carrying an ultraviolet-resistant coating; results will be definitive by 1968.

Figure 4 is a plot of successive positions during the first 96 days of a balloon launched from Christchurch on 28 April 1966; after 192 days it descended into the South Atlantic during the night of 4 November while on its 17th circuit of the globe. Detailed data on trajectories and winds for this and all other flights (including Antarctic launches) should be available to all by about March 1967—and at regular intervals thereafter.

Several development programs envisage a balloon-satellite system. France has a program (Project EOLE) whose initial aim is the flight in 1969 of 500 balloons at 300 mb in the Southern Hemisphere, with accurate tracking by satellite. (Initial EOLE flight tests in July and August 1966 showed evidence of an icing problem even at 300 mb.) The National Aeronautics and Space Administration is developing a system for interrogating and locating balloons and other moving platforms from a low-orbiting satellite named IRLS (Interrogation, Recording, and Location System); it will be tested during the Nimbus-B and Nimbus-D flights. Now being studied by NASA is the possible use of a low-frequency location system, in conjunction with a synchronous satellite, to provide accurate data on position.

While work continues on the sophisticated balloon-satellite systems of the future, it appears that we can take advantage of the extraordinary performance of our interim GHOST electronics package to provide useful operational weather data for the nations of the Southern Hemisphere. With rapid communication to a computer in Boulder, Colorado, Washington, D.C., or Melbourne, Australia, from only three stations—in New Zealand, South America, and Africa—we can provide trajectories and winds for as many as 50 balloons, and these data can be fed back to the Southern Hemisphere with only a few hours' delay. This service will double the volume of data on the upper air in the Southern Hemisphere, and at modest cost. With the cooperation of the nations concerned, this program can be in operation within 1 year.

On the planned flights at 30 mb, 2 kg of the capacity is unused. Our telemetry system can handle from one to four channels of data. Since we expect many of these balloons to remain at altitude for several years, we should like to encourage other scientists to consider piggyback experiments by which, from a platform at 24,000 m, they could do such things as measure long-term effects such as variation in intensity of incoming radiation, measure ozone, count rare events, or determine degradation of materials; the cost should be less than \$1 kg^{-1} day^{-1}.

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References and Notes

1. Conducted by the National Center for Atmospheric Research as a joint program of the New Zealand Meteorological Service and the Environmental Science Services Administration; the nations of the Southern Hemisphere are cooperating.
2. Designed by E. W. Lichfield and R. W. Frykman, *Electronics* (28 Nov. 1966), p. 98.
3. For additional information see: National Academy of Sciences, *NRC Publ. 1290* (Washington, D.C., 1966); V. E. Lally, *Bull. Amer. Meteorol. Soc.* **41**, 429 (1960).

12 December 1966

Structure of Silica Glass

Abstract. *From configurational entropy considerations, it is estimated that the grains in silica glass are far more likely to have a cristobalite structure than a pentagonal dodecahedral one.*

The idea that liquids preserve some of the structure of their corresponding solids is not new. Krishnamurti (*1*) concluded this from his studies of organic compounds, and Randall *et al.* (*2*) thought of glasses as having the structure of the corresponding crystals in domains of 10 to 100 Å. Zachariasen (*3*) stated: "The glasses are built up of extensive three dimensional networks without symmetry or periodicity, these networks being in other respects essentially the same as the ones we find in corresponding crystals."

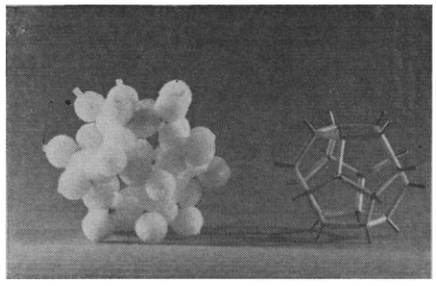
Warren (*4*) established that the tetrahedral coordination of oxygen around silicon, which characterizes the crystalline silicates, persists in glass. He concluded from his investigations that a random network represents the structure of glass better than an agglomerate of cristobalite crystallites and that if the cristobalite structure did exist in glass it was restricted to domains smaller than about 8 Å. The ideas of Zachariasen and of Warren are generally accepted.

