W_m, arising from the magnetic field a minimum. This energy is

$$W_m=\int \Psi^* H_m \Psi d\tau=\frac{1}{2m}\Sigma_\alpha \int \Psi_0^*\left[-\frac{ie\hbar}{c}\,\mathrm{div}(\mathbf{A}_\alpha+\mathrm{grad}\varphi_\alpha)\right]$$
$$-\frac{2ie\hbar}{c}(\mathbf{A}_\alpha+\mathrm{grad}\varphi_\alpha)\,\mathrm{grad}_\alpha+\frac{e^2}{c^2}(\mathbf{A}_\alpha+\mathrm{grad}\varphi_\alpha)^2\Psi_0 d\tau_1\cdots d\tau_n. \quad (6)$$

After an integration by parts, (6) can be written in the form

$$W_m=\frac{i}{c}\int(\mathbf{A}+\mathrm{grad}\varphi)\cdot\mathbf{j}_0(\mathbf{r})d\tau-\frac{2}{2mc^2}\int(\mathbf{A}+\mathrm{grad}\varphi)^2\rho_0(\mathbf{r})d\tau, \quad (7)$$

where $\mathbf{j}_0$ and ρ_0 are the current and charge densities in the absence of a field:

$$\mathbf{j}_0(\mathbf{r})=(ie\hbar/2m)\Sigma_\alpha\int(\Psi_0^*\,\mathrm{grad}_\alpha\Psi_0-\Psi_0\,\mathrm{grad}_\alpha\Psi_0^*)$$
$$\times\delta(\mathbf{r}-\mathbf{r}_\alpha)d\tau_1\cdots d\tau_n,$$
$$\rho_0=-e\Sigma_\alpha\int\Psi_0^*\Psi_0\delta(\mathbf{r}-\mathbf{r}_\alpha)d\tau_1\cdots d\tau_n. \quad (8)$$

We shall assume that $\mathbf{j}_0=0$ and $\rho_0=$const. The condition that W_m be invariant for small changes $\Delta\varphi$ in φ is then

$$\delta W_m=-(e\rho_0/mc^2)\int[(\mathbf{A}+\mathrm{grad}\varphi)\cdot\mathrm{grad}\Delta\varphi]d\tau=0,$$

or, after an integration by parts

$$\int\Delta\varphi\,\mathrm{div}(\mathbf{A}+\mathrm{grad}\varphi)d\tau-\int\Delta\varphi(\mathbf{A}+\mathrm{grad}\varphi)_\perp dS=0. \quad (9)$$

The second integral is over the surface, S. If (9) is to be satisfied for all $\Delta\varphi$ we must have

$$\mathrm{div}(\mathbf{A}+\mathrm{grad}\varphi)=0;\quad(\mathbf{A}+\mathrm{grad}\varphi)_\perp=0\text{ on }S. \quad (10)$$

Choosing φ in this way is equivalent to choosing the gauge so that (2) is satisfied and taking $\Psi=\Psi_0$.

We have used[3] this approach in a theory of superconductivity based on interactions between electrons and lattice vibrations.[4]

[1] F. London, Proc. Roy. Soc. **A152**, 24 (1935); Phys. Rev. **74**, 562 (1948).
[2] London (reference 1) has considered the extension of the theory to cover multiply connected regions.
[3] J. Bardeen, Phys. Rev. **80**, 567 (1950).
[4] J. Bardeen, Phys. Rev. **79**, 167 (1950).

Crystalline Magnetic Anisotropy in Zinc Manganese Ferrite

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December 11, 1950

We have grown crystals of zinc manganese ferrite whose composition is approximately $Zn_{0.55}Mn_{0.45}Fe_2O_4$. From the saturation magnetization, M_s, and from ferromagnetic resonance data, we have determined the crystalline magnetic anisotropy, K, of these crystals. The measurements were made at room temperature, by essentially the same procedure as the earlier measurements on nickel ferrite.[1,2] The value of M_s was measured by comparison with nickel ferrite in a hysteresis loop tracer; M_s for nickel ferrite has been measured by Guillaud and Roux[3] as well as by us.[2]

