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Letters to the Editor

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Growing Electromagnetic Waves

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UNDER this title J. H. Piddington has published a paper[1] in which he arrives at the following conclusions with regard to the theory of electromagnetoionic (EMI) waves:

(1) "The growth of radio and other electromagnetic waves predicted by the EMI theory is spurious and does not depend on any real transfer of energy from the gas to the waves.

(2) No new waves, other than four types already recognised, result from the various ion movements allowed in the EMI theory."

For this purpose he uses the Lorentz transformation and (effectively) the following criterion:

If an observer A is at rest relatively to the electron gas and a second observer B moves with a constant velocity relative to this gas, then the observations of A are real but those of B are unreal. (Piddington calls A the MI observer and B the EMI observer.)

On becoming aware of this fact many critical readers of Piddington's paper would find it difficult to proceed with it, for this criterion is directly contradicted by Einstein's principle of (special) relativity under which all inertial frames of reference are equally valid for expressing the laws of nature.

Thus, Piddington's conclusions (1) and (2) given above are based on a false criterion and therefore they have not been proved true.

On the other hand, the conclusions of the EMI theory are consistent with the principle of relativity, as may be seen by examining the relativistic formulation of it which was published previously by this author.[2]

Since this theory shows by means of generally accepted principles that spatially growing wave modes can exist and that when they exist there is a real transfer of energy from the streams of charged particles to the waves, Piddington's conclusions (1) and (2) are wrong.

The error in Piddington's views about the transfer of energy becomes clearer on noting that the *observed* transfer of energy is different in different frames of reference. This is shown by the following simple example: a light particle of mass m moves to the right with the velocity $v \ll c$, collides elastically with a heavy body of mass $M \gg m$ which is at rest relatively to an observer O_1, and rebounds to the left (with the velocity $-v$). This collision is also viewed by observers O_2 and O_3 who are moving relatively to the heavy body with the velocities v and $-v$, respectively. O_1 observes no resulting change in the energy of the particle, while O_2 and O_3 observe respectively a gain of energy and a complete loss of energy by the same particle. Each of these observations is physically real, and so none of them is illusory as Piddington's views would lead him to conclude.

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[1] J. H. Piddington, Phys. Rev. **101**, 9 (1956).
[2] V. A. Bailey, Phys. Rev. **83**, 439–454 (1951).

Application of an Approximate *F*-Center Wave Function. Magnetic Hyperfine Interactions in KCl†

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FEHER has recently used a double spin resonance technique to study the hyperfine structure of the *F*-center electron spin resonance line in KCl.[1] Both the isotropic (Fermi term),[2] and the anisotropic magnetic hfs constants, which we denote as a and b, respectively, were determined for the nearest neighbor potassium and chlorine ions.

Gourary and the author[3] have recently calculated the a's for the nearest neighbor ions in LiF, using a relatively simple *F*-electron wave function which had been orthogonalized to the ion-core orbitals by the Schmidt process. This function is

$$\varphi_F = N[\psi_F - \sum_i (i|F)\psi_i],$$

where the nonorthogonal function ψ_F was obtained from a variational calculation using a point ion lattice. This method is equally applicable to the calculation of the b's. Comparison of such a calculation with Feher's results is desirable, since it will provide another test of this *F*-center wave function, and give some idea as to its usefulness in future calculations.

The details of the calculation, which are given in I, will be summarized briefly. To calculate a or b for a given ion, one uses, respectively, Eq. (50) or (51) of I. ψ_F is the type III ground-state function of I. Hartree functions are used for the ion-core orbitals.[4] Asymptotic series for the overlap integrals are derived by expanding ψ_F about the ion being considered. With the exception of the diffuse Cl^- $3p$ function, these asymptotic series converged rapidly, and at most two terms were needed. If one uses only the first term, the results for ion s have the form

$$a(s)\cong A_s|\psi_F(s)|^2;\quad b(s)\cong B_s|(d\psi_F/dr)_s|^2,$$

where r is the distance from the center of the vacancy.[5] The coefficients A_s and B_s are properties of the ion and its nucleus alone, and ψ_F and its radial derivative are evaluated at the nucleus of the ion. The above formulas are useful for extrapolating results from one substance to another since the parameters of ψ_F vary smoothly with interionic distance.

The calculated results, in Mc/sec, are $a(\mathrm{K}^{39})=35$, $b(\mathrm{K}^{39})=1.0$, and $a(\mathrm{Cl}^{39})=12$. Feher's experimental results are $a(\mathrm{K}^{39})=21.6$, $b(\mathrm{K}^{39})=0.95$, and $a(\mathrm{Cl}^{39})=7.0$. The calculation of $b(\mathrm{Cl})$ has been omitted because of failure of the asymptotic series. More laborious methods could be used, but it is inadvisable in view of the sensitivity of calculations involving the negative ions to small changes in the variational parameters of ψ_F.

These results do show that the relatively simple wave function used can give the correct order of magnitude for most of the magnetic hfs constants. Consideration of these results and those of I indicates that the positive-ion results are the most reliable, the agreement improving with increasing interionic distance.

The author is indebted to Dr. G. Feher for the opportunity of seeing an advance description of his experiment. Miss Martha Neuman did the numerical calculations.