A grain structure such that silicon is linked to oxygen to silicon in some less than random manner for a few atomic distances is indicated by considerable physical and chemical evidence from a number of sources (*5*). Such a grain structure does not necessarily conflict with the Zachariasen-Warren theory but merely restricts the randomness to regions outside of these grains, that is, outside of a few SiO_4 tetrahedral distances instead of only one. The work of Warshaw (*6*) and of Zarcycki and Mezard (*7*) are particularly convincing of grain structure in the 25- to 150-Å range, and Oberlies and Dietzel (*8*) showed that the atomic arrangement in silica glass is probably not far removed from that in cristobalite.

The structure of these grains has been the subject of some debate. Do they contain cristobalite polyhedra or are they, as suggested by Bernal's (*9*) study of packing in liquids, composed of statistical molecular configurations with varieties of coordination patterns geometrically different in kind from any occurring in a regular solid? From experiments compressing plasticene spheres, Bernal concluded that arrangements in pentagonal faces are necessary to dense packing. Because a coordination number of 5 does not permit long-range order, any such arrangement of molecules must be fluid. Tilton (*10*) had previously postulated his Vitron theory of glass structure based on pentagonal dodecahedral assemblages.

Recently, Robinson (*11*) has computed the geometry of distorted pentagonal dodecahedra in some detail and he concluded that grains built upon this structure would give an x-ray diffraction pattern in agreement with experiment. However, x-ray techniques applied to glass yield accurate values of interatomic distances for only a few near neighbors, and, as Robinson points out, plane pentagonal rings and puckered hexagonal rings cannot be distinguished. Thus in order to choose, data from other sources are needed.

One serious difficulty with the pentagonal dodecahedral model is that it yields a density 10 percent less than that of the glass, and it is very difficult indeed to imagine a reasonable random packing arrangement of these structures which could increase the density by this much. On the other hand, the density of cristobalite appears to be about 0.5 percent greater than that of silica glass at high temperatures. A cristobalite-structured grain is also suggested by the ease with which silica glass devitrifies. This indicates rather



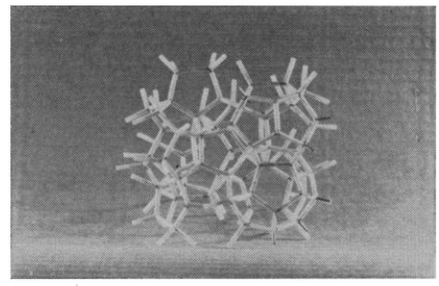


Fig. 1 (left). Models of pentagonal dodecahedra, with oxygen atoms omitted from one of them. Fig. 2 (right). Model of a grain built up of these units.

strongly that an element of very similar structure (*12*) acts as a nucleus for crystal growth.

Figure 1 shows three-dimensional models of pentagonal dodecahedra. The oxygen atoms have been omitted from one of them in order to show the bond directions more clearly. A single pentagonal dodecahedron would contain 5 SiO_2 if it were packed into a lattice in which each Si atom is shared by four dodecahedra. Figure 2 is a model of a grain built up of these units. Bonds become very strained beyond a few near neighbors unless the dodecahedra are stacked in single chains.

Figure 3 shows an elementary cristobalite polyhedron (containing 2 SiO_2 when packed in the lattice with each Si shared by six polyhedra), with and without oxygens, and portions of a cristobalite lattice, also with and without oxygens, assembled from these polyhedra. Figure 4 shows a grain composed of two sets of six cristobalite polyhedra joined by stacked pentagonal rings. The dissymmetry introduced by the pentagonal rings forces a line of broken bonds nearby. Obviously there are a large number of ways of joining a few elementary cristobalite polyhedra; Fig. 4 is only one example.

