Hamburg defining ten parts per million of nitrogen oxides as the upper level of effluent from fossil-fuel burners. This is quite a difficult limit to achieve because ordinary flame burners give off roughly ten times this amount of nitrogen oxides.

The logical answer is to imitate nature and to oxidize the hydrocarbon fuel catalytically, while extracting the electrons and useful energy directly through a membrane. But our knowledge and expertise of such processes is shockingly weak, despite the early discoveries of catalysis and fuel cells by Davy[4] and Grove[5]. A fuel cell works by reducing oxygen to O^{2-} at the cathode, while oxidizing fuel, ideally hydrogen, at the anode (Fig. 1). Ions created by this process (H^+ or O^{2-}) diffuse through the electrolyte membrane to balance the reactions. At the same time, electrons flow from the anode to the cathode through an external circuit. If the fuel is hydrogen, the only waste product is water. Other fuels, such as methane, can be used, but they have to be converted to hydrogen before entering the cell.

Lately, evidence has emerged that methane can be converted directly by a solid-oxide fuel cell, without any flame, using cerium oxide as the electrode catalyst[6]. A typical solid-oxide fuel cell uses a hard ceramic material such as zirconia (which conducts O^{2-} ions) as the electrolyte, and has nickel-based anodes. Park *et al.*[2] now suggest that copper with cerium or samarium oxide may be a better anode catalyst for direct oxidation of more complex hydrocarbons that exist in realistic fuels such as kerosene or diesel. The challenge is to find pathways through which ethane and butane, or even aromatics such as toluene, can be reacted without fouling up the process through damaging side reactions that tend to produce tar or carbon.

This is the challenge that has been picked up by Park and colleagues. They used a copper catalyst intimately in contact with cerium oxide to produce a porous anode material. When this operated on pure butane for 48 hours there was no sign of carbon deposition, but good evidence of complete chemical conversion and electron transfer through a zirconia electrolyte membrane. An ordinary cell would die in minutes under the same operating conditions because of carbon fouling. When the copper–ceria–samaria catalyst was used, even toluene showed reasonable reactivity and electron conversion. This is very encouraging because aromatics are usually prone to rapid graphite deposition, which destroys the catalyst.

The hope is that even gasoline or diesel fuel may soon be catalytically converted to energy and heat in a clean and powerful manner by such devices. But it may be easier to use partly oxidized fuels such as methanol or formic acid because these will work in aqueous solutions with catalytic electrodes. Such fuels react with oxidizing species at lower temperatures without carbon formation and may be ideal power supplies for computers or mobile phones[7]. But such intermediates, as with hydrogen or pure methane, might not be readily available in the quantities and economics we expect for regular fuels.

Of course, the fuel reactions in the device are not the only areas of ignorance. Fuel-cell systems are already semi-commercial but a number of issues remain to be resolved if the expected billion-dollar consumer market is to emerge in 2004 — the date set for car manufacturers in California to produce 5% zero-emission vehicles. One problem is the cost of electrolyte membranes, for both solid polymer and ceramic fuel cells, so the cost of materials will need to fall by an order of magnitude. The performance of a fuel cell may also be limited by peripheral equipment, which may represent 75% of the total device. Existing systems, such as the d.c./a.c. converter and heat exchanger, may not be well matched to the new fuel-cell technology. And particular problems, such as leakage through the polymer membrane or cracking of the ceramic electrolyte, remain to be sorted out. It is worth recalling that Nernst, the inventor of the zirconia electrolyte in the 1890s, praised the simultaneous invention of the telephone because it enabled him to call home to switch the device on, the warm-up time being so long. Solutions to these problems are now being found[8]. Only when this happens will the expected applications in domestic heaters, hybrid vehicles and distributed power plants become reality. ■

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1. Grove Symposium *J. Power Sources* March (2000).
2. Park, S., Vohs, J. M. & Gorte, R. J. *Nature* **404,** 265–267 (2000).
3. Houghton, J. *Global Warming* Ch. 3 (Lion, Oxford, 1994).
4. Davy, H. *Phil. Trans. R. Soc. Lond.* **107,** 45–85 (1817).
5. Grove, W. R. *Phil. Mag.* **14,** 127–130 (1839).
6. Murray, E. P., Tsai, T. & Barnett, S. A. *Nature* **400,** 649–651 (1999).
7. Büchi, F. N. (ed.) *Portable Fuel Cells Conference* (Bossel, Switzerland, 1999).
8. Kendall, K. US Patent No. 5,827,620 (1998).

Evolution

In search of the whales' sisters

Zhexi Luo

Which mammals are the closest relatives to cetaceans (dolphins, porpoises and whales)? That is, which mammalian group is their 'sister taxon'? There is a wide gulf between the morphological and molecular evolutionary studies on the question, for they give conflicting answers. In a paper in *Systematic Biology*, O'Leary and Geisler[1] highlight the importance of the early divergent lineages, or extinct fossil taxonomic groups, in resolving this intriguing problem.

The descent of whales from land-dwelling mammals is a compelling example of evolution. It is documented by a rich fossil record of intermediate forms spanning the land–water transition; and by morphological and molecular lines of evidence, both of which testify that cetaceans have a close affinity to the artiodactyl mammals, or ungulates with even-toed feet and double-pulley ankle, such as today's cow, camel and hippopotamus. But two central issues have yet to be settled. One is the identity of the cetacean sister taxon. The other is whether the cetaceans are 'nested' within the group of artiodactyls as a branch on the family tree of the living artiodactyls — in other words, whether cetaceans represent some ancient artiodactyls that became adapted to aquatic life.

What O'Leary and Geisler have done is to evaluate all the available morphological and molecular evidence[1,2]. They show that both issues hinge on the long-extinct fossil groups that were split early from extant cetaceans. The topology, or branching sequence, of the family tree of living artiodactyls and cetaceans depends on inclusion of these divergent lineages of cetaceans and their putative extinct relatives.

Among those possible fossil relatives are the mesonychids that lived from 60 to 30 million years ago. Their feet were even-toed and adapted for running, like those of modern artiodactyls, and their fish-eating or carrion teeth closely resemble those of the earliest whales. Since the 1960s[3], several morphological studies[1,2,4,5] (with one exception[6]) have considered that extinct mesonychids and cetaceans are sister taxa (Fig. 1a). The combined mesonychid–cetacean group is, in turn, related to living artiodactyls. In this scheme, living artiodactyls are recognized as a clade[1,2,5,7], a genealogical group that includes all descendants of a common ancestor.

In contrast, molecular studies[8–12] have generally concluded that hippopotamuses and cetaceans are more closely related to each other than either group is to other living artiodactyls (Fig. 1b). Consequently, the artiodactyls would be a grade that has similar evolutionary adaptations, but not a genealogical clade. Moreover, some molecular

100 YEARS AGO

On reading the letter of Prof. Dexter on "Assaults and Drunkenness" (p. 365), I notice that there is one great fallacy in the argument. When a man is intoxicated and commits an assault, the result is entered in police reports as "assault", the more serious offence overshadowing the less. So that, in all probability, many of the cases of assault referred to in the statement were also drunkenness, but were not tabulated as such. The temperature is an important element; for its variations are probably the cause of the change of character of the offences recorded. The same quantity of alcohol will, as has often been noticed, have very different effects in the summer and in the winter. In hot weather alcohol has a stimulating influence; this is much less marked in the winter, and during this season the sedative effect is certainly more noticeable. Studying Prof. Dexter's curves in this light, and assuming the absence of any other fallacies, we may reasonably conclude that the number of those arrested in drunkenness or its results varies but little throughout the year. Probably the same people supply the cases of drunkenness in winter and assaults in summer.

From *Nature* 15 March 1900.

