question about how this type of intervention affects the developing brain. A lesson of the Ahmari *et al*. study is that acute stimulation does not produce repetitive behaviors; multiple exposures to stimulation are needed for the phenotype to develop, which suggests that signs of compulsive disorders can be acquired through neuroplasticity. More work is needed to examine how optogenetic manipulation of key circuits early in life affects developmental trajectories to ensure no unintended effects. These current limitations notwithstanding, the cutting-edge and insightful research of Ahmari *et al*. and Burguière *et al*. illuminates the neurocircuitry of compulsive behavior with unprecedented clarity. Although there is still far to go, these discoveries represent a major leap forward toward eventual methods for "flipping the off-switch" on pathological compulsive behaviors.

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PHYSICS

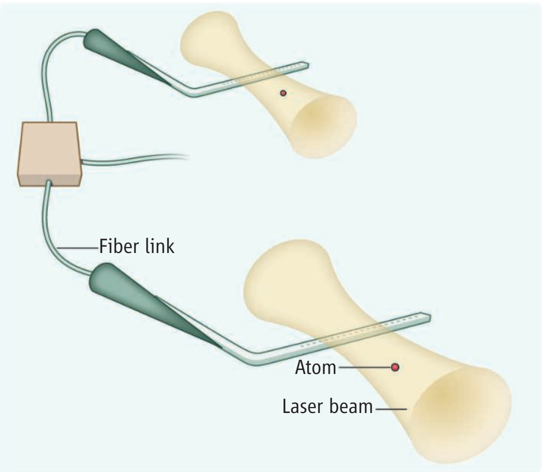
Interfacing Atoms and Light— The Smaller the Stronger

The strong interaction of neutral atoms with photons in a waveguide cavity may provide a way to create quantum information networks.

Matthias Keller

Most of us use the Internet to exchange information in everyday life. The ever-increasing rate at which Internet connections transmit data requires faster and faster conversion of local information into signals that can be easily transmitted over long distances. For example, the information sent by your computer is converted from electronic signals into optical signals, which are then sent through a network of optical fibers. Without the reliable and high-speed conversion of information from electronic to optical form, modern communication would not be possible. With the emergence of quantum technologies, most notably quantum information technology, the way we communicate is about to change fundamentally. On page 1202 of this issue, Thompson *et al*. (*1*) describe a system that has the potential to become an interface between atoms and optical signals and provide local information storage and transmission in the quantum domain.

In recent years, the processing of quantum information, where quantum-mechanical effects are used to potentially speed up computations, has been demonstrated in several systems (*2*–*6*). With these achievements, the question of long-distance communication in the quantum realm arises (*7*). As in the classical communication domain, a crucial building block consists of converters that can transform quantum information from one form into another, so-called quantum hybrid systems or quantum interfaces. Currently, the most successful implementation for such quantum interfaces for long-distance quantum communication is cavity quantum electrodynamics, where atoms interact with light in a cavity.



Toward quantum networks. Thompson *et al*. trapped atoms with laser beams in the vicinity of photonic waveguide cavities, as shown in the expanded view. The coupling interaction was determined by measuring the emission of photons that escaped the trap through the tip of a tapered optical fiber. These photons, guided by optical fibers, could potentially interact with other trapped atoms. The interactions in these quantum networks could provide a way to store and send quantum information.

Recently, the transfer of information between atomic states by single light particles (photons) or the entanglement of their states has been demonstrated (*8*–*10*). However, a technological challenge is still the fast, efficient, and faithful transfer of information between atoms and photons. To enhance the interaction between photons and atoms, both need to be tightly confined at the same location, and trapped for a sufficiently long time to allow the information transfer. The smaller the space in which both are confined, the stronger the interaction is, and the faster the interface operates.

In 1999, Ye *et al*. (*11*) trapped atoms in an optical cavity and demonstrated the control of the interaction between atoms and single photons. This technique was later used by Stute *et al*. (*8*) to demonstrate a quantum network. In a quest to increase the coupling strength between atoms and photons, Colombe *et al*. (*12*) combined a cavity, formed by laser-machined optical fiber ends with high reflective coating, with magnetically trapped atoms on a chip. Because of the small volume of such a cavity,

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the coherent coupling was greatly enhanced compared to conventional systems. In an alternative approach, Alton *et al.* (*13*) investigated monolithic microresonators in which photons were confined in whispering-gallery modes within a toroidal glass structure.

Thompson *et al.* have demonstrated the coupling of trapped neutral atoms with a photonic waveguide cavity (PWC). They have confined single atoms to a volume smaller than 0.007 μm^3 at a distance of 260 nm away from the PWC. In order to trap a single atom near the PWC structure, they used the reflection of a tightly focused laser on the waveguide structure. The reflected beam together with the incident beam forms a standing wave in whose maxima the atom is trapped. The exact position of the atom is determined by the reflected laser beam and depends on the structure of the waveguide itself.

