of block units differs on both sides of A , doubtless due to change of growth conditions.

A fuller report of the observations made will be communicated elsewhere.

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¹ Tolansky, S., *Proc. Roy. Soc., A*, **184**, 51 (1945).

² Tolansky, S., *Phil. Mag.*, **36**, 225 (1945).

Effect of Duration of Loading on the Strength of Glass

Murgatroyd and Sykes¹ report experiments in which they pre-stressed glass for a prolonged period at a stress thought to be sufficient ultimately to break it, and they afterwards broke the glass in a rapid loading test. They found that the pre-stressing had not significantly reduced the breaking stress in the latter test. Orowan² had previously suggested that if the time effect on the strength of glass was due to the spread of initial cracks as a consequence of atmospheric attack, the results of pre-stressing at a load sufficient ultimately to break the glass would be to reduce the strength under a subsequent short-time breaking test. Murgatroyd and Sykes therefore concluded that their results are incompatible with any theory which relates the decay in strength of glass to increase in length of cracks.

Orowan's deduction was based on the interpretation of Griffith's criterion of fracture, which regards crack-spreading at constant surface tension as contrary to the laws of thermodynamics below the Griffith load, but that it proceeds catastrophically as soon as the Griffith load is reached. In a paper I read to the British Rheologists Club in June last year³, I showed that crack-spreading by Griffith's mechanism in a material of atomic constitution is not catastrophic at the Griffith load. This load is the smallest at which a crack may start to spread by this mechanism. The rate of spreading depends on the rate at which thermal motions overcome atomic energy barriers, which may be very slow even at loads exceeding Griffith's criterion. Catastrophic fracture will not occur until the crack has attained a length such that the strain energy in the material at its end combined with the average thermal motion is sufficient to overcome the average energy barrier. Orowan's prediction therefore needs re-examination.

The severity of atmospheric attack will be a function of stress, and at sufficiently high stress it may possibly be regarded as solution of the glass in atmospheric moisture. For dilute solutions of non-electrolytes, solubility is usually proportional to vapour pressure, and simple thermodynamic calculation leads to the approximate relation

$$\ln \frac{p}{p_0} = \frac{V_m X^2}{2ERT}, \quad (1)$$

where p and p_0 are the vapour pressures with and without stress V_m is the specific volume of the solid, X is the stress, E the Young's modulus, R the gas constant, and T the absolute temperature. In accordance with the Griffith's crack hypothesis, the stress at the end of the cracks is some hundred times the average stress in the material. The vapour pressure at the ends of the cracks when the material is stressed near its breaking load is therefore estimated to be of the order of 10^{10} — 10^{10} times that elsewhere in the material. The rate of crack-spreading by evaporation can be estimated from kinetic theory, and if the material does not break until the vapour pressure becomes high relative to that at the end of the crack before it started spreading, the functional relationship between duration of loading t , and average stress f , to cause fracture assuming the whole-time effect is due to evaporation is

$$\left(\frac{A}{f^2 t_0}\right)^{1/2} = \left(\frac{A}{f^2 t}\right)^{1/2}, \quad (2)$$

where A is a constant depending on the properties of the material and the dimensions of the crack. The estimated time-effect due to evaporation is much less than the total time-effect found experimentally for glass. My purpose in quoting equation 2 is that the relationship between solubility and vapour pressure makes it probable that a somewhat similar expression may be expected to give the effect of time on strength due to solution of material at the ends of cracks. The theory used to deduce equation 2 gives for the length of crack (a) at constant load an expression of the form

$$a = -B \log (C - Dt). \quad (3)$$

For crack-spreading by evaporation, the constants C and D are very small numbers (of the order of 10^{-40}). For example, if the time to break was 10^5 sec., C might be 10^{-40} and D 10^{-45} . For 10^5 sec. the crack-length would be infinite, but for 9×10^4 sec. the crack-length would have increased by only 2½ per cent. The crack-length is thus effectively constant until a critical time is reached at which it increases extremely rapidly. Crack-spreading by solution would be expected to be much more rapid than by evaporation, and if an equation similar to expression 3 holds, the constants C and D would be much greater; but the crack-length may still remain sensibly constant until just before fracture. The results of Murgatroyd and Sykes are not necessarily, therefore, in conflict with the decay in the strength of glass subjected to prolonged loading being due to the spread of cracks.

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¹ Murgatroyd, J. B., and Sykes, F. S., *Nature*, **158**, 716 (1945).

² Orowan, E., *Nature*, **154**, 341 (1944).

³ Gurney, C., *Nature*, **156**, 306 (1945).

