PHYSICS TODAY

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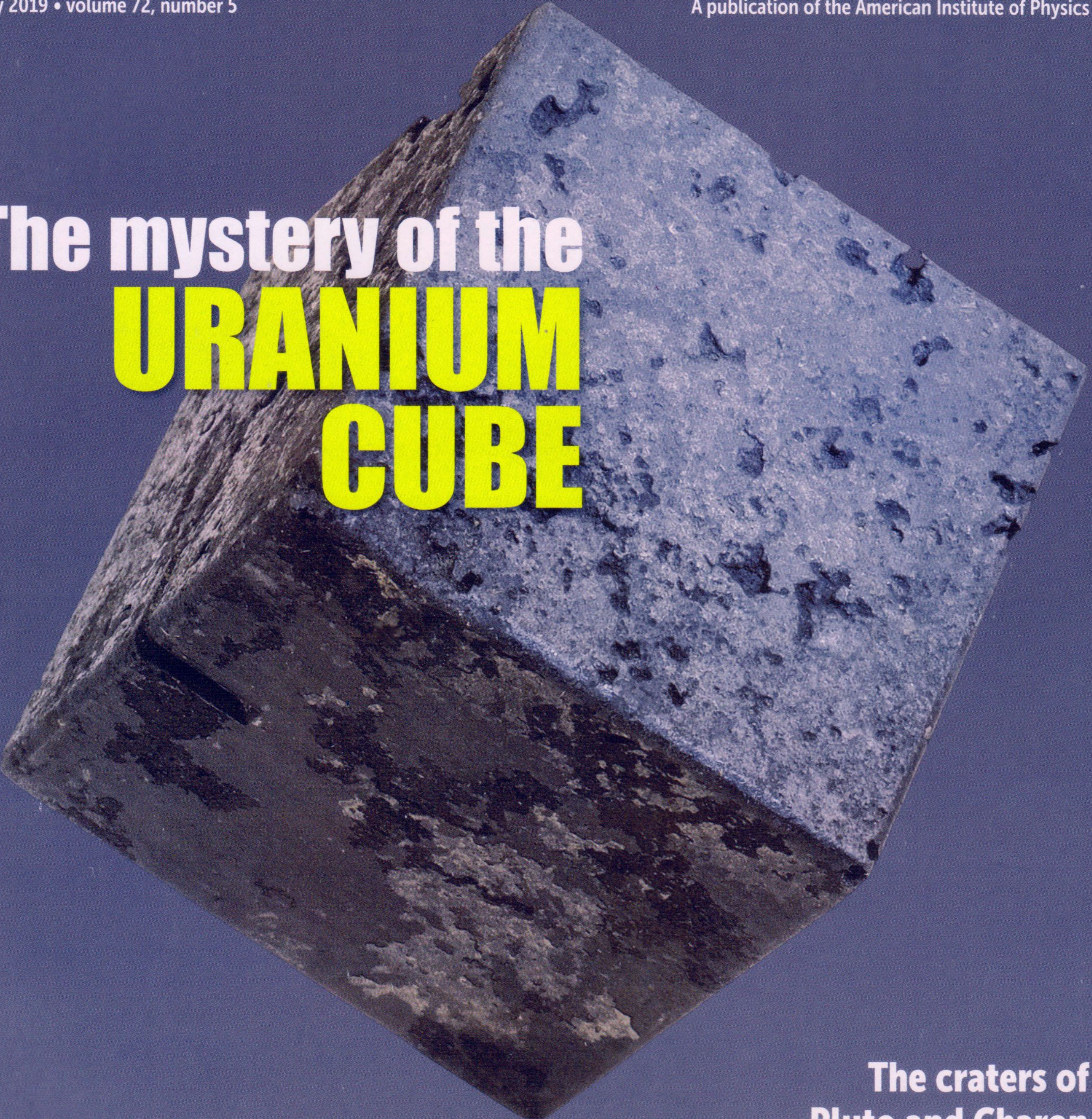