50 YEARS AGO

In 1921 birds described as tits were observed to prise open the wax-board tops of milk bottles on the doorsteps in Swaythling, near Stoneham, Southampton, and drink the milk. This is the first known record of an act which has now become a widespread habit in many parts of England and some parts of Wales, Scotland and Ireland, and which has to date been practised by at least eleven species of birds. The spread of the habit is interesting, because of the problems of behaviour involved. How far did the individual birds learn the habit from each other, or invent it for themselves? If most of them learnt it, by what process did they do so? How did, and how do, they detect the presence of food inside the bottle?… Without experimental evidence it is impossible to decide which senses are of use to the bird in indicating the presence of food. Several correspondents have found that bottles filled with water or even empty bottles are still attacked; but this conveys nothing if the previous history of the birds is not known.

From *Nature* 18 March 1950.

studies[12] suggest that mesonychids are not closely related to cetaceans; this is because the mesonychid–cetacean relationship implies a larger gap in the fossil record[9], and is therefore less plausible than the hippo–whale connection[12]. So, for all their congruence on the broad picture of ungulate–cetacean evolution, there is a big disagreement between morphological and molecular studies over these two phylogenetic issues.

What does that mean in terms of the origin of cetacean adaptations to aquatic life? If hippos and whales are sister taxa to the exclusion of mesonychids (as molecular studies suggest), then cetacean adaptations such as underwater nursing of offspring and nearly hairless skin could have originated in the most recent common ancestor of both groups (Fig. 1b); this implies that certain aquatic features had evolved before the origin of cetaceans[9]. The similar ear regions[4,5] and the fish-eating and carrion teeth must have evolved independently in mesonychids and in the earliest cetaceans because these derived features are absent in living hippos and their artiodactyl allies.

Alternatively, if mesonychids and cetaceans are sister taxa (as the best morphologi-

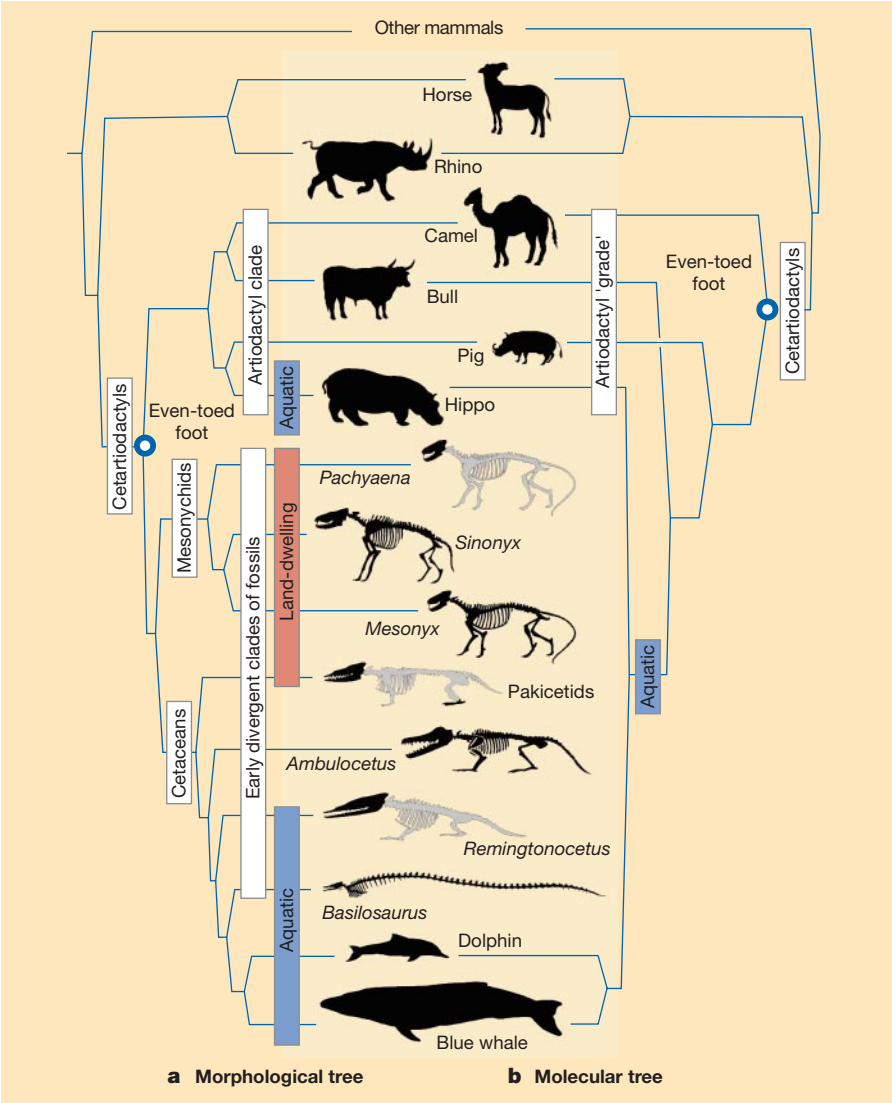

Figure 1 **Different interpretations of cetacean evolutionary history. Central players in both phylogenetic trees are the even-toed ungulates, the artiodactyls (the other, odd-toed, group of ungulates includes animals such as the horse). a, A phylogenetic tree based on morphological evidence, including O'Leary and Geisler's extensive sampling of early divergent lineages[1]. This scheme supports the traditional hypothesis that mesonychids are the sister taxon of cetaceans, and that artiodactyls are a monophyletic clade (a genealogical group that includes all descendants of a common ancestor) to the exclusion of living cetaceans. b, A tree based exclusively on molecular data from living ungulates and cetaceans. Here hippopotamuses and cetaceans are sister taxa, and artiodactyls are an evolutionary grade characterized by herbivory and even-toed feet for running. But they are not a good genealogical group unless cetaceans are considered to be a part of it. Living taxa are shown as silhouettes; early divergent taxa as skeletons; and incomplete fossils in grey. (Modified from refs 1, 2, 9 and 10.)**

cal evidence has it), then the aquatic adaptations of hippos and living cetaceans must be convergences that occurred well after the split of their respective lineages. This is because certain primitive cetaceans (pakicetids) have many ear[4] and ankle[6] structures typical of a land mammal, and mesonychids were fully terrestrial and adapted to running (Fig. 1a).

What about the relative strengths of the two lines of evidence? Morphological studies of ungulate–cetacean phylogeny take in a much wider range of taxa than the molecular studies. This is because the living artiodactyls and cetaceans available for molecular analyses represent only a few twigs of their bushy family trees that have survived pruning by extinction. As O'Leary and Geisler[1] point out, 90% of ungulate genera and more than 86% of the cetacean genera are extinct. Taking the mesonychid and cetacean fossil taxa into account produces a markedly different evolutionary history (Fig. 1a). From this, O'Leary and Geisler conclude that artiodactyls are a clade to the exclusion of cetaceans. Here we have a good example of the principle that including data from early divergent fossil lineages can shake, and reshape, the trees of living taxa based solely on molecular evidence.

However, for living taxa, use of sequences of genes and proteins is in some ways more powerful than use of morphological characters. In recent years, more genes in larger sequence samples have been added to the arsenal for estimating ungulate and cetacean phylogeny[9–12]. And the poor taxonomic sampling of some of the earlier molecular work has at least in part been redressed[10]. All in all, because molecular characters can vastly outnumber morphological features, they often prevail in simultaneous analyses of conflicting data sets. That is, in such analyses they effectively swamp the morphological estimates of ungulate–cetacean phylogeny.

Both morphological and molecular data are vulnerable to the problem of homoplasies — reversals to ancestral conditions or parallel changes in different lineages that can camouflage the true phylogeny. In this sense, neither approach is better than the other. For instance, the ear region of the skull, traditionally considered to be a good source of highly stable characters, shows some glaring homoplasies among the ungulates and cetaceans[4,5]. Moreover, the fossil record of many early divergent fossil taxa is incomplete, resulting in ambiguities in morphological estimates.

