

to have high levels of genetic diversity within species, and to be endemic to their particular ecosystem. They are thus of great relevance in considering biodiversity. A fuller theory of scaling behaviour is required to provide firmer connections between predicted and observed patterns of desertification — and so to provide a better understanding of the nature of transitions between green and desert phases. These belong to the family of non-equilibrium phase transitions seen in several different fields of research<sup>8,9</sup>. There is a great opportunity here for interdisciplinary work that would have potentially far-reaching consequences in conservation biology. ■

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## ATOMIC PHYSICS

# A whiff of antimatter soup

Clifford M. Surko

**A molecule consisting of two electrons and two anti-electrons is similar to, but different from, the familiar hydrogen molecule H<sub>2</sub>. Its creation heralds a new chapter in the formation of matter–antimatter states.**

Particles of antimatter might be rare, fleeting and seemingly unwelcome guests in our matter-dominated world, but they offer many opportunities to study new science and develop new technologies. Antimatter, and how the laws of physics apply to it, is therefore of fundamental interest, notwithstanding the challenges of making, manipulating and storing the stuff. On page 195 of this issue<sup>1</sup>, Cassidy and Mills report the breaking of new ground — the creation of the first-ever molecule of a species of matter–antimatter atom known as positronium.

The laws of physics, as we understand them, are symmetrical: for each type of ordinary-matter particle there is a corresponding antiparticle. The proton has the negatively charged antiproton; the electron has the positively charged positron. Such pairs of particles and antiparticles are now regularly created in laboratories around the world. But almost as soon as they are made, they disappear again with a puff and a flash of light, annihilating each other to leave only a trace of other particles or photons. The electron and positron, for example, annihilate into two or three photons with a total energy of 1,022 kiloelectronvolts (keV) — twice the electron mass, 511 keV. These photons are nothing other than highly energetic X-rays or  $\gamma$ -rays, and are routinely used to characterize materials for high-speed electronics, as well as to study metabolic activity in the brain in the technique known as positron emission tomography (PET).

Just as the electron and proton bind to form atomic hydrogen (H), so the electron and positron bind, albeit fleetingly, to form

a positronium atom (Ps). The existence of positronium was predicted<sup>2</sup> in 1946 by the theoretical physicist John Wheeler, and the atom was first isolated experimentally<sup>3</sup> by Martin Deutsch in 1951. Wheeler also posited the existence of a dipositronium molecule, Ps<sub>2</sub>, and even a triatomic variant, Ps<sub>3</sub>. It is Ps<sub>2</sub> that Cassidy and Mills have only now succeeded in producing<sup>1</sup> — and with it the first many-positron, many-electron system to be made in the laboratory.

It is tempting to view Ps<sub>2</sub> as a diatomic molecule similar to the hydrogen molecule, H<sub>2</sub>, but there are important differences. Unlike the proton and electron in a hydrogen atom, the positron and electron in positronium have the same small mass of 511 keV. As a result of the quantum uncertainty principle, neither the electrons nor the positrons in Ps<sub>2</sub> can be localized in the same way as the much heavier protons in H<sub>2</sub>. Thus, each of dipositronium's four particles has one repulsive partner (of the same type) and two attractive partners (of the opposite type). The four do a merry dance around each other in a fuzzy, lumpless soup with matter and antimatter flavours<sup>4</sup>.

Cassidy and Mills performed their experiments<sup>1</sup> by accumulating some 20 million positrons in a specially designed trap. They focused these positrons in a burst lasting less than a nanosecond onto a small spot on the surface of a porous silica sample. The positrons diffuse into voids in the silica, where they capture electrons to form positronium atoms. Before these atoms can annihilate, they form about 100,000 Ps<sub>2</sub> molecules on the interior surfaces of the voids. The presence of a surface is crucial — because the energy of the bound



## 50 YEARS AGO

“British public schools and the future” — [Another] demand which parents make on the public schools is impossible to justify on educational grounds and has social, political and moral implications. Many parents... send their sons to public schools because membership of these schools will be of service to them in their future careers. Although this charge may be exaggerated — the full effects of the establishment of grammar schools under the Education Act of 1902 have not yet been seen — the public school system undoubtedly confers advantages on its products which are denied to those from State schools. A system which enables less able men to come to the top and prevents the abler from doing so cannot be justified on human, economic or moral grounds. But even this does not provide a case for abolishing schools which have so much to commend them educationally; if the wrong boys are getting into public schools, other means of selecting them must be found.

From *Nature* 14 September 1957.

## 100 YEARS AGO

Theoretically at least most observers admit that the adoption of the scientific method in the management of the affairs of State is a preliminary necessity if national efficiency is to be secured... There is growing evidence, also, that politicians in most countries are beginning to realise that statesmanship is no exception to this rule, but, like other skilled labour, is most satisfactory when conducted on scientific principles. But whether British statesmen appreciate this truth to the same extent as those of other great nations is a matter of grave doubt. Their education generally has been of such a character as to leave them with a colossal ignorance of science and scientific methods; and it is only by overcoming the bias received at the public school and university that most of them come to understand the modern outlook.

From *Nature* 12 September 1907.

50 & 100 YEARS AGO

## EVOLUTIONARY GENETICS

## You are what you ate

It is hard to think of anyone who doesn't like starchy foods such as pasta, chips, rice or bread. But certain populations, for example hunter-gatherers living in the rainforests or near the Arctic circle, have historically existed on a diet rich in protein and low in starch. George Perry and colleagues conclude that such differences in the amount of dietary starch have moulded the human genome over time (G. H. Perry *et al. Nature Genet.* doi:10.1038/ng2123; 2007).