The mystery of the URANIUM CUBE

The craters of Pluto and Charon

Self-propelled microswimmers

Australia bets on hydrogen fuel

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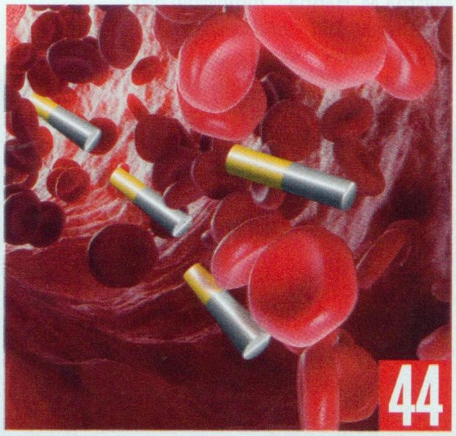

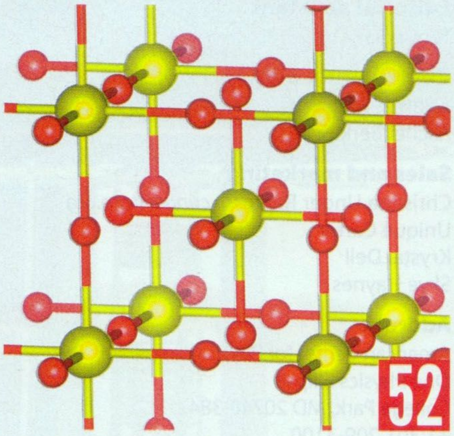

FEATURES

ON THE COVER: During World War II, a team of German scientists led by Werner Heisenberg attempted and failed to build a working nuclear reactor using the small, pockmarked uranium cube shown here and hundreds more like it. On **page 36**, Timothy Koeth and Miriam Hiebert recount their detective work over the past six years to uncover how the cube traveled from an underground laboratory in Berlin to College Park, Maryland. (Photo by Cynthia B. Cummings.)

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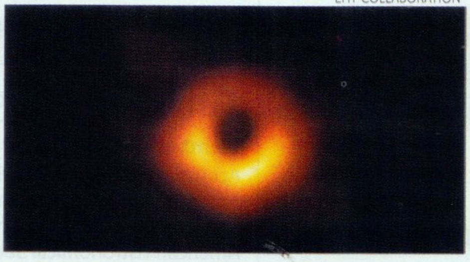

▶ Black hole revealed

On 10 April the world marveled at the silhouette marking the position of the first directly imaged black hole, M87*. The raw data behind that image were obtained during an April 2017 survey by eight telescopes scattered across the globe. PHYSICS TODAY breaks down the time stamps, calibration, computational imaging, and general relativistic modeling that enabled the Event Horizon Telescope team to transform petabytes of disparate radio astronomy data into one captivating image.
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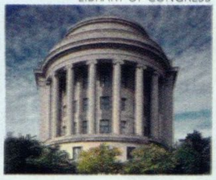

▶ Predatory publishing

Last year PHYSICS TODAY reported on scientific conferences run by a company that the Federal Trade Commission alleged was deceiving customers. Now OMICS International, which also publishes hundreds of journals, has been fined $50 million by a federal judge. PHYSICS TODAY examines the ruling and its implications.
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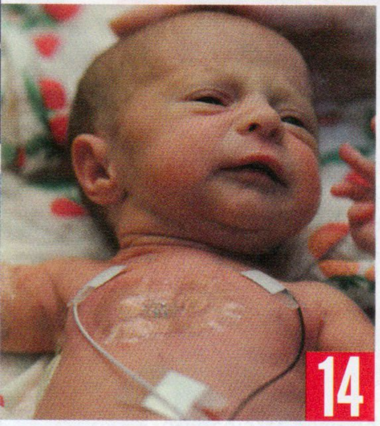

