

The behavior of the paramagnetic resonance spectra of these alums at low temperatures is similar to that observed in the optical spectra by Kraus and Nutting,<sup>12</sup> especially in the "shattering" of the ammonium alum, and the gradual transition in intensity from the high to the low temperature spectrum in the potassium alum. It may be that x-ray analysis will reveal structural differences such as those found in the aluminum alums<sup>13</sup> which can be correlated with the magnetic behavior. A further unexplained peculiarity of the alums is the Debye-type electrical relaxation discovered by Guillien.<sup>14</sup> Unfortunately his measurements do not cover a sufficient number of alums to detect correlatable differences in behavior.

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<sup>1</sup> Bleaney and Penrose, *Proc. Phys. Soc.* **60**, 395 (1948).

<sup>2</sup> J. Van Vleck, *J. Chem. Phys.* **7**, 61 (1939).

<sup>3</sup> Bagguley and Griffiths, *Nature* **160**, 532 (1947).

<sup>4</sup> Weiss, Whitmer, Torrey, and Hsiang, *Phys. Rev.* **72**, 975 (1947). Whitmer, Weidner, Hsiang, and Weiss, *Phys. Rev.* **74**, 1478 (1948).

<sup>5</sup> D. Halliday and J. Wheatley, *Phys. Rev.* **74**, 1712 (1948).

<sup>6</sup> Bagguley and Griffiths (to be published).

<sup>7</sup> Benzie and Cooke (to be published).

<sup>8</sup> See Gorter, *Paramagnetic Relaxation* (Elsevier Publishing Company, Inc., New York, 1947).

<sup>9</sup> B. Bleaney, unpublished, quoted by Van Vleck, *Phys. Rev.* **57**, 426 (1940).

<sup>10</sup> Casimir, de Haas, and de Klerk, *Physica* **6**, 365 (1939).

<sup>11</sup> de Klerk, Steenland, and Gorter, *Nature* **161**, 678 (1948).

<sup>12</sup> D. L. Kraus and G. C. Nutting, *J. Chem. Phys.* **9**, 133 (1941).

<sup>13</sup> Lipson, *Proc. Roy. Soc.* **151**, 347 (1935).

<sup>14</sup> Guillien, *Comptes Rendus* **209**, 21 (1939); **213**, 991 (1941); **217**, 443 (1943).

### Microwave Magnetic Resonance Absorption in Oxygen

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WE have detected the absorption arising from magnetic dipole transitions between adjacent Zeeman components of the rotational levels of the oxygen molecule. The apparatus is essentially a microwave analogue of the radio-frequency nuclear magnetic resonance method.<sup>1</sup> Power from a frequency-stabilized 9360 mc/sec. oscillator is coupled into an oxygen-filled, cylindrical cavity placed in a uniform axial magnetic field. The cavity resonates in the TM<sub>011</sub> mode so that the r-f and d.c. magnetic fields are perpendicular. A Wolaston wire bolometer is coupled to the cavity and forms one arm of a d.c. bridge. The axial magnetic field has a small 30 cycle/sec. modulation component so that in the region of an absorption line the microwave power into the bolometer is modulated, producing a 30 cycle/sec. unbalance signal in the bridge. This signal is amplified by a high-gain tuned amplifier and impressed on a lock-in mixer whose d.c. output indicates the magnitude and sign of the derivative of the absorption line (i.e.,  $d\chi''/dH$ , where  $\chi''$  is the imaginary part of the magnetic susceptibility).

At atmospheric pressure two broad absorption lines were found for fields ranging up to 9 kilogauss. As the pressure was lowered these showed increasingly complex fine-structure. At an oxygen pressure of 1.5 cm Hg twenty-seven partially resolved components could be identified in the region from 5.4 kilogauss to the highest fields used. They showed no simple regularities in spacing, which varied from 380 to 60 gauss, or in intensity, which varied by at least a factor five. The half-widths of several of the larger lines could be determined; they range from 40 to 80 gauss and do not show the expected linear dependence with the field. Further, the half-widths are greater than those deduced from the pressure broadening of the 0.5-cm absorption band<sup>2</sup> of O<sub>2</sub> by factors ranging from 4 to 8. The largest resolved lines at the 1.5-cm pressure have  $\chi''$  values estimated to be  $3 \times 10^{-10}$  c.g.s. Noise fluctuations are about two percent of this.

As might be expected, the spectrum is not in accord with the low field Zeeman theory. Assuming pure Hund case (b) coupling in the <sup>3</sup>Σ ground state of O<sub>2</sub>, the low field Zeeman formula predicts an absorption line at 6.9 kilogauss arising from  $\Delta M = \pm 1$  transitions between the Zeeman levels of the  $J=1$  and 2 components of the  $K=1$  rotational state, and a line at 10.3 kilogauss for the  $K=3$ ,  $J=2$  levels, as well as other lines at higher fields. However, even at 6.9 kilogauss the spin energy is a third of the average level-spacing in the spin triplets. Thus one expects a partial Paschen-Back effect for the fields used in the experiments. A more complete analysis of the line positions and intensities requires a high field Zeeman theory for molecular triplet states.

\* Assisted by the ONR.

<sup>1</sup> Purcell, Torrey, and Pound, *Phys. Rev.* **69**, 37 (1946).

<sup>2</sup> J. H. Van Vleck, *Phys. Rev.* **71**, 413 (1947); R. Beringer, *Phys. Rev.* **70**, 53 (1946).

### Three-Photon Annihilation of an Electron-Positron Pair

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AFTER we had submitted the proof of our paper by the above title,<sup>1</sup> it came to our attention that this subject has recently been discussed by L. D. Landau, E. M. Lifshits, and I. Pomeranchuk.<sup>2</sup>

Landau and Pomeranchuk's work includes a discussion of allowed and forbidden annihilation processes. The earlier work by J. Pirenne and by J. A. Wheeler, to which we refer in our paper, as well as the conclusions which we have drawn from a detailed study of the special case of the three-photon annihilation, are in agreement with the general results of these authors.

However, Lifshits gives a formula for the differential cross section for three-photon annihilation which is in apparent disagreement with our result. As a consequence, he finds a lifetime of the triplet ground state of the positronium atom ( $8.8 \times 10^{-8}$  sec.) which is shorter than ours by a factor 1.6.

Unfortunately, the brevity of Lifshits' report does not permit a comparison of the methods of calculation, and we have been unable to discover the source of the discrepancy.

<sup>1</sup> A. Ore and J. L. Powell, *Phys. Rev.* **75**, 1696 (1949).

<sup>2</sup> L. D. Landau, *Dokl. Akad. Nauk, SSSR* **60** (No. 2), 207 (1948). E. M. Lifshits, *Dokl. Akad. Nauk, SSSR* **60**, 211 (1948). I. Pomeranchuk, *Dokl. Akad. Nauk, SSSR* **60**, 213 (1948). See also *Physics Abstracts* **A52**, p. 125, abstr. 1005, 1006, 1007 (1949).

### Electrolytic Deposits of Po in Extremely Dilute Solutions

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DURING the course of experiments which we are carrying out on the electrochemical behavior of radio-elements in extremely dilute solutions (between  $10^{-10}$  and  $10^{-14}$ N) we have made some observations which we think present an interest for nuclear physics research.

We obtain polonium deposits, either by electrolysis of its acid solutions (HNO<sub>3</sub>, 1.5N) or by spontaneous deposition on surfaces of Au, Ag, Pt or Ni. After having measured the deposited quantity by means of a linear amplifier, the electrode is applied to an Ilford Nuclear Research plate type C2, and, after development, an examination of the plate enables us to establish the distribution of the Po atoms on the surface and that of the alpha ranges. This latter is generally based on