The crystals were grown in a manner similar to that by which nickel ferrite crystals were grown earlier.[2] A mix of 15 g borax, 6.4 g Fe_2O_3, 1.6 g ZnO, 1.4 g MnO was heated to 1325°C in a platinum crucible and held for 5½ hours. It was then cooled at approximately 100°C/hr simply by turning off the furnace. The resulting crystals ranged in size up to octahedra 1 mm on an edge. Most of them were not mechanically sound, but one good one was found which showed cubic symmetry magnetically. Chemical analysis showed that this material is approximately $Zn_{0.55}Mn_{0.45}Fe_2O_4$. There were no significant impurities.

The value of K/M for these materials at room temperature was determined from the variation with crystallographic direction of the magnetic field required to produce ferromagnetic resonance[1,4] at 24,160 Mc. The width of the resonance line, ΔH, and the g factor[5] were also observed. The variations in ΔH with crystallographic direction were not large enough to be significant. The results are given in Table I.

TABLE I. Measurements on zinc manganese ferrite.

K/M	M(cgs units)	K(ergs/cc)	ΔH(oe)	g
−21±5%	181±10%	−3800±15%	70	1.997

Check measurements were made on a second sample. This sample did not show cubic symmetry magnetically but the magnitude of the variations in the field required for resonance was the same.

Snoek[6] has suggested that the effect field due to magnetocrystalline anisotropy acting on a material in no external field will cause resonance or perhaps relaxation behavior in the initial permeability of the material; this behavior should occur at the frequency of the Larmor precession in the effective field. This effective internal field when the magnetization is along an easy direction ([111] in these crystals) is:[7]

$$H_{\mathrm{eff}}=-1.33K/M.$$

This leads us to expect this behavior at 78 Mc in this material. This frequency may be increased if the effective field is increased by the presence of free poles due to the domain pattern; it is therefore a lower limit in practice.

The authors wish to express their gratitude to Dr. E. A. Wood for x-ray assistance and to H. G. Hopper for technical assistance.

[1] Yager, Galt, Merritt, and Wood, Phys. Rev. **80**, 744 (1950).
[2] Galt, Matthias, and Remeika, Phys. Rev. **79**, 391 (1950).
[3] C. Guillaud, and M. Roux, Compt. rend. **229**, 1133 (1949).
[4] C. Kittel, Phys. Rev. **73**, 155 (1948).
[5] C. Kittel, Phys. Rev. **76**, 743 (1949).
[6] J. L. Snoek, Nature **160**, 90 (1947); Physica **14**, 207 (1948).
[7] L. R. Bickford, Jr., Phys. Rev. **78**, 449 (1950).

The Absence of Cross-Over Transitions in Tellurium Isomers

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A MODIFIED estimate of multipole radiation probabilities has been put forward recently by Weisskopf.[1] According to this theory, the probability λ of electric 2^e pole radiation is given by

$$\lambda=\frac{2(e+1)}{e}[1\cdot3\cdot5\cdots(2e+1)]^{-2}\frac{K^{2e+1}}{\hbar}e^2R^2l,$$

and the probability of magnetic 2^e pole radiation is lower than that of electric 2^e pole by a factor $\sim(\hbar/McR)^2$. K is the wave number, $2\pi\nu/c$, of the radiation, M is the nucleon mass, and R is the nuclear radius. It is to be realized that this formula, like previous ones based on older estimates, is claimed to be valid only to within a factor $\sim10^{\pm2}$. In the following note it is pointed out that Weisskopf's formula, unlike earlier ones, is consistent with the absence of cross-over transitions in the decay of several long-lived tellurium isomers.

Isomers of $Te^{121,123,125}$ have been observed[2] to decay in two successive transitions, the first being preponderantly magnetic 2^4 pole and the second being magnetic dipole. It was puzzling, on the basis of the older radiation formulas, that no cross-over transitions of an electric 2^5 character, between the long-lived and the ground states, were observed experimentally.

