TABLE I. Oxygen lines between 58,300 Mc and 59,900 Mc.

Molecule	Transition	Frequency (Mc)
$O^{16}O^{18}$	$K=9$ $J=8\rightarrow 9$	58,310
$O^{16}O^{16}$	$K=9$ $J=8\rightarrow 9$	58,324
$O^{16}O^{16}$	$K=3$ $J=4\rightarrow 3$	58,446
$O^{16}O^{18}$	$K=3$ $J=4\rightarrow 3$	58,650
$O^{16}O^{18}$	$K=8$ $J=7\rightarrow 8$	58,670
$O^{18}O^{18}$	$K=3$ $J=4\rightarrow 3$	58,900
$O^{18}O^{18}$	$K=7$ $J=6\rightarrow 7$	58,965
$O^{16}O^{18}$	$K=7$ $J=6\rightarrow 7$	59,075
$O^{16}O^{16}$	$K=7$ $J=6\rightarrow 7$	59,163
$O^{16}O^{18}$	$K=4$ $J=5\rightarrow 4$	59,220
$O^{16}O^{18}$	$K=6$ $J=5\rightarrow 6$	59,540
$O^{16}O^{16}$	$K=5$ $J=6\rightarrow 5$	59,590
$O^{16}O^{18}$	$K=5$ $J=6\rightarrow 5$	59,685
$O^{18}O^{18}$	$K=5$ $J=6\rightarrow 5$	59,810
$O^{18}O^{18}$	$K=5$ $J=4\rightarrow 5$	59,875

These are listed in Table I. Their positions are predicted closely by Schlapp's formula, as modified by Burkhalter *et al.*[1] with appropriate changes in constants because of the change in isotopic masses.

A sample of enriched oxygen was very kindly supplied by Professor A. O. Nier. After a brief discharge was run in this gas to approximate an equilibrium distribution, the relative intensities of $O^{18}O^{18}$ to $O^{16}O^{18}$ to $O^{16}O^{16}$ lines were roughly 1:5:15, as may be seen from Fig. 1. The three lines shown are the $K=7$, $J=6\rightarrow 7$ transition for the three different isotopic combinations.

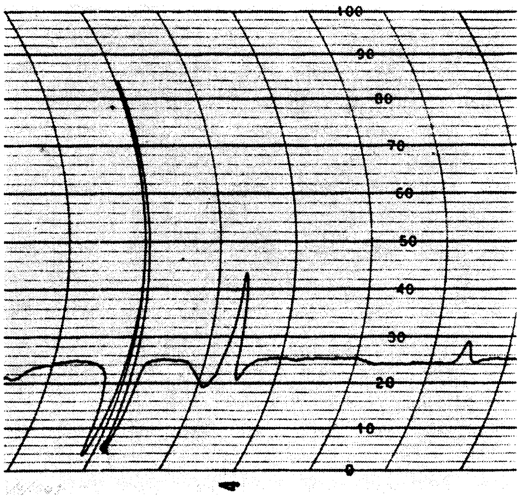

FIG. 1. The $K=7$, $J=6\rightarrow 7$ transition for the isotopic combinations $O^{16}O^{16}$, $O^{16}O^{18}$, and $O^{18}O^{18}$ (from left to right).

Other observations[2] on O^{18} had failed to disclose quadrupole hyperfine structure, and the $O^{16}O^{18}$ lines show no evidence of magnetic hyperfine structure, which indicates a zero spin for O^{18}. However, real proof that the O^{18} spin is zero must rest on the method of alternating intensities in the homonuclear molecule $O^{18}O^{18}$.

The $K=8$, $J=7\rightarrow 8$ transition, which should be at about 58,600 Mc; the $K=6$, $J=5\rightarrow 6$ transition at about 59,375 Mc; and the $K=4$, $J=5\rightarrow 4$ transition at about 59,400 Mc for $O^{18}O^{18}$ are all missing. Figure 2 shows the region of the latter two missing lines, bounded by the corresponding transitions for $O^{16}O^{18}$ which are off scale. In the case of spin = 1, these missing lines should be approximately 15 units high, and for higher spin values still stronger. Therefore, it can be concluded that the spin of O^{18} is zero, since the alternate rotational levels of $O^{18}O^{18}$ do not exist. The O^{18} nucleus also follows Bose-Einstein statistics, as does O^{16}, since the same rotational levels are forbidden in both cases.

Magnetic hyperfine structure has been found in the same sample for $O^{16}O^{17}$. Although no definite spin determination has as yet been made from this structure, the O^{17} spin is evidently greater than $\frac{1}{2}$.

