MATERIALS SCIENCE

Refrigeration based on plastic crystals

Materials called plastic crystals have been found to undergo huge temperature changes when subjected to small pressures near room temperature. Such materials could form the basis of future refrigeration technologies. See Letter p.506

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Materials known as plastic crystals are composed of molecules that interact through weak long-range forces. As a result, these materials are highly compressible and can be deformed in a reversible manner — hence the adjective ‘plastic.’ Under certain pressure and temperature conditions, molecules in plastic crystals can start rotating almost freely around their centres of mass. The centres of mass remain localized at well-defined and ordered positions in the crystal lattice, but the rotation leads to orientational disorder. On page 506, Li et al. report that the phase transition between molecular order and disorder in plastic crystals can be used for cooling purposes through the application of small pressures. Conventional refrigeration technologies are based on cycles in which greenhouse gases are alternately compressed and expanded. One kilogram of a typical refrigerant gas contributes as much to the greenhouse effect in our planet’s atmosphere as two tonnes of carbon dioxide, which is the equivalent of running a car uninterruptedly for six months (see go.nature.com/2ffbqvt). In addition, current cooling technologies cannot be scaled down to the dimensions of microchips, which hinders the development of faster and more-compact computers and portable electronic devices. There is therefore a pressing need to find eco-friendly and highly scalable cooling methods for improving many crucial technologies, as well as for protecting the environment.

Solid-state cooling is an environmentally friendly, energy-efficient and highly scalable technology that could solve most of the problems associated with current refrigeration methods. It relies on applying cycles of external magnetic, electric or mechanical fields to compounds called caloric materials. These compounds undergo temperature variations as a result of field-induced phase transitions that involve large changes in entropy — a measure of disorder.

Examples of caloric materials include ferroelectrics, organic–inorganic hybrid perovskites and fast-ion conductors. However, most known caloric materials are not ideal. Some have only modest refrigeration performances, for example, or operate at temperatures different from ambient conditions. And for others, durability and cycling rate can be affected by material fatigue and phase-transition hysteresis — in which the conditions required for completing a phase transition depend on the direction of the transition. Consequently, progress in solid-state cooling has been limited.

Li and colleagues’ work offers exciting possibilities. They have found that plastic crystals undergo huge temperature changes when subjected to small pressures near room temperature. These materials could be used for refrigeration, providing an environmentally friendly and efficient alternative to conventional cooling technologies.

Figure 1 | Phases and potential cooling application of plastic crystals. a, In materials known as plastic crystals, the orientations of the molecules can be either ordered or disordered. b, Li et al. demonstrate that these materials could be used for refrigeration. In this simple, four-step refrigeration cycle, a plastic crystal is initially in the disordered phase at a temperature $T_1$. First, pressure is applied to the crystal, which causes the ordered phase to be stabilized and the crystal’s temperature to increase to a value $T_2$. Second, a heat sink absorbs heat from the crystal and the crystal’s temperature returns to its initial value. Third, pressure is removed from the crystal such that the disordered phase is recovered and the crystal’s temperature decreases to a value $T_3$. Fourth, the crystal absorbs heat from a heat source and returns to its initial temperature, thereby cooling the heat source.
Lipopolysaccharide transport ratcheted up

A protein complex that moves molecules called lipopolysaccharides between the two cell–wall membranes of certain bacteria is a target for drugs. Structures reveal how this complex delivers its load irreversibly.

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Many bacteria that cause infections are surrounded by two distinct membranes, which form part of their protective cell wall. The surface of the outer membrane includes a tightly packed layer of glycolipid molecules known as lipopolysaccharides (LPSs), which provide a barrier against harmful detergents and antibiotics. The LPSs are synthesized in the inner membrane, before being transported and assembled in the outer membrane — the molecules are extracted from the external layer of the inner membrane and shuttled across a bridge to the outer membrane, before emerging on the cell surface. Two papers,\(^1,2\) in this issue now provide long-awaited details of the molecular processes that drive LPS transport.

The structures of six of the seven components of the LPS transport apparatus (known as LptA–G) have been fully characterized\(^4\). They reveal that a portal for LPS molecules forms from the LptD and LptE subunits in the outer membrane, and is connected to a pump in the inner membrane (formed from LptF, LptG and two LptB subunits) by a bridge, which includes one or more LptA subunits (Fig. 1). The pump is driven by the binding and hydrolysis of cytoplasmic ATP, the cell’s energy-carrying molecule, but how it binds to LPSs from the inner membrane and pumps them only in the outward direction was unknown. A full-length structure of the inner-membrane protein LptC was needed to complete the puzzle and to explain how the pump is connected to the bridge.

However, the fact that most molecules in plastic crystals are polar does not guarantee that applying electric fields to these materials will eliminate the effects of hysteresis. The reason is that incredibly large electric fields (about 1,000 kilovolts per centimetre) might be needed to induce any effect on the molecular rotations, as has been shown theoretically for organic–inorganic hybrid perovskites\(^10\). A possible solution to this problem might be to find or engineer ferroelectric plastic crystals, in which the ordered phase already exhibits collective polar order\(^11\). Despite these challenges, Li and colleagues’ work represents a step towards finding other caloric materials that have advantageous properties.

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