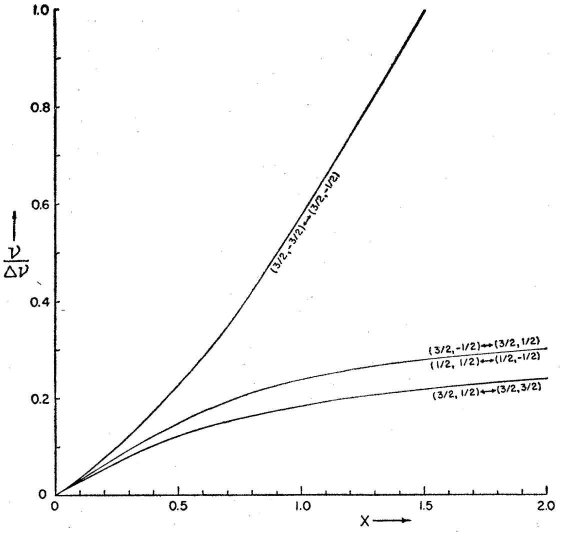

FIG. 2. Frequencies for those π-transitions of reference 4 which approach zero frequency with decreasing values of the magnetic field parameter $x=(g_J-g_I)\mu_0H/h\Delta\nu$.

It is likely that the structure is hyperfine, arising from an interaction between the magnetic moments of the odd electron and the N^{14} nucleus. Nitrogen is the only atom of the ion with an abundant isotope which possesses a magnetic nucleus, and the three components correspond to its spin of one.

Since the g-value of the central peak is close to that of a free electron spin (no orbital contribution to the splitting), we have attempted to apply the Breit-Rabi formulas[2] for the Zeeman effect of a system consisting of an s electron and a nucleus of spin 1 to this admittedly more complicated system. These formulas are consistent with the observed line separation in fields near 3200 oersteds if the zero field hyperfine splitting $\Delta\nu$ is 54 ± 1 Mc/sec. The assumption of Paschen-Back effect in these fields is supported by the work of Holmes,[3] who studied the isotope shifts for the low lying states of N^{14} and N^{15}; no hyperfine splittings were found, and an upper limit of 900 Mc/sec was set for them.

The paramagnetic resonance absorption of this ion in magnetic fields near 10 oersteds affords a simple test for the proposed model. The Breit-Rabi energy level scheme[4] predicts transitions in such low fields at ratios of frequency to field which differ markedly from that for a free electron spin because of the coupling between J and I. Figure 2 plots frequency *versus* the parameter[2] $x=(g_J-g_I)\mu_0H/h\Delta\nu$ for those π-transitions which should be observable with a recording rf spectrometer such as that designed and constructed in this laboratory by Schuster.[5] The two lowest frequency lines of Fig. 2 are observable by a magnetic field modulation technique only in the low field region where the slope of the ν *versus* x curve differs appreciably from zero. In addition to those transitions graphed in Fig. 2, there are of course π-transitions which approach $\Delta\nu$ itself with decreasing field; if $\Delta\nu$ is 54 Mc/sec, these frequencies are inaccessibly high for our spectrometer in its present form.

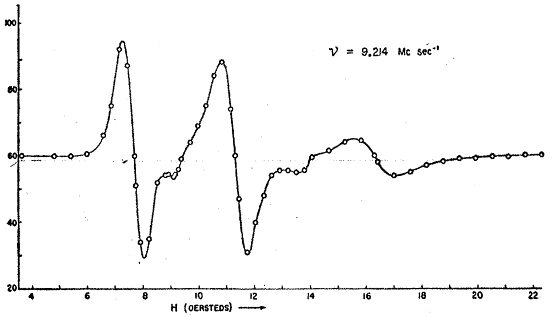

FIG. 3. Absorption derivatives for the paramagnetic resonance of peroxylamine disulfonate ion at 9.214 Mc/sec. The ordinates are in arbitrary units.

