Quasi-crystals

Respectable icosahedral symmetry

from Paul A. Heiney

THE structure and properties of icosahedral 'quasi-crystals' were among the topics discussed at the recent meeting of the American Physical Society (Baltimore, 25-29 March, 1985). Quasi-crystals seem to represent a new state of matter in which icosahedral point symmetry is combined with a modified form of translational order. The clue to their structure may lie in the properties of Penrose tilings of a plane (see ref. 1).

Icosahedral ordering was first observed (D. Shechtman, National Bureau of Standards) in rapidly quenched alloys of Al-Fe, Al-Mn, and Al-Cr (ref.2). Dendritic microcrystals up to 2μm in size show the sharp electron diffraction patterns more usually generated by crystals, but with icosahedral rotational symmetry (see figure). Elementary geometry shows that icosahedral symmetry is forbidden for crystalline solids. The usual explanation of electron diffraction peaks which are crystallographically disallowed involves multiple scattering from twinned microcrystallites, but in the present case, the twinning hypothesis appears to be denied by both convergent-beam electron microscopy and dark-field imaging, which are consistent with local icosahedral symmetry on length scales as short as 200Å.

Much of the more recent work has centred on optimizing conditions for the growth of large-grain pure samples in the Al-Mn system (R.J. Shaeffer, National Bureau of Standards and L. Bendersky, Johns Hopkins University). The icosahedral phase is produced either by quenching a stream of molten alloy on a rapidly spinning copper wheel or by sweeping an intense electron beam across the surface of the alloy. If the cooling rate is too great, there are fewer icosahedral grains and they are smaller; if it is too low, ordinary crystals of various Al-Mn compounds are formed. The stability of the icosahedral phase is enhanced by a small amount of Si. An unexpected new 'T' phase, formed at higher Mn concentrations, may be intermediate between the icosahedral phase and a normal crystal.

High-resolution X-ray powder diffraction measurements (P. Bancel, University of Pennsylvania) provide data for quantitative tests of various theories of icosahedral order. The X-ray diffraction peaks are described by an icosahedral indexing scheme with six Miller indices. It is inferred that the positional correlation lengths of several hundred angstroms, extracted from peak widths, are reduced by defects which nevertheless allow orientation order to be maintained across grains with dimensions of 1 μm. High-resolution transmission electron microscopy (R. Gronsky, Lawrence Berkeley Laboratory and L. Bursill, Arizona State University) shows details of the atomic structure. Images formed from the electron diffraction patterns by optical Fourier transformation are remarkably similar to those produced by the quasi-crystal models now developed; 5-fold atomic packing symmetry and defects such as dislocations and stacking faults are observed.

In the best-known theoretical model[3] for these materials, two or more unit cells are packed with unequal spacings to form a 'quasi-crystal' without normal crystalline translational symmetry (P.J. Steinhardt, University of Pennsylvania). Quasi-crystals are much more highly ordered than glasses, but have special symmetries that are impossible for crystals. Remarkably, although quasi-crystals are not periodic, a calculation of the diffraction pattern predicts sharp spots, as with a crystal. In an alternative approach[4] to icosahedral order,

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High-resolution transmission electron micrograph of 5-fold plane of quenched 6:1 Al-Mn. Bar, 2nm (courtesy R. Gronsky and L. Tanner).

quasi-crystalline lattices can be generated by projections from higher dimensions (D. Gratias, CECM/CNRS); the icosahedral lattice is generated by projecting a six-dimensional hypercubic lattice onto three dimensions. This mathematically elegant approach allows a straightforward calculation of X-ray diffraction intensities.

In another approach[5-7], based on Landau's theory of the emergence of symmetry during phase transitions such as solidification, the atomic structure is described as a set of mass density waves with adjustable magnitudes and phases. An icosahedral quasi-crystal is generated by six density waves directed toward the vertices of an icosahedron. This method lends itself naturally to calculations of the structural stability, thermodynamics, elasticity and the occurence of defects in the icosahedral phase. A careful treatment of dislocations (D. Levine, University of Pennsylvania) reveals that these defects are considerably more complicated than their crystalline analogues; each dislocation requires two vectors, rather than one, to describe it fully.

Conventional discussions of matter in the solid state which assume either crystallinity or almost total disorder are not easily applicable to quasi-crystals. Future research will address fundamental questions about the nature of vibrations, electron transport, mechanical strength, thermodynamic equilibrium and other properties of these new materials. The immediate challenge for experimentalists is to produce larger, more pure and better-characterized samples; and for theorists, is to develop the mathematical tools needed to deal with this intriguing new state of matter. □

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Cell motility

Fast axonal transport dissected

from Dennis Bray

ANYONE interested in cell motility likes to see things move. Electron micrographs have their place, as do two-dimensional gels. But for innocent enjoyment nothing beats a working model. Myofibrils isolated from a muscle contract explosively when ATP is added; bundles of microtubules from a sperm flagellum propagate waves and swim around. Marvellous! And now the machinery driving yet another type of cell movement — that of particle transport in the cytoplasm — has been isolated. As shown on page 245 of this issue[1], and in several other recently published papers, all you really need is a membrane vesicle and a microtubule.

For some time, it has been suspected that microtubules are involved in cytoplasmic transport. Membrane-bound organelles moving through a cell (see figure) are usually close to a microtubule, and drugs that disrupt microtubules often, but not always, paralyse these movements. Whole-cell studies of this kind have now been taken to their logical extreme by the discovery of an organism in which movement of organelles