The relative insensitivity of Young's modulus to single defects and its high sensitivity to complex groups makes it a useful property for the study of their formation in the graphite lattice.

P. R. GOGGIN

Metallurgy Division,
Atomic Energy Research Establishment,
Harwell, Didcot.

¹ Reynolds, W. N., and Goggin, P. R., *Phil. Mag.*, **5**, 1049 (1960).

² Goggin, P. R., and Reynolds, W. N., *Phil. Mag.*, **8**, 265 (1963).

³ Simmons, J. H. W., *Proc. Conf. Carbon* (1957).

⁴ Schweitzer, D. G., *Phys. Rev.*, **129**, 556 (1962).

⁵ Iwata, T., Fujita, F. E., and Suzuki, H., *J. Phys. Soc. (Japan)*, **18**, 197 (1961).

Use of Complex Ions in the Efficiency Tracing Method for the Standardization of Pure Beta-emitting Nuclides

THE absolute standardization of pure β -emitters by $4\pi\beta$ -counting involves errors due to uncertainties in self-absorption. This difficulty may be overcome by the use of the efficiency-tracing technique described by Campion *et al.*¹ The technique involves the inclusion of a suitable β - γ -emitting nuclide with the pure β -emitter in the deposited source and the use of β - γ -coincidence counting to determine the efficiency of detection of the betas arising from the β - γ or 'tracer' nuclide. Knowledge of the β -efficiency for the tracer in a series of sources may then be used to determine the absolute activity of the pure β -emitter.

Choice of a suitable tracer is limited by certain physical requirements. Ideally the spectral shapes of the tracer and the pure β -emitter should be identical. The β -end-point energies of the two nuclides should be close to one another. The decay scheme of the tracer should be simple, if possible with a single β -branch, and there should be little internal conversion.

Nuclides fulfilling the requirements for a simple decay scheme which also have maximum β -energies of less than 1 MeV are scandium-46, cobalt-60, bromine-82, niobium-95, cerium-141, lutecium-177, gold-198 and mercury-203.

The choice of a tracer is further restricted by certain chemical considerations. To ensure that the corrections are reliable it is essential that the tracer and the pure β -emitter are deposited uniformly throughout the volume of the source; any separation of the two nuclides will introduce errors. In practice, as ionic solutions are usually employed, the best results will be obtained with a tracer ion opposite in charge to the pure β -emitting ion. This encourages the formation of a deposit in which the two ions are evenly distributed, and in which, in favourable cases, they are incorporated in a common lattice as a clearly defined compound.

For the determination of anions such as $^{35}\text{SO}_4^-$ there is a wide choice of tracer cations, but for the measurement of cations the selection is very much more limited. Of the tracers mentioned here, only bromine-82 normally occurs as an anion. In order to rectify this position we suggest the use of anionic complexes of suitable nuclides as tracers for the measurement of pure β -emitting cations. Complexes of this kind can be readily formed by interaction of the cation and a suitable ligand. One such ligand is the cyanide ion, which will combine with cobalt, gold or mercury to give very stable anionic complexes.

Using a solution containing potassium cobaltcyanide prepared in this way from a cobalt nitrate solution labelled with cobalt-60 we have applied the technique to the standardization of calcium-45 and promethium-147. Full details of these measurements will be published elsewhere.

There is no reason why the technique should be limited to cyanide complexes and it seems probable that suitable complexes can be prepared for each of the tracer nuclides listed above. Although the number of pure β -emitting cations which require tracer measurements of this kind

is small, the wider choice of tracer offered by this technique should be of value in improving the accuracy of the standardizations.

T. T. GORSUCH
D. J. JENKINS
C. A. LUDBROOK

Radiochemical Centre,
Amersham,
Buckinghamshire.

¹ Campion, P. J., Taylor, J. G. V., and Merritt, J. S., *Intern. J. App. Rad. and Isotopes*, **8**, 8 (1960).

CHEMISTRY

Energy of Formation of D-Defects in Ice

MUCH of the literature dealing with the dielectric properties of ice¹ has used Bjerrum's concepts of D- and L-defects². A pair of D- and L-defects is formed (Fig. 1) when a water molecule in ice rotates through 120° around one of its O—H...O axes, thus leaving one pair of neighbour O...O atoms with no intervening hydrogen atom (L-defect), and another pair of neighbours O—H...H—O with two hydrogens (D-defect). A subsequent similar rotation of the appropriate molecule adjacent to the L-defect separates these two defects.

Recently, Dunitz³ has suggested that the repulsive interaction of the two hydrogen atoms in a D-defect is so great that its formation is unlikely. He proposes an alternative to the D-defect, called an X-defect, in which repulsive interactions of hydrogens are reduced. We wish to point out that if changes in bond-lengths and -angles in the neighbourhood of a D-defect are considered, then the H...H repulsion energy in this defect will be considerably less than that calculated by Dunitz. These changes, which we shall refer to as a 'relaxation' of the lattice, occur with relative ease owing to the relatively weak bonding in the neighbouring H...O bonds.

If no relaxation occurs in a D-defect, then the two hydrogen atoms are at a separation of 0.78 Å (O₁—H₁...H₂—O₂, Fig. 2). We have confirmed the result of Dunitz that their repulsive interaction energy in this case is about 60 kcal mole⁻¹.

Let us now allow relaxation to occur: O₁ moves a distance Δr to O'₁, and O₂ a similar distance in the opposite direction to O'₂. In addition the length of the bond O₁—H₁ is compressed from a to a'' . If we assume that O₃ is fixed, then the O₃—H₃...O₁ angle is reduced

Fig. 1. Formation of a pair of D- and L-defects in ice

Fig. 2. Changes in bond-lengths and -angles in the neighbourhood of a D-defect shown schematically. The actual lengths and angles are given in the text