

frictional brecciation. A similar interpretation seems to apply to the 'crush-conglomerates' described by Lamplugh⁷ from the Manx Slate Series. In the Lower Cambrian (?) of Howth, near Dublin, greywackes and shaly breccia—'sherd-schist'—appear to me to provide at a still earlier period an indication of contemporaneous disturbances.

As an example from another geosyncline, there are the graded sediments of the Middle Devonian of New South Wales. From these, Benson⁸ figures an example in which a claystone layer has two anti-dune wave-crests picked out in tuffaceous sand. He describes the latter as 'intrusive'. But it is more likely to have been carried into place by a tsunami. The specimen, I believe, has been figured upside down.

It may be added that a recurrence of seismic conditions in carboniferous times in the Dublin district seems to be indicated by anti-dune wave-crests in mud which have been found in beds of Yoredale age at Loughshinny. These beds show rapid alternations of shale and graded sand. Their evidence is corroborated by brecciation *pari passu* with deposition in D₂ limestone at Curkeen Hill quarry.

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¹ "Crush-Conglomerates in Ireland", NATURE, 53, 488 (1896); "An Account of the Portrairie Inlier (Co. Dublin)", *Quart. J. Geol. Soc.*, 53, 527-534 (1897).

² "Ordovician Submarine Disturbances in the Girvan District", *Trans. Roy. Soc. Edinburgh*, 58, 498-507 (1935).

³ "Submarine Faulting in Kimmeridgian Times: East Sutherland", *Trans. Roy. Soc. Edinburgh*, 57, 449-454 (1932).

⁴ "The Lower Palaeozoic Bedded Rocks of County Waterford", *Quart. J. Geol. Soc.*, 55, 728, 740-742 (1899).

⁵ "On Intrusive, Tuff-like, Igneous Rocks and Breccias in Ireland", *Quart. J. Geol. Soc.*, 57, 482-489, and especially Figs. 3, 5, etc. (1901).

⁶ "On the Igneous and Associated Sedimentary Rocks of the Glensaul District (County Galway)", *Quart. J. Geol. Soc.*, 66, 257, fig. 1 (1910).

⁷ "The Crush-Conglomerates of the Isle of Man", *Quart. J. Geol. Soc.*, 51, 563-588 (1895); "The Geology of the Isle of Man", *Mem. Geol. Surv.* 1903, pp. 55-71.

⁸ "The Geology and Petrology of the Great Serpentine Belt of New South Wales. Part V. The Geology of the Tamworth District", *Proc. Linn. Soc. New South Wales*, 40, 570, Fig. 11 (1915).

Density and Compressibility of Solid Hydrogen and Deuterium at 4.2° K.

It has been shown by Bennewitz and Simon¹ that the influence of zero-point energy on the properties of a condensed substance is very great for substances of low boiling point. The effect is most marked in helium², where it actually plays the chief part in determining the properties; but it is large, too, in hydrogen, a substance which is particularly interesting as it possesses two isotopes which have identical binding forces but very different zero-point energies.

Certain of the properties of the solid phases have been measured already, by Simon and Lange for hydrogen³ and by Clusius and Bartholomé for deuterium⁴, among them being the specific heats at constant pressure, the heats of evaporation and melting, and the molar volumes at the triple points. Clusius and Bartholomé have discussed in their very interesting paper the influence of zero-point energy by comparing the properties of the two isotopes. Nothing was hitherto known, however, of the compressibilities. These are of special interest because the zero-point energy gives rise to a pressure $p^{(0)}$,

and its variation with volume to a compressibility² $K^{(0)}$, which, as a preliminary estimate shows, will be an important part of the total compressibility. At the same time, a knowledge of the molar volumes at the boiling point of helium will give us very nearly their values at absolute zero, and, using the known values at the triple points, the mean thermal expansions.

For obvious reasons, we had to use a pycnometer method. The only substance available as a filling liquid is liquid helium, and since its compressibility is very much greater than that of solid hydrogen, the method cannot be one of high accuracy. But as hitherto even the order of magnitude was not known, we thought it worth while to carry out the experiment.

A vessel of known volume (about 4 c.c.) was attached to a helium liquefier of the expansion type; it was nearly filled with condensed hydrogen (or deuterium), and when this was solid, completely filled with liquid helium at a pressure of about 100 kgm./cm.². By letting out successive amounts of helium and measuring them as a gas at room temperature, and afterwards measuring in the same way the hydrogen, the density of the solid hydrogen at each pressure could be calculated. The results are given in the accompanying table.

	Hydrogen	Deuterium
Density (gm./cm. ³) at 1 kgm./cm. ² and 4.2°	0.0890 ± 0.0004	0.2059 ± 0.0010
Molar volume (cm. ³) at 4.2°	22.65 ± 0.1	19.56 ± 0.1
Compressibility (cm. ³ /kgm.) at 4.2° (average from 1 to 100 kgm./cm. ²)	(5.0 ± 0.5) × 10 ⁻⁴	(3.3 ± 0.7) × 10 ⁻⁴

As to the compressibilities, it may be remarked that the curve of volume against pressure is, as expected, not a straight line. In the above table, however, only the mean compressibility between 1 and 100 kgm./cm.² is given, since it is known more accurately than the compressibility at any given pressure. But it may be noted that the compressibility at 100 kgm./cm.² is for both isotopes roughly half that at 1 kgm./cm.². For the thermal expansion, assuming for a rough estimate that it is proportional to C_p , and combining the molar volumes at 4.2° with those at the triple points, we find that at a given temperature the expansion coefficient of deuterium is about half that of hydrogen.

We intend to publish a more detailed account of these experiments, and will postpone until then the theoretical discussion of our results, which we hope to consider also from the point of view of F. London's treatment of helium². Here we should like to point out only that, for hydrogen, $p^{(0)}$ amounts to about 1,000-2,000 atm., and $K^{(0)}$ accounts for a very great part of the total compressibility.

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¹ *Z. Phys.*, 16, 183 (1923).

² F. Simon, NATURE, 133, 529 (1934); F. London, *Proc. Roy. Soc., A.*, 153, 576 (1936).

³ *Z. Phys.*, 15, 312 (1923).

⁴ *Z. phys. Chem.*, B, 30, 237 (1935).