On the molecular side, DNA and protein sequences have parallel and back mutations. Even the newest studies using retroposons, which are the RNA-mediated insertion sequences interspersed in the genome, have their limitations. Retroposons show a low level of homoplasy[12,13], but mutational decay of the flanking region of retroposons may make them difficult to detect in older lineages. This means that retroposon-based estimates may not be effective for resolving lineages that go back more than 50 million years[14]. Cetaceans were already diversified by 53.5 million years ago, and their divergence from extant artiodactyls goes back much further[15,16] than that.

A way to untie this Gordian knot may be to seek out compatible aspects of the molecular and morphological data sets. Measurement of the hidden support and conflict between them[10] can help extract additional information. Also, morphological features should be better analysed for some living taxa for which extensive molecular data are available. Such studies may be just as helpful as discoveries of new fossils and genes in resolving details of the cetaceans' phylogenetic tree — most particularly, the question of which group is their sister taxon. ■

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1. O'Leary, M. A. & Geisler, J. H. *Syst. Biol.* **48,** 455–490 (1999).
2. O'Leary, M. A. *Cladistics* **15,** 315–330 (1999).
3. Van Valen, L. M. *Bull. Am. Mus. Nat. Hist.* **132,** 1–126 (1966).
4. Luo, Z. & Gingerich, P. D. *Papers on Paleontology (Univ. Michigan)* **31,** 1–98 (1999).
5. Geisler, J. H. & Luo, Z. in *Evolutionary Emergence of Whales* (ed. Thewissen, J. G. M.) 161–212 (Plenum, New York, 1998).

Fibre optics

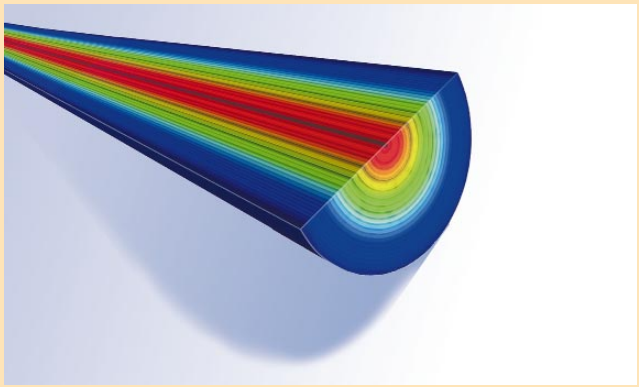
Transparent talk

Modern telecommunications rely on the transmission of light signals along fibre-optic cables — fast, but how to minimize signal degradation over large distances? The secret is to eliminate contaminants that cause unwanted absorption. These intruders tend to creep into the fibres during the manufacturing stages. Elsewhere in this issue (*Nature* **404,** 262–264; 2000), Gordon Thomas and colleagues reveal how the main culprit, water, sneaks in. Putting this knowledge into practice allows the manufacture of dry fibres with near maximal transparency and improved bandwidth.

The problem with water, in particular the hydroxyl (OH) group, is that it gets excited when irradiated by certain infrared wavelengths. As this band is used for telecommunications, precious signal power can be lost in vibration of the water molecules.

So where does the water come from? One process for making optical fibres involves heating silica rods with ultra-pure glass cores to very high temperatures. Once softened, the rods can be drawn out into fibres some tens of kilometres long. To achieve the necessary temperatures — in excess of 2,000 °C — it is common to use torches that burn hydrogen and oxygen: the perfect recipe for water.

But the incorporation of water into the silica rods is a more subtle matter. To investigate this process, Thomas and colleagues measured the transmission of infrared light through a small section of rod that had been cooled before drawing out, thereby 'freezing in' the water. They found that the absorption, and hence the hydroxyl concentration, is much stronger in the outer layers of the rod. This can be seen in the figure, which indicates the varying hydroxyl concentrations through a cross-section of the rod. (The colour scale is logarithmic, blue representing the highest concentrations.) Clearly, the water



diffuses from the outside in.

Given that the signals in optical fibres are confined to a narrow core region, the distribution of water in the rod might appear to be good news. But Thomas and colleagues found that the drawing process — which increases the aspect ratio by a factor of about a hundred million — lets the water in much further. They confirmed this by calculating the diffusion coefficient, a quantity that describes the flow of both water and glass during the contamination process. This parameter was much higher than expected from low-temperature diffusion, probably reflecting an increased mobility of hydroxyl groups in the hot, molten state.

There is no doubt that absorption by hydroxyl groups contributes significantly to transparency loss in optical fibres. Uncovering the physical origin of the contamination points to an obvious solution: pick a water-free heat source. **Karen Southwell**

6. Thewissen, J. G. M. & Madar, S. J. *Syst. Biol.* **48,** 21–30 (1999).
7. Luckett, W. P. & Hong, N. *J. Mamm. Evol.* **5,** 127–182 (1998).
8. Graur, D. & Higgins, D. *Mol. Biol. Evol.* **11,** 357–364 (1994).
9. Gatesy, J., Hayashi, C., Cronin, M. & Arcander, P. *Mol. Biol. Evol.* **13,** 954–963 (1996).
10. Gatesy, J., O'Grady, P. & Baker, R. H. *Cladistics* **15,** 271–313 (1999).
11. Ursing, B. M. & Arnason, U. *Proc. R. Soc. Lond. B* **265,** 2251–2255 (1998).
12. Nikaido, M., Rooney, A. & Okada, N. *Proc. Natl Acad. Sci. USA* **99,** 10261–10266 (1999).
13. Hillis, D. M. *Proc. Natl Acad. Sci. USA* **96,** 9979–9981 (1999).
14. Miyamoto, M. M. *Curr. Biol.* **9,** R816–R819 (1999).
15. Bajpai, S. & Gingerich, P. D. *Proc. Natl Acad. Sci. USA* **95,** 15464–15468 (1998).
16. Kumar, S. & Hedges, S. B. *Nature* **392,** 917–920 (1997).

Photonuclear physics

Laser light splits atom

Donald Umstadter

Lasers have become ubiquitous, being used in everything from a bar-code reader to a compact disk player. Who would have thought that they might be used to split the atom? A few scientists proposed to do just that more than a decade ago[1]. But accomplishing it in the laboratory had to await the maturity of new technology[2], which enabled the construction of the world's most powerful lasers at the Lawrence Livermore National Laboratory in the United States and at the Rutherford Appleton Laboratory in the United Kingdom. Now two independent research teams have used these lasers to split the uranium atom[3,4]. This work, reported in *Physical Review Letters*, is just the latest milestone in the race to discover what happens when matter interacts with the highest electromagnetic field strengths of light.

Over the past century, the peak power of artificial light sources has increased exponentially, from a kilowatt (10^3 watts) to a petawatt (10^{15} watts). This corresponds to an increase of more than a factor of ten each decade (Fig. 1). These dramatic advances have led to new physical insights and applications along the way. For instance, it was the invention of the cathode ray tube, used to make X-rays at the turn of the last century (and still used to this day for most television displays), that led to the discovery of electrons. Later, the invention of the laser increased the power of light to the point that it could accelerate an electron to close to the speed it naturally has as it orbits the nucleus of the atom. Remarkably, the distance required to reach this speed is but a millionth of a metre, the light's own wavelength. Having laser fields almost comparable to atomic fields has led to the discipline of physics known as nonlinear optics.

With the latest increase in laser power, electrons can now be accelerated to even higher speeds, close to the speed of light itself, again in a distance of just the laser wavelength. At such high speeds, electrons are governed by the laws of special relativity, leading to new types of nonlinear motion[5]. Gamma rays (energetic X-rays) are emitted when the highly energetic 'relativistic' electrons accelerate rapidly during a collision with neighbouring ions. If these gamma rays are energetic enough, they can then perturb the delicate stability of heavy nuclei such as uranium, causing it to split into lighter elements and neutrons in a process called photonuclear fission. This is exactly what the two groups of laser scientists have just demonstrated.