Dietary shifts — whether driven by the development of stone tools, by controlling fire or by domesticating plants and animals — have had a major role in human evolution. Perry and colleagues specifically looked at the effect of dietary starch on the number of copies of *AMY1*, the gene

that encodes the salivary amylase enzyme, which breaks down starch.

*AMY1* is one of the few genes in the human genome that show extensive copy-number variation between individuals. So the authors first looked at whether additional *AMY1* copies are functional. They found that extra *AMY1* copies do indeed endow the individuals carrying them with the capacity to produce more salivary amylase. The question then was whether the starch content of past diets dictates the present levels of amylase and, thus, *AMY1* copy number.

Perry *et al.* studied two groups: one consisted of four populations with a low-starch diet and the other of three populations from agricultural societies and hunter-gatherers in arid environments, who

traditionally eat high-starch food.

Strikingly, twice as many members of the high-starch-diet group had at least six copies of *AMY1*. This difference could not be explained by geographical factors because both groups contained people of Asian and African origin. Instead, the authors propose that variations in *AMY1* copy number are more likely to have been influenced by positive natural selection.

So what is the advantage of having more salivary amylase? Significant digestion of starch occurs during chewing. This is crucial, and probably vital, in people likely to suffer from diarrhoeal diseases. Moreover, after being swallowed, salivary amylase is carried to the stomach and intestines, where it aids other digestive enzymes.

Of the three copies of the *AMY1* gene registered in the reference sequence of the human genome, variations in nucleotide



sequences are small. This suggests that the duplication of these genes may have occurred relatively recently, possibly even since the evolution of modern humans about 200,000 years ago. So Perry and colleagues' results, and elucidation of copy-number variations in other human genes, could provide insight into our ecological and evolutionary history.

Sadaf Shadan

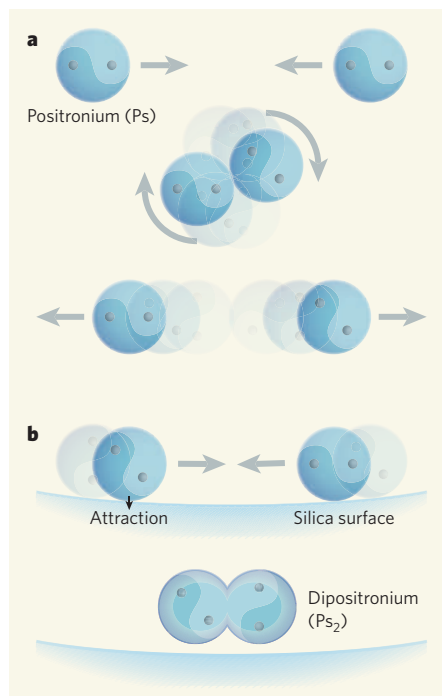
$\text{Ps}_2$  molecule is less than that of two Ps atoms moving separately, a third body is required to mop up the excess as recoil energy. The large surface area of Cassidy and Mills' porous silica trap thus provides an ideal place for the two positronium atoms to marry, with the surfaces mopping up the extra energy (Fig. 1).

Evidence for  $\text{Ps}_2$  formation comes from studying the temperature dependence of the 511-keV  $\gamma$ -rays that signal the annihilation. Molecules of positronium are formed from a slightly longer-lived version of the Ps atom in which electron and positron spins are aligned. When a molecule is created, a positron can grab an opposite-spin partner, and it thus annihilates more quickly. At lower temperatures, more  $\text{Ps}_2$  forms because the atoms are less energetic and stick more readily to the void surfaces. The authors observe an increase in the fast component of the  $\gamma$ -ray signal at lower temperatures, which they interpret convincingly as evidence that molecules are being formed.

The success of this experiment<sup>1</sup>, and particularly of the techniques the authors and their colleagues developed to achieve it<sup>5</sup>, holds much promise for creating other novel states of matter and antimatter. The current experiment corresponds to a  $\text{Ps}_2$  density of about  $10^{15} \text{ cm}^{-3}$  in the voids. Advances in positron technology should permit the creation of much higher density collections of electrons and positrons<sup>6</sup>, allowing us to ask whether  $\text{Ps}_3$  or more complicated positronium materials in Wheeler's progression<sup>2</sup> exist and, if so, what their nature is.

In addition, if one could increase the density of positronium atoms to  $10^{18} \text{ cm}^{-3}$ , the system is expected<sup>7</sup> to undergo a transition

at a temperature of 15 kelvin to a 'Bose-Einstein condensate', in which all atoms share the same quantum state. At even higher densities, one might expect the material to become



**Figure 1 | Positronium gets it together.** **a**, In free space, two atoms of positronium (each consisting of an electron and its antiparticle, the positron) cannot combine to form a molecule — owing to their excess of energy, they simply fly apart again. **b**, A third body, by contrast, such as Cassidy and Mills' silica walls<sup>1</sup>, can absorb this excess energy, allowing the two atoms to wed — albeit fleetingly.

a regular, crystalline solid. If one could make a Bose-Einstein condensate of  $\text{Ps}_2$  molecules at densities of  $10^{21} \text{ cm}^{-3}$ , there is the possibility of creating a laser using the  $\gamma$ -rays from the annihilation process. Because of their high energy, these photons have a very short wavelength, and could be used to probe objects as small as atomic nuclei.

Cassidy and Mills' work<sup>1</sup> thus heralds a new front in the study of antimatter and matter. In complementary work, scientists are asking questions about the chemical physics of antimatter — such as the binding of positrons to ordinary atoms<sup>8</sup> — and using the answers to develop new ways to study materials<sup>9</sup>. They are also coming closer to fundamental tests of the symmetry of antimatter and matter by comparing the properties of hydrogen and antihydrogen<sup>10,11</sup>. The pay-off of such tests could be an answer to the perplexing but vital question of why we are surrounded by matter, with so little evidence of antimatter in the Universe. ■

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