To probe the interaction between the light trap (PWC) and the atom, Thompson *et al.* attached the waveguide to the tip of a tapered fiber through which the photons can escape the trap. Thus, by measuring the photon emission from the fiber, the interaction between atom and photon could be probed. The authors observed a coupling strength of 600 MHz, which measures the rate at which excitation between the waveguide structure and the atom is exchanged and thus constitutes the upper limit of the information transfer between atom and light. The atom was held in the vicinity of the PWC for 250 ms before it left the trap and was lost.

The combination of a single atom coupled to a waveguide structure is a promising implementation of a quantum interface between atomic and photonic quantum states. It opens the possibility to couple atoms, either to the same PWC, or to remote fiber-linked PWCs, through photon exchange (see the figure). Although there are still many technological challenges to overcome, such as to increase substantially the trap lifetime near the surface of the PWC, or the improvement of the PWC quality, the work of Thompson *et al.* constitutes an important demonstration of a quantum hybrid system.

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MICROBIOLOGY

Seas of Superoxide

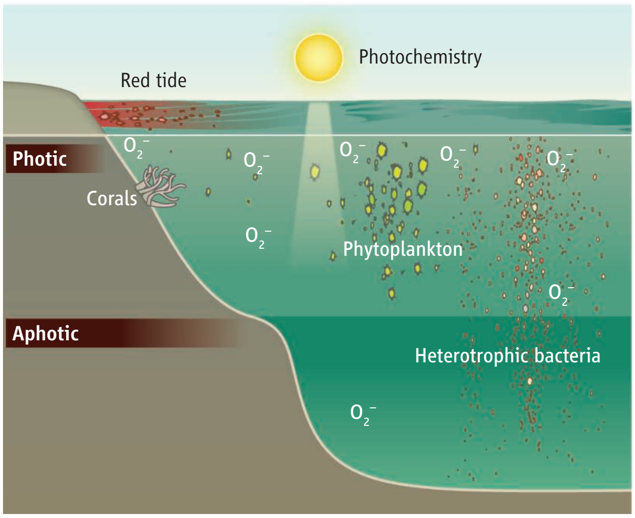
Superoxide in seawater may be produced by heterotrophic bacteria, with implications for trace metal cycling in the sea.

Yeala Shaked[1] and Andrew Rose[2]

In the past decade, sensitive analytical techniques have enabled a new look at the distributions, sources and chemical reactivity of superoxide (O_2^-) in the ocean. Until recently superoxide was thought to form solely through photochemical reactions in the surface ocean, but now biological processes are considered to be equally important in generating superoxide. On page 1223 of this issue, Diaz *et al.* (*1*) show that heterogeneous bacteria produce superoxide and potentially represent a substantial source of superoxide in the sea.

Superoxide is a reactive oxygen species that is highly toxic within biological cells, contributing to oxidative stress and cell death pathways, cellular aging, and pathologies, including cancer and Alzheimer's disease. Yet it is also vital for gene expression, intracellular signaling, and immune defense. Intracellular superoxide concentrations in biological systems are therefore tightly regulated, and its lifetimes within cells are extremely short. By contrast, in seawater, superoxide can persist long enough to diffuse well away from its source and react with organic and inorganic compounds.

Abiotic photochemistry in sunlit surface waters was long considered the major source of superoxide and other reactive oxygen species in natural waters (*2*, *3*). Recently, superoxide has been measured in a range of marine environments at picomolar to nanomolar concentrations (*4*–*8*). Unexpectedly, superoxide was found not only in the well-illuminated surface water but also in the deep ocean and at nighttime, albeit at lower concentrations (see the figure). That and the finding of particle-associated superoxide production (*4*–*7*) showed that there must be additional, possibly biological, sources of superoxide.



Superoxide in the ocean. In the photic zone, superoxide (O_2^-) is generated via photolysis of organic matter or by biological processes. In coastal waters, corals, macroalgae, and toxic red tide phytoplankton are potential sources of superoxide. In the open ocean, phytoplankton were regarded thus far as the dominant source of biologically produced superoxide. Diaz *et al.* show that extracellular superoxide is widespread among heterotrophic bacteria and may be an additional source of superoxide.

Enzymatic superoxide production on the outer cell membranes or plasma membranes is ubiquitous among plants, fungi, macroalgae, phytoplankton, corals, and bacteria (*6*, *9*–*12*). Toxic red tide algae of the genera *Chattonella* and *Heterosigma* produce superoxide at extraordinary rates (*10*) but only in coastal waters (see the figure). Other nontoxic rep-

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