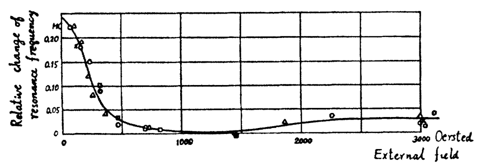

FIG. 2. Relative change in resonant frequency measured by a sample of 2.9×3.4 cm² in area and 0.053 cm in thickness. (Various marks indicate different series of experiments.)

Since the demagnetizing factor of the sample is not known accurately, we determined the true resonance field experimentally by the following procedure. The samples whose length is 2.9 cm and whose thickness is 0.053 cm, having various widths, are screwed on the end plate and resonance fields are measured successively. The values of resonance field are plotted against the width of the samples, as shown in Fig. 1(a). The value of resonance field extrapolated to zero width must correspond to the true resonance field with zero demagnetization field. The value thus obtained is 120 oersted, and the calculated g value of electron using (1) is 2.05, the error being about three percent.

Next, keeping the frequency of microwave constant, the plunger length corresponding to the resonance of the cavity is measured as a function of magnetic field. The relation between the plunger length and the change of resonant frequency of the cavity is calibrated by comparing it with a standard cavity wave-length meter. From these measurements we can calculate the change of resonant frequency of the cavity as a function of magnetic field, as shown in Fig. 2, in which the resonant frequency at 1200 oersted is accepted as a standard frequency.

From the above two experiments, we can calculate μ_R and μ_L, assuming that at very high field both μ_R and μ_L coincide with static μ. By the relation between complex permeability, $\mu=\mu'-j\mu''$, and μ_R and μ_L,[3] we calculated the values of μ' and μ'' as functions of magnetic field, which are shown in Fig. 3. The

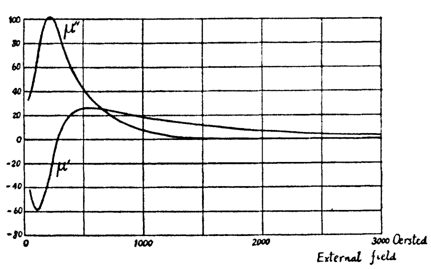

FIG. 3. μ' and μ'', measured by a sample of 2.9×3.4 cm² in area and 0.053 cm in thickness. Demagnetizing field is about 120 oersted.

result does not coincide quantitatively with the theoretical prediction by Kittel,[3] even if the relaxation force is assumed to be given by $-\lambda[\mathbf{M}-\chi_0\mathbf{H}]$, where λ/H is a constant, as Yager did.[2]

Further work is now going on.

[1] J. H. E. Griffiths, Nature **158**, 670 (1946); W. A. Yager and R. M. Bozorth, Phys. Rev. **72**, 80 (1947).
[2] W. A. Yager, Phys. Rev. **75**, 316 (1949).
[3] C. Kittel, Phys. Rev. **71**, 270 (1947); **73**, 155 (1948).
* We are indebted to Professor Y. Shirakawa of Tohoku University for obtaining these samples.

On the Calculation of Self-Energy of Particles

SURAJ N. GUPTA*
Cavendish Laboratory, Cambridge, England
December 2, 1949

IT has been shown in recent years that the self-energy of particles may be obtained in a covariant form by using an invariant perturbation theory developed by Tomonaga, Schwinger, Feynman, and others. However, it will be of interest to show that the covariant self-energy may be obtained even with the ordinary perturbation theory by using our generalization of a transformation due to Pauli and Rose.[1]

For instance, the calculation of the mesic self-energy of a nucleon with momentum $\mathbf{p}$ involves a summation over virtual states containing a pair of a nucleon and a meson with momenta $(\mathbf{p}-\mathbf{k})$ and $\mathbf{k}$, and energies E and ϵ respectively, where

$$E=\{M^2+(\mathbf{p}-\mathbf{k})^2\}^{\frac{1}{2}},\quad \epsilon=(\mu^2+k^2)^{\frac{1}{2}}. \tag{1}$$

Since $(\mathbf{p}-\mathbf{k}, E)$ and $(\mathbf{k}, \epsilon)$ are 4-vectors, their sum $(\mathbf{p}, E+\epsilon)$ is also a 4-vector, and hence

$$z\equiv\{(E+\epsilon)^2-p^2\}^{\frac{1}{2}} \tag{2}$$

is a Lorentz-invariant quantity. We can, therefore, obtain a covariant result by expressing the self-energy integral in terms of the variable z.

