

make sure that these curves could be used for the *K* plates used by us, we have calibrated some plates with α -particles of Po and with protons emitted from paraffine bombarded with Po α -particles.)

For the energy determination, we have calculated the range in the air and then used the known curves of Livingston and Bethe.

¹G. Ortner, Mitt. d. Inst. f. Radiumforsch. Wien, No. 436; Wien Ber. 149, 259 (1940).

²E. Bagge, Ann. d. Physik 39, 512 (1941).

³E. M. and E. Schopper, Physik. Zeits. 40, 22 (1939).

A New Band System in the Green Excited in a Mixture of Xenon and Oxygen and the Energy of Dissociation of CO

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A BULB containing pure Xe at about 100-mm pressure, excited by a high frequency discharge, glows with a pale purple color and develops purple streamers. If a little O₂ is present, however, and the discharge is weak and of



FIG. 1. Spectrogram of oxygen and xenon with Mo arc as reference.

very high frequency (4.5 megacycles), a beautiful apple-green glow is developed. The spectroscope shows the glow to consist of two lines or narrow bands at about 5677 and 5651A, and a system of bands beginning at about 5556A and shading off to the violet, traceable beyond 5000A. The accompanying spectrogram (Fig. 1) (with Mo arc spectrum included) and densitometer tracing (Fig. 2) show the appearance and wave-lengths of the bands. Some of the bands are shaded toward the red.

The band system was discovered in 1941 by two of us (A. P. and V. P.) in a bulb containing a mixture of Kr and Xe in which some impurity was suspected. It was next observed in the manufacture of flashtubes containing Xe. The conditions under which it was frequently seen suggested it might be associated with one of the constituents of air. Finally it was identified with O₂ by slowly leaking various gases into pure Xe while watching the color of the discharge. Very small amounts of O₂ were found to bring out the glow. In fact, so sensitive to O₂ is Xe at about 100 mm that as little as one part per million can be detected. The most favorable O₂ concentration is of the order of 0.05 percent.

CO₂ gives the bands almost as strongly as O₂. The bands also appear with H₂O vapor, but are much less strong. No bands were found with CO, nor with N₂, H₂, or CH₄.

The bands do not appear under similar circumstances with Kr or A.

This band system is, so far, unreported as far as the writers are aware. It is suggested tentatively that it may be owing to O₂ and that it may result from a resonant energy exchange with metastable Xe atoms. In this case, the excitation energy of the bands would lie well above the dissociation energy of O₂ (5.08 v).

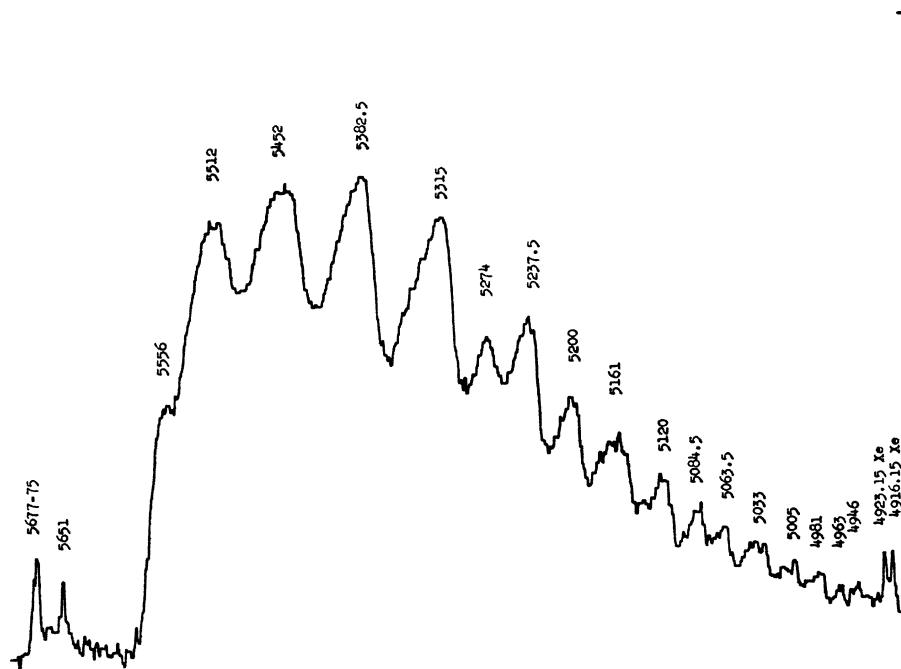


FIG. 2. Densitometer tracing of band spectra.

The suggestion is also made that CO₂ may be strongly dissociated by the metastable Xe atoms (and H₂O somewhat less strongly), thus producing oxygen atoms which combine to form the O₂ molecules; $D(\text{CO}_2) = 5.5 \text{ v}$, $D(\text{H}_2\text{O}) = 5.0 \text{ v}$. If so, the fact that CO did not yield the bands would indicate that the dissociation energy of CO is greater than the energy of the upper metastable state of Xe, namely 9.4 volts. (Energy of lower metastable state equals 8.3 v.) This appears to be direct evidence in favor of the 9.6-volt value of $D(\text{CO})$ as determined by Hagstrum and Tate¹ from appearance potentials in the mass spectrograph, or for the 11.11 v-value obtained in a recent spectral analysis by Gaydon and Penney,² but against the 9.14-volt value determined from certain predissociation data.³ The higher value appears to be more in accord also with thermochemical data as brought out by Hagstrum and Tate,¹ and also by Asundi and Samuel.⁴

¹ H. D. Hagstrum and J. T. Tate, *Phys. Rev.* **59**, 365 (1941).