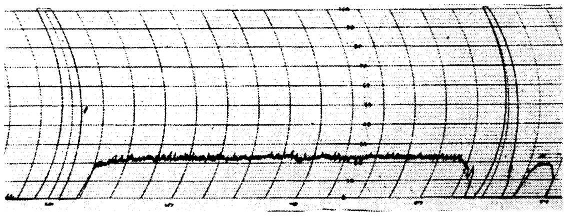

FIG. 2. Recording trace from the $K=4$, $J=5\rightarrow 4$ transition for $O^{16}O^{18}$ (on the right) to the $K=6$, $J=5\rightarrow 6$ transition for $O^{16}O^{18}$ (on the left). The missing $O^{18}O^{18}$ lines $K=4$, $J=5\rightarrow 4$ and $K=6$, $J=5\rightarrow 6$ should be about midway between them.

The microwave lines were detected with a recording Zeeman modulation spectrometer constructed by A. L. Schawlow, T. M. Sanders, and W. A. Hardy.

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* AEC Predoctoral Fellow.

† Work supported partly by the AEC and partly by a joint Signal Corps-ONR contract.

[1] Burkhalter, Anderson, Smith, and Gordy, Phys. Rev. **79**, 651 (1950).

[2] Townes, Holden, and Merritt, Phys. Rev. **74**, 1113 (1948).

Evidence for the Formation of Positronium in Gases*

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(Received March 13, 1951)

THE distribution of time delays between the emission of a nuclear gamma-ray from the decay of Na^{22} and the appearance of an annihilation quantum has been measured for positrons stopping in a large number of gases and gas mixtures, extending earlier measurements.[1] A complete interpretation of the results appears to be fairly complex and will be attempted in a more extensive communication. At this time we want to report on some definite proof of the abundant formation of positronium, the bound electron-positron system analogous to the hydrogen atom. The ground state of this atom is expected[2] to have a lifetime against two-quantum annihilation of about 10^{-10} sec if the spins are antiparallel and slightly over 10^{-7} sec if they are parallel,[3] decaying by three-quantum annihilation. Ore[4] has shown that, in general, there is no mechanism for the rapid destruction of the triplet state at low energies. One may expect, however, that in a gas containing molecules with an odd number of electrons, such as nitric oxide, the triplet state would be converted very rapidly to the singlet by an electron exchange. In NO this requires essentially no energy at room temperature, the energy difference for the two spin orientation being only about 13 millivolts. The cross section for this process may be very large, since it is a resonance effect involving the coulomb interaction rather than a magnetic conversion. (The latter is expected to be very slow.[4]) Thus, even a small admixture of NO should cause the very rapid annihilation of those positrons which would otherwise have decayed by three-quantum annihilation with a period of the order of 10^{-7} sec. Figure 1 shows this phenomenon. In nitrogen the number of delayed counts is reduced by a factor of three by the addition of 3 percent NO. These counts then appear instead in the "prompt" channel, not shown in Fig. 1. In freon the effect is even greater, hardly any delayed coincidences remaining upon addition of NO. The residue in N_2 is probably due to free positrons.

Oxygen has a similar but less pronounced action. In pure O_2 the number of delayed coincidences is about half as great as in N_2 (Fig. 1).

Confirmation of the above interpretation comes from the direct observation of the continuous gamma-ray spectrum due to the

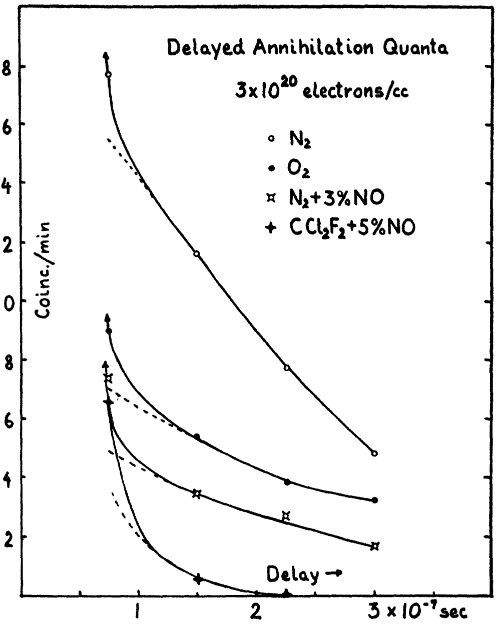

FIG. 1. Decay curves of positrons in several gases. The dotted lines are corrected for time resolution of the instrument.

three-quantum annihilation of triplet positronium in nitrogen. Figure 2 shows pulse height spectra obtained in a NaI scintillation spectrometer deliberately adjusted for low resolution to gain stability. It is seen that the photoelectron peak of the 510-kev radiation is markedly lower in pure N_2 while there is an increase of the number of lower energy electrons, compared with the spectrum from N_2+NO in which we expect almost pure two-quantum annihilation. The large number of small pulses present in both curves is due to scattered radiation from the walls of the gas vessel. The annihilation spectrum in pure O_2 resembles that in N_2+NO.