The grain structures depicted in Figs. 2 and 4 would probably yield indistinguishable x-ray patterns, since the number of atoms in exactly equivalent positions is small enough to broaden the peaks beyond resolution.

If pentagonal dodecahedra are the building blocks next above SiO_4 tetrahedra in glass, the cristobalite polyhedra must be broken down in melting into fragments containing less than the 6 SiO_2 which occur in the hexagonal rings. These fragments must then be joined to form pentagonal dodecahedra by new bonds. On the other hand, if vestiges of cristobalite structure persist in the liquid, the hexagonal rings not only need not be broken, but a number of the bonds joining the rings together could remain intact during melting. With no new bonds to be formed, the cristobalite structure should be distinctly favored over one requiring a more complicated process of formation.

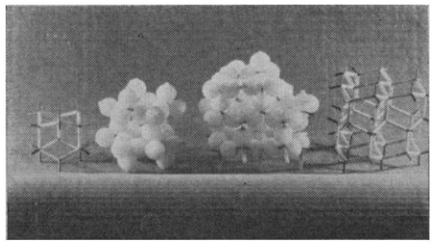
Some idea of the configurational entropies associated with these two types of structure can be obtained from the following considerations. A pentagonal dodecahedron has 30 edges, each consisting of two Si—O bonds, but it is not necessary to make anew all 60 of these bonds in order to form this geometry from a cristobalite lattice. The minimum number of new bonds required is 14. Fourteen are all that are needed starting with four pentafragments: two bonds to form two pentagonal rings from each of two fragments, two bonds to form a decagonal (belt) ring from two fragments, and ten bonds to join the two rings to the belt, completing the dodecahedron. Each of the ring-forming bonds can be made in only one way, each of the belt-forming bonds can be made in two ways, and each of the two sets of five bonds remaining can be made in two ways. The total number of possible bondings from 14 different bonds is 14!. Accordingly, the foregoing process can be assigned a probability of $(14!/2 \times 2 \times 2 \times 10 \times 10)^{-1}$, or 1 per 1.09×10^8.

A comparable beginning for reconstructing cristobalite polyhedra is penta-fragments plus single SiO_2 molecules; such a process requires the formation of seven bonds. The two bonds forming the hexagonal rings can be made in each of two ways, and the three bonds joining the two rings, in each of two ways, giving a probability of $(7!/2 \times 2 \times 6)^{-1}$, or 1 per 210. The ratio of these probabilities is 520,000 to 1 in favor of cristobalite. However, it seems reasonable to postulate unfragmented hexagonal rings existing in the melt, so that on the basis of bond formation, the probability of two of these joining to form a cristobalite polyhedron is 1/3. Of course, if the melting process permits some bonds joining hexagonal rings together to remain unbroken, a cristobalite structure already persists in the liquid and the probability of this structure is 1.

Therefore, it seems reasonable that a melting process that would convert cristobalite structure (12 SiO_2 per polyhedron) to a pentagonal dodecahedral arrangement (20 SiO_2 per polyhedron) involves, on a gram molecular weight basis, a configurational entrophy change of the order of $-(20/12)$ Rln $(1.09 \times 10^8/3)$, or -57 entropy units. It seems unreasonable that it would be less than $-(20/12)$Rln (520,000) or -43 entropy units. The observed entropy change accompanying the melting of cristobalite is 1 entropy unit (*13*).

Consequently, silica glass is pictured as consisting of grains of small numbers of cristobalite polyhedra, with these grains linked together to form a random three-dimensional network. This is what Randall, Rookesby, and Cooper proposed in 1930 (*2*), and does not seem to be in serious conflict with a random network theory.