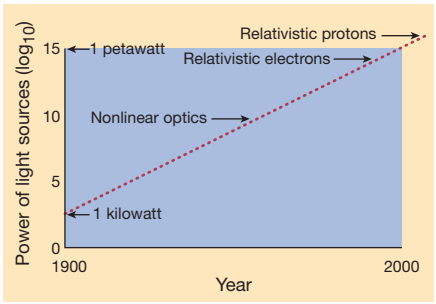


Figure 1 **As the power of laboratory light sources increases, the energy of accelerated particles increases accordingly, making laser-induced nuclear reactions possible. The most powerful lasers have now reached petawatt (10^{15} watts) peak powers, allowing them to accelerate electrons to relativistic speeds. The gamma rays produced by such electrons have been used in recent experiments to split the uranium atom[3,4].**

The fission of uranium usually brings to mind nuclear reactors. But before you get your hopes up that splitting atoms with lasers will solve the world's energy problems, it should be pointed out that more energy is required to power the laser than is released through the fission process. Besides, there are much more efficient ways to accelerate electrons and produce gamma rays than by using optical light — for instance, with accelerators driven by radio-frequency waves.

Because photofission has been studied with radio-frequency accelerators since they were invented decades ago, it is now quite well understood. In fact, a simple search of a database of physics journals for articles published since 1967 using the keyword "photofission" yields a total of 463 hits. Only seven of these appeared in the journal *Physical Review Letters*. Usually, the number of articles published in this exclusive physics journal on a particular topic tapers off as our fundamental knowledge of the subject increases. So why were references 1, 3 and 4 the only ones in the past 15 years to enjoy this privilege? As the authors readily admit, it seems less to do with what they tell us about photofission than with the tantalizing prospect that lasers can now be used to induce nuclear processes and the myriad applications that may follow.

The most familiar laser-driven nuclear process is fusion (the inverse of fission), in which lasers are used to heat hydrogen nuclei to temperatures greater than that of the Sun in order to fuse them together to make helium and release energy. Indeed, one of the main reasons for the current interest in the fission papers[3,4] is that the relativistic electrons produced by these experiments might some day be used as a spark plug to ignite a fusion reaction.

Another laser-driven nuclear reaction that might soon be possible is the creation of an ionized gas (plasma) of positrons as well as electrons. (Positrons are anti-electrons.) High-density antimatter is difficult to produce on Earth because it annihilates upon encountering ordinary matter, but it is of interest to astrophysicists because it might exist elsewhere in the Universe, for example in pulsars, quasars and black holes. Remarkably, with compact powerful lasers, dense electron–positron plasmas might soon be available for study in university laboratories.

Several groups have used electrons accelerated by high-power lasers to accelerate ions to high velocities[6,7]. The ions can be used to produce high concentrations of short-lived radioactive isotopes to tag cancer cells in nuclear medicine. More energetic protons from larger and more expensive radio-frequency-driven accelerators are even being used to kill cancer cells.

As the power of lasers continues to increase, the day will come when protons can even be accelerated to relativistic velocities and, possibly, directly by the laser field itself. (Protons are more difficult to accelerate than electrons because they are thousands of times more massive.) This next era of laser–matter interactions will involve all sorts of other nuclear reactions that could lead to novel applications, some of which are anyone's guess. ■

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1. Boyer, K., Luk, T. S. & Rhodes, C. K. *Phys. Rev. Lett.* **60,** 557–559 (1988).
2. Strickland, D. & Mourou, G. *Opt. Commun.* **56,** 219–221 (1985).
3. Ledingham, K. W. D. *et al. Phys. Rev. Lett.* **84,** 899–902 (2000).
4. Cowan, T. E. *et al. Phys. Rev. Lett.* **84,** 903–906 (2000).
5. Chen, S.-Y., Maksimchuk, A. & Umstadter, D. *Nature* **396,** 653–655 (1998).
6. Sarkisov, G. *et al. Phys. Rev. E* **59,** 7042–7054 (1999).
7. Krushelnick, K. *et al. Phys. Rev. Lett.* **83,** 737–740 (1999).