This proportion is similar to other estimates of ZIKV prevalence in Salvador[9]. Such a high level of anti-ZIKV immunity should protect this population from another epidemic ZIKV spread for many years.

To investigate whether prior exposure to DENV contributed to the risk of ZIKV infection in the community studied, the authors calculated the incidence of DENV infection using serum samples collected before the introduction of ZIKV in 2015. They used a logistic regression statistical approach to establish the probability of ZIKV infection as a function of the quantity of IgG antibodies that react against the NS1 protein of DENV, which they determined using two serological assays.

Curiously, two patterns were observed. The concentration of total DENV NS1-reactive IgG antibodies (irrespective of their subclass) was inversely correlated with the probability of ZIKV infection (Fig. 1). This observation suggests that DENV immunity has a protective effect against subsequent ZIKV infection. It also agrees with findings from a recent study of a population in Nicaragua[10], and might explain the low incidence of Zika that is observed in areas of southeast Asia where DENV is endemic and highly prevalent. However, when the authors examined the subset of DENV NS1-reactive molecules of the IgG3 subclass, they observed that the concentration of these antibodies correlated positively with the frequency of ZIKV infection. These findings suggest that a recent exposure to DENV transiently increases the susceptibility of an individual to ZIKV infection.

Whether DENV NS1-reactive IgG3 antibodies have a direct role in the molecular mechanisms that increase the risk of ZIKV infection remains unknown. The NS1 protein is not part of the virus particle and also is not targeted by neutralizing antibodies. Therefore, NS1-reactive antibodies do not block virus infection directly, although they might contribute to limiting virus spread following infection. It is not clear whether DENV NS1-reactive IgG3 antibodies react against ZIKV.

The biological basis for the transient nature of the IgG3 response to flaviviruses is not fully understood. If IgG3 antibodies are indeed a marker of recent DENV exposure, it will be relevant to explore how changes in the repertoire or functional properties of cross-reactive antibodies in the months following DENV infection contribute to vulnerability to, or protection from, subsequent infection by ZIKV. Such studies might identify relationships between antibody binding sites on the virion and antibody function. These functional correlates could then be investigated further in animal models of infection, or used to identify a protective immune signature that could be monitored in trials of candidate vaccines.

Despite great strides in the understanding of the specificities and functions of human antibodies produced in response to flavivirus infections, much remains to be discovered about how they act together to protect against infection or occasionally worsen disease[11]. The analysis of well-characterized study populations in areas where these diseases are endemic, using innovative serological methods, holds great promise for identifying elements of the immune response and mechanisms of disease that will guide the development of countermeasures[3,5,10]. These same resources will be key for evaluating the impact of ZIKV immunity on subsequent DENV infections. ■

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QUANTUM PHYSICS

The next step in making arrays of single atoms

Three studies have demonstrated the cooling and trapping of single strontium and ytterbium atoms in two-dimensional arrays. Such arrays could lead to advances in atomic-clock technology and in quantum simulation and computing.

MARK SAFFMAN

The world around us is made of atoms. There are enormous numbers of them, even in small objects such as the computer chips and solid-state lasers that are the building blocks of the information age. Erwin Schrödinger, one of the inventors of quantum mechanics, wrote[1] in the 1950s that "we never experiment with just one electron or atom". However, laser-based techniques developed over the past 40 years are now routinely used to slow atomic motion and to isolate, trap and control certain individual atoms in focused laser beams. Two papers in *Physical Review X*, by Cooper *et al.*[2] and Norcia *et al.*[3], and a third published on the arXiv preprint server by Saskin *et al.*[4], report that these techniques can be extended to atoms that have two outer (valence) electrons, which opens up applications.

Research groups around the world use patterns of light to trap arrays of individual atoms in one, two and three dimensions for experiments in quantum simulation and computing[5,6]. These optical traps for atoms are analogues of the optical-tweezer technique used to confine large or electrically neutral particles, which has transformed the biological sciences[7] and was recognized with one-half of the 2018 Nobel Prize in Physics. The ability to trap individual particles is also having a substantial impact on the fields of atomic and quantum physics.

The methods of laser-based cooling and trapping as applied to electrically neutral atoms were first developed using alkali elements — those that occupy the first column of the periodic table. Alkali atoms have a single valence electron that interacts strongly with laser light at visible or near-infrared wavelengths. This strong interaction allows the atoms to be cooled and trapped relatively easily. Although remarkable advances have been achieved using alkali atoms, researchers have not shied away from exploring other columns of the periodic table in search of atoms with more-advantageous properties.