With the spectrometer operating at a fixed frequency of 9.214 Mc/sec, we have observed the three transitions of Fig. 2 at resonant fields of 7.73 ± 0.10, 11.32 ± 0.10, and 16.34 ± 0.10 oersteds (Fig. 3). The Helmholtz coils were calibrated by means of an organic free radical whose g-value had been compared in low fields with that of the proton.[4] The three resonant field values of Fig. 3 yield from the Breit-Rabi formulas $\Delta\nu$-values of 58 ± 4, 54 ± 2, and 55.7 ± 1.0 Mc/sec, respectively. The relatively large errors are attributable to denominators, in the expressions for $\Delta\nu$, which involve subtraction of comparable terms. However, the values listed above are in sufficiently good agreement with the microwave measurement to lend support to the proposed model.

Experiments to improve the accuracy of the $\Delta\nu$-measurement by studying transitions which approach $\Delta\nu$ in zero field are now in progress.

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Hyperfine Structure in the Spectrum of Erbium

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SOME time ago Ross and one of the authors[1] published a diagram in which the isotope shift per one 6s electron in the neutral atom, per addition of two neutrons, was plotted for many heavy elements *versus* the neutron number. In order to complete the diagram in which erbium data were lacking, the hyperfine structure of the erbium spectrum was studied and the work of Wilets and Bradley[2] was extended.

A water-cooled hollow-cathode discharge tube containing some erbium oxalate was used as the light source, and a Fabry-Perot etalon was used in order to examine the hyperfine structure.

More than twenty lines were found to possess a measurable isotope shift. Since natural erbium[3] is known to have the abundance Er^{170} 14.2, Er^{168} 26.9, Er^{167} 24.4, Er^{166} 32.9, Er^{164} 1.5, and Er^{162} 0.1 percent, the correlation of the components to respective isotopes could be done easily. However, the Er^{162}-component was not observed owing to its small abundance. The isotope Er^{167} which is known[4] to have a spin of 7/2, was found in many lines to have components distributed between the Er^{168}- and the Er^{166}-components. Table I lists the isotope shift in some typical lines of

TABLE I. Isotope shift in the erbium spectrum.

Line (A)	170 − 168 (cm⁻¹)	168 − 166 (cm⁻¹)	166 − 164 (cm⁻¹)	(170 − 168) : (168 − 166) : (166 − 164)
5172.8[a]	0.0381	0.0341	···	1 : 0.90 : ···
4944.4[a]	0.0482	0.0447	0.043	1 : 0.93 : 0.89
4722.7[b]	0.0527	0.0480	0.046	1 : 0.91 : 0.87
4606.6[b]	0.0482	0.0445	0.042	1 : 0.92 : 0.87
4086.7[b]	0.040	0.037	0.035	1 : 0.92 : 0.88

[a] The Er^{170}-component lies on the lowest frequency side.
[b] The Er^{170}-component lies on the highest frequency side.

erbium. The weighted mean of the last column gives $(170-168)$: $(168-166):(166-164)=1:0.92\pm0.05:0.88\pm0.07$, where the disturbance of the Er^{167}-components is roughly taken into account in considering the limits of error.

Classification of the erbium lines into arc and spark lines was also tried, and it was found that λ5173 belongs to the Er I spectrum. It seems probable that the isotope shift in λ5173 represents approximately the contribution of one 6*s* electron to the isotope shift in the neutral erbium atom, because it fits reasonably well in the diagram referred to at the beginning of this letter.

The present work was started in the Department of Physics of the University of Wisconsin by Mr. J. S. Ross and one of us (K.M.), and resumed in Tokyo by us. One of us (K.M.) would like to express his appreciation for the kind cooperation of Mr. Ross in the work.

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Is There a Neutral μ-Meson?

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THE recent experiments of Sagane, Gardner, and Hubbard[1] on the continuous beta-spectrum in the μ^- decay seem to indicate that the spectrum goes to zero at the upper limit. The same authors put the value of the upper limit at 53±2 Mev, which is in agreement with the accepted view that the μ^- meson decays into an electron and two neutrinos. However, it seems to us that such a conclusion is perhaps premature, and that one should consider again the possibility of a neutral μ-meson of finite mass.

