Now a frequency $N$ in wave-numbers $\propto 1/\lambda$ and, on differentiation, $\delta N \propto \delta\lambda/\lambda^2$, so that for a given spectrometer $\delta N \propto s/\lambda$, since $\delta\lambda$ and $\lambda$ are both proportional to $d$. Thus for $\delta N$ to be constant $s$ must be proportional to $\lambda$.

The energy reaching the detector of a grating spectrometer is proportional to $sJ_\lambda \, \delta\lambda$, where $J_\lambda \, \delta\lambda$ represents the quantity of radiation between $\lambda$ and $\lambda + \delta\lambda$, and after substituting for $\delta\lambda$ this is proportional to $s^2 \lambda \, J_\lambda$. Fortuitously, for a black-body at $2000°$ K. the variation of $J_\lambda$ with wave-length is such that for constant energy on the detector $s$ is nearly proportional to $\lambda$ from 2 to $20\mu$ and consequently $\delta N$ is almost constant over this range. More detailed information is given in Table 1 and it will be seen that at wave-lengths beyond $20\mu$ the energy falling on the detector cannot be maintained without sacrificing resolution. At $125\mu$ the maximum slit-width of 15 mm. (5 : 1 reduction on 3-mm. aperture of a Golay cell) has been reached in the example given.

As the wave-length increases beyond $20\mu$, $J_\lambda$ becomes proportional to $\lambda^{-4}$ with ever increasing accuracy (Rayleigh–Jeans law) and the energy reaching the detector therefore tends to be proportional to $s^2\lambda^{-3}$. If this quantity is maintained constant, $s^2 \propto \lambda^3$ and $\delta N \propto s/\lambda \propto \lambda^{\frac{1}{2}}$, approximately in accordance with values of $\delta N$ given in Table 1.

Table 1

| $\lambda$ ($\mu$) | $J_\lambda$ | $\lambda J_\lambda$ | $s$ (mm.) | Spectral interval $\delta N$ (arbitrary units) | Energy on detector $s^2\lambda J_\lambda$ |
|---|---|---|---|---|---|
| 2 | 8·2 | 16·4 | 0·1 | 1 | 0·164 |
| 10 | 0·088 | 0·88 | 0·5 | 1 | 0·220 |
| 20 | 0·0067 | 0·134 | 1 | 1 | 0·134 |
| 50 | 0·0₃191 | 0·0096 | 4 | 1·6 | 0·154 |
| 125 | 0·0₅51 | 0·0₃64 | 15 | 2·4 | 0·144 |

In the corresponding case when resolution is limited by diffraction rather than by energy, $\delta N$ is of course independent of wave-length.

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¹ Lord, E. C., and McCubbin, T. K., J. Opt. Soc. Amer., 47, 689 (1957).

## Strength Impairment Mechanism of Glass in Aqueous Systems

RECENTLY we conducted a precision tension ('Instron') strength study of two glass fibre fabrics exposed to several different environments. The resulting data are summarized in Fig. 1. When one considers a logical basis for the experimental data, it appears that the water deterioration of glass is a chemical solution process. There is a two-fold evidence for this view. First, the higher $p$H exposures of the glass fibres give rise to a greater weakening than with a simple water exposure. This agrees well with the observed solubility versus $p$H relations of typical glasses, and it implies that the molal activation energies for glass fracture in a glass system with microcracks present therein are lower in the high $p$H solutions[1,2]. Such high $p$H solutions might be found useful to accelerate or expedite glass fractures where this slight solution effect can be tolerated. Second, the drying out of the glass fibres after exposure did not serve to restore the full original strength of the glass fibres. If only a physical adsorption were involved a full reversibility could be expected.
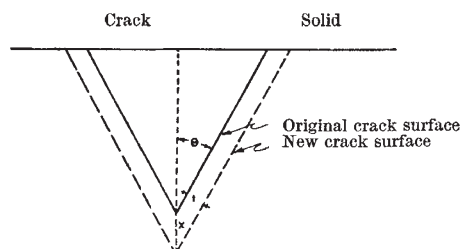


Fig. 1. Relationship of crack angle and rate of attack (chemical). (The effect of stresses superimposed is to make $X$ larger than this theoretical maximum. $\theta$, Crack angle ; $X$, increase of crack depth $= t \operatorname{cosec} \theta$ ; $r$, rate of attack $\alpha \, t$.
Table of values ($t = 1$) from $X = t \operatorname{cosec} \theta$

| | | |
|---|---|---|
| 1° | 57·3 | |
| 2° | 28·6 | Shows rate of change. The high values for sharp cracks in 'constant' geometry case as $dx/d\theta = -t \operatorname{cosec} \theta$ at $\theta$. |
| 5° | 11·5 | |
| 7° | 8·20 | |
| 10° | 5·76 | |
| 15° | 3·86 | |
| 20° | 2·92 | |
| 30° | 2·00 | |

The literature shows considerable evidence of aqueous (both vapour and liquid) weakening ; but this appears to be the first indication of the effects of $p$H therein and of the probable strength-impairment mechanism implied thereby[3,4]. The subject glass fibres were of commercial grade, hence they may be expected to have contained numerous microcracks. If the chemical solution were vigorous enough, then presumably the defective surface layers could be removed and the unit glass fibre strength would be significantly increased ($\times$ 2–4) over the original

Table 1. SUMMARY OF INSTRON TENSILE TEST DATA*

| | Glass Fabric A | | Glass Fabric B | |
|---|---|---|---|---|
| 1. Air strength (Av. of 20) | 4·82 lb. | | 6·49 lb. | |
| 2. Wet strength (3-4 hr. exposure) | 4·11 | | 3·68 | |
| 3. Wet and dried | 4·58 | | 6·44 | |
| 4. Wet cement strength (average of 5) | $p$H 11 Cement | $p$H 13 Cement | $p$H 11 Cement | $p$H 13 Cement |
| 1-2 hr. | 3·62 | 2·85 | 3·64 | 3·55 |
| 3-3½ hr. | 4·18 | 2·63 | 3·69 | 3·65 |
| 5-5½ hr. | 4·23 | 2·68 | 3·65 | 3·77 |
| 8-8½ hr. | 4·39 | 3·11 | 3·88 | 3·79 |
| 24-24½ hr. | 4·68 | 3·08 | 4·16 | 3·96 |
| 120 hr. (10) | 4·23 | 4·00 | 5·98 | 5·23 |

* All are averages of ten specimens unless otherwise noted.

levels[5]. Our results (Table 1) suggest that aqueous chemical solution or film formation is the basic mechanism of the glass fibre deterioration which we have observed. From the literature, it is of interest to note that the water reaction impairment of glass is evidently operative even under ordinary laboratory atmosphere circumstances, for otherwise the paraffin oil (sodium dried) case would not have conferred the reported 20 per cent strength increase[6]. We believe that our finding helps to correlate many apparently unconnected empirical results in the literature and affords predictions of glass fibre and other glass behaviours in various engineering environments.

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¹ Stanworth, J. E., 'Physical Properties of Glass', 156 (Oxford University Press, 1950).
² ibid., 114.
³ Morey, G. W., 'The Properties of Glass', 330 (Reinhold Publishing Corp., New York, 1954).
⁴ Ref. 1, 95.
⁵ Ref. 1, 92.
⁶ Ref. 2, 330.