The three current papers demonstrate the ability to cool and trap single strontium[2,3] and ytterbium[4] atoms in 2D arrays of up to roughly 100 optical traps. Strontium is an alkaline-earth element — an element from the second column of the periodic table. Strontium atoms have two valence electrons and a more complex structure of electronic energy levels than alkali atoms. Although ytterbium is not an alkaline-earth element, ytterbium atoms also have two valence electrons and have properties and an energy-level structure that are similar to those of strontium atoms.

These two-valence-electron atoms have transitions of electrons between energy levels that, as in alkali atoms, can be used for

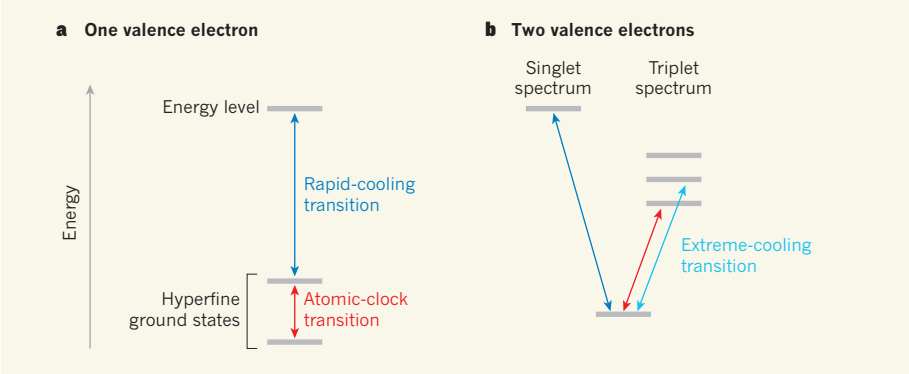

Figure 1 | Atomic energy-level structures. **a**, Atoms that contain one outer (valence) electron have a rather simple structure of electronic energy levels. Transitions of electrons between certain levels can be used to rapidly cool the atoms, whereas transitions between two levels, called hyperfine ground states, can be used to build a microwave-frequency atomic clock. **b**, Atoms that contain two valence electrons, such as strontium and ytterbium, have two separate energy-level spectra: a singlet spectrum and a triplet spectrum. These atoms have transitions that can be used for rapid cooling, as in one-valence-electron atoms. But they also have transitions that can be used in optical atomic clocks and to reach extremely low temperatures. Three papers[2–4] now report the cooling and confinement of individual strontium and ytterbium atoms.

rapid cooling. But they also have transitions that can be used to reach even lower temperatures. Such transitions are not present in alkali atoms (Fig. 1).

The demonstration of arrays of two-valence-electron atoms is an exciting development for other reasons. In the International System of Units (SI), the second is currently defined using the transition between two energy levels called hyperfine ground states in an atom of the alkali element caesium. This transition is associated with the emission or absorption of microwave-frequency light. However, advances in the past decade have shown that higher-accuracy atomic clocks can be built using transitions in atoms or ions at optical frequencies. The atoms that currently provide the most precise optical atomic clocks in the world[8] are the same as those that have now been individually trapped: strontium and ytterbium.

The new results have two implications for the development of future atomic clocks. In current practice, such clocks are based on lattices that have ensembles of up to a thousand atoms at each lattice site. Within each site, the atoms are randomly distributed, and the weak, but non-negligible, interactions between atoms contribute to uncertainty in time readings obtained from the clock. The ability to build arrays of strontium and ytterbium atoms one atom at a time will enable the spatial distribution of the atoms, and therefore their interactions, to be engineered in ways that could reduce sources of uncertainty.

The second implication for clock development is intimately connected to the potential use of strontium and ytterbium atoms as quantum bits (qubits) in quantum-information processing. There are several options for qubit encoding, because these atoms have both fermionic and bosonic isotopes — isotopes whose total numbers of protons and neutrons are odd and even, respectively. For the fermionic isotopes, qubits can be encoded in energy levels known as Zeeman substates. This encoding could involve a single qubit as in ytterbium-171, which has two substates, or many qubits as in strontium-87, which has ten substates[9]. For the bosonic isotopes, qubits can instead be encoded in the energy levels that form the basis of the optical atomic clock.

Once qubits have been encoded in suitable energy levels, interactions between qubits can be engineered to carry out operations called quantum logic gates and to produce quantum states that are entangled (correlated in a non-classical way). This engineering could be achieved using collisional interactions, as has been demonstrated for alkali atoms[10], or by using long-range interactions between atoms that are in excited 'Rydberg' states[6]. The latter interactions are the leading contender for quantum logic gates based on neutral-atom qubits.