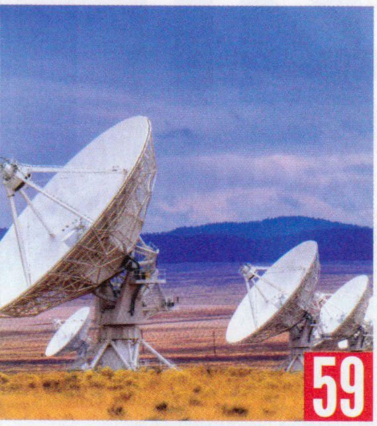

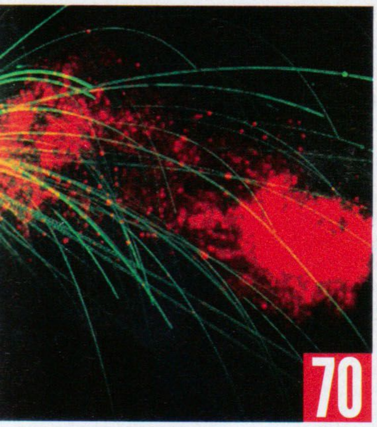

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Commentary

Basic research in a time of crisis

THE GREENLAND TELESCOPE is one of more than eight in the global Event Horizon Telescope array that aims to observe the immediate environment of black holes. The technology used to synchronize the member telescopes derives from the same basic research that enables detailed, synchronous climate-change measurements by today's weather satellites. (Photo by Nimesh A. Patel.)

Pierre Teilhard de Chardin, a paleontologist, geologist, philosopher, and Jesuit priest, wrote, "The history of the living world is an elaboration of ever more perfect eyes in a cosmos in which there is always something new to be seen." Teilhard's epigram provides a stunning description of mankind's longing to understand the natural world, which is to say mankind's instinct for science.

Today it is essential that science continue to flourish because society desperately needs science to deal with the growing problems due to our changing climate—ocean-level rise, destructive storms, forest fires, drought, and above all, the need for new sources of energy. But society also desperately needs science that although not focused on those problems could be crucial for solving them. A glance at some modern developments shows why.

Teilhard's phrase "ever more perfect eyes" accurately portrays the evolution of telescopes from crude optical devices at the dawn of the 17th century to today's space telescopes. That fabulous development was driven by curiosity about the nature of the universe: It was the product of basic research, which is motivated by the joy in understanding the natural world, in contrast to applied research, which is motivated by the need to solve a particular problem. Teilhard's phrase is a pretty good description of basic research.

Albert Einstein's search for a theory of gravity—his general theory of relativity—is an iconic example of basic research. The problem he struggled to solve, to create a theory that avoided some inconsistencies in Newton's theory of gravity, worried hardly anyone else and had no conceivable use, at least not at that time.

A startling consequence of Einstein's theory is that gravity affects time. A clock on top of a mountain runs faster than an identical clock at sea level, although not by much: At the peak of Mount Everest, a clock runs fast by only a few millionths of a second each month.

Einstein's prediction for the effect of gravity on time stimulated an experimental search. It originated on 21 January 1945 when a *New York Times* article carried the headline "'Cosmic pendulum' for clock planned." It was the report of a speech at an American Physical Society meeting in New York City; the speaker was I. I. Rabi, a physicist at Columbia University. Rabi proposed creating a clock whose "ticks" were governed not by the swing of a pendulum but by pulsations in an atom on one of its natural frequencies that could be measured by a technique he had invented.

The accuracy of such an atomic clock could be fabulously high. The newspaper article reported, "Professor Rabi said that he would like to see someone build an atomic clock that would be capable of providing, for the first time, a terrestrial check on the Einstein postulate that the gravitational field produces a change in the frequency of radiation." Thus the creation of atomic clocks sprang directly from curiosity about whether gravity affects the rate of a clock—that is, whether gravity affects time. Lacking any other conceivable application for such an accurate clock, the quest is a perfect example of basic research.

Nobody rushed to build an atomic clock after Rabi's 1945 talk. The research establishment was in disarray from World War II, and there were some technical barriers. Serious work on atomic clocks started around 1950, and in 1954 the first such clock was demonstrated in the UK. It came to be known as the cesium-beam atomic clock.

In 1956 Norman Ramsey, a former student of Rabi's, proposed a different type of atomic clock that would be capable of investigating Einstein's prediction about gravity and time. The device, known as the hydrogen maser, was demonstrated in 1960. Today hydrogen masers are found in most primary timekeeping laboratories along with other atomic clocks that set the international time.

Although the hydrogen maser was created to verify Einstein's conjecture about time and gravity, its unanticipated applications are noteworthy. For instance, it made the radio astronomy technique known as very long baseline interferometry (VLBI) possible. In each radio observatory, a nearby maser provides a time-stamp signal that permits distant laboratories to synchronize their observations. With VLBI, astronomers can create radio telescope antennas that are effectively the size of Earth; they enable astronomers to create maps of hydrogen throughout the universe with astonishing detail and to look back in time toward the infancy of the cosmos.