The reason is the following. If the μ^- decay is similar to the ordinary beta-decay as is suggested by the value of the lifetime of the μ-meson, then one would expect that the shape of the spectrum would not differ in a qualitative way from the so-called statistical factor which arises from the available phase space. Now, it is well known[2] that for the decay into electron and two neutrinos the statistical factor gives a finite value at the upper limit, which is $\frac{1}{2}\mu c^2$. This is because of the fact that at the upper limit the electron and the neutrinos go off in opposite directions, and since the momentum of the electron can be balanced by the momenta of the two neutrinos in an infinite number of ways, there is still phase space available at the upper limit. The simplest way to obtain a zero value at the upper limit is, therefore, to assume that the μ^- meson decays into a neutral meson of finite mass μ_0 and an electron and a neutrino. The statistical factor then goes to zero, since the μ_0 momentum will then balance the electron momentum at the upper limit. The value of the upper limit will be reduced by $(\mu_0/2\mu)\mu_0 c^2$, so that an experimental uncertainty of 2 Mev would still allow a mass μ_0 of the order of $40m$.

These simple considerations were, of course, well recognized in the theoretical discussions of the μ-decay by Tiomno and Wheeler[3] and by Michel.[4] However, since at that time only the Wilson chamber data of Leighton, Anderson, and Seriff[5] on the μ-decay spectrum were available, which were more compatible with a finite value at the upper limit, the reaction $\mu^{\pm}\rightarrow e^{\pm}+2\nu$ seemed to be the most natural assumption to make. It is, of course, not impossible to obtain a zero value at the upper limit with the same assumption, but it requires a special form of the beta-interaction between the four spinor fields. This possibility has recently been investigated in an interesting report by MacCallum and Wightman[6] especially in connection with the question whether there is a universal beta-interaction, which would account both for the μ-decay and for all the known facts of beta-radioactivity. It may well be that this is the correct point of view and there is no doubt that the data of Sagane and co-workers can be represented in this fashion. However, we think that one should not forget the possibility of a finite mass for the μ_0 meson. The choice of the beta-interaction becomes then much more flexible and much less can be concluded from the μ-decay spectrum.

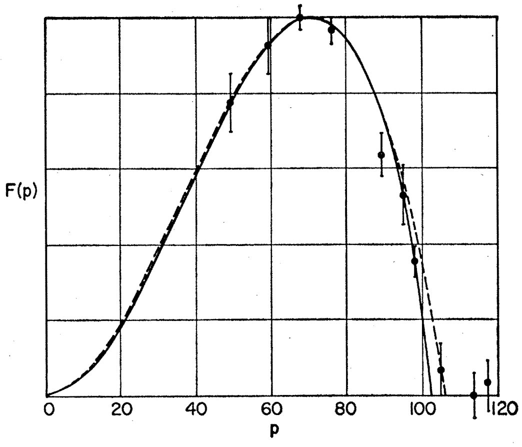

FIG. 1. Comparison of μ-decay spectrum with theory.

The situation is perhaps best summarized by Fig. 1, where the experimental data are compared with two theoretical curves. The dotted curve represents the equation[7]

$$F(p)dp\sim(\mu-2p)p^2dp,$$

and results from the scalar interaction with so-called charge retention (which means that the spinors of μ-meson and electron, and the spinors of the two neutral particles are paired together) and with zero mass for the μ_0 meson. This is one of the few interactions which fit the data. The full curve represents the equation

$$F(p)\sim p^2\left\{5\mu(\mu-2p)\left(\mu-\frac{28}{15}p\right)+\mu_0{}^2(\mu-\tfrac{2}{3}p)\right\}\frac{(\mu^2-\mu_0{}^2-2\mu p)^2}{(\mu-2p)^3}$$

and results from the tensor interaction with the usual pairing $(\mu^-, \mu_0)(e^-, \nu)$ of the spinor fields and with the mass $40m$ for the μ_0 meson. We have not investigated whether this is the best choice; there are no doubt many other possibilities.

In conclusion we may perhaps point out, that if there is a triad of μ-mesons, one would expect that they are connected with the triad of π-mesons in a similar way. This means that the reaction $\pi_0\rightarrow\mu_0+\nu$ should occur with the same coupling constant as the reactions $\pi^{\pm}\rightarrow\mu^{\pm}+\nu$. It could presumably, therefore, not compete with the decay of the π_0 meson into two γ-rays, but it would have as a consequence that the μ_0 meson could decay into a neutrino and two photons. The lifetime would be of the order of 10^{-9} sec, and the photons would be rather soft, so that the detection will be difficult. However, it would make the μ_0 meson much less elusive than the neutrino.

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