Distribution of Energy Levels for the Liquid-Drop Nuclear Model

THE Bohr liquid-drop model, because of the strong interaction between nuclear particles, has proved suggestive in giving insight into some of the fundamental properties of nuclei, particularly the extremely rapid rise in the density of levels as the excitation energy is increased. Taking for the normal modes of surface (capillary) waves, for which the wave number does not exceed k , the asymptotic expression

$$a(k) = \frac{\pi x}{4}, \quad x = \frac{\sigma k^2}{\pi^2}, \quad (1)$$

σ being the area of the surface, the level separation $D(U)$ is given¹ (ignoring the effect of volume (acoustical) waves) by

$$D(U) = \lambda e^{-S}; \quad (2)$$

$$S = 3.39 (AU^2/\Gamma P)^{2/7}, \quad \lambda = 2.75 (\Gamma P/A)^{1/7} U^{5/7}, \quad (3)$$

where U is the energy of excitation, A is the mass number and Γ , P are each equal to 10 mV. when the nuclear radius R is assumed to be $R = r_0 A^{1/3}$, $r_0 = 2.05 \times 10^{-13}$ cm. The values (taken from Bethe²) for $U = 10$ mV. and for various values of A are given in the following table.

LEVEL SEPARATION FOR $U = 10$ mV.

A	10	20	50	100	200
$D(U)$	2.8×10^4	6.1×10^4	4.8×10^4	4.6×10^4	2.6
$D_1(U)$	7.8×10^3	2.4×10^4	2.8×10^4	3.9×10^3	3.4×10^2
$D_1(U)/D(U)$	28	39	58	85	131

It seems worth while to consider the effect on level-spacing of employing, instead of the asymptotic expression (1), the more accurate expression

$$a(k) = \frac{\pi x}{4} - x^{1/2} + O(x^{17/8}), \quad (4)$$

where the order term (the last term on the right-hand side) is due to Vinogradov². The values $D_1(U)$ of the level separation based on (4) are given in the third row of the table. It can be shown that $D_1(U)/D(U)$ has a minimum for $UA^{1/2} \sim 1.25$. The accurate enumeration of the surface modes gives a level-spacing which for heavy nuclei is about 10^2 times larger than the observed value. The level-spacing could be reduced to the order of the observed value by increasing r_0 , but the change required is too large to be reasonable.

A detailed paper with other applications of (4) will appear in the *Proceedings of the National Institute of Sciences, India*.

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¹ Bethe, *Rev. Mod. Phys.*, **9**, 86 (§ 53C) (1937).

² Vinogradov, *Bull. Acad. Sci. USSR.*, **7**, 313 (1932).

Vibrational Levels in the Red CuO-Bands

ROSEN¹ has recently reported an investigation on the band-spectrum of CuO and given formulae for the representation of the band-heads, as the result of a vibrational analysis. I have performed a rotational and vibrational analysis of five bands in the red part of the CuO-spectrum², and I have computed the following formula for the band-origins:

$$v_0 = 16273.9 + 285.6(v' + \frac{1}{2}) - 9.2(v' + \frac{1}{2})^2 \\ - [318.6(v'' + \frac{1}{2}) - 4.4(v'' + \frac{1}{2})^2].$$

The constants in this formula differ from the constants in Rosen's formula, particularly in the ground-state, where Rosen's values are about twice as great as my values. I had intended to wait until my investigation on the blue and green bands of CuO, which continues my work on the red band-system, had been completed before drawing further conclusions from the vibrational analysis; but Rosen's report makes a comparison between his and my formula for the red band-system desirable.

1. It can be said that the red band-system of CuO consists of four groups of bands at 6045 Å., 6150 Å., 6300 Å. and 6400 Å. These groups appear on my plates of the complete spectrum. The band-heads were measured by Pearce and Gaydon³. My values agree with their values. I have deduced my formula from the first two groups, assigned to the sequences beginning with the 1-0 band and 0-0 band. Now, if my formula is applied to compute the bands belonging to the sequences beginning with the 0-1 band and the 0-2 band, it turns out that the bands belonging to these two sequences are neatly arranged around the two latter groups of bands. Rosen's formula does not give the same correspondence between calculated and actually measured bands.

2. The band-heads at 6147.3 Å. and 6045.0 Å. are not accounted for in Rosen's formula, which means that in Rosen's view these bands must correspond to some sort of doublet structure. This is directly contradicted by the rotational analysis. So far back as ten years ago, Loomis and Watson⁴ emphasized that this type of doublet structure was not very probable.