impact on this devastating condition. Finally, treatments that would target not just Aβ but also other disease pathways, such as tau accumulation and inflammation, might form the ideal approach. ■

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MATERIALS SCIENCE

A tale of two tilings

Sharon C. Glotzer and Aaron S. Keys

What do you get when you cross a crystal with a quasicrystal? The answer is a structure that links the ancient tiles of Archimedes, the iconic Fibonacci sequence of numbers and a book from the seventeenth century.

Quasicrystals are mosaic-like arrangements of atoms that have symmetries once thought to be impossible for crystals to adopt[1]. Primarily observed in certain metal alloys, these unusual structures are stronger and less deformable than analogous regular crystals, and have unusual frictional, catalytic and optical properties. Several applications have been proposed for quasicrystals — for example, some could be used as materials for photonic circuits[2]. But for this application to be realized, the atomic dimensions of a quasicrystal must first be scaled up almost 1,000-fold. On page 501 of this issue[3], Mikhael *et al.* describe quasicrystals at just such a scale, made from microscopic plastic beads. To their surprise, they also discovered a new kind of structure: a rare type of one-dimensional quasicrystal that can be thought of as a cross between a two-dimensional quasicrystal and a regular crystal.

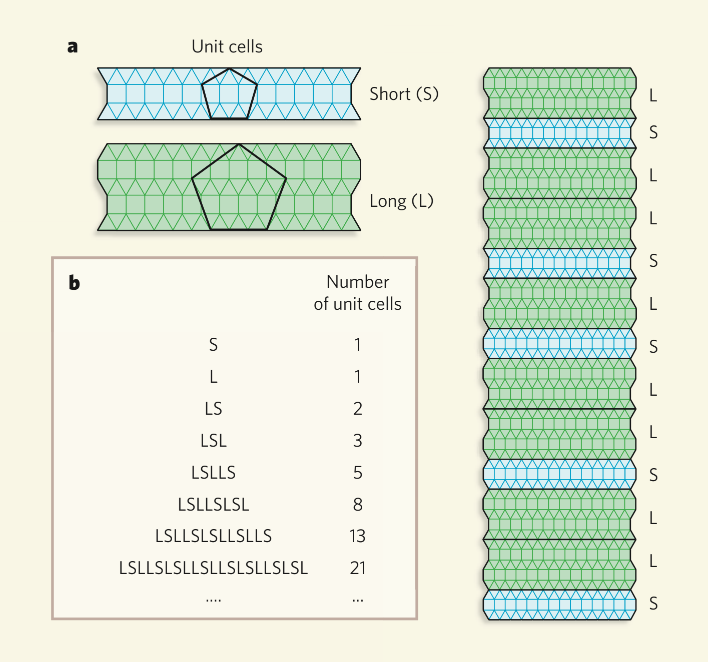
Mikhael *et al.* grow single layers of colloidal particles on a templated surface designed to attract those particles and arrange them into pentagons — the primary motif of a quasicrystal with tenfold (decagonal) symmetry. They do this by arranging five laser beams to form an interference pattern that confers decagonal symmetry to the surface's potential, which interacts with the particles[4]. By tuning the strength of the surface potential using the lasers, the team controls the formation of the growing structures: regular crystals form when particle–particle interactions dominate, and quasicrystals form when particle–surface interactions dominate. The resulting quasicrystals exhibit rings of ten particles surrounding a central particle (see Fig. 1c on page 501).

Quasicrystals are often considered to be intermediate between glasses (amorphous solids) and crystals[5]. But can a structure be intermediate between a crystal and a quasicrystal? Conventional thinking says no — long-range ordering must be either periodic (crystalline) or aperiodic (quasicrystalline), with little room in between. But Mikhael *et al.*[3] find that, when the particle–particle and particle–surface interactions in their system are similar in strength, an intermediate phase forms that combines elements of both crystalline and quasicrystalline ordering. In fact, the particles assemble into something that closely resembles an Archimedean tiling pattern.