Alternatively, many-atom entangled quantum states could be produced directly, without resorting to a laborious sequence of pairwise interactions, using methods known as Rydberg dressing techniques[11]. Irrespective of the approach chosen, the availability of entangled atoms would have the potential for achieving clock precision in which the uncertainty is inversely proportional to the number of atoms — a substantial improvement over the usual case of uncorrelated atoms, in which the uncertainty is inversely proportional to the square root of the number of atoms.

There is good reason to think that, with further development, arrays of single two-valence-electron atoms will lead to advances in optical atomic clocks. Although the focus has been on neutral-atom clocks, those based on ions have comparable accuracy, but their stability is limited because they use only a single ion. Arrays of single neutral atoms could

50 Years Ago

A two-armed bandit is two one-armed bandits. Suppose that you are playing a two-armed bandit and that at each play you are only interested in whether you win or lose. If the probabilities of winning are constant for a particular machine from one play to another, but are different between the machines and in any case are unknown to you and if, moreover, you can only remember what happened for the last *r* plays, what strategy should you adopt if your aim is to maximize your number of wins? … Sequential decision problems of essentially this sort occur quite frequently … Smith and Pyke … have developed what appear to be the best decision rules and now S. M. Samuels, in a paper called "Randomized rules for the two-armed bandit with finite memory" … shows that, by a very simple addition to these rules, startlingly better results may be obtained.

From *Nature* 29 March 1969

100 Years Ago

The Marconi Wireless Telegraph Co. is to be congratulated on having established experimental wireless telephonic communication between Clifden … in Ireland, and Cape Grace, in Canada … The improvements which have been made in thermionic valves — for instance, the reduction of the air-pressure in the valve to the one-hundred-millionth of a millimetre of mercury — have increased their sensitivity enormously. In addition, by connecting them "in cascade" there appears also to be no limit to the sensitivity that can be attained … Wireless telephone transmission is specially interesting, as it is free from many of the defects of ordinary telephony … There seems no reason to doubt that in a short time wireless telephony will be established between every country on the globe.

From *Nature* 27 March 1919

provide the best of both worlds: the accuracy of ion clocks and the stability that comes from using many atoms, without the uncertainty that stems from multi-atom interactions in present-day neutral-atom clocks.

Whether or not two-valence-electron atoms will prove to be superior to alkali atoms for quantum simulation and computing remains to be seen. Experiments have already demonstrated high-quality measurements of the quantum state of single strontium atoms[12]. The outlook for corresponding advances in Rydberg gates for computation is less certain, because the properties of Rydberg states in two-valence-electron atoms are more complex, and less-well studied, than those in alkali atoms. More work is required to accurately characterize these properties before a definite conclusion can be drawn. Nevertheless, the availability of arrays of single strontium and ytterbium atoms will provide a crucial experimental tool for such studies. ■

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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

CLAUDIO CAZORLA

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.*[1] 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[2], organic–inorganic hybrid perovskites[3] and fast-ion conductors[4]. 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

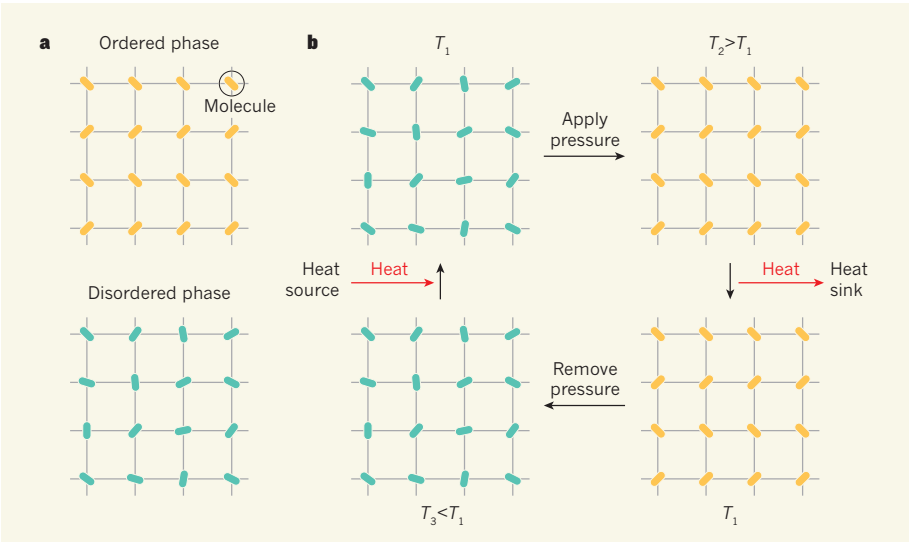

Figure 1 | Phases and potential cooling application of plastic crystals. **a**, In materials known as plastic crystals, the orientations of the molecules can be either ordered or disordered. **b**, Li *et al.*[1] demonstrate that these materials could be used for refrigeration. In this simple, four-step 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.