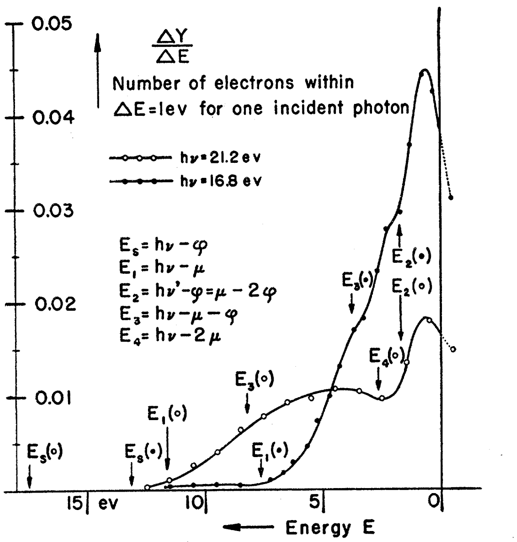

FIG. 2. Differential energy distribution of electrons emitted from beryllium for two different photon energies.

from level φ, adding another group ($E_3=h\nu-\mu-\varphi$). If $h\nu>2\mu$, the primary photoelectron has enough energy for a "secondary ionization" leading to another group having the maximum energy $E_4=h\nu-2\mu$ outside the metal. It should be pointed out that E_1 and E_4 do not depend on the work function explicitly, and E_2 is the same for different wavelengths of the primary radiation. Beryllium has been chosen to illustrate this model, because the simple assumption of only one definite level seems to be a fair approximation. Figure 2 presents experimental energy distribution curves for two different wavelengths ($h\nu=16.8$; 21.2 ev). If one uses $\mu=9.2$ ev as estimated from the experimental spectral yield distribution, and $\varphi=3.7$ ev, then the energies E_1, E_2, E_3, and E_4 derived from this model are those indicated by vertical arrows in Fig. 2. No matter how much of our model will survive further theoretical investigation, the experimental curves of Fig. 2 show clearly that only a negligible number of emitted electrons could have come from levels near the top of the Fermi band, and that a fairly sharp increase of the cross section for photon-electron interactions in a metal occurs at much deeper levels than those which are important for thermal emission, field emission, and the common photoelectric surface effect.[3]

[1] Quantitative indications of extremely high photoelectric yields in the vacuum ultraviolet have been reported by C. Kenty, Phys. Rev. 44, 896 (1933); R. F. Baker, J. Opt. Soc. Am. 28, 60 (1938); H. E. Hinteregger and K. Watanabe, J. Opt. Soc. Am. 43, 604 (1953); Wainfan, Walker, and Weissler, J. Appl. Phys. 24, 1318 (1953).

[2] J. Dickey, Phys. Rev. 81, 612 (1951), found no agreement of photoelectron energy distribution curves for Na and K with the shapes expected from common theories although his highest photon energy was only 6.7 ev.

[3] Some additional publications of interest in connection with this Letter are: I. Tamm and S. Schubin, Z. Physik 68, 97 (1931); M. M. Mann and L. A. Du Bridge, Phys. Rev. 51, 120 (1937); H. Y. Fan, Phys. Rev. 68, 43 (1945).

Nuclear Magnetic Octupole Moments of the Stable Gallium Isotopes*

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THE three zero-field hyperfine structure intervals of the metastable $^2P_{\frac{3}{2}}$ state of Ga^{69} and Ga^{71} have been remeasured[1] to higher precision to establish the existence of a nuclear magnetic octupole moment.

The atomic-beam magnetic resonance method was employed; the transitions were induced by the Ramsey technique[2] of separated oscillating fields. One oscillating field was phase modulated at 93 cps with respect to the other so that the oscillating fields were alternately in phase and 180° out of phase. The alternately in-phase and out-of-phase Ramsey patterns produced were electronically subtracted by a synchronous detector and displayed on an oscilloscope (see Fig. 1).