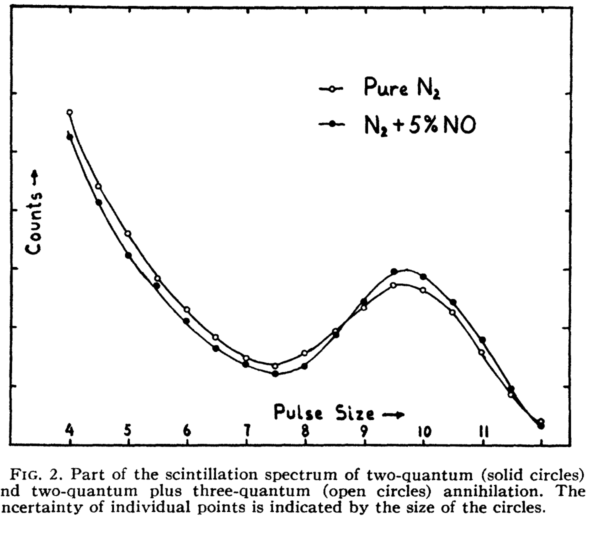

FIG. 2. Part of the scintillation spectrum of two-quantum (solid circles) and two-quantum plus three-quantum (open circles) annihilation. The uncertainty of individual points is indicated by the size of the circles.

The slight shift of the photoelectron peak to lower energies in N_2 is due to the large number of quanta just below 510 kev from the three-quantum process[3] falling within the experimental width of the two-quantum line. A similar phenomenon may explain the low value of the annihilation energy obtained by DuMond.[5]

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* Supported in part by the joint program of the AEC and ONR.

[1] J. W. Shearer and M. Deutsch, Phys. Rev. **76**, 462 (1949).

[2] J. Pirenne, Arch. Sci. phys. et nat. **29**, 257 (1947).

[3] A. Ore and J. L. Powell, Phys. Rev. **75**, 1696 (1949).

[4] A. Ore, Yearbook 1949 (University of Bergen), No. 12.

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Infrared Absorption and Intrinsic Semiconductivity of Condensed Aromatic Systems

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(Received March 8, 1951)

IN order to explain the temperature dependence of the resistivity of polycrystalline graphite and carbons, it seems necessary to assume the existence of an energy gap between the filled and upper bands.[1] The familiar progressive change in color of condensed aromatic compounds with the size of the molecule is believed to be a manifestation of the change in this energy gap, which, as it decreases to zero, leads to the semimetallic properties of graphite.

The presence of aromatic rings in pyrolyzed cellulose products is known.[2] The writer has studied the infrared absorption of Cellophane char films ($\sim 20\mu$ thick). The transmission curves for several films are presented in Fig. 1, and their charring temperatures are given in Table I.

The curves reveal two main features. One is a band of complete absorption extending through the visible region and terminating in the infrared. The limit of this band is seen to move progressively toward longer wavelengths as the treatment temperature increases. The other feature is the presence of characteristic bands corresponding to different types of bonds present in the char. As will be shown, the shifting band is of an electronic origin and corresponds, probably, to motion of electrons in the aromatic lattice. Midpoints of the transparency expressed in electron volts

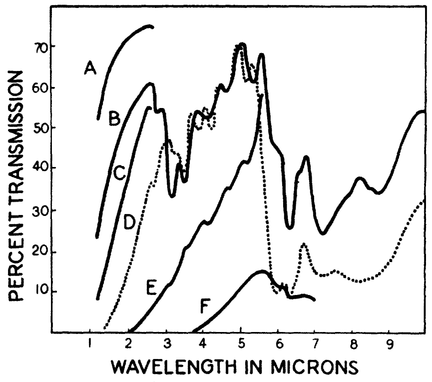

FIG. 1. Infrared transmission curves for Cellophane char films.

TABLE I. Transparency and resistance data.

Sample	Treatment temp. °C	Midpoint of transparency in ev	ΔE in ev from R *vs* T
A	300	1.2	...
B	350	0.87	...
C	425	0.71	0.8
D	500	0.50	0.62
E	540	$\geqslant 0.33$	0.41
F	630	$\leqslant 0.28$	0.22
G	700	~ 0.2	0.09
H	800	...	0.03