The observed changes in characteristics produced by forming are given in Table I for both *n*- and *p*-germanium. The conventional direction of current is positive for flow of positive charge from point to germanium. This is the forward rectifying direction for *n*-type semiconductors and the reverse for *p*-type. These qualitative changes can be interpreted in terms of changes in ϕ_s if we assume that a *positive* forming current *increases* ϕ_s and that a *negative* forming current *decreases* ϕ_s. These changes are in the directions which would result from the movement of donor or acceptor ions from the interior of the germanium to the surface under the influence of the field of the forming current.

TABLE I. Changes in characteristics of rectifying junctions produced by forming.

Forming current	*n*-Germanium Forward current		*p*-Germanium Forward current	
	Forward current	Reverse current	Forward current	Reverse current
Unformed	Large; mostly holes; good emitter of holes	Small; good rectifier	Small; mostly holes; poor emitter of electrons	Large; poor rectifier
Negative	Hole current smaller	Greater; collector formed	Electron current increased, emitter formed	Little change
Positive	Little change	Smaller	Little change	Greater

As illustrated in Figs. 1a and 1b, which respresent unformed points, there is a good rectifying junction with *n*-germanium and a poor one with *p*-germanium. Because of the inversion layer, the forward current in the former case consists largely of holes, although conduction electrons are normally in excess in the interior. A decrease in ϕ_s, caused by a negative forming current, as shown in Fig. 1c, enhances the electron current in the reverse direction in *n*-germanium and improves the point as a collector. This is accompanied by a decrease in hole current in the forward direction. For *p*-germanium, as shown in Fig. 1d, a negative forming current may produce an inversion layer of *n*-type conductivity, and thus increase the emission of electrons. The reverse characteristic, while altered in shape, is not changed greatly in magnitude. A positive forming current decreases ϕ_s, as shown in Figs. 1e and 1f, making the reverse current in *n*-germanium smaller and impairing the rectification in *p*-germanium.

Actually, there are probably large variations in ϕ_s over the contact area, and the changes of ϕ_s indicated in Fig. 1 should be interpreted merely as giving the trends in a qualitative way. For example, it is necessary to have only a few "low spots" in the barrier to give a relatively large reverse current through a point contact to *n*-germanium, and a few spots with an inversion layer may be sufficient to make a reasonably good emitter function in *p*-germanium.

[1] J. H. Bardeen and W. H. Brattain, Phys. Rev. **75**, 1208 (1949).
[2] W. G. Pfann and J. H. Scaff, Phys. Rev. **76**, 459 (1949).
[3] Experimental results of W. H. Brattain and G. R. Price.

Composite of Experimental Measurements of the Energy-Distribution among Beta-Particles from Tritium

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THE beta-decay of tritium (radiohydrogen, $_1H^3$), though of very long life, is evidently "allowed," and is characterized by an extraordinarily low energy. Since there has occasionally been some doubt as to the validity of the Fermi theory of allowed transitions in the low energy region, as for instance for Cu^{64}, it is of considerable interest to see how well the theory agrees with the observed beta-spectrum of tritium. For Cu^{64} it was necessary[1] to consider relativistic and screening effects on the electron wave function in order to obtain essential agreement with the Fermi theory in the low energy part of the spectrum, and energies of the order of 0.1 Mev were "low." For H^3, the whole spectrum lies at such extremely low energies (<20 kev) that relativistic effects must be negligible. Further, since the effect of screening is not important if $(2\pi/137)(Z/\beta)$, the ratio of the wave-length of the outgoing electron to the radius of the *K*-shell, is small in comparison with unity, screening should not appreciably affect the H^3 decay. (For a 10-kev electron from H^3 $2\pi Z/137\beta \sim 0.23$, whereas for a 0.1-Mev electron from Cu^{64} $2\pi Z/137\beta \sim 2.4$.) Obviously the beta-decay of tritium represents a simple and relatively critical test of the theory in the low energy limit.

