The authors went on to perform a metagenomic analysis of the symbionts in the gill tissue, and found that a key gene for hydrogen oxidation (*hupL*, which encodes part of the hydrogen-oxidizing enzyme [NiFe]-hydrogenase) is located on a DNA fragment that also contains sulphide-oxidation genes. This strongly suggests that the sulphide-metabolizing symbionts are responsible for hydrogen consumption. To get specific confirmation of this, Petersen *et al.* used fluorescent probes that target the *hupL* gene and the hydrogenase protein in the symbionts. They observed that sulphide-oxidizing symbionts in the gill were lit up by the *hupL* probe, whereas neighbouring methane-oxidizing bacteria were not. Collectively, the authors' observations present a compelling case that the long-known bacterium–mussel symbiosis can operate using a previously unknown metabolism.

It is likely that other symbioses will be discovered that also use hydrogen as a fuel source, given that symbioses involving relatives of the mussels' sulphide-oxidizing symbionts are widespread in reducing environments. Indeed, the authors find[1] that symbionts of the vent-dwelling shrimp *Rimicaris exoculata* have *hupL*, providing genetic evidence that crustaceans might also tap into hydrogen as an energy source through symbiosis. Follow-up studies should now determine the full extent of hydrogen use by symbionts, as well as the environmental and biological factors that influence when and where hydrogen utilization occurs in chemosynthetic ecosystems.

Petersen and colleagues' work exemplifies the technology-driven revolution that is occurring in the biological sciences. The continuous development of ever more powerful and specific molecular tools allows taxonomic identity and gene content to be linked to metabolic potential and activity, and to be visualized in context. As these techniques converge with new instrumentation that allows the *in situ* characterization of physicochemical parameters — even in environments as remote and extreme as hydrothermal vents — biologists are freed from their reliance on model organisms in artificial surroundings. Now, more than ever, our understanding of biology can be placed in the correct environmental and ecological context, enabling the discovery of previously unknown activities that support life. ■

Victoria J. Orphan *is in the Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125, USA.* **Tori M. Hoehler** *is at the NASA Ames Research Center, Moffett Field, California 94035, USA.*
e-mails: vorphan@gps.caltech.edu; tori.m.hoehler@nasa.gov

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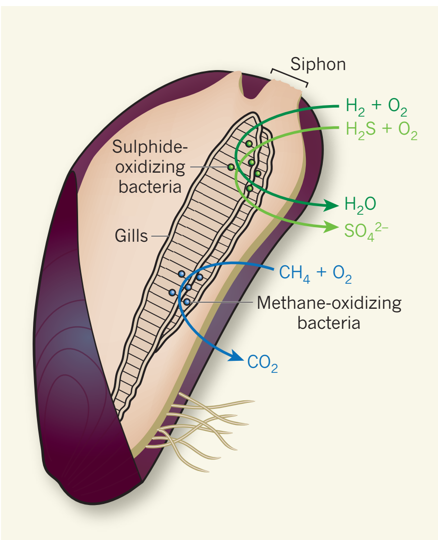

Figure 2 | Hydrogen-consuming symbiosis. *Bathymodiolus puteoserpentis* mussels live at hydrothermal deep-sea vents, which emit hydrogen, methane (CH_4) and hydrogen sulphide (H_2S), among other chemicals. The mussels draw water through their siphons and into enlarged respiratory gills that house symbiotic bacteria. Some of these bacteria harness energy by oxidizing methane to carbon dioxide (blue arrow), whereas others do this by oxidizing hydrogen sulphide to sulphate (SO_4^{2-}, light green arrow). Petersen *et al.*[1] report that the sulphide-oxidizing bacteria also use hydrogen as an energy source, oxidizing it to water (dark green arrow).

