

The Time Effect in the Fracture of Glass and Other Materials

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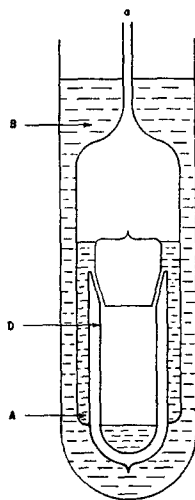


FIG. 1.

The experimental arrangement is illustrated in Fig. 1. The vessel *B* represents the main helium bath. Immersed in *B* is the vessel *A*, of which a small Dewar, *D*, formed an integral part. The top of *D* was closed off by an evacuated glass plug ground to fit the Dewar. Atmospheric helium⁶ could be condensed in *A*, via the tube *a*. It was found that at 4.2°K the flow of helium through the ground joint at the top of *D* was negligible, even though the level of the liquid in *A* was well above the ground joint. From estimates of this minute flow, the channel width of the ground joint was assessed at 1 micron.

When the whole arrangement was cooled below the lambda-point, the liquid flowed rapidly from *A* into *D*, at 1.5°K the rate being 1.25 cc per minute, until the level in *A* fell just below the rim of the ground joint. From then on liquid would have flowed into *D* through the supra-surface film at a rate of approximately 10^{-2} cc per minute. The liquid remaining in *A* was evaporated at this stage, and subsequently the liquid in *D* was evaporated and its vapor collected separately.

The abundance ratio of helium isotope He³ in the vapor collected during two different runs was kindly measured for us by Professor Alfred O. Nier and Mr. L. T. Aldrich² to whom we wish to express our appreciation of their cooperation. The He³/He⁴ ratio for *A* was 1.85×10^{-6} and 1.55×10^{-6} for the two runs, this increase over the normal concentration for atmospheric helium² depending on the initial volume condensed. For the vapor from *B* the average values were 0.37×10^{-6} and 0.35×10^{-6} .

One may conclude that the He³ was at least partially filtered out by flow through the channel. It was difficult to estimate how complete this filtration might have been since in cooling from 4.2°K some liquid was condensed from the vapor already present in *D*. Calculation of this effect indicates that the filtration was almost complete, and certainly much more effective than might be concluded from direct calculation from the figures given above. Experiments to determine this effect more exactly are being pursued and will be given in detail elsewhere.

The method of filtration of the isotope He³ by superfluid flow in the liquid phase, whether through supra-surface films³ or through narrow channels in the bulk liquid, is one which, apart from its theoretical interest,^{4,5} may lead to an isolation of the rare isotope in sufficient quantities for many applications. Such work is now in progress.

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¹ L. W. Alvarez and R. Cornog, *Phys. Rev.* **56**, 379, 613 (1939).

² L. T. Aldrich and A. O. Nier, *Phys. Rev.* **70**, 983 (1946); see also H. A. Fairbank, C. T. Lane, L. T. Aldrich, and A. O. Nier, *Phys. Rev.* **71**, 911 (1947).

³ J. G. Daunt, R. E. Probst, H. L. Johnston, L. T. Aldrich, and A. O. Nier, *Phys. Rev.* **72**, 502 (1947).

⁴ J. Franck, *Phys. Rev.* **70**, 561 (1946).

⁵ We are grateful to Linde Air Products for kindly providing large quantities of atmospheric helium.

The Time Effect in the Fracture of Glass and Other Materials

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August 11, 1947

ONE of the important problems in the mechanical properties of glass as well as of other substances is that of the delayed time to fracture. Specimens which do not fail during the time it takes a load to build up to its maximum value may subsequently fracture under the steady application of the load even in the absence of the chemical effects of the atmosphere, which will be the case considered here.

Considerable data have been accumulated and a variety of methods of plotting functions of fracture stress against functions of time have been advanced in the hope that one of them would yield a straight-line relationship and thereby disclose some rational explanation of the phenomenon. Most of the methods of plotting seem to show about equally good approximations to a straight line. This may be because of the experimental errors involved as well as the limited extent of the data.

The author proposes to treat the problem from the point of view of chemical-reaction rate theory in which the breaking of bonds between ions or atoms is the product of the reaction. Although this method has been used before,¹ no account has been taken of either the rate at which the external loads are applied or of the effect of the breaking of bonds upon the remaining ones. The present treatment is an attempt to take both cases into account.

In the usual notation,² the net number of jumps of the flow unit per unit time (rate at which bonds are broken) in the presence of a potential gradient is given by:

$$\frac{dN}{dt} = \frac{2kT}{h} e^{-\frac{\Delta F^*}{RT}} \sinh \frac{w}{kT}, \quad (1)$$

where *N* is the number of bonds broken and *w* is the work done per flow unit in the process. The latter may be related to the force, *f*, necessary to break a bond through $w = f(\lambda/2)$, where λ is some distance through which *f* must act to break the bond.

Equation (1) may be written:

$$dN/dt = A \sinh Bf, \quad (2)$$

where A and B do not depend upon the applied potential gradient.

If the load acts in a steady manner, it may be assumed as a first approximation that the force tending to break a bond increases directly with the number of bonds which have already been broken. Consequently, $f = f_0 + cN$, where f_0 is the force tending to break the bond when the load is first applied. Substituting this relation into Eq. (2), integrating, and assuming that when fracture takes place the number of bonds broken is large, there results

$$f_0 = D \log \coth Et \quad (3)$$

as the relation between the initially applied stress, f_0 , and the time to fracture, t ; D and E are constants which may be expressed in terms of A , B , and c . Through A and B the temperature dependence of the process may be studied.