Several direct determinations have recently been made of the energy-distribution function for the H^3 beta-particles. Curran, Angus, and Cockcroft[2,3] have published four sets of data, and Byatt, Rogers, and Waltner[4] one. Hanna and Pontecorvo have published data for the upper-energy region,[5] and so have Graves and Mayer.[6] All these investigators report essential agreement with the Fermi theory in the particular energy regions used. To show the basic consistency of these measurements and, taken together, their ultimate degree of accord with the Fermi theory, we have constructed a composite of the various published spectra. From Fermi plots (using the non-relativistic Coulomb field factor) of each set of data, scale-factors were obtained which would adjust and normalize that set to a common pair of variables; after the adjustment of each set, averages were taken at convenient intervals, a very few points being discarded on the basis of applicable statistical criteria. The composite so obtained is shown by the points in Figs. 1 and 2, together with the spectrum as predicted by the Fermi theory. Even though the published data are not in all cases corrected for "resolution," this method of striking

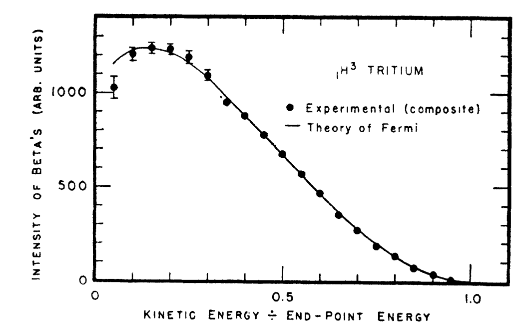

FIG. 1. The continuous beta-spectrum from tritium. The points are averages of the several sets of extant data. The average deviations are equal to or less than the radii of the points as plotted, except where otherwise indicated.

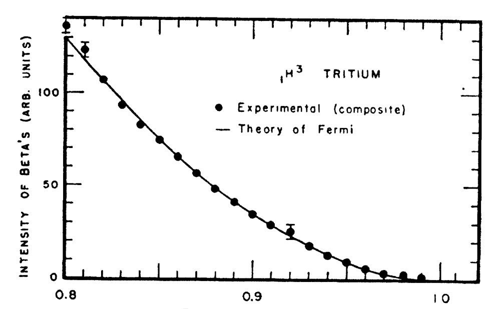

FIG. 2. High energy portion of the continuous beta-spectrum from tritium.

an average would seem to be largely valid for distributions if not for end-point energies.

In view of the great difficulty of measuring the beta-spectrum of H^3, the concordance of adjusted data is remarkable. In terms of average deviations from the mean, it appears that the shape of the distribution function is now known to a precision of about 3 percent from 0.5 to 5.5 kev, about 1 percent from 6 to 11 kev, about 5 percent from 11.5 to 17.5 kev, and about 25 percent on up to within 2 percent of the end-point energy. Equally remarkable is the fact that the deviations of the composite from the theoretical spectrum are generally comparable with (in most cases less than) the corresponding average deviations of the measurements, except at the very lowest and highest energies where the measurements are very uncertain. A Fermi plot of the points in Figs. 1 and 2 is extremely satisfying from 2.5 to 18 kev; although the point at 0.9 kev is somewhat low, the points at 1.8 kev and above 18 kev are high (this last one about 100 percent).

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Natural Ferromagnetic Resonance

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WHILE studying the magnetic properties of a number of magnesium ferrites, and related spinels, evidence was obtained in a few cases of a resonance with sufficiently small damping to produce a peak in the curve of permeability *versus* frequency for unmagnetized samples. Figure 1 shows the results

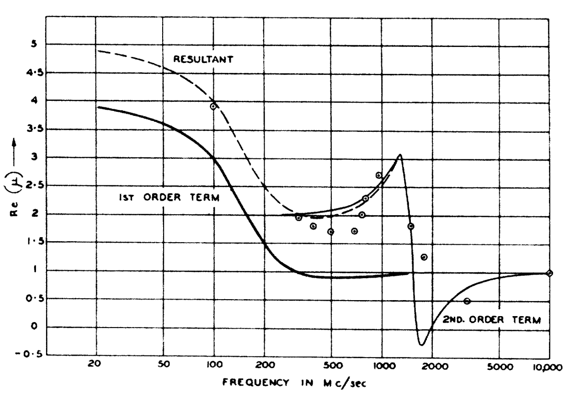

FIG. 1. Natural ferromagnetic resonance. ⊙ ⊙ ⊙ are points measured on Mg ferrite sample.

