Optically condensed matter

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One of the forefronts of solid state physics has been the synthesis of crystals of exotic symmetry. Quasicrystals are the latest in this family. But the architectural symmetry of crystals is to be ultimately traced to the forces of interaction between the constituent atoms or molecules, over which one does not have control. In the early seventies Ashkin[1] of AT and T Bell Laboratories initiated a programme of literally constructing a crystal by 'other' means. The first successful attempt of truly 'designing and fabricating' such crystals was reported recently by Burns, Fournier and Golovchenko[2]. They built two-dimensional crystals with dielectric spheres of micron size as 'atoms'. An optical standing-wave pattern with a regular array of nodes and antinodes was created in a fluid medium (like water) containing these spheres. These spheres later organized themselves by occupying the antinodes, being driven there by the optical forces. A variety of two-dimensional crystals, including a quasicrystal, the current curiosity in condensed matter physics, have been manufactured.

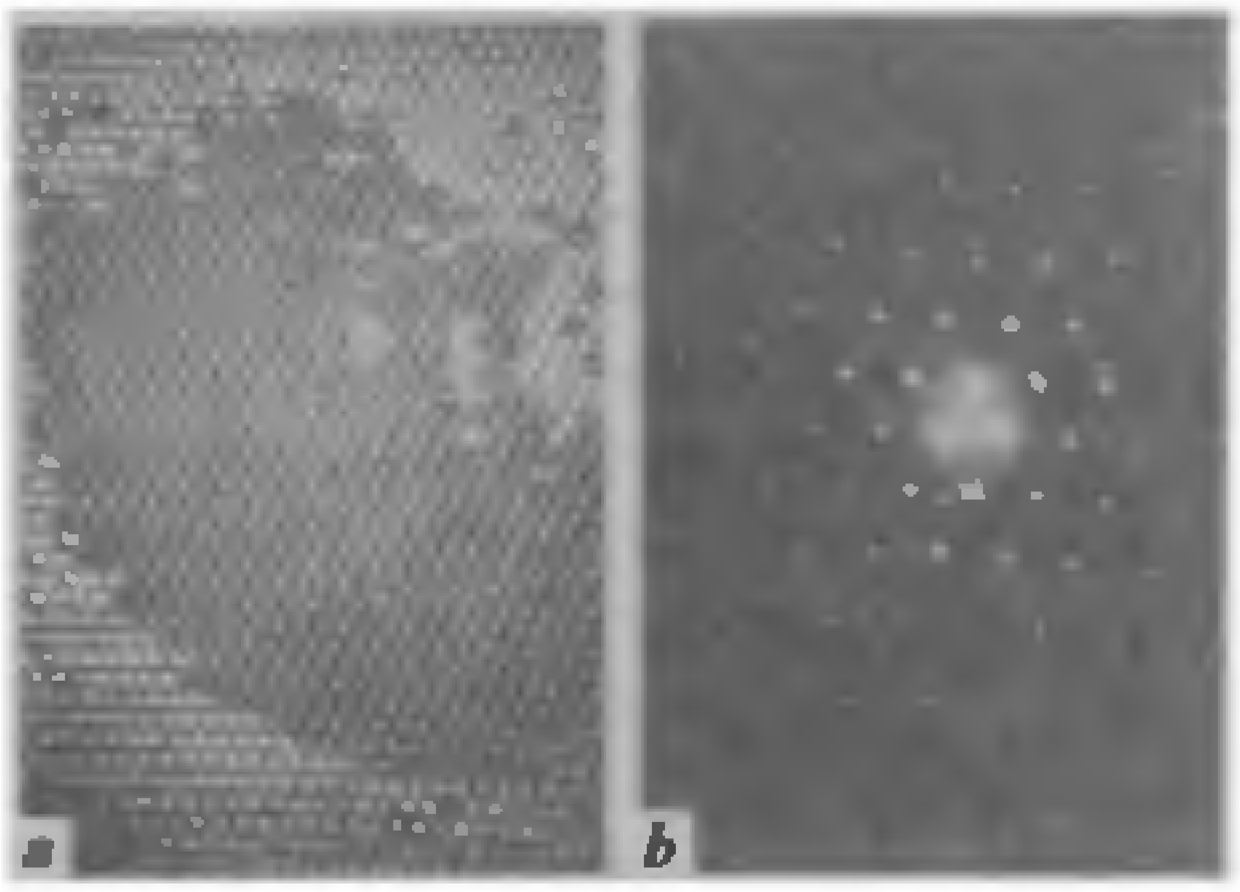

Figure 1. Optical hexagonal crystal.
a, Crystallization of dielectric spheres in a 2D hexagonal optical lattice created by three equally inclined identical laser beams. ***b***, its optical diffraction pattern. [From Burns, M. M., Fournier, J.-M. and Golovchenko, J. A., *Science*, 1990, 249, 749]

Light from a 10-W argon-ion laser working at 5145 Å was first split into multiple beams that could be carefully controlled, and later brought to a common focus on a sample cell which contained the spheres to be crystallized. In a few seconds, the radiation pressure from the incident laser light lifted the spheres from the bottom to the top of the cell, where they collected at the periodic positions of the intensity maxima of the standing-wave field. The standing-wave intensity modulations effectively trapped the spheres even against the ever-present Brownian motion. The structure, along with the accompanying diffraction pattern, can be seen in an imaging system. With two beams one gets a periodic row of optical traps resulting in a 1D lattice in one direction and with fluid order for spheres along the orthogonal direction, i.e. the length of the trap. Three equiangular beams give rise to a 2D hexagonal lattice (see Figure 1). Interestingly, with five equiangular beams, one gets a 2D quasicrystal (see Figure 2). Quasicrystals have long-range orientational order, but no long-range positional order. In these experiments the spheres were trapped at positions of intensity maxima. However, extrapolating from experiments of Ashkin[1] we can expect in future crystals with particles at nodes if they are metallic spheres.

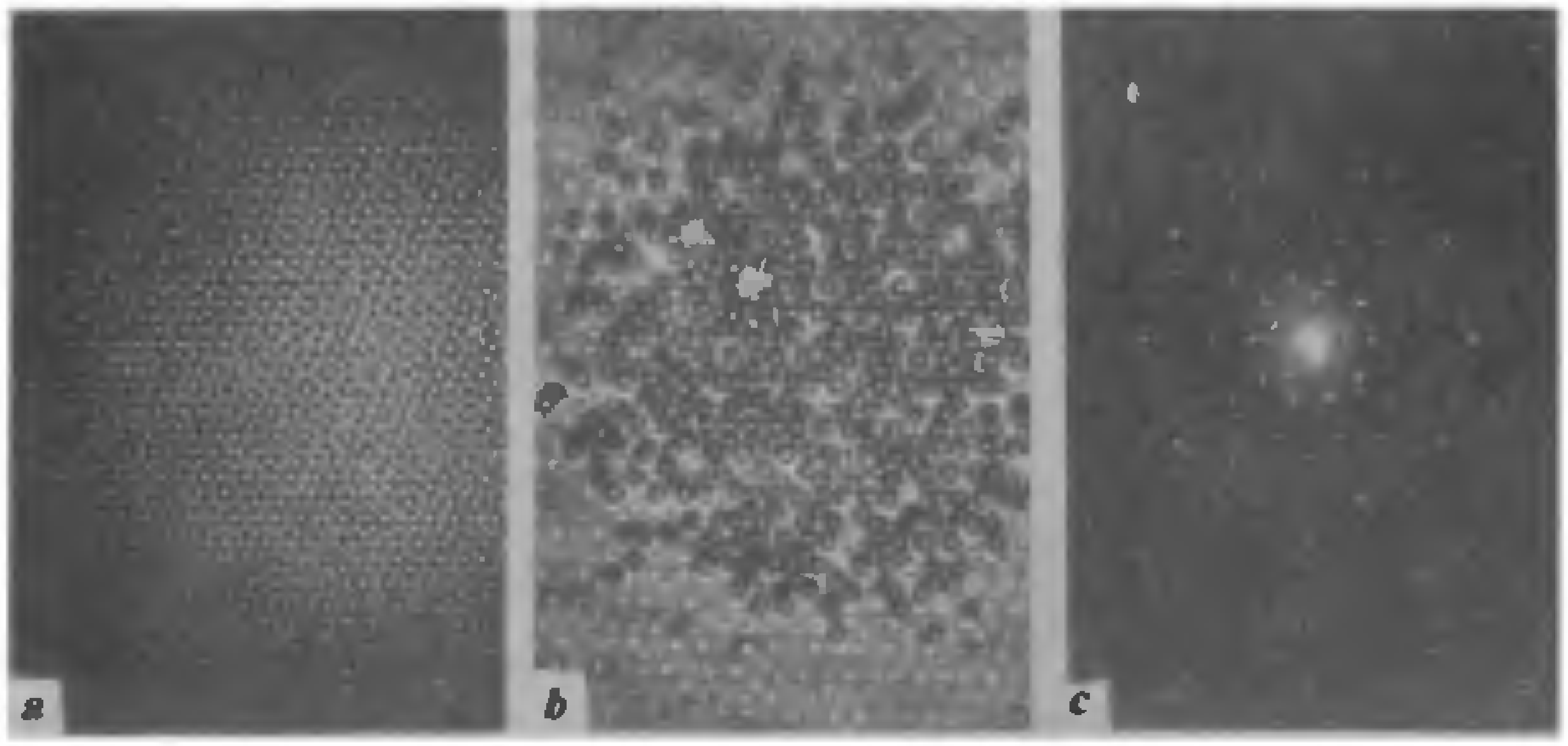

Figure 2. Optical quasicrystal.
a, A 2D quasicrystal lattice due to five equally inclined laser beams. ***b***, condensation of spheres; ***c***, the associated diffraction pattern [From Burns, M. M., Fournier, J.-M. and Golovchenko, J. A., *Science*, 1990, 249, 749]

During the course of these crystallization studies Burns *et al.*[3] discovered a new type of interaction between spheres. An 'optical well' was created with a single Gaussian beam 15 or 20 times larger than an individual sphere. When spheres were added, one by one, into this trap, a close-packed crystal of spheres began to appear centred on the beam. The exchange of light energy between the scatterers results in a force of interaction. As a result any two spheres get locked at separations that are integral multiples of the wavelength of the optical field. This fact is borne out by their experiments as well. This 'new' optical binding results from the time-averaged magnetic force from retarded radiation field current–current interactions.

Such optically organized spheres—called 'optical matter'—represent an important field of study, since optically induced forces are amenable to continuous external control both in intensity and geometry. By contrast, in ordinary matter this flexibility is not available. As the authors speculate, the statistical mechanics of such structures should provide a wealth of material for future experimental and theoretical research. By *in situ* freezing, hardening or curing of the fluid medium, it should be possible to get structures that are stable in the absence of a sustaining light.

In view of the fact that anisotropic particles orient themselves with respect to the laser beam[1], we can hope for optically condensed crystals with orientational order as well, due to aligned anisotropic particles.

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1. Ashkin, A., *Science*, 1980, **210**, 1081.
2. Burns, M. M., Fournier, J.-M. and Golovchenko, J. A., *Science*, 1990, **249**, 749.
3. Burns, M. M., Fournier, J.-M and Golovchenko, J. A., *Phys. Rev. Lett.*, 1989, **63**, 1233

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