For this, we carry out the transformation from the variables $\mathbf{k}$ to the variables ϕ, v, and ω, where ϕ is the azimuthal angle around the axis parallel to $\mathbf{p}$, and

$$v=E-\epsilon,\quad \omega=E+\epsilon. \tag{3}$$

Computing the functional determinant, we obtain for the elements of volume the relation

$$d\mathbf{k}/E\epsilon=(1/2p)d\phi dv d\omega. \tag{4}$$

The limits of integration of ϕ are

$$0\leqslant\phi\leqslant 2\pi. \tag{5}$$

To obtain the limits of v, we note that

$$(E^2-\epsilon^2-p^2-M^2+\mu^2)^2=4(\mathbf{k}\cdot\mathbf{p})^2\leqslant 4k^2p^2,$$

or

$$(v\omega-p^2-M^2+\mu^2)^2\leqslant p^2\{(\omega-v)^2-4\mu^2\},$$

or

$$v^2(\omega^2-p^2)+2v\omega(\mu^2-M^2)+(p^2+M^2-\mu^2)^2+4\mu^2p^2-p^2\omega^2\leqslant 0.$$

Hence the two limits of v are given by

$$v=\frac{(\omega(M^2-\mu^2)\pm pF(z))}{z^2}, \tag{6}$$

where

$$F(z)\equiv\{z^4-2(M^2+\mu^2)z^2+(M^2-\mu^2)^2\}^{\frac{1}{2}}. \tag{7}$$

The limits of ω are

$$\{(\mu+M)^2+p^2\}^{\frac{1}{2}}\leqslant\omega\leqslant\alpha, \tag{8}$$

the least value of ω corresponding to $\mathbf{k}=\mu/(\mu+M)\mathbf{p}$. Since according to (2)

$$z=(\omega^2-p^2)^{\frac{1}{2}} \tag{9}$$

it follows that the limits of z are

$$(\mu+M)\leqslant z\leqslant\alpha. \tag{10}$$

It should be noted that the transformation given above is the most general one, and covers all possible cases. If we put $\mu=M$, we obtain the transformation given by Pauli and Rose[1] for the treatment of vacuum polarization. On the other hand, if we put $\mu=0$, we get the transformation used by the present writer[2] to calculate the self-energy of the electron.

Using the above general transformation, we have calculated the self-energy of the nucleons due to the pseudoscalar as well as the vector meson field with the two types of coupling in each case (Moller-Rosenfeld-Schwinger mixture). It is found that the self-energy W is in general of the form

$$W=\delta M\cdot\frac{M}{(M^2+p^2)^{\frac{1}{2}}}+\delta N\cdot\frac{p^2}{(M^2+p^2)^{\frac{1}{2}}}, \tag{11}$$

where δM and δN are divergent functions of z but independent of p. The first term in (11) may be absorbed by a renormalization of the mass of the nucleon. On the other hand, the second term in (11), which arises from the direct coupling terms in the interaction, disappears on regularization developed by Feynman[3] and by Pauli and Villars.[4] It will be interesting to compare the present situation with the electromagnetic self-energy of the mesons as investigated by Heitler and McConnell.[5]

I wish to express my thanks to Dr. S. T. Ma for many stimulating discussions. I am also indebted to Professor H. A. Bethe for some valuable comments.

* State Scholar of the Government of India.

[1] W. Pauli, and M. E. Rose, Phys. Rev. **49**, 462 (1936).
[2] S. N. Gupta, Proc. Phys. Soc. (to be published).
[3] R. P. Feynman, Phys. Rev. **74**, 1430 (1948).
[4] W. Pauli and F. Villars, Rev. Mod. Phys. **21**, 434 (1949).
[5] W. Heitler and J. McConnell, Nature **164**, 218 (1949).

Nuclear Gamma-Radiation of Cu^{61}

F. Boehm, J. P. Blaser, P. Marmier, and P. Preiswerk
Department of Physics, Swiss Federal Institute of Technology, Zürich, Switzerland
December 5, 1949

THE positron spectrum of Cu^{61} has been examined recently by Cook and Langer[1] with a large magnetic spectrometer. The experimental curves of these authors show a deviation from the Fermi distribution which is much larger than for Cu^{64} and it seems possible that not all of this deviation arises from instrumental factors. It is pointed out by different authors[2,3] that Cu^{61} does not emit nuclear gamma-rays which means that the spectrum of Cu^{61} must be simple. On the other hand the measurements of Cook and Langer can hardly be understood without the assumption of a complex spectrum. To examine this discrepancy, we started a search for gamma-radiation in Cu^{61}.

By irradiation of a nickel target with protons from the cyclotron we get very strong sources of Cu^{61}. After chemical separation and precipitation as chloride the Cu^{61} samples have been examined in a magnetic lens spectrometer for conversion-electrons and for photo-electrons. The following gamma-rays have been found:

$$E_{\gamma 1} = (0.652 \pm 0.005) \text{ Mev}$$
$$E_{\gamma 2} = (0.279 \pm 0.005) \text{ Mev}$$
$$E_{\gamma 3} = (0.070 \pm 0.001) \text{ Mev.}$$

The first and the second of these gamma-rays, γ_1 and γ_2, have been detected by photo-electron conversion from a lead radiator (Fig. 1). The relative intensity of these gamma-rays may be estimated by comparison with the photo-lines of the annihilation radiation taking into account the variation of the photoelectric cross section with energy, and the fact that two gamma-rays of the annihilation radiation are due to one positron. One gets for the intensity of γ_1 and γ_2 relative to the total number of decays respectively (9 ± 4) percent and (5 ± 3) percent. The ratio of K-capture to positrons in the 1.205 Mev transition has previously been assumed to be 0.3.

