methanol[1] (Fig. 1). One can thus modify the peptide architecture at will to fabricate either quantum dots or nanotubes. The synergistic effect of millions of quantum dots in a single nanotube might make them a promising material for new types of optical devices, such as light-emitting diodes and lasers.

The optical and electronic properties of inorganic quantum dots can be fine-tuned by varying the size of the nanostructures. Could the properties of peptide quantum dots also be fine-tuned? The answer is probably yes. Because the size of peptide quantum dots is governed by the specific amino acids in the peptide, a large number and variety of naturally occurring and/or synthetically customized amino acids could be used in countless combinations. In this way, it might one day be possible to tweak the size and properties of peptide quantum dots. Indeed, the authors[1] have already shown that a dipeptide made from a phenylalanine and a tryptophan amino acid forms a quantum dot that has different optical and electronic properties from that of the diphenylalanine analogues.

Peptide quantum dots represent arguably one of the simplest forms of quantum dot, but they also offer distinct advantages over other types. First, they are made of natural amino acids that are synthesized by plants and animals, so they shouldn't be too harmful to the environment. Their degradation products will also be harmless natural amino acids. This is unlike most inorganic quantum dots, especially those made of heavy metals. Second, the preparation of dipeptide quantum dots requires the formation of a single peptide bond, which makes them cheap and easy to produce at very high purity. Finally, given the availability of a wide range of amino acids that have diverse properties, perhaps peptide quantum dots will be discovered that have properties not yet observed in other such materials. Nevertheless, much theoretical work is needed to guide further development of peptide quantum dots. Let us hope that Gazit, Rosenman and colleagues' findings will attract people from other disciplines to further advance this nascent field.

Although nature has produced numerous wonderful peptides and proteins, if peptides had been proposed as potentially useful synthetic materials two decades ago, few people would have taken the idea seriously. But today, the use of peptide and protein materials is thriving in diverse areas that could never have been imagined. If quantum dots can be made from peptides, what other surprises might be in store? As Louis Pasteur best put it: "Chance favours the prepared mind." Gazit, Rosenman and colleagues' work[1] should help us to open our minds to be ready for more remarkable discoveries. ■

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1. Amdursky, N., Molotskii, M., Gazit, E. & Rosenman, G. *J. Am. Chem. Soc.* **132,** 15632–15636 (2010).
2. http://nobelprize.org/nobel_prizes/chemistry/laureates/2000
3. Kol, N. *et al. Nano Lett.* **5,** 1343–1346 (2005).
4. Kholkin, A., Amdursky, N., Bdikin, I., Gazit, E. & Rosenman, G. *ACS Nano* **4,** 610–614 (2009).
5. Reches, M. & Gazit, E. *Science* **300,** 625–627 (2003).
6. Amdursky, N., Gazit, E. & Rosenman, G. *Adv. Mater.* **22,** 2311–2315 (2010).
7. Amdursky, N. *et al. Nano Lett.* **9,** 3111–3115 (2009).

QUANTUM OPTICS

Particles of light

Bose–Einstein condensation, which demonstrates the wave nature of material particles, now offers further illumination of wave–particle duality: it has been observed in light itself. SEE LETTER P.545

JAMES ANGLIN

"Art is the Tree of Life. Science is the Tree of Death." So wrote the visionary English poet and artist William Blake[1] in 1826, contrasting the limitless creativity of art with the limiting rigidity of science. Blake understood the science of his day — well enough, for instance, to lump together "The Atoms of Democritus And Newton's Particles of Light", and compare them both to sand[2]. In Blake's time, both were conceived of as indivisible and indestructible, their motion governed by Newtonian mechanics. Nothing represented his harsh view of science better than the implication that, if light corpuscles could be neither created nor destroyed, then the Universe contained a fixed amount of light, which could never be increased (Fig. 1). On page 545 of this issue, Weitz and colleagues[3] demonstrate that, even if that were true, the wave nature of light would still persist, through the Bose–Einstein condensation of photons. They also demonstrate the creativity that thrives within scientific rigour.

Modern physics teaches that light has wave as well as particle properties. But one of the most basic differences between the wave and particle theories is rarely emphasized in textbooks. Classical light waves are not conserved like the atoms of Democritus, but can easily be excited and absorbed. So, a lamp may run out of battery power, but it does not run out of light. In this respect, Newton's particle theory of light was as false as the caloric theory of heat, according to which heat was a conserved substance held in matter like water in a sponge. In fact, both heat and light are simply convertible forms of energy. And it was the thermodynamics of light that led Planck and Einstein to the quantum unification of wave and particle theories.

Unlike classical particles, quantum particles such as electrons and photons can in general be created and destroyed, and so the issue of whether the amount of light is fixed is now separate from the discussion of wave and particle behaviour. A basic question therefore seems natural: what would light be like if photons were, like atoms, wave-like but conserved? Weitz and colleagues[3] have answered this question experimentally. By confining light within the narrow slice of space between two barely separated mirrors, and filling this slab-like cavity with a dye material, they have achieved thermal equilibration of light as a gas of conserved particles, rather than ordinary black-body radiation. The critical step in

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Figure 1 | The Ancient of Days painted by William Blake. "Nothing represented his harsh view of science better than the implication that, if light corpuscles could be neither created nor destroyed, then the Universe contained a fixed amount of light, which could never be increased."

realizing such unusual thermalization is confining the light in one direction, so that every photon is forced to have a frequency at least as high as that of a standing wave. Because the separation between the mirrors is only a few micrometres, this minimum photon frequency is high — crucially, much higher than the frequency corresponding to the temperature of the dye.

This large frequency difference makes the energy budget of the system resemble the finances of a peculiar commercial firm that sells both skateboards and satellites. In the firm's ledgers, the billions column and the millions column must always be balanced separately, because the total volume of the skateboard business never amounts to a single satellite. In the Weitz group's system of dye and light, the thermal energy and the energy of excitations at the standing-wave frequency are similarly each conserved separately, because their scale discrepancy prevents one from balancing the other. And this means that the number of photons between the mirrors changes as photons are absorbed and re-emitted by the dye, but only in the same way that the number of atoms in a gas changes, locally, as the atoms drift around. In technical terms, the light in the Weitz group's experiment reaches thermal equilibrium with a chemical potential as well as a temperature, just like gases cooled to nanokelvin temperatures in magnetic traps. The textbook example of what this can allow is Bose–Einstein condensation, which confers the properties of classical wave physics on a gas of conserved quantum particles below a critical temperature, and is intimately related to the phenomena of superfluidity and superconductivity. The Weitz group has observed Bose–Einstein condensation of light, in remarkably close analogy to that of atoms.

As well as being a landmark achievement in itself, making photons behave thermodynamically as atoms, even to the point of Bose–Einstein condensation, illustrates a broader theme in current physics. Atomic gases have been made to behave as laser light[4], and even as black holes[5]. The 'holes' left when electrons in graphene sheets are energetically displaced reproduce the behaviour of relativistic positrons[6]. Quantized spin-wave excitations in magnetic films have been made to behave as quantum gases[7], and atomic gases have been made to behave as ferromagnets[8]. The discernible trend is that everything is becoming everything else. Physics is the art of the interchangeable.

The purely scientific merit in this trend is that demonstrating the interchangeability of physical details clarifies the few universal patterns and principles that really are conserved — the atoms, as it were, not of matter or of light, but of reality. In this sense, the reductionist progress of science proceeds at full tilt. But in the proliferation of startling masquerades, physical science is also taking on more than ever the aspect of a creative art, in a medium that, with the advances of modern technology, is proving far less constraining than it once seemed. Light is unlimited — or not, as we choose. Blake spoke too soon. ■

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1. Ellis, E. J. (ed.) *The Poetical Works of William Blake* Vol. 1, 435 (Chatto & Windus, 1906).
2. Stevenson, W. H. (ed.) *The Poems of William Blake* 481 (notebook drafts) (Longman, 1971).
3. Klaers, J., Schmitt, J., Vewinger, F. & Weitz, M. *Nature* **468,** 545–548 (2010).
4. Taubes, G. *Science* **275,** 617–618 (1997).
5. Lahav, O., Itah, A., Blumkin, A., Gordon, C. & Steinhauer, J. Preprint at http://arxiv.org/abs/0906.1337v1 (2009).
6. Novoselov, K. S. *et al. Nature* **438,** 197–200 (2005).
7. Demokritov, S. O. *et al. Nature* **443,** 430–433 (2006).
8. Jo, G.-B. *et al. Science* **325,** 1521–1524 (2009).

MECHANOREGULATION

Cellular seat belts

Accurate cell division depends on proper attachment of chromosomes to the microtubule-based division apparatus. An impressive *in vitro* study shows how applied force plays a pivotal part in regulating such attachment. SEE LETTER P.576

YUTA SHIMAMOTO & TARUN M. KAPOOR

The main safety feature of seat belts is that if the vehicle jolts, an abrupt pull locks the belt, keeping the passenger in place. Cells also seem to carry a nanoscale version of seat belts: the kinetochores — macromolecular machines that consist of more than 50 different proteins and connect chromosomes to dynamic microtubules of the cell-division apparatus — keep the chromosomes from accidentally ending up in the wrong daughter cell (Akiyoshi *et al.*[1], page 576 of this issue).

Stable propagation of genomes through mitotic cell division depends on the equal partitioning of replicated DNA, which is packaged into sister chromatids. Equal division depends on chromosome bi-orientation — that is, attachment of sister chromatids to microtubules that extend from opposite ends of the bipolar spindle (Fig. 1a). Failure of bi-orientation is common, but the improper attachments that emerge somehow get corrected[2]. Classic studies in grasshopper cells indicated[3] that differences in physical forces acting on a chromosome could be crucial for distinguishing between correct and incorrect attachments. But how force-based regulation may work has remained largely mysterious. A major barrier to progress has been the biochemical complexity of the kinetochores[4] and, therefore, the tremendous difficulty in isolating them in a functional form.

Enter Akiyoshi and co-workers[1]. The authors tagged different kinetochore proteins and developed conditions to isolate functional kinetochores from dividing yeast cells. Budding yeast is an ideal model system for such studies: not only can it be easily manipulated genetically, but also its kinetochore binds only one microtubule — unlike a human kinetochore, which can bind more than 20 microtubules. Nonetheless, the kinetochore architecture is essentially conserved across

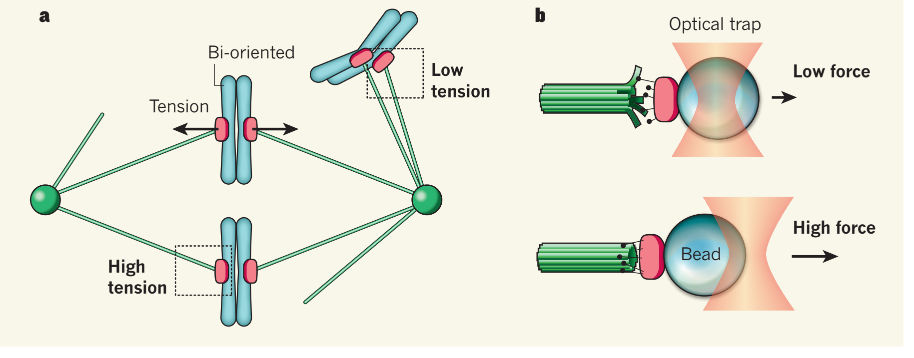

Figure 1 | Tension and chromosome-attachment state. a, Spindle microtubules (green) capture sister chromatids (blue) through kinetochores (pink). Tension across bi-oriented chromosomes is higher than across improperly attached chromosomes (dashed boxes). **b**, To investigate how force affects chromosome–microtubule attachment, Akiyoshi *et al.*[1] isolate minimal kinetochores, attach them to a bead and pull the bead with optical tweezers. They find that the reconstituted kinetochores attach to microtubules *in vitro* and that high tensile force enhances the lifetime of the attachment.