found for a particular magnesium ferrite. In the region where the resonance occurred, the measurements were carried out in terms of standing-wave observations in a coaxial line containing the sample adjacent to the short-circuited end. Care was taken that higher modes, which might propagate within the sample, were not excited. The results may be interpreted in terms of an extension of the Landau-Lifshitz theory[1] as amended by Kittel.[2] It may be deduced from Kittel's formula,

$$\frac{\chi}{\chi_0}=\frac{\omega_0^2+\lambda^2\mu_0+j\omega\lambda}{\omega_0^2+\lambda^2\mu_0-\omega^2+j\omega\lambda(1+\mu_0)}$$

that the real part of χ, $Re(\chi)$, can only be become negative if $\lambda<\omega_0$ but that it can exceed its static value χ_0 only if $\lambda<\omega_0/\mu_0$. Now, in fact, it has been found that all ferrites which are appreciably ferromagnetic show negative values of $Re(\chi)$ over some part of the range 1000 Mc/sec. to 10,000 Mc/sec., but hitherto none has been found with the positive peak in $Re(\chi)$. Where the positive peak has occurred in our results it has been superimposed upon a basic curve of falling χ, as seen from Fig. 1. The complete susceptibility can thus be regarded to a second approximation as the sum of two parts, each part represented by an equation of the above form. In the example given, the basic part contributes about three-fourths of the total low frequency susceptibility, has a resonance frequency, $\omega_0/2\pi$, of about 140 Mc/sec., and a damping ratio λ/ω_0 of about 0.5; the remaining one-fourth of the *LF* susceptibility has a resonance frequency of about 1500 Mc/sec. and a damping ratio of about 0.1. The observed shape of this resonance, however, appears to be much less sharp than that required by the formula; the addition of a third component enables a better fit to be obtained.

If Frenkel's form[3] of the absorption is used in place of Kittel's, the general frequency behavior is similar, but $Re(\chi)$ is then negative for $\omega>\omega_0$ for all values of the relaxation time τ, while $Re(\chi)/\chi_0$ exceeds unity at some frequency only if $\tau>\pi/\omega_0$. A slightly better fit to the observed points is obtainable with two components of Frenkel's form than of Kittel's, and the relaxation time for both components is near 10^{-9} sec.

At low frequencies the formula gives a loss component which varies with frequency in the same way as an eddy current loss, and it has been found that the measured apparent eddy current loss of several ferrites is of the order of magnitude predicted by the formula from high frequency measurements.

It has also been observed that the application of a sufficiently strong transverse static magnetic field restores the 10,000 Mc/sec. susceptibility to about one-fourth the *LF* value. This suggests that the first term (which is dominant at low frequencies) is insensitive to external fields, whereas the second term behaves as implied in Kittel's analysis, i.e., ω_0 increases with increase of the static field.

The interpretation of the two resonance frequencies in terms of internal fields would seem to imply rather smaller fields than have hitherto been suggested but the precise magnitudes involved would seem to depend considerably on the geometry assumed for them.

Acknowledgment is made to the Chief Scientist of the Ministry of Supply and to the Engineer-in-Chief of the General Post Office for permission to make use of the information contained in this letter.

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Beta-Spectrum and Decay Scheme of $_{65}Tb^{160}$

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December 22, 1949

THE β-spectrum of Tb^{160} has been investigated in the Argonne 180° spectrometer. The purified sample of Tb_4O_7 from Oak Ridge was bombarded in the Argonne heavy water pile for about 90 days and allowed to cool for about one month. The activity of a portion of the sample was then followed for $\sim$3 months indicating a half-life of 71 ± 1 day.

The source of $\sim$0.1 mg/cm² was prepared on a Nylon backing