The intensities of γ_1 and γ_2 decay with the half-life of $3.35h$ characteristic of Cu^{61}. Contaminations can therefore be excluded.

The line γ_3 has been found as an internal conversion line in both a magnetic lens and a magnetic semicircular spectrometer. Its K/L conversion ratio was found to be 10 ± 3. Therefore this transition probably has a dipole character. Assuming a K internal conversion coefficient of about 10 percent (Hebb and Nelson), and comparing the line area with that of the positron spectrum, we find the intensity of this gamma-line relative to the number of decays to be (4 ± 2) percent. No harder gamma-radiation than 0.652 Mev could be found.

These gamma-rays give evidence for a complex decay of Cu^{61}. We may assume that the complexity arises from a positron transi-

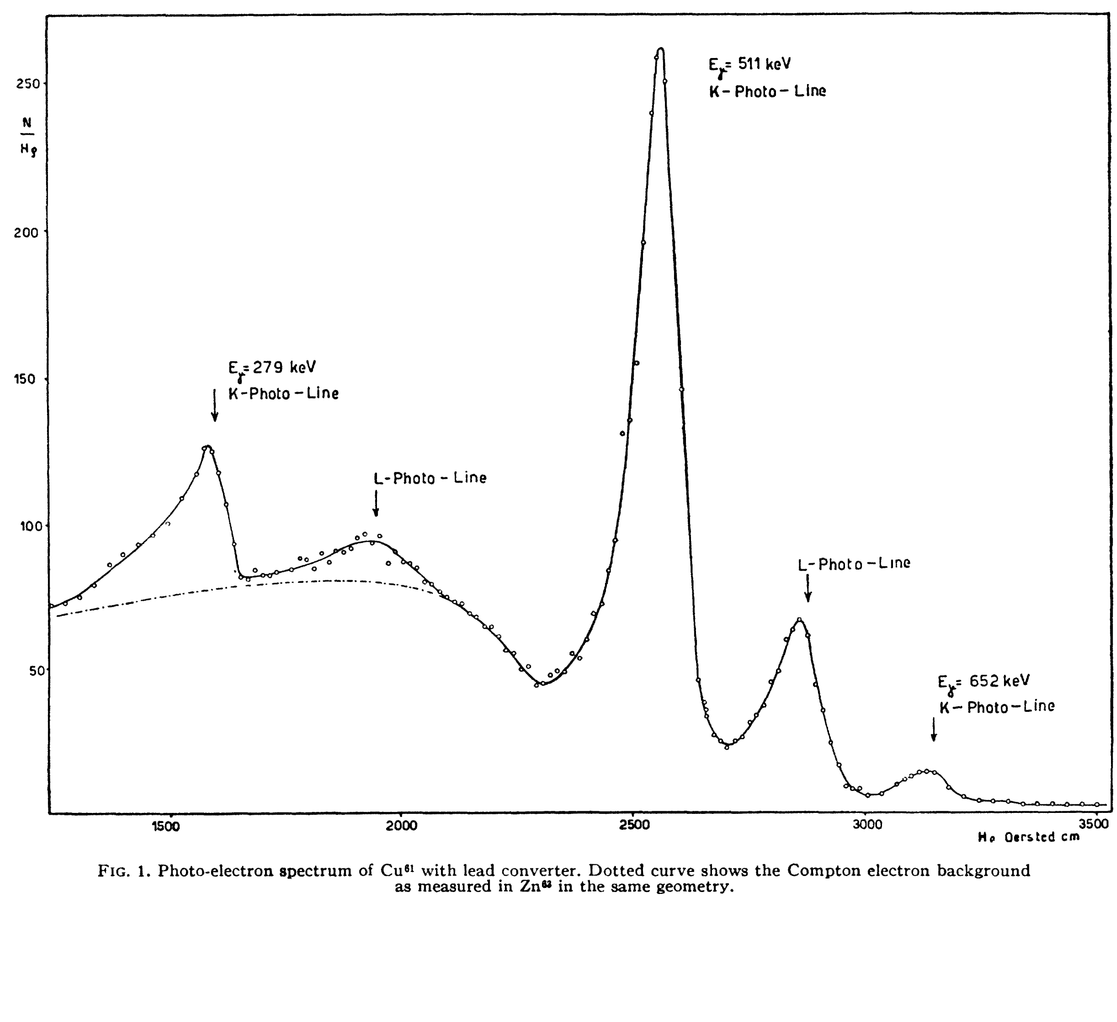

FIG. 1. Photo-electron spectrum of Cu^{61} with lead converter. Dotted curve shows the Compton electron background as measured in Zn^{63} in the same geometry.