According to this interpretation, the cristobalite-tridymite-quartz transitions should occur in the appropriate temperature intervals within each individual



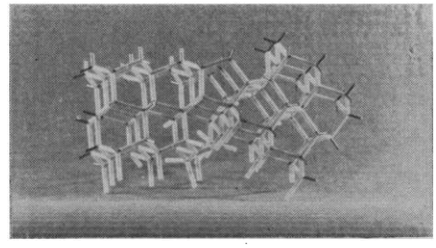


Fig. 3 (left). An elementary cristobalite polyhedron, with and without oxygens, and portions of a cristobalite lattice, with and without oxygens. Fig. 4 (right). A grain composed of two sets of six cristobalite polyhedra joined by stacked pentagonal rings.

grain. These effects would, of course, be greatly reduced compared with those in the macrocrystals, because of dilution by the random parts of the network. However, if they could be detected, they would give some measure of the number of atoms in regular array with respect to those in random array. It might be informative to examine data in the transition region with this in mind.

With the liquid preserving the structure of the crystal to this extent, it is natural to think of melting as introducing an ever-increasing number of defects into the lattice, decreasing the grain size to some small but critical value where long-range order ceases and the structure fails.

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References and Notes

1. P. Krishnamurti, *Indian J. Phys.* **3**, 225 (1929).
2. J. T. Randall, H. P. Rookesby, B. S. Cooper, *Z. Krist.* **75**, 196 (1930); *J. Soc. Glass Technol.* **14**, 219 (1930); *Nature* **125**, 458 (1930).
3. W. H. Zachariasen, *J. Chem. Phys.* **3**, 162 (1935); *J. Am. Chem. Soc.* **54**, 3841 (1932).
4. B. E. Warren, *Z. Krist.* **86**, 349 (1933); ———, H. Krutter, O. Morningstar, *J. Am. Ceram. Soc.* **19**, 202 (1936); B. E. Warren and J. Biscoe, *ibid.* **21**, 49 (1938).
5. R. B. Sosman, *The Phases of Silica* (Rutgers Univ. Press, New Brunswick, N.J., 1965), chap. 14; E. A. Porai-Koshits, *Structure of Glass* (U.S.S.R. Acad. of Science, 1960; transl. by Consultants Bureau, New York, 1960), pp. 9–16, particularly p. 12.
6. J. Warshaw, *J. Am. Ceram. Soc.* **43**, 4 (1960).
7. J. Zarcycki and R. Mezard, *Phys. Chem. Glasses* **3**, 163 (1962).
8. F. Oberlies and A. Dietzel, *Glastech. Ber.* **30**, 37 (1957).
9. J. D. Bernal, *Nature* **183**, 141 (1959); *Liquids: Structure, Properties, Solid Interactions*, J. Hughel, Ed. (Elsevier, New York, 1965), pp. 25–50.
10. L. W. Tilton, *J. Res. Natl. Bur. Std. A* **59**, 139 (1957).
11. H. A. Robinson, *J. Phys. Chem. Solids* **26**, 209 (1965).
12. For the purpose of this discussion, the structural elements of cristobalite and tridymite are the same. The type of binding is not significantly different even though the two forms have different crystal symmetries.
13. C. E. Wicks and F. E. Block [*U.S. Bur. Mines Bull.* **605** (1963)] give 1.84 kcal at the melting point, 2001°K.
14. I am indebted to Dr. Dan McLachlan, Jr., and Dr. Henry H. Blau for helpful discussions.

5 October 1966

Susceptibility to Two Strains of Friend Leukemia Virus in Mice

Abstract. *A mutant strain of the Friend leukemia virus is described. The parental virus strain, passaged through ICR/Ha mice, shows no or very little activity by the spleen-focus assay in BALB/c mice (by comparison with highly susceptible DBA/2 and ICR/Ha mice) and produces typical Friend disease in these mice only exceptionally; susceptibility to this strain of virus is recessive in the (C57BL/6 × DBA/2) F_1. By contrast, the mutant virus strain is as active in BALB/c mice as in DBA/2 or ICR/Ha mice; susceptibility to the mutant virus strain is dominant in the (C57BL/6 × DBA/2) F_1.*

The problem of the host strain specificity of the Friend leukemia virus in mice has been investigated a number of times since Friend's report (*1*) of a very narrow range of strain susceptibility. BALB/c mice appear to be highly susceptible to the virus in some studies (*2*), while in others they appear quite resistant, the difference being attributed sometimes to the mouse substrain used and sometimes to the virus strain used. Although "BALB-adapted" virus has been reported (*3*), the nature of the adaptation has not yet been elucidated.

We now report the comparison of two strains of Friend virus (FV), one obtained from the other by passage through mouse hosts relatively resistant to the parental virus strain.

Except for commercially obtained, random-bred ICR/Ha Swiss albino mice, all mice were from our own inbred colonies. The mice were usually 6 to 12 weeks old when inoculated with virus. The inbred strains used were: DBA/2, BALB/c, C3Hf/Bi, A, and C57BL/6; in addition, certain F_1 hybrids between them were also used.

Virus preparations were obtained as follows. The greatly enlarged spleens from mice injected with virus 2 to 3 weeks previously were homogenized in nine times their weight of cold phosphate-buffered saline. The homogenates were centrifuged relatively slowly, the supernatant was recentrifuged for 4 minutes at about 7000*g* and this second supernatant, either as such or after filtration through Selas 02 filter candles, was used as the basic virus inoculum.

Our "parental" strain of FV, established in 1965 from Friend's line passed continuously through DBA/2 mice (191 passages), has been passed exclusively through ICR mice; we refer to it as Friend-S (F-S) virus. This F-S virus was injected at passage two into six BALB males, of which two developed splenomegaly after a prolonged period of latency (4 to 6 weeks, as compared with 2 weeks in the ICR passage animals). The spleen of one of these was used to establish a separate line of virus which has been passed exclusively through BALB mice; this virus strain is designated Friend-B (F-B) virus.

Two criteria of virus susceptibility have been used in these studies: (i) the activity, determined by the spleen-focus assay (4), of a virus preparation in an unknown mouse strain by comparison with its activity in the strain of origin, and (ii) the ability of mice of a given strain to sustain virus growth upon serial passage.

Preparations of the parental F-S virus strain routinely show the same high activities when assayed in either ICR or DBA/2 mice, and either mouse strain readily supports the serial passage of F-S virus. On the other hand, no activity is generally observed when adult BALB or C57BL mice are used. However, BALB mice are not totally resistant to the virus, for the typical disease syndrome may be induced in them by the injection into adults of exceptionally large doses of F-S virus or by inoculating them up to 10 days postnatally with more usual virus doses. F-S virus has never produced either overt Friend disease or spleen foci in any mice of the C57BL strain in our laboratories.

From these facts it emerges that three classes of strain susceptibility to F-S virus can be defined. Class I mice (DBA/2, ICR/Ha; also C3Hf/Bi) are highly susceptible as adults to the virus. Class II mice (BALB/c; also A) are relatively resistant to the virus as adults, but as babies they are susceptible. Class III mice (C57BL/6) are highly resistant under all circumstances investigated.

Preparations of the variant F-B virus show approximately the same activity whether ICR, DBA/2, or BALB mice are used for their assay. No activity is seen in C57BL mice. The disease syndrome produced in susceptible animals by F-B virus appears grossly similar to that of F-S virus, although periods of latency may be slightly shorter with the former and, in general, extracts containing F-B virus demonstrate somewhat higher virus titers than do similarly prepared extracts containing F-S virus. Baby mice of susceptible strains, inoculated with preparations of F-B virus, show a much higher rate of infant mortality than when F-S virus is inoculated.

Despite the fact that a given F-B virus preparation shows identical