Recent progress has been reported on a new frontier of gravity. At the center of our

Craters on Pluto and Charon show that Kuiper belt collisions are rare

There are far fewer small bodies in the solar system's outer reaches than there would be if collisions were common.

The number of known objects in the solar system's asteroid belt, between the orbits of Mars and Jupiter, has exploded in recent years. In 2000 just a few thousand asteroids had been numbered, meaning that they'd been observed precisely enough to determine their orbits. Since then, the catalog has grown to more than half a million, with tens of thousands of additions each year.

The increase is easily explained. Newer telescopes can detect smaller asteroids—with diameters as small as hundreds of meters—and there are vastly more small asteroids than large ones. The size distribution reflects the asteroid belt's collisional equilibrium. For billions of years, asteroids have crashed into each other, sometimes sticking together and sometimes breaking into pieces, and the balance of those processes has reached a rough steady state.

Something fundamentally different seems to be going on in the Kuiper belt, the torus-shaped zone of dwarf planets and smaller objects beyond the orbit of Neptune. In 2015 NASA's *New Horizons* probe transmitted the first close-up images of Pluto—the best known resident of the Kuiper belt—and its largest moon Charon (shown in figure 1). The images showed hundreds of craters on both bodies, formed by the impacts of Kuiper belt objects (KBOs) of various sizes.

Now Kelsi Singer (Southwest Research Institute in Boulder, Colorado) and her colleagues on the *New Horizons* team have analyzed the crater size distributions.[1] The smallest craters they observed still outnumber the larger ones, but by more than an order of magnitude less than collisional equilibrium would predict. The result, which implies that KBO collisions are not frequent enough for the Kuiper belt to have reached collisional equilibrium, provides an important new constraint on models of how the solar system formed 4.5 billion years ago.

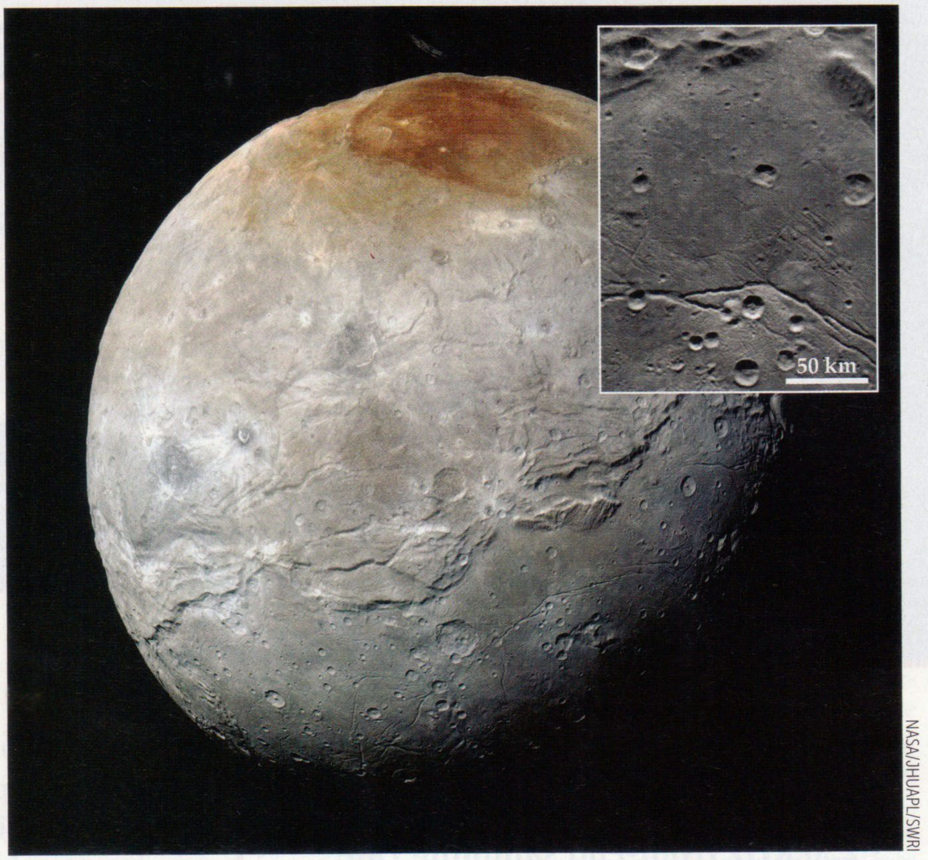


FIGURE 1. IMAGES OF CHARON, captured in July 2015 by NASA's *New Horizons* probe, show parts of the moon's surface to be peppered with craters, a record of 4 billion years of impacts by Kuiper belt objects.