Relative probabilities of magnetic 2^4 and electric 2^5 transitions have been calculated and are tabulated in Table I. Columns 2 and 3 give, respectively, the energies of the long-lived magnetic

TABLE I. Transition probabilities in long-lived tellurium isomers.

Isomer	2^4m (kev)	2^5el (kev)	$\lambda 2^5/\lambda 2^4$ (old)	$\lambda 2^5/\lambda 2^4$ (new)	$t_{\frac{1}{2}}$ (sec) (new)	$t_{\frac{1}{2}}$ (sec) (exp)
Te^{121}	82	295	3.5×10^{3}	0.4	3.7×10^{7}	$1.33\times10^{7}(154d)$
Te^{123}	88.5	247.5	7.0×10^{2}	7.0×10^{-2}	2.7×10^{7}	$9.0\times10^{6}(104d)$
Te^{125}	109.7	145.1	1.0	2.0×10^{-4}	1.2×10^{7}	$5.0\times10^{6}(58d)$

2^4 transitions and of the expected cross-over electric 2^5 transitions. Column 4 gives the ratios of the total transition probabilities based on older formulas, as, for example, that used by Axel and Dancoff[3] in their classification of nuclear isomers. The same ratios, based on the new formula of Weisskopf, are given in column 5. Total transition probabilities include corrections required to take into account internal conversions, the coefficients of which were obtained from Rose's accurate tables,[4] either directly or by extrapolation. Values of K to L ratios were also required, and these were taken from the graphs of Lowen and Tralli.[5] Uncertainties involved in the knowledge of theoretical K to L ratios at this stage will not significantly change the transition probabilities of Table I.

Experimentally, all electric 2^5 transitions can be excluded at present to within approximately 5 percent of the magnetic 2^4 transitions. From Table I it is clear that although the older estimates would indicate the cross-over 2^5 transitions to be more probable than the 2^4, the new estimates of transition probabilities are essentially in agreement with experiment.

Theoretical lifetimes for the converted magnetic 2^4 transitions are listed in column 5. The new values are again in significantly better agreement with experimental lifetimes than are the older values.

It is interesting also to compare estimated lifetimes of the intermediate tellurium states with the upper limits established experimentally for these lifetimes. Theoretical estimates based on old and new formulas are shown in columns 3 and 4, respectively, of Table II. In one case, the 35.4-kev excited state of Te^{125}, the

TABLE II. Lifetimes of intermediate states of tellurium isomers.

Isomer	2^4m (kev)	$t_{\frac{1}{2}}$ (sec) (old)	$t_{\frac{1}{2}}$ (sec) (new)	$t_{\frac{1}{2}}$ (sec) (exp)
Te^{121}	213	7.65×10^{-10}	1.3×10^{-11}	$<3\times10^{-9}$ [a]
Te^{123}	159	3.05×10^{-9}	2.55×10^{-11}	$<2\times10^{-8}$ [b]
Te^{125}	35.4	4.6×10^{-7}	1.85×10^{-10}	$<5\times10^{-9}$ [c]

[a] M. Deutsch and W. E. Wright, Phys. Rev. **77**, 139 (1950).
[b] S. Frankel (thesis, University of Illinois, 1949).
[c] K. McGowan, Phys. Rev. **77**, 138 (1950).

present experimental evidence decides strongly in favor of the new estimates as opposed to the old.

Valuable criticism of this investigation by John M. Blatt is gratefully acknowledged.

[1] Privately circulated notes, to appear as part of a book on nuclear physics.
[2] R. D. Hill, Phys. Rev. **76**, 333 (1949); J. C. Bowe and G. Scharff-Goldhaber, Phys. Rev. **76**, 438 (1949); Katz, Hill, and Goldhaber, Phys. Rev. **78**, 9 (1950).
[3] P. Axel and S. M. Dancoff, Phys. Rev. **76**, 892 (1949).
[4] Rose *et al.*, *Tables of K-Shell Conversion Coefficients.*
[5] N. Tralli and I. S. Lowen, Phys. Rev. **76**, 1541 (1949).

