

tions found by Haerberli *et al.*, should be attributed to delta-ray formation. Furthermore, Eq. (9) has some value in that it is not only an extremely simple way to represent large amounts of experimental data, but is useful in attempting to separate sudden changes (due, for example, to the discharge of metastable states) in  $(1/W)$  as a function of  $z$  from the more gradual ones that Eq. (9) is intended to represent.

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### Proton Relaxation in Water

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A determination of the thermal relaxation time of protons in pure water gives the value  $3.6 \pm 0.2$  sec, in very good agreement with theory. The  $O_2$  molecule in aqueous solution seems to have a  $\mu_{\text{eff}}$  of 1.2 Bohr magnetons for the relaxation processes.

WE have recently performed a series of measurements of the thermal relaxation time of protons in pure water and in water containing oxygen in solution. The methods used are based on measurements of amplitude of the "in phase" nuclear signals caused by the total reversal of the magnetization. Two observations with different sweep frequencies and with resonance field centered with respect to the sweep, or one observation with resonance field not centered (Fig. 1), enable one to determine the relaxation time. This latter method is similar to that used by Conger and Selwood.<sup>1</sup> To obtain good accuracy with the first method, one of the two sweep periods must be several times greater than the relaxation time. We have therefore arranged a device for observation and registration of the nuclear signals with modulation frequencies of the constant field as low as 0.02 cycle/sec.

We find with both methods  $T_1 = 3.6 \pm 0.2$  sec for the thermal relaxation time of protons in water completely free of oxygen and  $T_1 = 1.4 \pm 0.1$  sec for water saturated with oxygen at a pressure of one atmosphere. The time we find for pure water is considerably different from that found by Purcell *et al.*<sup>2</sup> (2.3 sec), but it is in very good agreement with their theory if one assumes for

the rotation of the water molecule a correlation time of  $1 \times 10^{-11}$  sec and for the translational motion of two molecules separated by a distance  $r$  a correlation time equal to the time they take to travel over the distance  $r$ . Our result seems to justify this assumption.

Our measurements show that the influence of oxygen in solution, which was already noticed in the first observations of Bloch *et al.*,<sup>3</sup> is smaller than one could

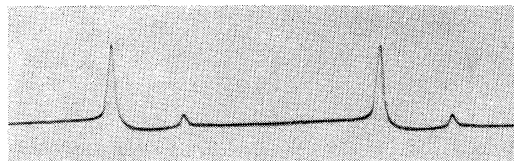


FIG. 1. "In phase" proton signals in pure water due to total reversal of the magnetization. Resonance field not centered with respect to the sweep. Sweep period, 5.7 sec.

expect from the magnetic moment of the oxygen molecule which is 2.8 Bohr magnetons. The  $\mu_{\text{eff}}$  of the  $O_2$  in the relaxation processes seems to be 1.2 Bohr magnetons. This could be caused by the formation of molecular complexes (like  $O_4$  molecules with a zero moment), or by the influence of the electronic relaxation on the correlation time. This latter process seems to influence the nuclear relaxation also in other cases.<sup>2,4</sup>

<sup>1</sup> R. L. Conger and P. W. Selwood, *J. Chem. Phys.* **20**, 383 (1952).

<sup>2</sup> Bloembergen, Purcell, and Pound, *Phys. Rev.* **73**, 679 (1948); N. Bloembergen, *Nuclear Magnetic Relaxation* (M. Nijhoff, The Hague, 1948).

<sup>3</sup> Bloch, Hansen, and Packard, *Phys. Rev.* **70**, 474 (1946).

<sup>4</sup> R. L. Conger, *J. Chem. Phys.* **21**, 937 (1953).

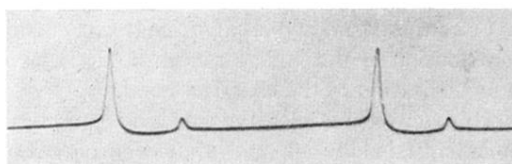


FIG. 1. "In phase" proton signals in pure water due to total reversal of the magnetization. Resonance field not centered with respect to the sweep. Sweep period, 5.7 sec.