² A. G. Gaydon and W. G. Penney, *Proc. Roy. Soc. A* **183**, 374 (June, 1945).

³ For a review see G. Herzberg, *Molecular Spectra and Molecular Structure* (Prentice-Hall, Inc., New York, 1939), Chap. VIII.

⁴ R. K. Asundi and R. Samuel, *Ind. Acad. Sci.* **3A**, 562 (1936).

Resonance Absorption by Nuclear Magnetic Moments in a Solid

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IN the well-known magnetic resonance method for the determination of nuclear magnetic moments by molecular beams,¹ transitions are induced between energy levels which correspond to different orientations of the nuclear spin in a strong, constant, applied magnetic field. We have observed the absorption of radiofrequency energy, due to such transitions, in a *solid* material (paraffin) containing protons. In this case there are two levels, the separation of which corresponds to a frequency, ν , near 30 megacycles/sec., at the magnetic field strength, H , used in our experiment, according to the relation $h\nu = 2\mu H$. Although the difference in population of the two levels is very slight at room temperature ($h\nu/kT \sim 10^{-5}$), the number of nuclei taking part is so large that a measurable effect is to be expected providing thermal equilibrium can be established. If one assumes that the only local fields of importance are caused by the moments of neighboring nuclei, one can show that the imaginary part of the magnetic permeability, at resonance, should be of the order $h\nu/kT$. The absence from this expression of the nuclear moment and the internuclear distance is explained by the fact that the influence of these factors upon absorption cross section per nucleus and density of nuclei is just cancelled by their influence on the width of the observed resonance.

A crucial question concerns the time required for the establishment of thermal equilibrium between spins and

lattice. A difference in the populations of the two levels is a prerequisite for the observed absorption, because of the relation between absorption and stimulated emission. Moreover, unless the relaxation time is very short the absorption of energy from the radiofrequency field will equalize the population of the levels, more or less rapidly, depending on the strength of this r-f field. In the expectation of a long relaxation time (several hours), we chose to use so weak an oscillating field that the absorption would persist for hours regardless of the relaxation time, once thermal equilibrium had been established.

A resonant cavity was made in the form of a short section of coaxial line loaded heavily by the capacity of an end plate. It was adjusted to resonate at about 30 mc/sec. Input and output coupling loops were provided. The inductive part of the cavity was filled with 850 cm³ of paraffin, which remained at room temperature throughout the experiment. The resonator was placed in the gap of the large cosmic-ray magnet in the Research Laboratory of Physics, at Harvard. Radiofrequency power was introduced into the cavity at a level of about 10⁻¹¹ watts. The radiofrequency magnetic field in the cavity was everywhere perpendicular to the steady field. The cavity output was balanced in phase and amplitude against another portion of the signal generator output. Any residual signal, after amplification and detection, was indicated by a microammeter.

With the r-f circuit balanced the strong magnetic field was slowly varied. An extremely sharp resonance absorption was observed. At the peak of the absorption the deflection of the output meter was roughly 20 times the magnitude of fluctuations due to noise, frequency, instability, etc. The absorption reduced the cavity output by 0.4 percent, and as the loaded Q of the cavity was 670, the imaginary part of the permeability of paraffin, at resonance, was about $3 \cdot 10^{-6}$, as predicted.

Resonance occurred at a field of 7100 oersteds, and a frequency of 29.8 mc/sec., according to our rather rough calibration. We did not attempt a precise calibration of the field and frequency, and the value of the proton magnetic moment inferred from the above numbers, 2.75 nuclear magnetons, agrees satisfactorily with the accepted value, 2.7896, established by the molecular beam method.

The full width of the resonance, at half value, is about 10 oersteds, which may be caused in part by inhomogeneities in the magnetic field which were known to be of this order. The width due to local fields from neighboring nuclei had been estimated at about 4 oersteds.

The relaxation time was apparently shorter than the time (\sim one minute) required to bring the field up to the resonance value. The types of spin-lattice coupling suggested by I. Waller² fail by a factor of several hundred to account for a time so short.

The method can be refined in both sensitivity and precision. In particular, it appears feasible to increase the sensitivity by a factor of several hundred through a change in detection technique. The method seems applicable to the precise measurement of magnetic moments (strictly, gyromagnetic ratios) of most moderately abundant nuclei.

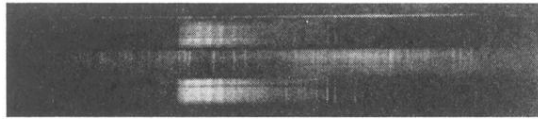


FIG. 1. Spectrogram of oxygen and xenon with Mo arc as reference.