VELOCITY OF ULTRASONIC WAVES IN SOLUTIONS OF ELECTROLYTES

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ABSTRACT. An equation for the velocity of ultrasonic waves in solutions of electrolytes has been developed on the basis that electrostatic forces between the ions increase the pressure whereby the volume elasticity is increased, increasing the velocity.

Mohanty and Deo (1955) published their results on ultrasonic velocities in zinc and magnesium sulphate solutions at different concentrations and over different ranges of temperatures. Similar experimental results published by Krishnamurthi (1950, 51) are available for solutions of electrolytes like potassium iodide, potassium bromide, potassium fluoride, sodium fluoride, sodium nitrate, potassium nitrate, strontium nitrate and barium nitrate.

Whereas it is easier to explain the variation of ultrasonic velocities in case of solutions of non-electrolytes, the treatment becomes extremely difficult for solutions of electrolytes.

Salts are ionised in solution and consequently the electrostatic forces exerted by the ions cause an extra local pressure and since the pressure of the liquid is increased, the liquid becomes harder to compress, *i.e.*, the compressibility β or $-\dfrac{dv}{vdp}$ decreases. In other words, we may also say that back and forth motions of the particles or the ions are guided by two forces; firstly, the normal pressure P experienced by the particles as if the salt was non-ionised and secondly, the pressure P' due to the electrostatic forces in case of electrolytes. These two pressures combined together, contribute towards the compressibility of, or the velocity in, the solutions of the electrolytes. From the equations.

$$I = 2\pi v V d A^2 \qquad \ldots \quad (1)$$

$$\dot{x} = 2\pi v A \qquad \ldots \quad (2)$$

$$p = -\frac{K}{V} \cdot \dot{x} \qquad \ldots \quad (3)$$

we may write,

$$V = \frac{p^2}{2Id} \qquad \ldots \quad 4)$$

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where I is the intensity of ultrasonic waves in ergs/sec/sq. cms. ν is the frequency; V is the velocity of the waves in the medium, d is the density of the solution; A is the maximum particle displacement ; $\dot{x}$ is particle velocity; K is the volume elasticity.

As already stated this pressure p is the sum of the two pressures P and P' and equation (4) may be written as,

$$V = \frac{(P+P')^2}{2Id} \qquad \text{... (5)}$$

Now P' may be calculated as given below The potential of an ion in solution may be written from Debye-Huckel theory of electrolytes as

$$\psi_i = \mp \ \frac{Z_i c \kappa}{D} \qquad \text{... (6)}$$

where Zi is the valency of an ion, ϵ is electronic charge, D is dielectric constant of the medium and

$$\kappa = \left(\frac{4\pi\epsilon^2 \Sigma \, n_i \, Z_i^2}{DkT} \right)^{1/2} \qquad \text{... (7)}$$

(where k is Boltzmann constant given by $\frac{R}{N}$; N being the Avogadro number and R the gas constant, T is temperature, n_i is the number of ions per c.c. of ith kind.

From the well known laws of electrostatics the force per unit area between two charged particles at a potential difference of ψ is given by

$$\text{force per unit area} = \frac{D\psi^2}{8\pi}$$

where D is the dielectric constant of the medium. Hence force per unit area, *i.e.* pressure is given by

$$P' = \frac{D\left(\mp \ \dfrac{Z_i \epsilon \kappa}{D} \right)^2}{8\pi}$$

$$= \frac{Z_i^2 \epsilon^2 \kappa^2}{8\pi D} \qquad \text{... (8)}$$

Thus from equations (5) and (8)

$$V = \frac{\left[P + \dfrac{Z_i^2 \epsilon^2 \kappa^2}{8\pi D} \right]^2}{2Id} \qquad \text{... (9)}$$

Equation (9) may be simplified with the help of the following equations,

$$\frac{NC_i}{1000} = n_i \qquad \qquad \dots (10)$$

$$\Sigma\, C_i\, Z_i^2 = 2\mu \qquad \qquad \dots (11)$$

where C_i is the number of gm. ions per litre ; μ is ionic strength.

The final form of the equation may be written as,

$$V^{\frac{1}{2}} = \frac{P}{(2Id)^{\frac{1}{2}}} + \frac{BZ_i^2\,(2\mu)}{D^2 T(Id)^{\frac{1}{2}}} \qquad \qquad \dots (12)$$

where
$$B = \frac{N^2 \cdot c^4}{1000 \cdot 2\sqrt{2R}}$$

Assuming the pressure P in equation (12) to be constant (this includes one constant term and the other term for osmotic pressure which can be expanded for accuracy) to an extent of approximation, equation (12) represents a straight line. In figure 1 we have plotted $(V \cdot d)^{\frac{1}{2}}$ against μ (ionic strength) from the
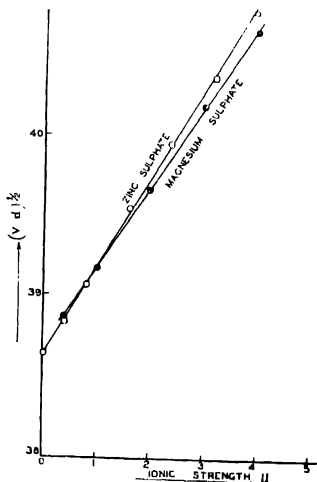

Fig. 1.

data published by Mohanty and Deo (loc. cit), for zinc and magnesium sulphate. The graphs are straight lines. It is interesting to note, as is expected from our

equation, that the slopes of the straight lines for the two electrolytes are almost the same.

REFERENCES

Krishnamurthi, Bh., 1950, *J. Sci. Ind. Res.*, **9B**, 251,
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Mohanty, B. S. and Deo, B. B., *Ind. J. Phys.*, 1955, **29**, 578.

1. GRAPH 1. Plot of $(V.d)^{\frac{1}{4}}$ against μ,