QUANTUM INFORMATION

Microwave ion-trap quantum computing

A new type of ion-trap quantum technology has been developed that uses microwave radiation to perform computations. It will considerably simplify the practical implementation of large-scale quantum computers. SEE LETTERS P.181 & P.185

WINFRIED K. HENSINGER

The strange phenomena of quantum physics, such as the possibility of a single atom being in two different places simultaneously, have mystified experienced physicists and students alike. These phenomena are not just theoretical curiosities: a new, practical, field of quantum physics has become particularly vibrant during the past ten years. It concerns harnessing the power of quantum effects to produce an innovative type of technology — quantum technology. This has the potential to revolutionize computing. Although ways to implement this technology are being pursued in various physical systems, quantum computing using trapped ions[1–3] has undoubtedly been the most successful so far. In this issue, Ospelkaus *et al.*[4] (page 181) and Timoney *et al.*[5] (page 185) describe a trapped-ion approach that further bolsters the enormous potential of this system for the implementation of large-scale quantum computers.

Ospelkaus *et al.*[4] report the realization of quantum gates using microwave radiation instead of laser beams, which have until now been used to implement such gates. Quantum gates are the analogues of classical logic gates, and are used to perform computations in a quantum processor. Timoney *et al.*[5] discuss a new approach to quantum computing — involving microwaves — that is highly resilient to noise (often referred to as decoherence) acting on the physical system used to execute the computations. Decoherence has the potential to destroy quantum effects and interfere with the operation of a quantum processor. Timoney and colleagues' scheme effectively shields the quantum processor from decoherence.

Quantum gates executed in a quantum processor are based on the creation of entanglement. Entanglement is one of the non-intuitive phenomena of quantum physics, whereby the properties of multiple systems, such as groups of ions, are correlated. Ordinarily, the outcome of measuring a particular property on an ion yields a completely random result. But measuring the same property on each ion of a set of entangled ions produces correlated results. Non-entangled ions do not produce such correlations. An easy way to understand the situation is to imagine two people each tossing a coin. The outcome of each coin toss is random. However, if the coins were entangled in a particular way, the outcome of the coin toss would always be the same for both coins — with both people getting heads or tails.

The past few years have witnessed ground-

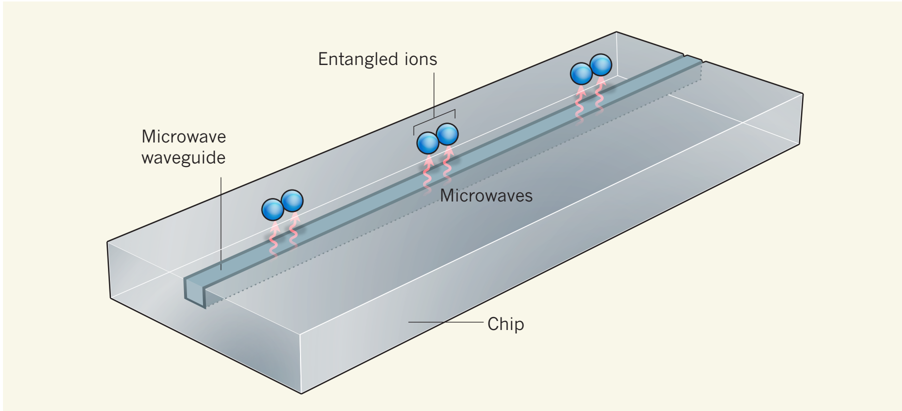

Figure 1 | Microwave ion-trap chip. Ospelkaus and colleagues' approach[4] to entangling pairs of ions and generating a quantum gate involves launching microwaves into a waveguide incorporated on a chip.

breaking advances in quantum-information processing using trapped ions, including the entanglement of up to 14 ions[6], and the development of other entanglement-based protocols, such as the realization of a number of quantum algorithms[3] and of teleportation[7,8]. These advances have been made in experiments in which laser beams are used to perform entanglemewnt operations. In 2001, Mintert and Wunderlich had the visionary idea[9] of implementing quantum gates using long-wavelength radiation, such as microwaves or radio waves. Whereas laser beams must be carefully aligned to interact with the trapped ions that are to be entangled, microwaves can be applied via waveguides (structures that can guide radiation) that are part of the chip on which the ion trap is integrated[10], and so do not require alignment.

