The Theory of the Paramagnetism of Oxygen and Nitric Oxide.

THE two important paramagnetic gases are oxygen and nitric oxide, and to account numerically for their susceptibilities has long been a puzzle. The new quantum mechanics, together with recent spectroscopic data for nitric oxide, seem at last to solve the difficulties.

Sommerfeld (" Atombau," p. 641) has shown that the susceptibility of oxygen can be explained by assuming that, despite the presence of two nuclei, the magnetic behaviour of the O_2 molecule is like that of an *atom* in a ^3S state. This apparently involves the unreasonable hypothesis that the angular momentum responsible for the magnetic moment is directly quantised relative to the magnetic field rather than relative to the rest of the molecule. In S states the angular momentum, to be sure, arises entirely from internal spins, and spin axes are more loosely coupled than the orbits themselves. Even so, however, the internal forces doubtless ordinarily (except in highly excited states) predominate over the external field ; for the latter can, in fact, be made as small as we please.

The solution of this dilemma is, I believe, found in a very general derivation I am publishing elsewhere (*Phys. Rev.*, May 1927) of the Langevin formula $N\mu^2/3kT$ for the susceptibility χ. This proof uses the new quantum mechanics and supposes only that the molecule have a ' permanent ' moment μ, and that the separation between component energy levels of the normal state be small compared to kT. This condition is doubtless fulfilled in O_2, for frequencies of nuclear rotation are ordinarily small compared to kT/h, and the superposed precession of the spin axis is much slower in S than in P or D states because of the vanishing orbital angular momentum. If μ arises entirely from spin moment, then by the new mechanics we get $\mu^2 = 4s(s+1)M^2$, where M is the Bohr magneton $he/4\pi mc$ and $s = 1/2$ for doublet terms, $s = 1$ for triplets, etc., thus giving agreement with Sommerfeld's susceptibility formula for atomic S terms. There is now, however, nothing in the proof to prevent the spin axis being quantised either (a) relative to the axis of figure or (b) relative to the axis of temperature rotation (Hund's classification), or even from being coupled in a manner intermediate between (a) and (b).

The case of nitric oxide is particularly interesting. The spectroscopic data of Jenkins, Barton, and Mulliken (NATURE, 119, 118; 1927) and others, show that the normal state of nitric oxide is a ^2P doublet. The upper and lower components have respectively $\sigma = 3/2, 1/2$, and are separated by $122 \, \mathrm{cm}^{-1}$. Here σ is the angular momentum about the axis of figure, measured in multiples of the quantum unit $h/2\pi$, and equals $\sigma_k + \sigma_s$, where $\sigma_k = 1$ is the component of orbital angular momentum along this axis, and $\sigma_k = \pm\frac{1}{2}$ is the corresponding component for the spin angular momentum. Because the spins have twice the normal ratio of magnetic moment to angular momentum, the upper and lower components therefore have respectively magnetic moments $2M$ and 0 along the axis of figure. Calculations of the susceptibility for a mixture of molecules with two and zero Bohr magnetons, with relative abundance determined by the Boltzmann temperature factor, do not, however, agree with experiment. This failure is due to neglect of the component of spin magnetic moment perpendicular to the axis of figure. We may, on the other hand, disregard the perpendicular component of orbital moment, as this doubtless precesses very rapidly. If the precession frequency $\Delta\nu$ of the spin axis about the axis of figure were small compared

to kT/h, we could simply take $\mu^2/M^2 = \sigma^2{}_k + 4s(s+1) = 4$ in the derivation of the Langevin formula cited above. Actually $\Delta\nu$ is 122c, and so ·special calculations with the new mechanics are necessary, which yield

$$\chi = \frac{4NM^2}{3kT} \cdot \frac{1 + (x-1)e^{-x}}{x(1+e^{-x})}$$

where $x = h\Delta\nu/kT$. This gives a susceptibility at room temperatures corresponding to $9 \cdot 12$ Weiss magnetons, which agrees excellently with Bauer and Piccard's experimental value $9 \cdot 20$. The hope of Jenkins, Barton, and Mulliken that their spectroscopic data would permit the quantitative calculation of susceptibility is thus fulfilled. Details of the computations will be published elsewhere.

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Influence of Carbon Monoxide and Light on Indophenol Oxidase of Yeast Cells.

WARBURG (*Biochem. Zeitschr.* **177**; 1926) has shown recently that carbon monoxide at a high partial pressure inhibits the respiration of yeast and cocci cells. He also found that a respiratory substance involved in this process has a much higher affinity for oxygen than for carbon monoxide, and that the carbon monoxide compound of this substance is dissociated by the visible rays of light.

Warburg's results as to the inhibition of respiration by carbon monoxide have been extended by Haldane (NATURE, 119, 352; 1927) to the wax-moth and cress plants.

The main object of my study was to localise the action of carbon monoxide, and to find whether the substance influenced by it has any connexion with the known respiratory substances.

Cytochrome, which is present in yeast cells, does not combine with carbon monoxide. The ordinary (unbound) hæmatin which is also present in yeast cells has, on the contrary, a much greater affinity for carbon monoxide than for oxygen, and, when reduced, it combines, even at a very low partial pressure, with carbon monoxide. Thus, none of the four different iron-porphyrin compounds of living yeast cells is responsible for the phenomenon discovered by Warburg.

In addition to hæmatin compounds, yeast cells contain a polyphenol oxidase which can be demonstrated when the reducing power of the cells is inhibited by urethane, cooling on ice, or heating yeast suspension (in phosphates at pH 7·3) to 50°- 52° C., and keeping it at that temperature for an hour. 2 c.c. of a 5 per cent. suspension of baker's yeast heated to 50° C. gives a strong reaction with 0·5 c.c. of ' Nadi ' mixture composed of equal parts of 0·01 M. dimethyl-para-phenylenediamine hydrochloride in 50 per cent. alcohol, 0·01 M. alphanaphthol in 50 per cent. alcohol, and 0·1 per cent. sodium carbonate in water.

The indophenol reaction of yeast is inhibited by boiling, by potassium cyanide and by carbon monoxide. The influence of carbon monoxide can be demonstrated in the following manner: 2 c.c. of the above yeast suspension is put in each of six slightly modified Thunberg's vacuum tubes and 0·5 c.c. of ' Nadi ' reagent added into the bent portion of their hollow stoppers. These tubes, standing in the same rack, are filled with various gas mixtures ; they are then reversed, the yeast suspension being mixed with ' Nadi ' reagent, shaken for 1-5 minutes in the dark, and examined. The following are the results of such an experiment: