Does glass creep?

The excellent article by James Phillips (February, page 27) prompts me to ask your talented readership this question: Do ancient glass window panes *really* show signs of creep? It is commonly asserted that they do. I doubt any reader of PHYSICS TODAY has sat through an introductory talk on the kinetics of glasses without being exhorted to rush out and examine an old window pane.

This assertion has always worried me. Glasses, it seems, should not flow at all much below their glass transition temperature (T_g). This statement is based on the argument that a little below T_g, a genuine (though inaccessible) second-order transition exists. If this were not so, one would run into trouble with the incorrigible glass formers: A super-cooled liquid gives up its configurational specific heat at a lower temperature (T_g) than the corresponding crystal-forming liquid, thus the loss of entropy on vitrification exceeds the loss on crystallization. Extrapolating to ever slower determinations of T_g (and hence lower values of T_g), one is forced to the conclusion that below some temperature, T_2, the entropy of the glass is less than that of the crystal—even negative at low enough temperatures! Julian Gibbs and coworkers[1] set things straight by arguing that at T_2 only one configuration is available to the glass so that the configurational entropy vanishes. Above T_2 there is a smallest size of "cooperatively rearranging regions" which dominates the flow properties of the glass. When this "region" is the sample itself (at T_2) flow must vanish—even on infinite time scales. I should add that though simple, this phenomenological model has been most successful.[2] It is tempting to add a modern touch to it by identifying the microscopic structure of the "cooperatively rearranging region" with the "weakly interconnected clusters" of Phillips (at least above T_2).

At this point I must confess that I do not know what the canonical cathedral window is made of, but it is surely an inorganic glass with $T_g \sim 1000$ K. In that case T_2 is most probably well above[2] the frosty European ambient temperature! Austen Angell told me recently that he had expressed just this concern while visiting Corning Glass and was delighted to hear that they have tested this long-standing assertion. I gather authentic cathedral glass was subjected to a stress large enough to mimic several hundred years of gravitation in a few months. The results were negative; no flow was detected. One must, it seems, argue that prior to the discovery of float glass, the glaziers of old handled their wedge-shaped panes in the easiest manner!

There is more to this than the verisimilitude of the stories we tell our freshman classes. The topological approach of Phillips predicts a static domain structure, and with this picture one might expect "flow" well below T_g (as Phillips points out[1]). My question remains, however: Has the phenomenon really been demonstrated?

References

1. G. Adam and J. H. Gibbs, J. Chem. Phys. **43**(1), 139, 1965. (and references therein).
2. See, for example, Table 3 in chapter 1 of *Glass Structure by Spectroscopy*, J. Wong and C. A. Angell (Dekker; 1976).

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THE AUTHOR REPLIES: Stuart Lindsay's comment is well taken. Creep is a well-established phenomenon in non-crystalline solids,[1] but common observation may easily be misled by the convenience of handling wedge-shaped panes. One also has misgivings about the effects that could be produced by a weak force such as gravity.

Structural relaxation on a molecular scale as a function of temperature has recently been studied very carefully by x-ray diffraction in g-As_2Se_3 in an experiment stimulated in part by my theory. Busse and Nagel[2] found that with an accuracy of 1% a diffraction feature generally assigned to an interlayer spacing in the glass actually increased in strength by 5% with temperature beginning near $T = 2T_g/3$. They attribute this increase (which is exactly the opposite of what is found in crystals, where the observed reduction is explained in terms of Debye–Waller factors) to flattening of the layers with thermal expansion, in effect internal molecular flow associated with thermal fluctuations.

One last work on the old chestnut of macroscopically observable creep. My own feeling here is that the phenomenon, even if not true, can be thought to be something that ought to be true. This is because it is a useful stimulant to the thinking of many scientists who do not distinguish sufficiently carefully between crystalline and non-crystalline solids apart from saying that the former have periodic structures with long-range order while the latter do not. Indeed one may go further and separate non-crystalline solids into glasses and merely amorphous solids which crystallize rather than melt upon annealing at typical rates (10 Kelvin/min.). All of these distinctions can be made quantitative by studying molecular structure on a scale of 30-1000Å. At present, as I indicated in the article, the data are fragmentary and the subject both controversial and topical.

References

1. T. Takamori and M. Tomozawa, J. Am. Ceram. Soc. **63**, 126 (1980).
2. L. E. Busse and S. R. Nagel, Phys. Rev. Lett. **47**, 1848 (1981).

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Arms reduction proposal

I would like to propse the following nuclear arms reduction treaty: Nations possessing nuclear weapons would establish an independent international agency (IIA) and would agree by treaty to deliver some specified amount of weapons-grade fissionable material to IIA each year. IIA, open to all nations for inspection, would verify both the quality and quantity of material delivered using radiochemical techniques.

IIA would use this material to enrich and fabricate nuclear power reactor fuel rods, which it would lease to non-contributing nations which have signed a non-proliferation treaty. IIA would monitor the use of these leased fuel rods, insuring that fissionable material was not diverted, and that the appropriate electrical power was obtained for the fuel expended. IIA would reclaim expended fuel rods for re-processing or disposal.

The advantage of this treaty is that it eliminates the "on site" inspections which have been so difficult to negotiate. IIA, open for inspection to all nations, would eliminate a certain amount of weapons-grade fissionable material, and therefore a certain number of weapons, from the nuclear arms stockpile each year.

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RF tokamak drive

In reference to your recent news story "RF Drives Tokamak Plasma Currents" (March, page 19), I would like to point out that the theory of RF current drive described therein was developed by Nathaniel Fisch and should be referred to as the "Fisch theory" rather than the "Fisch–Bers theory" as it appears in the text of the article.

The topic of your article is of great current interest in the fusion field and I congratulate you on bringing this activity to the attention of the physics community at large.

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