must be moved in order to produce the most rapid convergence to a true structure.

It is not to be expected that such a refinement technique will lead to very precise co-ordinates, since to say that $|F_0|$ is zero can, in fact, mean only that it is less than some arbitrary lower limit of size. However, in view of the great ease of obtaining the observational material, it is suggested that the above technique may prove a useful addition to the existing armament of structure analysis.

ANDREW D. BOOTH

Birkbeck College Electronic Computer Project.
21 Torrington Square,
London, W.C.1.
July 30.

¹ Booth, "Fourier Technique in X-Ray Organic Structure Analysis" (Camb. Univ. Press, 1948).

² Avrami, *Z. Kristall.*, **100**, 381 (1939).

³ Hughes, *J. Amer. Chem. Soc.*, **63**, 1737 (1941). Booth, *Proc. Roy. Soc., A*, **197**, 336 (1949).

⁴ Booth, *Nature*, **161**, 765 (1948).

Internal Stresses caused by Disorder in Vitreous Materials

It is now generally recognized that one of the main characteristics of a vitreous material is that its atomic structure has no long-range order¹. This means that the individual interatomic bonds will not have the length and direction which they have in a crystal, and, because of this, these bonds will not have their normal strength. If it is assumed that the bonds within a certain small region are subjected to a similar distortion, then it will be correct to think of this region as being subjected to a mechanical stress. It is of some interest to calculate the order of magnitude of these internal stresses.

It is clear that the resultant of all the internal stresses in the material must be zero. One of the simplest cases of a distorted structure in which the internal stresses are balanced is the edge dislocation. The equations governing the stresses in such a dislocation have been derived by Nabarro². It can be shown from his equations that the stresses near the centre of the dislocation are of the order of $2G/\pi$, where G is the shear modulus of the material. (It should be realized that this value is obtained from equations based on the assumption that Hooke's law applies for strains of the order of those present in a dislocation; this is, of course, not strictly true.) It is reasonable to assume that regions exist in a typical glass where the distortion is of a type similar to that existing in an edge dislocation, that is, it is a shear distortion; and that the stresses resulting from this distortion will be of the same order as those in a simple edge dislocation.

One consequence of this assumption will now be examined. Griffith³ has shown that the theoretical strength of glass is of the order of 1,000 kgm. per sq. mm. Now it has just been suggested that internal stresses may exist in glass which cannot be removed by annealing, and which may be of the order of $2G/\pi$. Taking a typical value of G for glass of 0.25×10^{11} kgm./sq. mm., the value for the internal stresses is calculated to be about 1,600 kgm./sq. mm. Of course, the internal stresses cannot be greater than the theoretical strength of the material. The values just given for the theoretical strength of glass and for the stresses due to disorder merely indicate the order

of magnitude of these stresses; but the values obtained do suggest that, because of the large internal stresses of the material, it may be necessary to apply only a relatively small external stress to cause fracture of the material. It is therefore suggested that the relatively low breaking strength of glass may be partly due to its disordered structure; but it is realized, of course, that in massive glass articles (bottles, sheet glass, and so forth) at least, the flaws in the material which are always present as a result of the manufacturing process and the handling of the article in service may also have a marked effect on the strength.

The expression for the maximum stress of the centre of a dislocation suggests that there may be some relationship between the tensile strength and the shear modulus of glass. This is confirmed, to some extent, by experiment. Thus Murgatroyd⁴ has found that, for fibres of a soda lime silica glass between 10 and 100 microns in diameter, the tensile strength increases with decreasing diameter and, at the same time, the shear modulus decreases. This is in agreement with the views just put forward; a decrease in the shear modulus will cause a decrease in the stresses due to disorder, so that a larger external stress will have to be applied for the internal stresses to reach the theoretical strength of the glass. If it is assumed that the greatest internal stress is given by the expression $2G/\pi$, then it is found that the sum of the greatest internal stress and the applied breaking stress is almost constant. This is shown by the results given in the accompanying table.

Fibre dia. (μ)	G (10^8 kgm./sq. cm.)	Max. internal stress = $2G/\pi$ (10^8 kgm./sq. cm.)	Applied breaking stress (10^8 kgm./sq. cm.)	Max. internal stress + applied breaking stress (10^8 kgm./sq. cm.)
40	2.49	1.585	0.170	1.755
80	2.63	1.675	0.100	1.775
110	2.68	1.705	0.070	1.775

Other measurements which have been carried out on finer fibres of fused silica are not consistent among themselves. Thus Reinkober⁵ has found that, for silica fibres of diameter less than 20 microns, there is a rapid increase in the shear modulus with decreasing fibre diameter, whereas Eberhardt, Kern and Klumb⁶ have found that for silica fibres of the same diameter there is a slight decrease in shear modulus with decrease in diameter.

I am indebted to Mr. J. E. Stanworth, of this laboratory, for a number of useful discussions during the preparation of this communication; I am also indebted to Mr. L. J. Davies, director of research, British Thomson-Houston Co., Ltd., for permission to publish the work.

H. RAWSON

Research Laboratories,
British Thomson-Houston Co., Ltd.,
Rugby.
July 21.

¹ Stanworth, J. E., "Physical Properties of Glass", chap. 2 (Oxf. Univ. Press, 1950).

² Nabarro, F. R. N., *Proc. Phys. Soc.*, **59**, (2), 256 (1947).

³ Griffith, A. A., *Phil. Trans. Roy. Soc., A*, **221**, 163 (1920); International Congress for Applied Mechanics, Delft, 1924, p. 61.

⁴ Murgatroyd, J. B., *J. Soc. Glass Tech.*, **28**, 368 (1944).

⁵ Reinkober, O., *Phys. Z.*, **33**, 32 (1932).

⁶ Eberhardt, E., Kern, H., and Klumb, H., *Z. angew. Phys.*, **6**, 209 (1951).