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INSIDE SCIENCE
LASERS AT WORK

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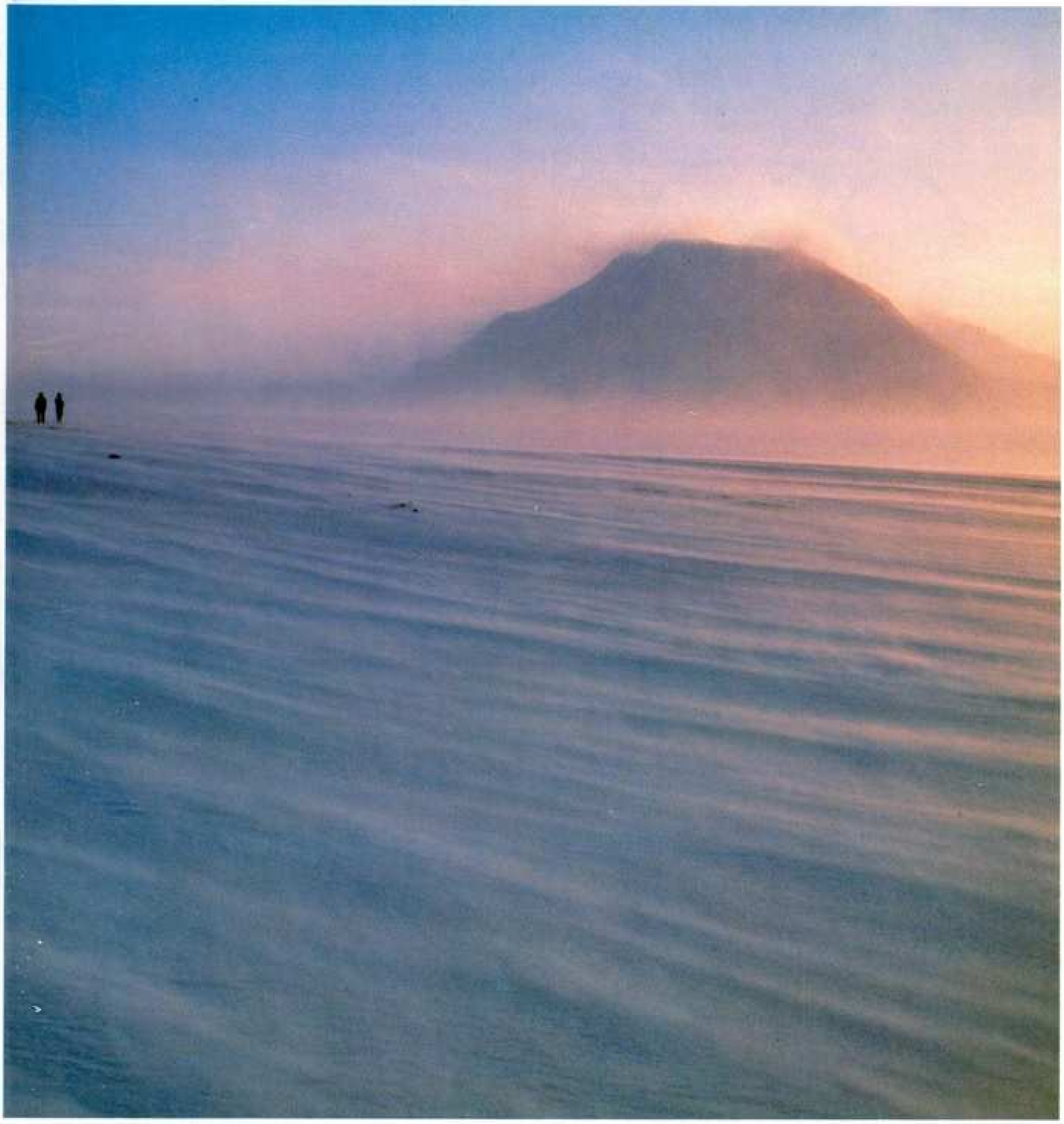


THE END OF THE ICE AGES

Snapshots of a chemical reaction

DIY satellites • Carry on cassava

Musical instrument plays quasicrystal tune

Piyush Ojha

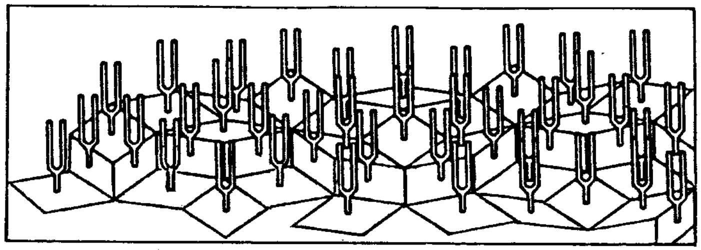
THE symmetry properties of a crystal lattice are crucially important in determining the energies and momentum that its electrons are permitted to have. These quantities in turn determine the physical and electrical properties of the bulk material. But for a class of crystals, known as quasicrystals, which exhibit a partial symmetry, physicists have no theory which predicts the motion of the electrons. The underlying symmetry is simply too complicated to deal with mathematically.