For long times, Eq. (3) may be written:

$$f_0 = 2De^{-2Et}. \quad (4)$$

For short breaking times, the effect of the rate of loading is predominant, and the additional stresses in the remaining bonds due to the breaking of bonds may be neglected. Assuming that the rate of loading is constant, f may be expressed in the form

$$f = rt. \quad (4)$$

Substituting this into Eq. (2) and integrating leads to

$$t = (1/Br) \cosh^{-1}[(BrN_B/A) + 1],$$

N_B being the number of bonds broken to bring about fracture. If the rate of loading is high and the first term in the parentheses large, this becomes approximately

$$t = (0/Br) \log Fr, \quad (5)$$

where F is a constant. This is a relation between the time to fracture, t , and the rate of loading, r . It is interesting to note that Eq. (5) also implies the temperature dependency of the process through the constant B and through F , which in turn depends on A and B . In a paper which the author expects to publish soon, the details and a comparison with experimental data will be given.

* Consultant to Glass Science, Incorporated.

¹ E. S. Machlin and A. S. Nowick, N.A.C.A. Tech. Note No. 1126 (September, 1946).

² Glasstone, Laidler, and Eyring, *The Theory of Rate Processes* (McGraw-Hill Book Company, Inc., New York, 1941).

A Formula to Detect Association in Liquids

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THERE are various formulas in literature which distinguish a normal liquid from an abnormal or associated liquid. In the following we present another such theory.

For normal liquids

$$E\chi/V\alpha = T,$$

and for associated liquids,

$$E\chi/V\alpha > T,$$

in which E is cohesive energy in ergs per mole, expressed as the latent heat of vaporization minus RT , and written positive.

χ is the isothermal compressibility in absolute units (barye⁻¹),

V is the molar volume in ccms,

α is the coefficient of cubical expansion, and

T is the absolute temperature.

As an example, we compute the formulas at 20°C = 293°A. (See Table I.) The data for the liquids were mainly taken

TABLE I. $E\chi/V\alpha$ for liquids.

No.	Liquid	$\frac{E}{\times 10^{-7}}$ ergs	χ $\times 10^{12}$	V	α	$\frac{E\chi}{V\alpha}$
Class I						
1	Pentane	27000	200	114.9	.001589	295
2	Iso-pentane	25920	225	117.0	.001533	325
3	Hexane	31390	150	130.3	.001445	250
4	Heptane	35000	134	146.3	.00115	279
5	Octane	37620	121	162.4	.001124	249
6	Decane	48280	102	194.3	.000988	256
7	Ether	27010	200	104	.001656	310
8	Acetone	32016	100	73.5	.001487	292
9	Cyclohexane	31080	109	105.4	.00114	282
10	Cyclohexanol	50000	55	105.5	.000804	324
11	Carbon tetrachloride	32953	105	96.5	.001206	297
12	Chloroform	30989	100	80.2	.001254	308
13	Carbon disulphide	28138	75	60.3	.0011823	296
14	Ethylene chloride	33810	80	78.9	.00112	308
15	Ethylene bromide	42255	60	86.1	.000942	312
16	Methyl iodide	39110	56	62.2	.001273	276
17	Methyl acetate	33670	90	79	.00136	281
18	Ethyl bromide	29403	105	74.6	.00141	293
19	Ethyl iodide	31980	95	80.8	.001179	310
20	Ethyl formate	35558	75	80.2	.001378	241
21	Ethyl acetate	34359	113	97.9	.001359	292
22	Ethyl propionate	40800	98	115.0	.001344	264
23	Ethyl <i>n</i> -butyrate	46440	95	132.2	.001156	289
24	<i>n</i> -Propyl acetate	42840	100	115.1	.001214	306
25	Benzene	33883	92	89	.00124	282
26	Aniline	31080	44	84	.000855	265
27	Nitrobenzene	43970	54.5	105	.0008263	276
28	Chlorobenzene	42750	75	101.7	.0009967	316
29	Bromobenzene	58090	50	105	.00091505	302
30	<i>O</i> -Xylene	39220	75	118	.000973	257
31	<i>m</i> -Xylene	38160	85	122	.001009	274
32	<i>p</i> -Xylene	37600	80	124	.001011	240
33	Toluene	35420	92	106.3	.001099	279
34	<i>p</i> -Toluidine	46200	50	112.2	.0008681	259
Class II						
1	Methyl alcohol	37440	95	140	.001229	735
2	Ethyl alcohol	41860	90	98	.000739	520
3	<i>n</i> -Propyl alcohol	42600	90	75	.000956	533
4	<i>i</i> -Propyl alcohol	41400	100	75	.001094	493
5	<i>n</i> -Butyl alcohol	46620	99	91.4	.000950	488
6	<i>i</i> -Butyl alcohol	45880	93	103.6	.0009	458
7	<i>n</i> -Amyl alcohol	47520	85	110	.000907	403
8	Allyl alcohol	40600	80	70	.0001241	500
9	Glycol	50840	34	56	.0006375	484
10	Glycerine	924000	22	73	.000505	552
11	Formic acid	28520	55	37.7	.000999	416
12	Acetic acid	27600	98	56	.001065	454
13	<i>n</i> -Valeric acid	54129	90	108.8	.0009886	453
14	Mercury	5897934	3.4	14.81	.00018169	745
15	Water	41706	45.5	18.06	.0002097	5010

from International Critical Tables and tables of Landolt-Bornstein. Generally, a direct value of E and χ at 20°C and one atmospheric pressure was not available, and a rough reduction was made simply by guessing. The absence of round figures in most of the E values does not indicate the order of accuracy attained, but that the reduction was made for a value per g and then the value was multiplied