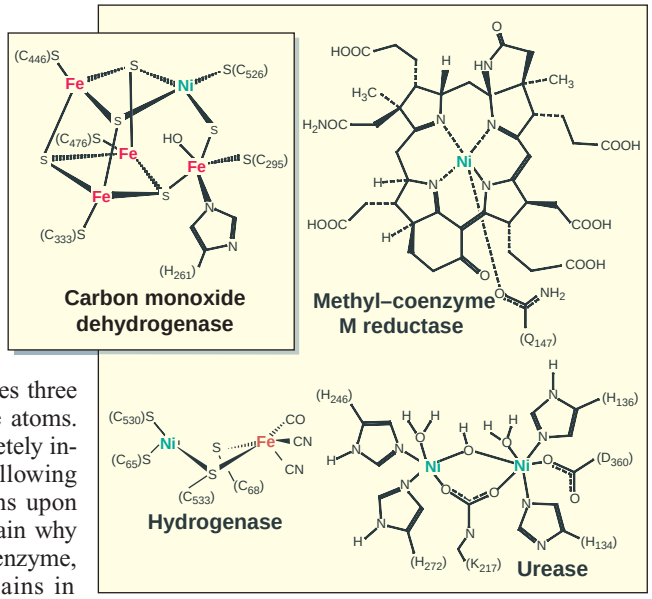
served, as is now evident from the crystal structure. The coordination of nickel in the active site of all nickel-containing CO dehydrogenases should therefore be very similar.

The biggest surprise from the crystal structure is the novel [Ni-4Fe-5S] cluster in the active site (see the figure). The nickel is bound by four S atoms and shares three S atoms with the four Fe atoms. The nickel atom is completely integrated in the cluster, allowing delocalization of electrons upon reduction. This may explain why even in the CO-reduced enzyme, the nickel formally remains in the Ni^{2+} oxidation state (and thus silent in electron paramagnetic resonance spectra) despite the fact that the nickel is the likely site of CO oxidation. But this will have to be shown directly by determining the structure of the enzyme with CO bound; the reported structure is that of the dithionite-reduced enzyme, which probably does not bind CO.



Active site nickel centers. The oxidation state of nickel in active CO dehydrogenase, hydrogenase, and urease is +2, and in active methyl-coenzyme M reductase, it is +1. In the catalytic cycle of CO dehydrogenase, methyl–coenzyme M reductase, and hydrogenase, the nickel center changes its redox state, whereas in that of urease it does not.

Active CO dehydrogenase from *Clostridium thermoaceticum* was obtained by cloning and heterologous expression of its gene in *Escherichia coli*, an organism that does not naturally contain this nickel enzyme (*14*). This indicates that the [Ni-4Fe-5S] cluster can be assembled in *E. coli*.

Another surprise is that nickel CO dehydrogenase is a functional homodimer, in which each monomer harbors one active site [Ni-4Fe-5S] cluster and one [4Fe-4S] cluster; an additional [4Fe-4S] cluster bridges the two subunits. The location of the five metal clusters relative to one another in the dimer indicates that electron transport proceeds from the active site [Ni-4Fe-5S] cluster of one subunit to the [4Fe-4S] cluster of the other subunit and then to the bridging [4Fe-4S] cluster. From the latter, the electrons can be transferred to the iron-sulfur protein electron acceptor (*4*).

The crystal structure was obtained for an enzyme with a specific activity of 14,000 μmol min^{-1} mg^{-1}. Previous analyses with other methods were mostly performed with enzymes with much lower specific activity. This indicates that considerable amounts of inactive enzyme were present and may explain some of the differences in properties reported.

Some aerobic bacteria can also grow on CO, but their CO dehydrogenase contains molybdenum and copper rather than nickel. The Mo-Cu enzyme (*15*) and the nickel enzyme (*4*) are not phylogenetically related, and their crystal structures have completely different topologies. The two enzymes do, however, catalyze essentially the same reaction with different electron acceptors—the same and not the same (*16*).

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PERSPECTIVES: LASER PHYSICS

Getting to Grips with Light

Tom Brown, Wilson Sibbett, Ewan M. Wright

What is light? This question might at first sight seem an odd one to ask—light is all around us and generally taken for granted. But any attempt to really get to grips with the nature of light takes one on a fascinating journey into the heart of physics. The report by Shelton *et al.* on page 1286 of this issue (*1*) does just that and opens up important areas of research in the generation and synthesis of light fields.

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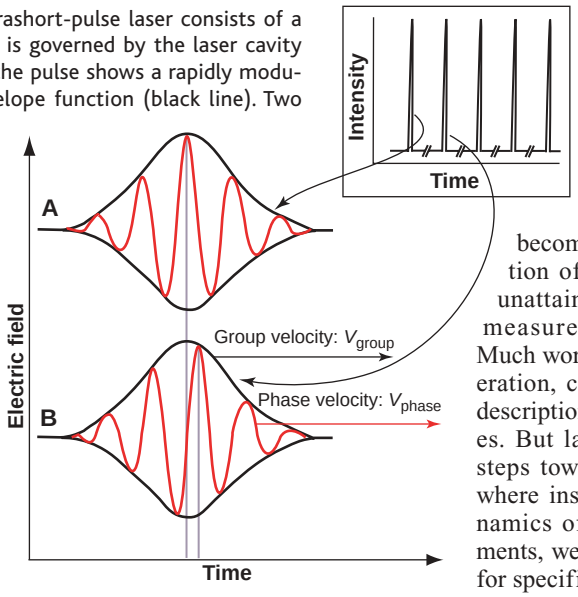
Light can be thought of as a wave made up from very fast oscillations in an electric field. A typical light wave may have a wavelength of 800×10^{-9} m, which, bearing in mind the speed of light ($\sim 3 \times 10^8$ m/s), gives a frequency for the wave of 3.75×10^{14} Hz. This means that one cycle of the electric field in the light wave takes place in just 2.7×10^{-15} s, or 2.7 femtoseconds (fs). In most situations, this fast variation in the electric field is too rapid to be noticed, and what is observed rather is the envelope function that modulates the underlying fast carrier variation.

Laser systems provide the ideal tool to investigate the properties of light. The light beams produced by a laser are coherent; that is, a fixed phase relationship exists in the output, in contrast to light encountered in every day life. Some modern laser systems are designed to produce light in the form of very short, regularly spaced pulses rather than in the more familiar continuous wave (CW) or "always-on" format (*2*). The pulse periodicity is governed by the physical size of the laser, and the output is a sequence of abrupt short pulses (see the inset of the figure). The pulse duration is short compared with the pulse repetition rate, and the average power from such systems is thus relatively low, but the peak power of the pulses is several orders of magnitude higher.

Recent studies have shown that ultrashort-pulse lasers made from crystals of titanium-doped sapphire can produce pulses of light with durations of less than 5 fs, corresponding to only two cycles of the electric



Ultrashort optical pulses. The output of an ultrashort-pulse laser consists of a stream of regularly spaced pulses whose spacing is governed by the laser cavity geometry (**inset**). More detailed examination of the pulse shows a rapidly modulating carrier field (red line) and an overall envelope function (black line). Two pulses emitted by the laser need not have the same carrier phase despite having an identical envelope function. This is illustrated by the difference in the position of the peak of the carrier amplitudes between pulses A and B and is caused by the difference between the group velocity V_{group} and phase velocity V_{phase} of the pulse. The drop lines are provided as a guide to the eye. To achieve coherent combination of pulses, the pulses must be not only synchronized in time, but their carrier phase must also be fixed through active control of the laser cavity.

field carrier underlying the pulse envelope (*3*). At such short pulse durations, the behavior of the carrier has substantial effects on both individual pulses and the train of pulses as a whole (see the figure).

In the general case, the speed of the pulse envelope or group velocity, V_{group}, and the speed of the underlying carrier wave, $V_{carrier}$, are not the same. As a result, there may be a carrier phase difference between pulses from oscillators (see the figure). This process undermines the possibility of producing a combination of the two pulses that remains coherent.

Much recent work has focused on controlling the carrier phase (*4*–*8*). Techniques for locking the carrier phase of individual pulses have been developed. Locking the carrier phase results in a stream of truly uniform optical pulses that are identical in all respects to one another. A central goal of this work has been the generation of ultrastable optical frequency combs to provide new levels of accuracy in optical frequency–based spectroscopy and high-precision metrology (*8*–*10*).

By successfully combining the output from two oscillators to produce a bandwidth of coherent light pulses that is greater than that available from a single laser, Shelton *et al.* have advanced one step toward the fabrication of designer-made light pulses for use in applications ranging from the coherent control of dynamical processes to the ultraprecise measurement of optical frequency standards. Two criteria must be fulfilled in their experiments: The repetition rate of the two lasers combined in their experiments must be controlled precisely to ensure that the laser pulses are emitted at the same time from each oscillator, and the phase within the pulses generated in each system has to be locked. Only when these variables are adequately controlled for each laser oscillator can the two separate coherent pulses be synchronized with respect to one another. When combined, these two pulses may therefore be viewed as a single pulse. Provided that the lasers are operating at different center wavelengths, the "superpulse" thus produced has a broader range of wavelengths than either of the two individual pulses. The duration of an optical pulse is inversely proportional to its bandwidth, and the composite pulse should therefore be shorter than either of the input pulses. Shelton *et al*. indeed deduced this from their experimental observations.

Ultrashort-pulse lasers are beginning to provide access to a fascinating regime where we can better understand and control the foundations of light. With such techniques, it may become possible to control the evolution of pulses and provide previously unattainable levels of accuracy in the measurement of optical frequencies. Much work remains to be done in the generation, characterization, and theoretical description of extremely short light pulses. But laser scientists are making first steps toward creating "designer pulses" where instead of letting the intrinsic dynamics of the pulse control our experiments, we can tailor the pulses we require for specific applications.

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PERSPECTIVES: ECOLOGY AND CONSERVATION

Whose Fish Are They Anyway?

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The bluefin tuna has inspired art and literature, driven sport and commercial fisheries, and been the object of scientific debate, catch and allocation negotiations, and even fist fights (*1*). Weighing as much as 700 kg and often sighted at the ocean surface, they are valued above all other fish species for sushi and sashimi—one 200-kg bluefin recently sold at auction in Japan for a record $390 per pound (*2*).

Atlantic bluefin tuna have been the subject of one of the most controversial fishery management sagas ever. At the core of the controversy is the dramatic decline in the abundance of the western Atlantic bluefin since the 1970s (see the figure) and the question of "whose fish are they?" The decline in the western Atlantic bluefin has intensified the question of "who gets the fish?" The U.S. fishing industries (both recreational and commercial) have argued that assessments of the western Atlantic bluefin population would be more optimistic if their movements between the western and eastern Atlantic were taken into account. They also have argued that they are being penalized for overfishing of bluefin by fishermen in the central and eastern Atlantic, including the Mediterranean Sea. A 1994 National Research Council (NRC) report on the western Atlantic bluefin population concluded that the trans-Atlantic movements or "mixing" of bluefin tuna needed to be taken into account, but that it would be impossible to do this reliably without better data (*3*).

In their elegant study on page 1310 of this issue, Block *et al*. (*4*) now provide valuable information on the migratory and diving behavior of the free-ranging bluefin

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