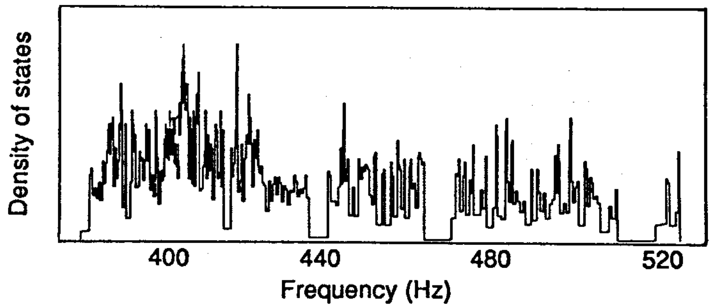
Now Shanjin He and Julian Maynard of Pennsylvania State University have built a "tuning fork" model of a quasicrystal (*Physical Review Letters*, 17 April, p 1889) with the vibrations of the forks mimicking the vibrations of the electrons. The model reveals features unique to the quasiperiodic symmetry, such as the appearance of distinctive gaps and bands in the sound spectrum which are in the ratio of the so-called golden mean $(\sqrt{5}+1)/2$. The model gives theorists clues as to how to build a rigorous theory of quasicrystals.

Quasicrystals were discovered only five years ago. They are thought to exhibit a type of long-range symmetry found by Roger Penrose of the University of Oxford. In 1974, Penrose found a way of tiling a flat plane in such a way that the pattern has a five-fold rotational symmetry; that is, the pattern is unchanged when rotated through one-fifth of a complete turn or 72 degrees. Previously, people had thought it impossible to tile a plane with five-fold symmetry without leaving gaps.

With conventional tiling of a plane, a single shape, such as a hexagon, is repeated periodically. Penrose tiling, on the other hand, makes use of two geometric figures. The figures, both rhombuses, one fat, one thin, have equal edge lengths but different internal angles. Penrose tiling is not periodic because the two rhombuses appear in the ratio $(\sqrt{5}+1)/2$, the golden mean of Greek architecture, which is an irrational number.

Normal crystals are both spatially ordered and orientationally ordered. This means that they are composed of a stack of identical copies of a fundamental structural unit cell, and all the unit cells are orientated in the same way. The Penrose tiling of quasicrystals, on the other hand, has perfect orientational order but only approximate translational order.





Tuning fork crystal: the forks are mounted at the centre of the tiles of a Penrose pattern and joined by wires. When the instrument is strummed, certain frequencies bands are absent

He and Maynard have constructed a "musical instrument" to investigate the mathematical properties of electron waves in a medium with the quasiperiodicity of Penrose tiling. They can do this because the quantum mechanical system is mathematically identical to the acoustic system. Technically, their experiment simulates the Schrödinger wave equation with a quasiperiodic, or Penrose tile, potential.

He and Maynard construct a "tuning fork" crystal by gluing identical tuning forks in the centre of each rhombus of a Penrose pattern in a sturdy aluminium plate. Each fork vibrates at 400Hz, which is near A flat above middle C. The researchers orient all the prongs in the same way and link each tuning fork to its neighbours by steel wires. This ensures that the vibrations of each fork are communicated to the rest of the network at the speed of sound in the wire material.

He and Maynard then measure the "musical range" of their instrument, that is, the notes it can sustain. They do this by bringing a vibrating electromagnet near it and recording its response with the pickup of an electric guitar.

The experimenters find that the resonant notes fall in allowed bands with prominent gaps between them, very much like the allowed energies of electrons in a normal crystal. The golden mean, so important in the underlying symmetry of the Penrose pattern, runs like a leitmotif throughout the range. Consecutive bandgaps as well as consecutive bandwidths are in the ratio of the golden mean or its integral powers.

He and Maynard note that with rings of several tuning forks, there is an opportunity for constructive or destructive interference among the waves. The researchers believe that this may explain the spectrum of frequencies, in particular the distinctive gaps where no vibrations are allowed.

He and Maynard also measured with appealing simplicity the state of the motion of each tuning fork. They glued a tiny mirror on the end of each prong and mounted the whole assembly on one wall of a dark room. It was then set vibrating and rapidly scanned by a tunable laser beam. The reflected beam recorded an amplified image of the motion of the tuning forks on photographic paper which was mounted on the opposite wall of the dark room. In this way, the researchers recorded several patterns with five-fold symmetry as well as other symmetries. □

Amino acids give clue to mass extinction

GEOCHEMISTS in California have found amino acids at the boundary between the Cretaceous and Tertiary periods. The acids seem to be extraterrestrial in origin and support the idea that the impact of a major body, more than 10 kilometres across, killed off the dinosaurs 65 million years ago. Until now, the main evidence for this theory has been the high concentration of iridium, a rare element in the Earth's crust, at the Cretaceous/Tertiary boundary. Some, however, have disputed that the iridium was extraterrestrial in origin, invoking a volcanic origin instead.

The chemists, Meixun Zhao and Jeffrey Bada of the Scripps Institution of Oceanography in La Jolla, discovered the amino acids in sediment at Stevns Klint in Denmark (*Nature*, 8 June, p 463). They found traces of both α-amino-isobutyric acid and racemic isovaline. The amino acids are exceedingly rare on Earth but are major amino acids found in carbonaceous chondrites, unusual meteorites rich in organic material. Carbonaceous chondrites compose a few per cent of meteorites.

Zhao and Bada used standard chromatographic techniques to isolate the amino acids. Their chiral analysis showed the isovaline to be racemic, containing both right- and left-handed forms, a result which would not be expected if their sample had been biologically contaminated. On the other hand, there are problems with the results. The amount of α-amino-isobutyric acid is about five times the maximum expected from a carbonaceous chondrite. Considerable destruction of organic material would be expected after its heated passage through the atmosphere.

According to Zhao and Bada, this might not be a problem if the body which struck the Earth was a comet. Little is known, however, about organic material in comets. The data obtained by the Soviet Vega mission to Halley's Comet showed no evidence of amino acids. On the other hand, the elements which compose amino acids are much more abundant in comets than meteorites.

A second problem is that although the two amino acids are abundant above the Cretaceous/Tertiary boundary, they are absent in the boundary clay itself. Zhao and Bada say further analysis is needed to find whether it is in fact present in this layer. □