

Short, Intense Laser Pulse Makes Crystal Transparent

Although ruby is almost opaque to certain light frequencies, it can be made transparent to one of those frequencies according to Erwin Hahn and Samuel McCall of the University of California, Berkeley. The trick is to apply a sharp pulse of intense, coherent light at a frequency that matches a resonant transition in ruby. If the ruby is cold enough the pulse will be transmitted and the light can be slowed down to as little as 1% of its usual velocity. This self-induced transparency, predicted theoretically a year and a half ago by Hahn and McCall, was recently reported by them (*Phys. Rev. Letters* 18, 908).

Theory. When the sample is struck by a short, intense pulse of appropriate frequency, atomic electrons absorb energy but then return it to the beam in the original direction. In a crude analogy, a rolling ball (light pulse) is aimed at a straight-line row of pendulums (absorbing material), where each pendulum is a fixed ball hanging on a rigid rod suspended from a pivot. If the rolling ball hits the fixed ball of the first pendulum head on and hard enough (intense light burst enters the material), the rolling ball momentarily gives up a large share of energy to the first pendulum and slows down. The

pendulum swings through a full 360-deg circle and spans the rolling ball on its backside. This second impact restores energy, which was lost during the previous impact, to the rolling ball and it revives the ball's motion in the direction of original travel. The process can repeat itself along the line of pendulums. Below some critical energy (if the first pendulum cannot swing slightly beyond 180 deg) the pulse is absorbed.

In their analysis Hahn and McCall assume that the magnitude of the electric field vector varies slowly compared to the optical frequencies. Simplifying Maxwell's equation to obtain a first-order equation, they find (in the limit that damping is not important) a traveling-wave solution in which the electric field vector varies as $\text{sech}(t/\tau - z/V\tau)$. This is a transverse plane wave in x and y , which propagates in the z direction, has a final pulse width τ and a pulse velocity V .

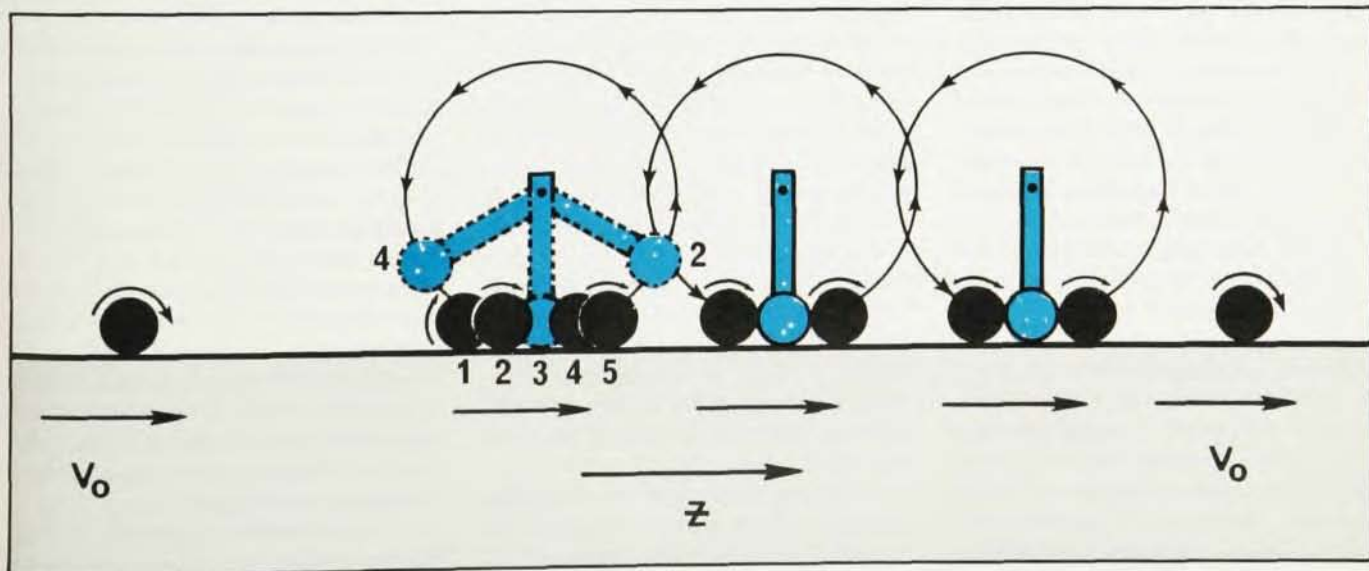
Experiment. Hahn and McCall use a Q-switched ruby laser as a pulse source to excite a resonant transition in a ruby crystal. They cool the crystal so that relaxation does not severely reduce the coherence of the effect. The phenomenon will occur if the in-

coming pulse width is less than or comparable to the optical relaxation time of the absorbing ions, and if the pulse power exceeds a critical value for a given pulse width.

Energies of 3–10 millijoules were used in 5–20-nsec pulses. Since the lasing transition is a doublet, the sample is cooled to liquid-helium temperature and the laser to liquid-nitrogen temperature. The low-frequency component of the sample doublet just happens to match the high-frequency component of the laser doublet.

Besides making the ruby transparent, the transmission phenomenon observed in the Berkeley experiment delays the pulse by about 100 nsec (at most); so the sample appears to have an index of refraction about 100 times its usual value. The pulse slows down while the electric field is interacting with the optical two-level

PENDULUM ANALOG of self-induced transparency. Pendulum row (sample) is struck by rolling ball (light pulse), which gives most of its energy to first pendulum ball and slows down. Pendulum turns 360 deg and spans rolling ball on backside. Second impact restores energy to rolling ball and it moves in original direction. Process can repeat along pendulum row.



system at a given position z in the sample. Energy is first absorbed from the leading edge of the pulse by the ions, and the ions then return the energy to the lagging edge of the pulse. The pulse will thus linger at z until the polarization produced by the ions decays to zero as the electric-field energy is finally returned to the traveling wave pulse. Thus the pulse is delayed, and when it reaches the next group of ions to be excited the process repeats itself.

To achieve greater delays one can increase the number of chromium atoms or increase the pulse width. There is a limit to the applicable pulse width, however, since it cannot exceed the energy damping time of the system. To achieve greater transparency and overcome damping one must apply a shorter pulse with a width much less than the damping time.

The effect is understood to apply only to absorbing transitions in insula-

tors where the wavelength of light is short compared to the overall attenuation length that one would have with a weak beam being absorbed according to Beer's Law. An extremely granular medium (with discontinuities greater than a wavelength) would not work.

In principle, Hahn and McCall note, the transmission effect could be seen in any two-level system involving magnetic or electric multipole transitions that are resonant to traveling waves in the form of radio, microwave or phonon pulses.

The delay should be useful for studying short-duration atomic and electronic motion. Now that mode-locked laser pulses as short as 10^{-12} – 10^{-13} sec are available, the transparency effect could be produced in media with damping times just as short. The delay effect may also have commercial applications in communications and computers.

Hahn and McCall's analysis also covers the dynamics of a pulse sent into a sample that is prepared initially in the excited state—the sample will behave as a laser amplifier. —GBL

US, USSR Venus Probes Await October Encounters

As this issue of *PHYSICS TODAY* reaches you, two Venus probes have completed about half of their 340-million-km journeys to the cloud enshrouded planet. Venus 4 left the Soviet Union on 12 June on a journey that the Russian news agency Tass said was to take "more than four months." Mariner 5 left Cape Kennedy two days later and is intended to encounter Venus on 19 Oct. Eight hours after launch Tass reported that the Soviet automatic space station was in a proper trajectory to reach Venus and all equipment aboard was functioning properly. After course correction, made on 19 June, Jet Propulsion Laboratory, project manager for the National Aeronautics and Space Administration probe, said that Mariner 5 could be expected to pass within 4100 km of Venus.

Venus, our evening star, is the planet nearest to earth and the brightest body in our heavens except the sun and moon. It circles the sun in an orbit three quarters the size of earth's and has about earth's diameter and mass. Recent measurements indicate

that it rotates about once every 250 earth days.

Nevertheless Venus remains largely unknown because of the density of its cloud cover. Its atmosphere is estimated to be from five to several hundred times the density of the earth's. Atomic hydrogen and oxygen are assumed to exist in the upper portions, but 99% of the atmosphere is unknown.

Much of what is known about the Venus environment has been determined by four earlier probes: Venus 1, a Soviet probe that went by at about 100 000 km in 1961, Mariner 2, which passed within 32 000 km in 1962, Venus 2, which came within 40 000 km in February 1966 and Venus 3, launched four days after Venus 2. Venus 2 was apparently on a picture-taking mission, but its radio failed. Venus 3 failed to respond to commands that would have ejected a soft-landing device and crashed into the planet.

Mariner 5 is designed to determine precisely the mass and position of Venus, to measure the density and



the temperature of the planet's exosphere, to observe its trapped radiation and magnetic fields if they exist, to observe protons and electrons forming the solar wind and to refine presently accepted values of the mass of the moon and the astronomical unit (mean sun-to-earth distance). Venus 4, Tass reported, is scheduled to fly near Venus and not land on the planet's surface. The Soviet spacecraft will use both ultraviolet and infrared radiations to investigate the surface.

Experiments that will be performed with the probe are as follows:

S-band occultation. When the probe encounters the planet, transmission through the Venusian atmosphere of the telemetry signal will, it is hoped, determine the density of the atmosphere and how it varies from top to bottom. The frequency shift that occurs should give this information at least down to the level at which density is so great that it traps the radiation and does not let it escape to earth.

Dual-frequency propagation 423.3- and 49.8-MHz signals are being transmitted from the Stanford 46-meter antenna to the spacecraft where a receiver compares phase shifts. Comparison reveals the number of electrons encountered by the signals between earth and satellite.

Solar-plasma measurement. A proton detector will determine energy and direction of protons boiling off from the sun in the solar wind. Particle energies from 45 to 9400 eV are separated into 32 bands by voltage filters, and direction is determined by a three-sector detector.

Trapped radiation detection. Three Geiger-Müller tubes and a cosmic-ray