Natural quasicrystal found in a museum specimen

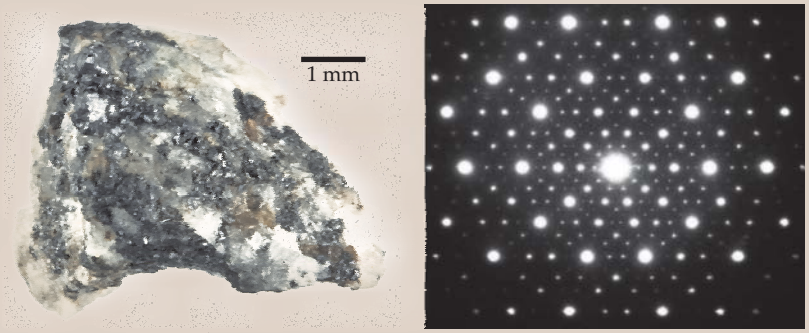
The hallmark of a conventional crystal such as table salt is translational symmetry; a single unit cell repeats at regular intervals. That defining symmetry imposes long-range correlations, but it also greatly restricts the rotational symmetry that crystals can exhibit. Celebrated theorems nearly 200 years old permit only two-, three-, four-, and sixfold symmetry axes.

Quasicrystals do not have the translational symmetry of crystals, but they do have a subtle long-range order. Along any symmetry axis of a quasicrystal, the placement of atoms can be expressed as a sum of two or more periodic functions. But the wavelength ratio for any two of those functions is irrational, and as a result, no single periodic function can represent the atomic positions. The atoms' quasiperiodicity—indeed, "quasicrystal" is short for quasiperiodic crystal—implies long-range correlations and, as with conventional crystals, allows quasicrystals to display sharp, structure-revealing diffraction patterns. The freedom from translational invariance enables quasicrystals to have a wealth of rotational structures not allowed in crystals; the first quasicrystal to be discovered, for example, displayed fivefold symmetry axes (see reference 1 and PHYSICS TODAY, February 1985, page 17).

To date, more than 100 quasicrystal specimens have been synthesized in the laboratory. Now Luca Bindi of the Natural History Museum of Florence in Italy, Princeton University's Paul Steinhardt, and colleagues from Princeton and Harvard universities have reported the first observation of a natural version of one of those quasicrystals[2]—icosahedral $Al_{63}Cu_{24}Fe_{13}$. The material, a 100-μm grain, is from a mineral assemblage (left figure) now housed in the Florence museum, where it is listed as coming from the Koryak region of far-eastern Russia. The main component in the assemblage is khatyrkite ($CuAl_2$), but the sample also includes cupalite (CuAl) and other minerals.

The search that led to the natural quasicrystal began about 10 years ago. By that time the International Centre for Diffraction Data (ICDD) had published a catalog of 80 000 x-ray powder diffraction patterns obtained from both synthetic materials and minerals. Because the smashed-up crystals of a powder have random orientations, the sharp diffraction spots that one would obtain with a pure crystal or quasicrystal are smeared into circles. Nonetheless, one might hope that the spacing of the circles would reveal the underlying symmetry of the powdered material. Could the ICDD database be systematically explored and possible quasicrystal candidates identified?

That was the challenge Steinhardt posed a decade ago to Peter J. Lu, then his undergraduate thesis student. Lu rose to the task, and in 2001 he, Steinhardt, and two other Princeton colleagues announced the results of their systematic search through the ICDD catalog, including a list of quasicrystal candidates that merited further study.[3] At the end of the paper, Lu and Steinhardt invited anyone with a plausible quasicrystal candidate to get in touch with them for possible collaboration. Two years ago Bindi took them up on their offer: After a painstaking search through numerous minerals and consultations with his US-based colleagues, he identified the Florence museum's khatyrkite sample as possibly hosting a quasicrystal. The US team then probed a small piece of it with transmission electron microscopy. Diffraction patterns such as the 10-fold symmetric pattern shown in the right figure identified quasicrystal regions. Subsequent x-ray fluorescence analysis of pure quasicrystal grains determined the material's chemical formula.



Geologists and physicists have much to learn about the conditions under which quasicrystals form. The study of natural materials can help address that question and may turn up new, never previously contemplated structures. **Steven K. Blau**

References

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The rate at which they could generate random bits was limited not by any aspect of their procedure but by the characteristic time scale of the chaotic laser intensity oscillations. They found that at sampling rates up to 1.7 GHz, their method generated sequences in real time that passed statistical tests for randomness. Small drifts in the lasers' average intensities, however, could throw off the sequence's balance of ones and zeroes, so the lasers needed to be kept carefully tuned.

Significant discard

The Bar-Ilan researchers sample the intensity of a single, inexpensive, edge-emitting diode laser—again, with a sampling time incommensurate with the laser feedback time—digitize the measurements using an eight-bit analog-to-digital converter, and compute the differences between pairs of successive measurements. For each difference, an eight-bit binary number, they discard the three most significant bits and keep only the five least significant.

Their method avoids the problem of sensitivity to intensity drifts: Even if the distribution of intensity measurements is skewed to one side or the other, the differences between measurements must be symmetrically distributed—what goes up must come down. Using only the least significant bits of each difference measurement allows them to avoid any measurable correlation between measurements made during different repetitions of the oscillation cycle. It also allows them to make measurements slightly more frequently, up to 2.5 GHz. Since each new measurement adds five bits to their sequence, they can generate up to 12.5 billion random bits per second.

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References

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