Multiple Scattering of Electron Pairs from (Li, p) Gamma-Rays in Photographic Emulsions

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November 20, 1950

IN order to check multiple Coulomb scattering results obtained for high energy cosmic-ray particles with photographic emulsions,[1] we have made scattering measurements on electron pairs observed in emulsions exposed to Be^8 γ-rays from the bombardment of an evaporated lithium target with a 450-kev resolved proton beam. Ilford G5 emulsions 400μ thick were irradiated with about 10 milliroentgens of γ-radiation.

The scattering method follows that developed by Fowler,[2] in which the perpendicular coordinates of a track are recorded at equal intervals along the axis of motion of the microscope stage to which the track is made approximately parallel. The arithmetic mean $\langle|D|\rangle_{Av}$ of the second differences of the perpendicular coordinates is related to the projected mean angle between successive chords at intervals q by the expression $\langle\alpha(q)\rangle_{Av}=\langle|D|\rangle_{Av}/q$. From the multiple scattering theory of Williams,[3] as formulated by Rossi and Greisen,[4] $\langle\alpha(q)\rangle_{Av}=(K/p\beta)(q/100)^{\frac{1}{2}}$ degrees[5] where $K=32.7$, p is the particle momentum in units Mev/c, β is the velocity in units of c, and q is in microns of emulsion.

Observations have been made on a total of 100 electron pairs at intervals of 20 divisions (1 div$=0.88\mu$) for about 700μ along each track. Figure 1 shows the scattering distribution for one of

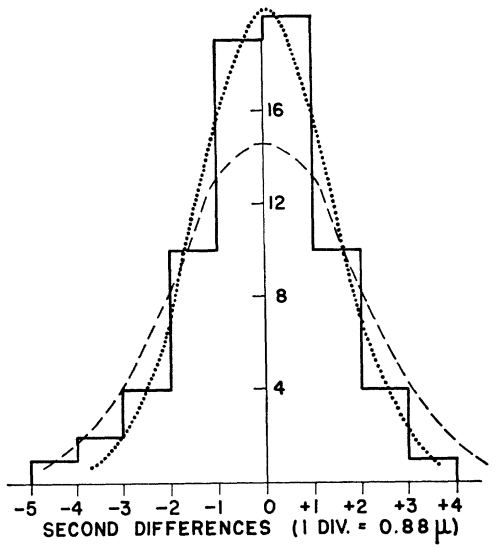

FIG. 1. Distribution of second differences for the tracks of an electron pair with equal energy division. The histogram represents 71 combined values for overlapping intervals of 40 div, and the dotted curve is a Gaussian with the same arithmetic mean ($\langle|D|\rangle_{Av}=1.09\pm0.09$ div).

the pairs which represents a case of almost equal energy division from the incident γ-ray. Using the observed value for $\langle|D|\rangle_{Av}$ the calculated total energy of each electron is 12.7 Mev, which corresponds to a γ-ray energy of 25.4 ± 2 Mev. This is to be compared with the maximum Be^8 γ-ray energy[6] (17.6 Mev). It would appear from this example that the experimental scattering distribution is approximately Gaussian, but K is too big.

The γ-ray energies deduced from the experimental values of $\langle|D|\rangle_{Av}$ for 100 electron pairs are shown in Fig. 2. Curve A is the Be^8 γ-ray spectrum as given by Walker and McDaniel[6] for a thin lithium target at 460-kev proton energy with a magnetic pair spectrometer. This shows the pronounced 17.6-Mev line and a very broad lower energy line. Curve B shows our results for 70 pairs observed in a plate exposed to γ-rays in the forward proton direction. Besides a shift of the spectrum to higher energies, this curve shows some evidence for two peaks, whose relative intensities differ considerably from those shown by Walker and McDaniel. It is difficult to attribute the shape of curve B as being a distortion of curve A due to some feature of the scattering method. We have therefore exposed plates at 90° to the proton beam direction to test for any noticeable angular asymmetry in the relative intensities of the two γ-ray lines.[7,8] Curve C shows preliminary results for 30 electron pairs from this irradiation, in which there is an indication of two γ-ray groupings which more