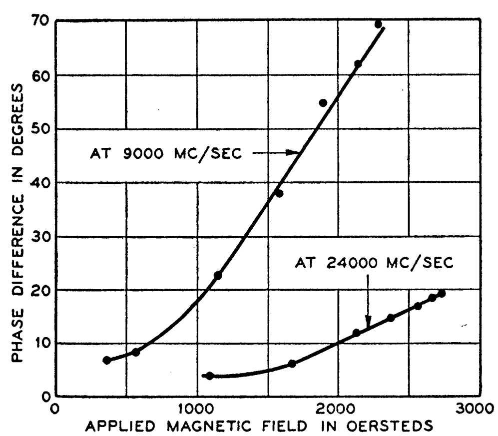

FIG. 1. Phase difference as a function of applied magnetic field, at 24,000 Mc/sec and 9000 Mc/sec.

If ω is much higher than the resonance frequency, so that ω_0^2 and $M\gamma\omega_0$ can be neglected compared to ω^2, the above equation can be simplified to

$$\mu_\perp=[1-(\gamma M\omega_0+\gamma^2M^2)/\omega^2]\mu_0. \tag{3}$$

The relative phase retardation of the wave with its magnetic vector parallel to H_0, with respect to the wave whose magnetic vector is perpendicular to H_0, is therefore given by

$$\theta_\gamma=2\pi l\left(\frac{1}{\lambda_{\parallel}}-\frac{1}{\lambda_\perp}\right)=\frac{l(\epsilon\mu_0)^{\frac{1}{2}}}{2}\left[\frac{\gamma^2M^2}{\omega}+\frac{\gamma^2MH_0}{\omega}\right]. \tag{4}$$

This is to be compared to the Faraday rotation angle given by Hogan:[1]

$$\theta_F=\tfrac{1}{2}l(\epsilon\mu_0)^{\frac{1}{2}}[\gamma M]. \tag{5}$$

It is thus seen that far above resonance, the double refraction effect will be much smaller than the Faraday rotation and will be inversely proportional to frequency. It is also to be noted that the relative phase retardation is a linear function of the applied steady magnetic field after the material is saturated, unlike the Voigt and Cotton-Mouton effects which are quadratic functions of the magnetic field, since these latter deal with nonsaturable materials.

In the experimental setup to check the above relations, the ferrite sample is placed in a dominant mode circular wave guide with reflections eliminated by proper tapering and with cross polarizing absorbers used to prevent cross-polarized reflections from the rectangular guide ends. The transverse magnetic field is applied at 45° to the rf E vector. The phase difference is measured by noting the ellipticity of the output with linearly polarized input. The results for measurements made at 24,000 Mc/sec and at 9000 Mc/sec are shown in Fig. 1. The measurements at these two frequencies were made with the same type of ferrite but with somewhat different geometrical shapes. From the results one notes that the phase difference is a linear function of the magnetic field over the high field range and that the effect is much smaller at the higher frequencies as predicted by the above analysis.

[1] C. L. Hogan, Bell System Tech. J. 31, 1 (1952).
[2] C. Kittel, Phys. Rev. 71, 270 (1947).
[3] D. Polder, Phil. Mag. 40, 99 (1949).

Internal Conversion of the Sr^{88} Gamma-Rays*

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WHEN investigating the decay of 105-day Y^{88}, Peacock and Jones[1] determined the internal conversion coefficients of the 0.9- and 1.85-Mev Sr^{88} gamma-rays as 2.7×10^{-4} and 1.3×10^{-4}, respectively. Using the theoretical data then available, these authors characterize the 1.85-Mev transition as electric dipole, the 0.9-Mev transition as magnetic dipole. Ling and Falkoff[2] based their analysis of the angular correlation data[3] on this assignment and showed that the spin combination 2–1–0 with a mixture of $E2$ and $M1$ for the 900-kev transition fits the experimental results.

Recently Bunker, Langer, and Moffat[4] found that the disintegration of Rb^{88} leads to the same levels in Sr^{88}. They assigned even parity to all the levels in Sr^{88}, discarding the conversion experiments.

In view of this disagreement we decided to reinvestigate the internal conversion of the Sr^{88} gamma-rays. This seemed the more important, as at least one experiment had indicated an electric dipole transition which is a type of transition rarely found in radioactive decays.

Using a Y^{88} source obtained from the MIT cyclotron group,[5] we compared with a lens spectrometer of 2.5 percent resolution the internal conversion electron peaks with the photoelectron peaks from a gold converter of known efficiency. In Table I the experimental conversion coefficients are compared with the theoretical values of Rose *et al.*[6] The agreement between the two experiments is satisfactory. The conversion coefficients characterize the 900-kev transitions as $E1$, the 1.85-Mev transition as $M1$ or $E2$.

TABLE I. Internal conversion coefficients of the Sr^{88} gamma-rays. The experimental values are total conversion coefficients, the theoretical values K-conversion coefficients.

	Experiment α		Theory α_K			
	Peacock and Jones	This paper	$E1$	$E2$	$M1$	$M2$
$10^5\times\alpha_K$ (0.9 Mev)	27	34 ± 7	28	68	66	165
$10^5\times\alpha_K$ (1.85 Mev)	13	17 ± 4	7.8	15	15.5	29

For the explanation of the angular correlation experiments one is now faced with the necessity of having to mix $E1$ and $M2$. If such a mixture occurs, it provides us with information concerning the reduction of the $E1$ matrix element. However, before this question can be decided, better angular correlation data are necessary.