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[1] G. Feher, Phys. Rev. **105**, 1122 (1957).

[2] First determined by Kip, Kittel, Levy, and Portis, Phys. Rev. **91**, 1066 (1953).

[3] B. S. Gourary and F. J. Adrian, Phys. Rev. **105**, 1180 (1957). Hereafter referred to as I.

[4] K^+: D. R. Hartree and W. Hartree, Proc. Roy. Soc. (London) **166**, 450 (1938). Cl^-: D. R. Hartree, Proc. Roy. Soc. (London) **156**, 45 (1936).

[5] Earlier, D. L. Dexter [Phys. Rev. **93**, 244 (1954)], and J. A. Krumhansl [Phys. Rev. **93**, 245 (1954)], proposed similar methods for calculating a. Krumhansl's method is used in I to get $a(\mathrm{K}^{39})=29$ Mc/sec. However, their methods are not immediately applicable to the calculation of b.

Paramagnetic Resonance Hyperfine Structure of Np^{239}†

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THE discrepancy between the spin value of Np^{239} as measured by Conway and McLaughlin[1] using optical hyperfine structure ($I=\frac{1}{2}$), and the value inferred from various decay scheme studies[2] ($I=\frac{5}{2}$) has led us to redetermine the spin by an independent method: microwave paramagnetic resonance absorption.[3] Using this technique Bleaney, Llewellyn, Pryce, and Hall[4] have investigated the paramagnetic resonance of long-lived Np^{237} incorporated as $\mathrm{NpO_2}^{+2}$ ions in a single crystal of $\mathrm{UO_2Rb(NO_3)_3}$. Their results are in good agreement with a spin Hamiltonian:

$$\begin{aligned}\mathcal{H}=g_{\parallel}\beta H_zS_z+g_{\perp}\beta(H_xS_x+H_yS_y)+AS_zI_z\\ +B(I_xS_x+I_yS_y)+P[I_z^2-\tfrac{1}{3}I(I+1)];\quad(1)\end{aligned}$$

where x, y, z are the crystalline field principal axes, $S=\frac{1}{2}$, $I(\mathrm{Np}^{237})=\frac{5}{2}$, $g_{\parallel}=3.40$, $g_{\perp}\cong0.2$, $A=(+)0.1654$ cm^{-1}, $B=0.0178$ cm^{-1}, $P=(-)0.0301$ cm^{-1}, $\beta=$ Bohr magneton. We have prepared 4 μg ($\sim$1 curie) of Np^{239} by thermal-neutron irradiation of U^{238} in the Materials Testing Reactor at Idaho Falls, Idaho. This was incorporated, together with 3 μg of Np^{237}, as $\mathrm{NpO_2}^{+2}$ in a single crystal of $\mathrm{UO_2Rb(NO_3)_3}$ weighing about 200 mg; $\mathrm{KBrO_3}$ was added to the aqueous growing solution to maintain the Np (VI) oxidation state. The crystal was installed in the microwave cavity of the paramagnetic resonance apparatus previously described[5] with the crystalline z axis approximately parallel to the dc magnetic field H. Examination of the spectrum at 4.3°K showed a pair of lines near $g_{\parallel}\cong3.4$ which we attribute to Np^{239}. We thus conclude that $I(\mathrm{Np}^{239})=\frac{1}{2}$, confirming the earlier result of Conway and McLaughlin.[1] The Np^{239} resonance lines were first seen with a signal-to-noise ratio of about 20; this decreased to unity after about 12 hours because of radiation damage. No lines attributed to Np^{237} were observed, presumably because the large quadrupole interaction in this case makes them more susceptible to radiation damage. Thus our experiment does not rule out the possibility that there is perhaps an isomeric state of Np^{239} with $I=\frac{5}{2}$.

Detailed resonance data were obtained by rotating the wave guide and cavity containing the crystal about an axis perpendicular to the H field. The position of the two Np^{239} lines was found to fit within about 1% the first order theoretical expression $H_{\mathrm{res}}\cong(h\nu\pm\frac{1}{2}A)/g_{\parallel}\beta\cos\theta$, which is obtained from the Hamiltonian (1) for $I=\frac{1}{2}$, assuming $\theta<45°$, where θ is the angle between H and z, and ν is the microwave frequency (9380 Mc/sec in our case). The best fit is obtained by taking $g_{\parallel}=3.40$, $A(\mathrm{Np}^{239})=0.0503\pm0.0005$ cm^{-1} and $\cos\theta=\cos\alpha\cos\psi$ where ψ is the (variable) angular position of the crystal about an axis perpendicular to H, and $\alpha\cong19°$ is the fixed minimum angle between z and H. The angle α should be zero if the crystal were perfectly aligned in the cavity; in our case this is not true because the active crystal was quickly aligned by simply sighting with the eye. The excellent fit of the observed lines to the theory establishes them as certainly a hyperfine doublet, and we believe that the observed spectroscopic splitting factor $g_{\parallel}$ establishes their chemical identity. They clearly could not be due to Pu^{239} ($I=\frac{1}{2}$) as $\mathrm{PuO_2}^{+2}$, for which Bleaney *et al.*[4] report $g_{\parallel}=5.4$, $g_{\perp}\sim0$, $A=0.0862$