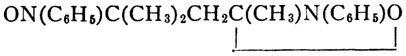
## Microwave Resonance Absorption in a Paramagnetic Organic Compound

A. N. Holden, C. Kittel, F. R. Merritt, and W. A. Yager
*Bell Telephone Laboratories, Murray Hill, New Jersey*
April 4, 1949

MICROWAVE resonance absorption was observed at 24,446 Mc/sec. at room temperature in a powdered crystal specimen of an organic free radical compound. Free radicals are organic compounds which have an odd number of electrons and thus have an unpaired electron spin. The unpaired spin leads to paramagnetism. The compound with which we have worked has the chemical formula  $ON(C_6H_5)C(CH_3)_2CH_2C(CH_3)N(C_6H_5)O$ and is a substituted nitrogen oxide. Its paramagnetic properties were reported by Kenyon and Sugden,[1] who found that the value of the Curie constant corresponded closely to a spin of $\frac{1}{2}$. This is compatible with our microwave results. Approximate measurements of the magnetic susceptibility at liquid air, dry ice, and room temperatures by Mr. E. A. Nesbitt of this laboratory show the expected Curie-type behavior.

The compound, named $\beta$-(phenyl nitrogen oxide)-$\beta$-methyl pentane-$\delta$-one oxime *N*-phenyl ether, was prepared by the method used by Banfield and Kenyon.[2] It forms bright red crystals which are stable at room temperature. The microwave measurements were made by placing about 1 cc of the crystals in a wave guide between the pole pieces of an electromagnet. The transmitted power was measured as a function of the intensity of the static magnetic field. It was observed that the insertion dielectric loss of the specimen was much smaller than that of the hydrated paramagnetic salts with which we have previously worked.

The change in transmitted power as a function of the intensity of the static magnetic field is plotted in Fig. 1. The resonance peak is exceptionally strong and sharp; in fact it is by far the sharpest peak yet reported for electronic paramagnetic resonance. The half-width at half-power is 20 oersteds. The $g$ value as calculated from the resonance condition $\hbar\omega = g\mu_B H$ is 2.02. Our present experimental accuracy in the determination of absolute magnetic field intensity is about 1 percent, so that the free spin $g$ value of 2.00 is within the present experimental error. It is possible to determine the center of our line to a relative precision of 2 oersteds or less, whereas the relativistic radiation reaction shift would amount to about 10 oersteds. This proposed application assumes that spin-orbit coupling effects do not contribute sensibly to the measured $g$ value; a provisional argument can be suggested in support of this assumption, based on the apparent lack of anisotropy in the $g$ value, despite the high structural anisotropy of the molecule itself.

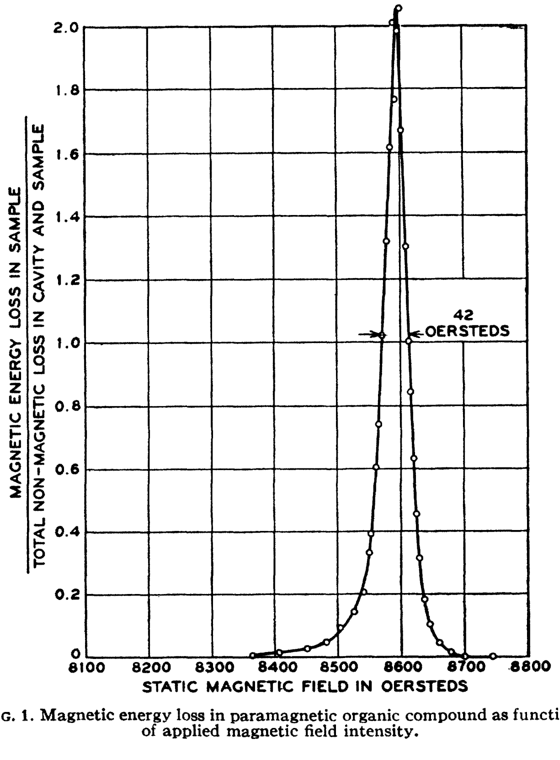


FIG. 1. Magnetic energy loss in paramagnetic organic compound as function of applied magnetic field intensity.

The sharpness of the resonance is probably accounted for by the low value of the spin ($S = \frac{1}{2}$) and by the relatively great magnetic dilution of the material. Measurements at a 3-cm wave-length are in agreement with the measurements at 1 cm.

We wish to thank Mr. E. A. Nesbitt for making the susceptibility determinations.

---

[1] J. Kenyon and S. Sugden, J. Chem. Soc. 170–171 (1932).
[2] F. H. Banfield and J. Kenyon, J. Chem. Soc. 1612–1629 (1926).

---

## Strings, Poles, and the Electron

John A. Eldridge
*State University of Iowa, Iowa City, Iowa*
February 18, 1949

A COMPARISON of Dirac's treatment of magnetic poles with strings[1] and Wilson's discussion of the single pole[2] is of interest. Dirac considers the relation between a charge $e$ and a pair of magnetic poles $\pm g$. The poles are connected by a "string" so as to introduce a solenoidal field (which I represent by $\mathbf{B}$) as well as an irrotational field (which I represent by $\mathbf{H}$). $\mathbf{B}$ and $\mathbf{H}$ have the properties of the conventional magnetic fields and so the string represents a region of magnetic polarization $\mathbf{M}$. $\mathbf{B} = \mathbf{H} + 4\pi\mathbf{M}$. For purpose of comparison we modify Dirac's development. We suppose the string to be a straight line between the poles. Since $\mathbf{B}$ is solenoidal it has a vector potential $\mathbf{A}$ which encircles the string. Consider a particle with mass $m$ and charge $e$ at a distance $r$ from a line passing through the poles (the string or its extension). Its momentum is $m\mathbf{v} + e\mathbf{A}/c$ and its angular momentum about the line is $m\mathbf{r}\times\mathbf{v} + e\mathbf{r}\times\mathbf{A}/c$. We are interested in the second term which is the angular momentum associated with the cross products of the electric and magnetic fields. The magnetic moment per unit length in the string is $g$. For an infinitely long string $A = 2g/r$ and the angular momentum in the field is $2eg/c$. We now assume that when $e$, $g$ have the elementary values $e_0$, $g_0$ the angular momentum is $\hbar$. Therefore $g_0 = \hbar c/2e_0$, which is Dirac's conclusion. The derivation demands infinitely long strings. Since the poles are at infinity it is $g_0$, linear density of magnetic moment along the string, which now appears to be the quantity of physical interest.

Wilson considers the relation between a charge and a single pole. Again the momentum of the system is the momentum of the particles plus the momentum of the crossed fields. There is now no solenoidal field and hence no vector potential but Wilson shows that the angular momentum of the field about a line joining the charge and pole in $eg/c$. He assumes that when the charges and poles have their elementary values that the angular momentum is $\frac{1}{2}\hbar$. This gives $g_0 = \hbar c/2e_0$ for the elementary pole.

It seems likely that poles must exist in pairs. For a system consisting of a charge and a pair of opposite poles the angular momentum in the field will not have a definite value but will approach zero if the distance between the poles is made small in comparison with their distances from the charge. The result becomes definite if the poles have an infinite separation with the charge at a finite distance from their line of separation. The angular momentum associated with the fields of the in-