Archimedean tilings are periodic arrangements of regular polygons laid edge-to-edge in a plane. Their defining feature is that only one kind of vertex must exist — that is, where the corners of the polygons meet at a point, any given corner must always meet the same combination of corners from other polygons. Archimedean tilings have been used in art and architecture since antiquity, but it was the astronomer Johannes Kepler who first classified them in his book, *Harmonices Mundi*, in 1619. Kepler showed that there are eleven different kinds of tiling, eight of which contain more than one type of regular polygon. One tiling consists entirely of equilateral triangles, and is denoted (3^6) to indicate that six triangles meet at each vertex. This structure describes the crystal that Mikhael *et al.* observe when particle–particle interactions dominate. Another Archimedean tiling denoted $(3^3,4^2)$ consists of alternating rows of squares and triangles.

Mikhael and colleagues' new arrangement of particles is similar to the $(3^3,4^2)$ arrangement, with some (3^6) vertex configurations added in a peculiar way. The particles form alternating rows of squares and triangles, which are interrupted intermittently by 'defects' — additional rows of triangles that introduce (3^6) vertex configurations to the tiling (Fig. 1). The particles still align locally with the decagonal, quasicrystalline template, but a mismatch between the periodic tiling and the aperiodic substrate arises over longer distances. This is where the defects come in — the extra rows of triangles correct the mismatches.

The defects result in two distinct 'unit cells' (basic arrangements from which the tilings are constructed) that have different heights (Fig. 1). The heights of the cells correspond to the heights of the large and small pentagonal arrangements that are conferred on the particles by the underlying template field. The cells stack in a quasiperiodic pattern known as a Fibonacci chain. Named after a famous mathematician of the Middle Ages, this pattern is often found in nature, and describes the



	Number of unit cells
S	1
L	1
LS	2
LSL	3
LSLLS	5
LSLLSLSL	8
LSLLSLSLLSLLS	13
LSLLSLSLLSLLSLSLLSLSL	21
....	...

Figure 1 | A tiling structure based on the Fibonacci chain. a, Mikhael ***et al.***[1] **have discovered a new arrangement that can be adopted by particles in two dimensions. The structure, shown here in idealized form, consists of two unit cells of different widths (short, S, or long, L) that stack up on top of each other. The heights of the cells correspond to the heights of the small and large pentagons, whose size ratio is given by the 'golden mean'. Particles sit at the vertices of the tiles. b, The order of unit cells is described by a Fibonacci chain — a quasiperiodic sequence that starts from just one unit cell and expands by applying the substitution rules L→LS, S→L at each step. The sequence with 13 elements describes the arrangement of unit cells in the structure shown on the right.**

structure of one-dimensional quasicrystals[1]. In Mikhael and colleagues' system, the Fibonacci chain determines the sequence of long and short cells. Because the Fibonacci chain is self-similar, the structure can also be described by simpler unit cells consisting of single rows of squares and triangles.

When grown on an icosahedral quasicrystalline surface, certain copper alloys also adopt a curious phase in which the atoms have a Fibonacci spacing[6]. The exact structure of the phase has not yet been identified, but its diffraction pattern is identical to that of Mikhael and colleagues' Archimedean-like arrangement of particles. If the two phases are indeed the same, it would demonstrate the universality of the underlying physics that controls the templated growth of these unusual structures. Furthermore, it would extend the growing use of colloids as minimal models of atoms for studying self-assembly[7] and other physical processes.

Archimedean tilings can also form from macromolecules that consist of three chemically distinct polymers, covalently bonded together at one end to form a three-armed 'star'[8]. Under certain conditions, these systems spontaneously form cylinders that have a cross-section corresponding to one of four Archimedean tilings. Two of these structures have useful optical properties and, like quasicrystals, hold promise for photonic applications.

It is not clear whether Archimedean-like tilings have a general role as intermediates between periodic and aperiodic structures. Such intermediates must be able to locally align with both the corresponding quasicrystal and crystal structures, and be able to incorporate aperiodically arranged defects. The ability to mix and match motifs may give Archimedean-tiling motifs a unique flexibility that makes them prone to forming aperiodic arrangements. For example, the dodecagonal quasicrystal[9], which exhibits 12-fold, rather than 10-fold, rotational symmetry, is made up of three different Archimedean vertex configurations, also called quasicrystal approximants.

Ultimately, we should not think of Mikhael and colleagues' structure[3] as a flawed Archimedean tiling. The underlying structure is a perfect Fibonacci chain, the elements of which are decorated with infinite rows of Archimedean tiles. From this perspective, it is a unique kind of one-dimensional quasicrystal, periodic in one dimension, but quasiperiodic in the other. This is what you get when you cross a crystal with a quasicrystal — a beguiling new tiling built upon iconic mathematical foundations. ■

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GENOMICS

Thoroughly modern meiosis

Michael Lichten

Meiotic recombination shuffles the genome, so each generation inherits a new combination of parental traits. Combining traditional and modern approaches, new work pinpoints where recombination occurs genome-wide.

During meiosis, a diploid cell (with two copies of each chromosome, one from each parent) undergoes two rounds of cell division, producing haploid gametes — in animals, these are sperm or eggs containing a single copy of each chromosome. Genetic recombination, which occurs at high levels during meiotic cell division, is crucial for chromosome separation in the diploid-to-haploid transition, and mixes parental genomic sequences to generate genetic diversity in the next generation. On page 479 of this issue, Mancera *et al.*[1] present the first comprehensive description of the meiotic recombination events that occur across an entire genome during a single meiosis, and provide tantalizing mechanistic insight into this process.

Much understanding of recombination mechanisms comes from studies in fungi such as budding yeast (*Saccharomyces cerevisiae*), where all four haploid meiotic segregants can be recovered. Genetic analysis of this ensemble of meiotic products, called a tetrad, led to the identification of fundamental features of meiotic recombination, such as gene conversion — the unidirectional replacement of genetic information on one parental chromosome by genetic information from another chromosome[2]. But such analysis is labour-intensive and limited in scope. Because of the limited availability of conventional genetic markers, only a small portion of the yeast genome has been examined in detail, and hundreds of tetrads need to be analysed to detect recombination events in sufficient numbers.

Mancera *et al.* overcame these limitations by combining traditional tetrad analysis with modern high-throughput molecular methods for the genome-wide scoring of sequence variations (polymorphisms). They mated two budding-yeast strains that are cross-fertile but have diverged evolutionarily, and that have sequence differences (mostly single-nucleotide changes) at almost 70,000 genomic sites[3]. Of these, 52,000 polymorphisms could be scored as genetic markers, allowing the detection of recombination throughout the genome at an unprecedented level of resolution and efficiency. The authors captured most of the recombination events that occurred in each of 51 separate meioses (6,289 events in total), and this allowed them to address several

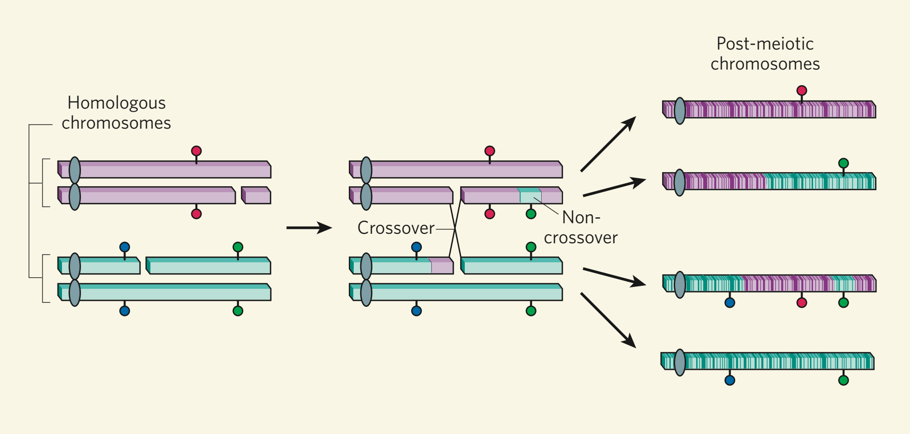

Figure 1 | **Detecting meiotic recombination.** Meiosis-induced DNA double-strand breaks are repaired by either crossover or non-crossover recombination, both of which are associated with gene conversion. Recombination between two parental homologous chromosomes can be detected only if they differ in genetic markers. In the example shown, tetrad analysis using conventional genetic markers (blue, red and green lollipops; centre) detects events with much less resolution than the high-density marker analysis (purple and green cross-hatches; right) used by Mancera *et al.*[1].