RESEARCH NOTES

Some measurements of isothermal compressibility by a capacitance method

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Abstract. The compressibility of some alkali halides has been measured by a fairly direct method involving a capacitance change. In order to see whether the large spread in compressibilities reported in the literature might be due to an unexpectedly large impurity effect, measurements were made on several samples of potassium chloride of differing purity; however no large impurity effect was found. A by-product of the investigations was the measurement of the variation with pressure of the dielectric constant of a hydrocarbon oil, and this showed unusual features.

1. Introduction

The compressibility of many substances has been measured by a variety of methods, which have been reviewed by Huntington (1958). The most direct methods, such as those used by Bridgman (1949), involve measuring a change in a linear dimension of a sample under hydrostatic pressure. Less direct methods involve calculation of the compressibility from other elastic constants, and in particular methods involving the speed of ultrasonic waves have received considerable attention (see e.g. Nikanorov and Stepanov 1963). While the potential accuracy of these latter methods is high, a comparison of the results so far obtained by various workers shows serious discrepancies; for example the isothermal compressibility of sodium chloride at room temperature has been quoted as low as $4 \cdot 11 \times 10^{-6}$ b^{-1} and as high as $4 \cdot 51 \times 10^{-6}$ b^{-1} (1 $b = 10^6$ dyn cm^{-2}). In connection with some work on the variation with pressure of the dielectric constant of the alkali halides (Jones 1967) we required to know the compressibility of the samples with an accuracy to 1% or better, and thought it advisable to make some measurements on the compressibility of the materials we were using, especially since this could be done with rather small modifications to the apparatus already available for the dielectric constant work. It is also desirable to know to what extent small amounts of impurities or defects influence the compressibility.

2. Method

The method is similar to that of Bridgman in that the sample is under hydrostatic pressure and the change in linear dimension is measured with respect to a relatively incompressible support of known compressibility. Instead of using a variable resistance or sliding fit, however, we used a capacitance change to measure the contraction. This change can be measured inside the pressure vessel with great precision, in spite of the changes in lead-through capacitance, by means of a transformer bridge (Thompson 1958). The dielectric of the capacitor is the pressure-transmitting fluid itself, a hydrocarbon oil DTD 585. This changes its dielectric constant considerably under pressure, but this effect can be allowed for by the inclusion of a second capacitor in the pressure vessel. By this means the effect on the capacitance of the change in effective area of the capacitor plates can also be eliminated. The apparatus in the pressure vessel is shown schematically in figure 1. The relatively incompressible support in the lower cell and the spacers in the upper cell are made of mild steel, which was chosen for two reasons. Firstly, as Bridgman (1949) has pointed out, the compressibility of various steels is not very different from that of iron itself. Indeed, the compressibility of mild steel as determined at the National Physical Laboratory is only 2%

higher than Bridgman's absolute determination for cast iron.   Hence we may assume that the compressibility of any given sample of mild steel is probably known to well within 10%. Secondly, all materials investigated were about ten times as compressible as mild steel, except for lithium fluoride, which was about three times as compressible, and sodium fluoride, which was about five times as compressible.   Hence uncertainty in the compressibility of the steel introduces systematic errors of the order of 1% for most of the alkali halides.   When the effect of impurities is being studied this systematic error is irrelevant.
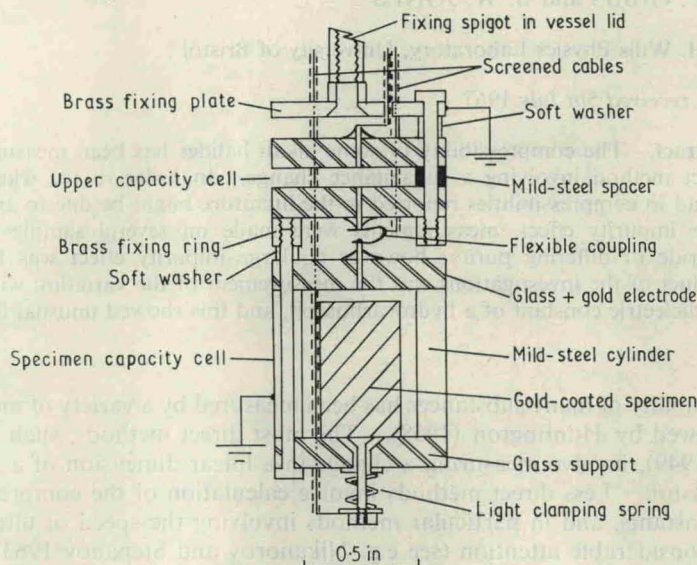

Figure 1.   Compressibility cell.

Specimens were prepared by cleaving the longest possible block of crystal.   The end faces were lapped flat and parallel to about 0·0002 in.   A 12 BA flat-headed screw was cemented to the bottom face of the specimen with Araldite.   Gold was evaporated on to all six faces of the block, which was then held down on the lowest plate glass disk by a light spring and a nut.

The two electrodes in the upper capacity cell and the upper electrode in the lower capacity cell were prepared by evaporating gold on to the glass disks, and on the two upper electrodes a central area was isolated from the rest by cutting a circular gap about 0·001 in. wide. In the case of the lower cell the central area was considerably smaller than the end face of the crystal block, and the outer annuli formed guard rings which were earthed.   By combining the results from both cells the fractional change in length of the specimen is obtained in terms of the capacitance changes, various known apparatus dimensions and the compressibility of mild steel.   Thus we have

$$\frac{\Delta l}{l_0} = \frac{d_0}{l_0} \left\{ \left(\frac{\Delta C}{C_0}\right)_u - \left(\frac{\Delta C}{C_0}\right)_l - \left(\frac{\Delta C}{C_0}\right)_u \left(\frac{\Delta C}{C_0}\right)_l + \frac{1}{2}\left(\frac{\Delta C}{C_0}\right)_l^2 + \frac{\beta_{Fe}}{3}\left(\frac{h_0}{d_0} - 1\right) \Delta P \right\}$$

where l_0, h_0, d_0 are the zero-pressure lengths of the specimen, mild-steel support and mild-steel spacers respectively, Δl is the change in specimen length corresponding to a pressure ΔP above zero pressure, $(\Delta C/C_0)_u$ and $(\Delta C/C_0)_l$ are the fractional capacitance changes in the upper and lower cells at a pressure ΔP, and β_{Fe} is the compressibility of mild steel. The value used for β_{Fe} was $0·595 \times 10^{-6}$ b^{-1} (Kaye and Laby 1966, p. 33).

The capacitance measurements were made with a Wayne Kerr B921 bridge operating at 1 kHz.