Far out

In the wake of the 1930 discovery of Pluto, several astronomers, including Gerard Kuiper, speculated that more small bodies might occupy the same general region at the outer edge of the known solar system. But it wasn't until 1992 that David Jewitt and Jane Luu made the first observation of a KBO other than Pluto or Charon (the latter discovered in 1978).

More KBO discoveries followed, and their number grew to hundreds and then thousands. (See the article by Mike Brown, PHYSICS TODAY, April 2004, page 49.) The 2005 discovery of Eris, a KBO more massive than Pluto and almost as large, made clear that not only was Pluto not alone in the Kuiper belt, it wasn't uniquely outstanding among KBOs. The realization prompted the International Astronomical Union to issue a new formal definition of "planet," and Pluto famously—or infamously—no longer qualified.

Pluto and Eris are both more than 2000 km in diameter, and Charon is about half that. All three can be seen by Earth-based telescopes, even at their great distance. But it's much harder to observe smaller KBOs, especially those with diameters less than tens of kilometers, so the overall KBO size distribution has been shrouded in mystery.

There have been a few clues. Occasionally KBOs get kicked out of their orbits and launched toward the inner solar system. Some leave craters on the icy moons of the gas-giant planets that were imaged by probes such as *Galileo* and *Cassini*, and

Australia sees big opportunity in hydrogen energy

As one company brings a hydrogen-carrying fuel to market, researchers focus on ammonia as an optimal storage compound for export.

Over the next 10–20 years, motor vehicles and trains powered by carbon-free hydrogen fuel cells could become commonplace. With limits on greenhouse gas emissions looming and with their streets choked with exhaust, Japan and other energy-importing East Asian nations are already searching abroad for sources of readily usable hydrogen.

If renewable energy is to supplant fossil fuels on a global scale, wind and solar power from nations with abundant resources will need to be moved across oceans to energy-poor countries. Hydrogen, which can be cleanly burned or used to generate electricity in fuel cells, is a convenient energy carrier—a clean alternative to liquefied natural gas.

Despite its huge, largely unpopulated land mass and abundant sunshine, Australia has been slow to capitalize on its vast solar and wind energy potential. But policymakers are beginning to recognize the economic development potential of exporting cleanly generated hydrogen gas. Federal and state governments are backing demonstration projects. Hydrogen is an issue in the parliamentary election due to take place this month: The Labor opposition party has pledged to invest Aus$1 billion ($711 million) to develop and deploy a hydrogen export industry.

