the mechanisms of this organic-to-inorganic exciton transfer.

Transforming the triplet excitons produced via SF into useful photocurrent remains an open challenge, but the results of these two papers represent an important step along the way. The hybrid organic–QD materials studied by these two groups represent an exciting frontier in optical materials that may have far-reaching implications for future development of solar cells. ❐

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MATERIAL WITNESS

BEYOND THE CRYSTAL

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The International Year of Crystallography has understandably been a celebration of order. From Rene-Just Haüy's prescient drawings of stacked cubes to the convolutions of membrane proteins, *Nature Milestones in Crystallography*[1] revealed a discipline able to tackle increasingly complex and subtle forms of atomic-scale regularity. But it seems fitting, as the year draws to a close, to recognize that the road ahead is far less tidy. Whether it is the introduction of defects to control semiconductor band structure[2], the nanoscale disorder that can improve the performance of thermoelectric materials[3], or the creation of nanoscale conduction pathways in graphene[4], the future of solid-state materials physics seems increasingly to depend on a delicate balance of crystallinity and its violation. In biology, the notion of 'structure' has always been less congruent with periodicity, but ever since Schrödinger's famous 'aperiodic crystal' there has been a recognition that a deeper order may underpin the apparent molecular turmoil of life.

The decision to redefine crystallinity to encompass the not-quite-regularity of quasicrystals is, then, just the tip of the iceberg when it comes to widening the scope of crystallography. Even before quasicrystals were discovered, Ruelle asked if there might exist 'turbulent crystals' without long-ranged order, exhibiting fuzzy diffraction peaks[5]. The goal of 'generalizing' crystallography beyond its regular domain has been pursued most energetically by Mackay[6], who anticipated the link between quasicrystals and quasiperiodic tilings[7]. More recently, Cartwright and Mackay have suggested that structures such as crystals might be best characterized not by their degree of order as such but by the algorithmic complexity of the process by which they are made — making generalized crystallography an information science[8]. As Mackay proposed, "a crystal is a structure the description of which is much smaller than the structure itself, and this view leads to the consideration of structures as carriers of information and on to wider concerns with growth, form, morphogenesis, and life itself."[6]

These ideas have now been developed by Varn and Crutchfield to provide what they call an information-theoretic measure for describing materials structure[9]. Their aim is to devise a formal tool for characterizing the hitherto somewhat hazy notion of disorder in materials, thereby providing a framework that can encompass anything from perfect crystals to totally amorphous materials, all within a rubric of 'chaotic crystallography'.

Their approach is again algorithmic. They introduce the concept of 'ε-machines', which are minimal operations that transform one state into another[10]: for example, one ε-machine can represent the appearance of a random growth fault. Varn and Crutchfield present nine ε-machines relevant to the crystallography of ordered and disordered materials, and their operation to generate a particular structure is a kind of computation that can be assigned a Shannon entropy, like more familiar computations involving symbolic manipulations. Any particular structure or arrangement of components can then be specified in terms of an initially periodic arrangement of components and the amount of ε-machine computation needed to generate from it the structure in question. The authors demonstrate how, for a simple one-dimensional case, diffraction data can be inverted to reconstruct the ε-machine that describes the disordered material structure.

Quite how this will play out in classifying and distinguishing real materials structures remains to be seen. But it surely underscores the point made by D'Arcy Thompson, the pioneer of morphogenesis, in 1917: "Everything is what it is because it got that way."[11] ❐

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