What's more, it is much easier and less costly to generate microwave radiation than it is to use the complicated laser systems currently employed, and highly stable microwave sources are readily available. Large-scale quantum computers may require many millions of individually trapped ions, each constituting a single quantum bit (the basic unit of information storage in a quantum computer). As a result, creating the required number of laser beams to entangle the ions may entail significant engineering and come at a considerable cost. By contrast, the use of microwave radiation for the same purpose would be much easier and would make the construction of a large-scale ion-trap quantum-information processor much simpler.

Based on their proposal[11] to make use of the oscillating magnetic fields that are inherent to microwave radiation (the original proposal by Mintert and Wunderlich[9] requires static magnetic fields in addition to microwaves), Ospelkaus *et al.*[4] have realized the first microwave quantum gate. They achieved this by using a waveguide integrated into a microchip (Fig. 1) that holds the ion-trap structure. The microchip contains electrodes that produce electric fields capable of trapping two ions just above the chip's surface. Multiple pulses of microwave radiation are then applied to the trapped ions through the waveguide, effectively entangling the two ions and successfully executing a quantum gate.

Meanwhile, Timoney *et al.*[5] trapped individual ions and applied a number of microwave pulses to them. This approach sets the ions to a state in which they are decoupled from outside noise. An easy way to visualize this is by considering the suspension of a common car. Springs in the car's suspension system decouple the car frame from the wheels, largely isolating the driver from vibrations caused by uneven road surfaces. In a similar way, Timoney and colleagues' scheme allows trapped ions to be isolated from external disturbances that would otherwise have the potential to disturb the operation of a microwave trapped-ion quantum processor.

The achievements of Ospelkaus *et al.*[4] and Timoney *et al.*[5] constitute step-changing innovations for quantum computing with trapped ions because they will probably aid the production of large-scale ion-trap quantum computers on foreseeable timescales. Quantum computing is likely to revolutionize many areas of science, and we have only just started to appreciate its true potential. ■

Winfried K. Hensinger *is in the Department of Physics and Astronomy, University of Sussex, Brighton BN1 9QH, UK.*
e-mail: w.k.hensinger@sussex.ac.uk

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50 Years Ago

The Prehistoric Chamber Tombs of France. By Glyn Daniel — To win appreciation for some phase of antiquity on the strength of modern excavations is far easier than what has been undertaken here — where the antiquities concerned have been known for centuries, until only yesterday often excavated badly, and celebrated in a literature in which perverse and obsolete terminologies have run riot. Dr. Daniel, supported by his wife, and with backing from many quarters as well as friendly French co-operation, has for long been working towards a systematic account of the megalithic and related stone tombs of France, their form and contents, and their placing in the frame of European prehistory in the third and second millennia B.C., to which in general they belong. This book, by no means his first study of megalithic structures, is his best so far. It is not too hard to read.
From *Nature* 12 August 1961

100 Years Ago

In the July number of *The American Naturalist* Dr. O. P. Hay reopens the discussion with regard to the position of the limbs in Diplodocus and other sauropod dinosaurs, criticising the views of those who assert that these reptiles carried themselves in elephantine fashion, and maintaining his own opinion that the general pose was more after the crocodilian style … Mr. Hay expresses doubts as to whether the erect bird-like posture attributed to the carnivorous dinosaurs of the Jurassic is really true to nature … In reference to the opinion of Dr. Matthew that Sauropods were too bulky to have lived on land, it is added that "the law to which he gives expression does, of course, prescribe a limit to the size an animal can attain, but who has yet determined what that limit is?"
From *Nature* 10 August 1911