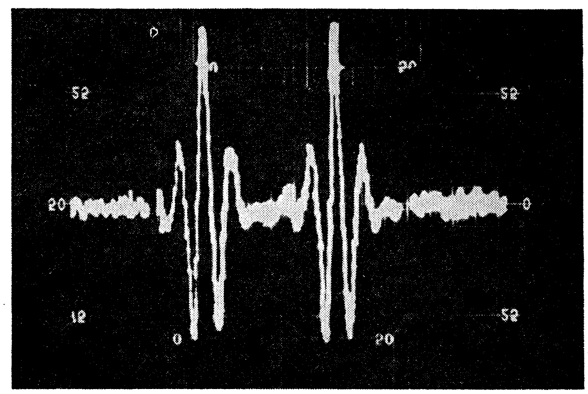

FIG. 1. Typical oscilloscope photograph showing the quadratic Zeeman splitting of the ($F=2$, $m_F=0$)↔(1,0) and (2,1)↔(1,1) transitions in an external magnetic field of 0.4 gauss. The Ramsey technique (see reference 2) of separated oscillating fields was used. The two blank portions of the trace calibrate the picture in frequency. The width at half-maximum of each central peak is 500 cps.

The intervals were measured in several external fields ranging from 0.2 gauss to 1 gauss, extrapolated to zero field, and corrected[3] for the perturbing effects of the neighboring $^2P_{\frac{1}{2}}$ ground state as well as the admixture of (4s)(4p)(5s) electronic configuration (see Table I).

The magnetic dipole, electric quadrupole, and magnetic octupole interaction constants,[4] a, b, and c, are calculated from the corrected intervals to be

Ga^{69}

a: 190.794280±0.000150 Mc/sec
b: 62.522470±0.000300 Mc/sec
c: 84±6 cps

Ga^{71}

a: 242.433950±0.000200 Mc/sec
b: 39.399040±0.000400 Mc/sec
c: 115±7 cps,

TABLE I. Measured and corrected hfs intervals of the metastable $^2P_{\frac{3}{2}}$ state of Ga^{69} and Ga^{71}.

	Ga^{69} (Mc/sec)	Ga^{71} (Mc/sec)
	Measured	
$F=0\leftrightarrow F=1$	128.27730 ± 0.00020	203.04340 ± 0.00020
$F=1\leftrightarrow F=2$	319.06706 ± 0.00020	445.46960 ± 0.00020
$F=2\leftrightarrow F=3$	634.90183 ± 0.00020	766.69580 ± 0.00020
	Corrected	
$F=0\leftrightarrow F=1$	128.27650 ± 0.00030	203.04133 ± 0.00040
$F=1\leftrightarrow F=2$	319.06373 ± 0.00050	445.46566 ± 0.00060
$F=2\leftrightarrow F=3$	634.90597 ± 0.00060	766.70181 ± 0.00080

where the uncertainty is the root-sum-square of the uncertainties in each of the terms of the equations which yield the interaction constants in terms of the intervals.

The data cannot be explained by the mechanism of off-diagonal terms in the interaction matrix giving rise to octupole-like $(\mathbf{I}\cdot\mathbf{J})^3$ terms, since $(ab)^{69}/(ab)^{71}$ and $(b^{69})^2/(b^{71})^2$ are greater than unity, and c^{69}/c^{71} is less than unity. To within the quoted uncertainty, $a^{69}/a^{71} = c^{69}/c^{71}$.

Schwartz has evaluated the nuclear octupole moment, Ω, and finds

$$\Omega^{69} = (0.107\pm0.02)\times10^{-24} \text{ nuclear magneton cm}^2,$$

and

$$\Omega^{71} = (0.146\pm0.02)\times10^{-24} \text{ nuclear magneton cm}^2.$$

Here, as in the corrected intervals, the quoted uncertainty includes the experimental error and the uncertainty in theoretical evaluation.

The results and experimental procedure will be presented in greater detail in a later paper.

The interest and encouragement of Professor J. R. Zacharias during the investigation are gratefully acknowledged.

* This work was supported in part by the Signal Corps, the Office of Scientific Research, Air Research and Development Command, and the Office of Naval Research.

[1] Previous measurement by P. Kusch and G. E. Becker, Phys. Rev. **73**, 584 (1948).

[2] N. F. Ramsey and H. B. Silsbee, Phys. Rev. **84**, 506 (1951).

