OBITUARY

David Turnbull (1915–2007)

Pioneer of the kinetics of phase transformations in condensed matter.

David Harker's challenge to David Turnbull, his colleague at the General Electric Research Laboratory, was clear: "If you can undercool molten copper by more than a few degrees, I'll eat my hat!" Turnbull had just told his audience at a 1948 dinner meeting of the Science of Metals Club in Schenectady, New York, that he had undercooled liquid mercury several tens of degrees below its thermodynamic crystallization temperature by dispersing it into small droplets, and thereby isolating into individual droplets the small bits of 'dirt' that ordinarily cause crystal nucleation. At the end of the talk he had speculated that, if similarly treated, not just mercury, but also metals that crystallized into simpler structures would exhibit such large liquid undercoolings. After the meeting, Turnbull quickly showed with a hot-stage microscope that small droplets of copper, silver, gold and many other metals could be cooled to temperatures far below their crystallization points. Harker graciously accepted the results: he appeared at the next meeting with a hat made of Swiss cheese.

Harker's scepticism was not unreasonable. Because the density and bonding in the crystalline and liquid phases of monatomic metals are similar, it was generally assumed that the short-range order in both phases was similar as well, and hence that the liquid structure could easily collapse into the crystalline one at minimal undercooling. Turnbull's experiments radically changed this picture: the structure of a liquid differs profoundly from that of a crystal. His experiments inspired Charles Frank's proposal of icosahedral short-range order in liquids, which needs to be reconstructed to be transformed into that of the close-packed crystals. This insight, combined with John Bernal's analysis of the dense random packing of hard spheres, became the basis of our current understanding of a simple liquid as a polytetrahedral structure.

Turnbull also realized immediately that his undercooling results implied that it should be possible to cool liquid metals into the glassy state if the viscosity rose sufficiently sharply on cooling. With Morrel Cohen, he developed the now widely used free-volume model, the first and elegant microscopic

explanation of viscosity rise on the basis of the probability of density fluctuations. These insights convinced him of the universality of the glass transition and led him to predict that alloys with deep eutectics were the best candidates for formation of a metallic glass. This was confirmed by Pol Duwez's discovery in 1959 of an amorphous phase in an Au–Si eutectic alloy. Turnbull and his students later demonstrated that these amorphous metallic phases were true glasses, in that they exhibited the characteristic features of the fluid-glass transition: discontinuity in the specific heat and in the coefficient of thermal expansion, and a rapid change of the viscosity with temperature.

Based on his understanding of the kinetics of crystal nucleation and the viscosity, Turnbull proposed the ratio of the glass-transition temperature and the liquidus temperature as a criterion for the ease of glass formation. The value of this criterion was demonstrated in 1982, when he, together with Lindsay Greer and their students, showed that a $Pd_{40}Ni_{40}P_{20}$ liquid, when sufficiently cleaned of heterogeneous nucleants, could be made into a glass of centimetre size: the first bulk metallic glass. Metallic glasses have found uses in a variety of applications: as highest-efficiency transformer cores, which are currently saving billions of kWh a year in energy losses; as hard metals in coatings; and as high-strength-to-weight alloys for consumer electronics casings, medical implants and sporting goods. Equally important is their scientific interest: because of their structural simplicity, they provide a unique window on the enduring challenge of understanding the complexity of liquids and glasses.

David Turnbull is one in a line of distinguished physical chemists, going back to J. W. Gibbs, who have profoundly influenced materials science. His work laid the basis of our understanding of the kinetics of phase transformations in condensed matter. He showed how a quirky, complex phenomenon like crystal nucleation could yield exciting and rigorous science. He also made key contributions to grain-boundary diffusion, fast diffusion of noble metals in semiconductors and polyvalent metals, crystal growth, grain growth and recrystallization.

His work has been amply recognized by his peers. He received the Japan Prize in 1986, the second year the prize was awarded. In 1979, he received the Von Hippel Award, the highest award of the Materials Research Society. The Society later also established an annual Lectureship in his name.

But even with all his scientific distinction, David Turnbull, who died on 28 April 2007, will probably be remembered most as a remarkable human being who touched the lives of all who had the good fortune to know him. His modesty and understatement were legendary, as were his wisdom, generosity and breadth of knowledge. He was unsurpassed at recognizing and bringing out the individual strengths of his associates at General Electric and, after 1962, of his students and postdocs at Harvard. In his autobiography, available on the Materials Research Society website, David relates how he would have liked to continue to work the family farm in western Illinois. A childhood asthmatic condition put him on his way to Monmouth College and the University of Illinois to become the scientist many of us are deeply grateful to have had among us.

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