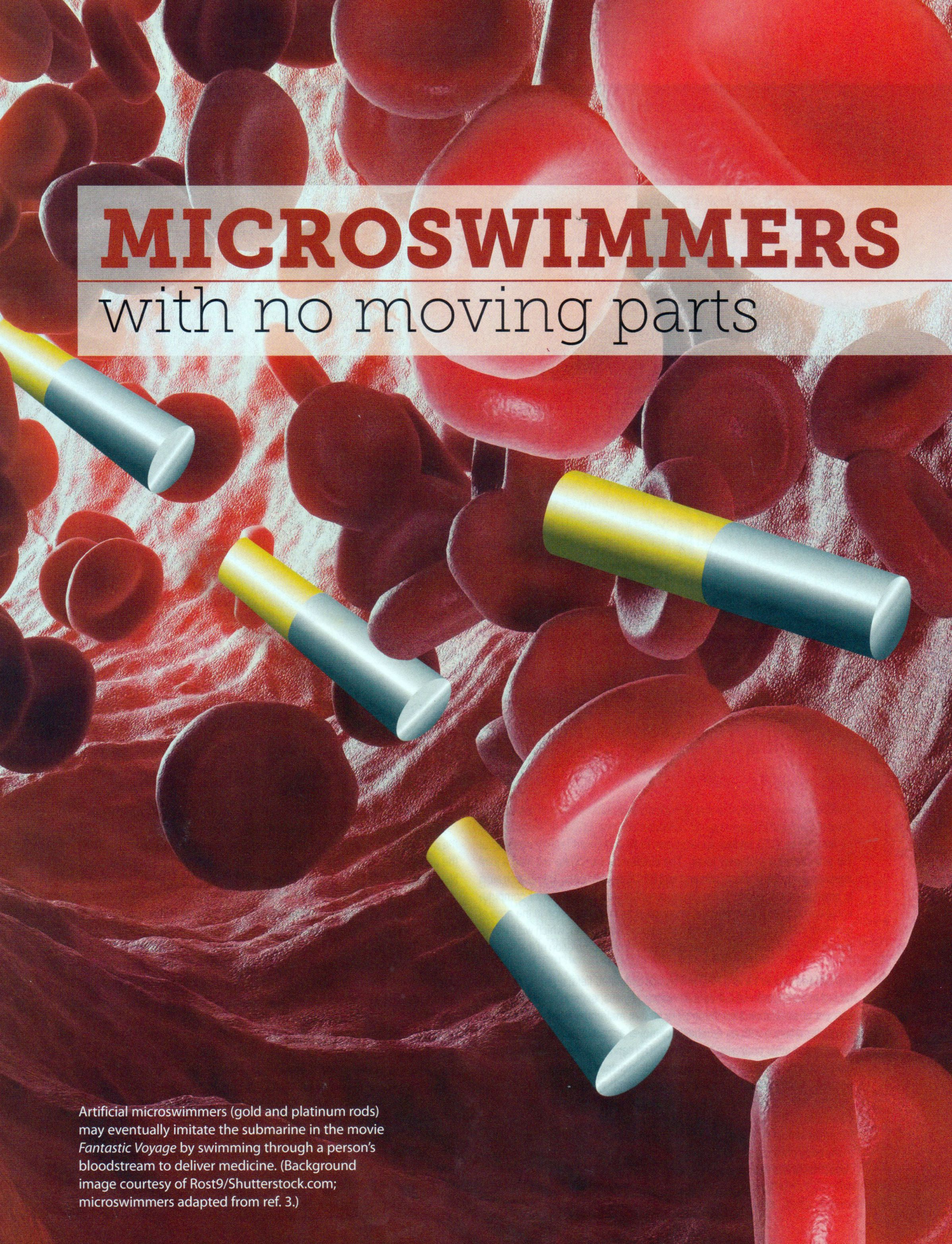
The ruling coalition government has not proposed a similar plan. Instead, it promised that by the end of the year it would develop a national hydrogen strategy that will consider both export and domestic uses. The plan is to be developed by a task force headed by Alan Finkel, the country's chief scientist. A 68-page white paper he prepared for the government stated that hydrogen exports could generate Aus$1.7 billion annually and a total of 2800 new jobs by 2030.

CSIRO ENERGY

CSIRO ENERGY BUILT AND DEMONSTRATED this vanadium-based membrane system for extracting pure hydrogen from ammonia. It's currently being scaled up to produce 200 kg/day.

Hydrogen itself, however, may not be the ideal shipping or storage medium. California has most of the 6100 fuel-cell vehicles (FCVs) on US roads today. The majority of the cost of hydrogen, currently about $14 per kilogram at the pump in California, comes from compressing, transporting, and storing it at pressure. Liquefying hydrogen requires temperatures below −253 °C and heavily insulated storage containers. The US Department of Energy says that to compete with gasoline, hydrogen should be priced down at $6/kg.

MICROSWIMMERS
with no moving parts



Artificial microswimmers (gold and platinum rods) may eventually imitate the submarine in the movie *Fantastic Voyage* by swimming through a person's bloodstream to deliver medicine. (Background image courtesy of Rost9/Shutterstock.com; microswimmers adapted from ref. 3.)

THE QUEST FOR ROOM-TEMPERATURE SUPERCONDUCTIVITY IN HYDRIDES

Warren Pickett and Mikhail Eremets

Whereas previous discoveries of superconductors were largely serendipitous, the latest advances have emerged from the close coupling of theoretical predictions and high-pressure experiments.