[3] We are indebted to C. Schwartz for the calculation of the interval corrections.

[4] For the interaction Hamiltonian, as well as an explicit definition of the constants a, b, and c, see Jaccarino, King, Satten, and Stroke, Phys. Rev. **94**, 1798 (1954). For gallium, the definition of b given should be taken with opposite sign.

Scattering of Gamma Rays by Nucleons*

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THE cross section for the scattering of photons of energy $\hbar\omega$ by any nonrelativistic, bound system in which the number of particles is conserved has been shown[1] to be proportional to ω^4 for wavelengths large compared to the dimensions of the system if the Thomson scattering and scattering by the static magnetic moment are neglected. The proof depends only on the gauge invariance of the Schrödinger equation, not at all on the detailed distribution of currents and charges in the system. It is natural to raise the question of whether the same theorem may be established for other systems, for example, if the nucleon is treated as a structured system in which the number of pions is not a good quantum number.

It turns out that it is possible to extend the theorem to a much more general class of bound systems, the only condition on the system other than gauge invariance being that its wave function must be normalizable. The proof follows closely that given by Sachs and Austern.[1] It makes use of the condition of gauge invariance in the form

$$e^g H_m\{\mathbf{A}\}e^{-g} = H_m\{\mathbf{A}+\text{grad}G\},$$

where $H_m\{\mathbf{A}\}$ is the Hamiltonian of the matter field in the presence of an external electromagnetic field having vector potential $\mathbf{A}$, $G(\mathbf{r})$ is an arbitrary function which in fact may be any electromagnetic field operator that commutes with $\mathbf{A}$, and

$$g = (ie/\hbar c)\int G(\mathbf{r})\rho(\mathbf{r})d^3r,$$

where $\rho(\mathbf{r})$ is the charge density operator of the matter field.

A calculation of the scattering of gamma rays by nucleons by Sachs and Foldy[2] based on nonrelativistic, no-recoil, pseudoscalar meson theory led to a result contrary to the above-stated result. It was found that the scattering amplitude contained a spin-dependent term proportional to the frequency at long wavelength, and that this term was not related to the static magnetic moment.[3] This contradiction has to do with the fact that the unrenormalized nonrelativistic meson theory does not lead to a normalizable state vector as is required to establish the theorem. In fact, the results of SF were finite by virtue of a cancellation between infinite integrals, and in particular, the questionable term resulted from that cancellation. Such cancellations are usually ambiguous and some convergence procedure must be established to eliminate the ambiguity.

The problem has been reconsidered by one of us (RHC) on the basis of a pseudovector interaction containing a finite source. The finite source theory has been made gauge invariant by introducing the necessary line currents. The state vector is then normalizable and all relevant integrals are finite. If the source size is allowed to become small without limit, the scattering amplitude differs from that obtained by SF simply by the elimination of the term that violates the general theorem.

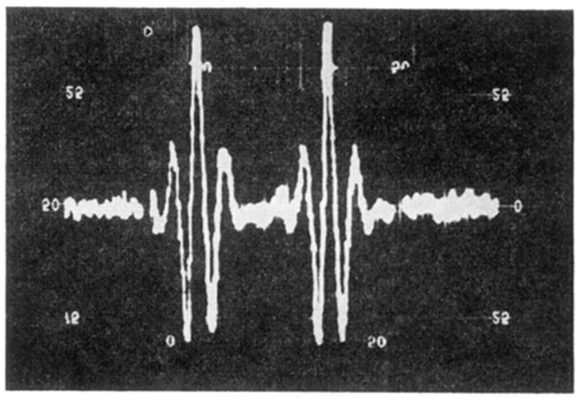

FIG. 1. Typical oscilloscope photograph showing the quadratic Zeeman splitting of the $(F=2, m_F=0)\leftrightarrow(1,0)$ and $(2,1)\leftrightarrow(1,1)$ transitions in an external magnetic field of 0.4 gauss. The Ramsey technique (see reference 2) of separated oscillating fields was used. The two blank portions of the trace calibrate the picture in frequency. The width at half-maximum of each central peak is 500 cps.