Making waves that travel like beams

"Fire the photon torpedoes," Captain Kirk commands with cool leadership. Helmsman Sulu responds, and two twinkling blobs of light shoot out from the *Enterprise*. On their journey toward a Klingon warship, the blobs hold their shape. They do not spread out. The energy they contain does not dissipate.

This is science fiction. Evidence is mounting, though, that things like photon torpedoes might be creeping toward reality.

Three scientists report in the Jan. 9 Physical Review Letters that they can create complex ultrasonic pulses that do not spread, or diffract, when traveling short distances in water. The researchers call these unusual waves "acoustic directed-energy pulse trains," or ADEPTs. Other researchers have worked on related phenomena with names like electromagnetic directed-energy pulse trains and electromagnetic missiles.

Within the mathematical expressions describing the properties of propagating waves are hints that specially constructed waves – ADEPTs, for example – might be good for the "localized, slowly decaying transmission of energy in space-time," the researchers say. Such waves would not spread out, according to Richard W. Ziolkowski, a physicist at the Lawrence Livermore (Calif.) National Laboratory and one of the authors of the report. Livermore colleague D. Kent Lewis and Bill D. Cook (both mechanical engineers) of the University of Houston are coauthors.

The physical existence of such waves could make for a host of exotic applications, Ziolkowski told Science News. For example, a satellite might gather solar energy and then send it in pencil-like beams to small receivers at or near the Earth's surface. Point-to-point radio communication could be as private and tap-obvious as are the conversations of two children talking via string-joined paper cups. Energy-bearing beams that don't dissipate even after traveling thousands of miles would be of great interest to the Department of Defense. Its Innovative Science and Technology Office – part of the Strategic Defense Initiative Organization – has been supporting research in this area, including earlier theoretical studies by Ziolkowski.

As normal waves propagate, they spread out according to the laws of diffraction. Millions of widely separated listeners can hear the same radio program because the electromagnetic signals carrying the show spread out in a growing spherical wavefront starting at the broadcast tower. The same holds for almost any type of electromagnetic or acoustic wave that people might observe as, say, visible light, X-rays or sound.

But what's gained in transmission coverage is lost in power. The energy traveling within a typical wave distributes over increasingly larger areas and becomes less intense. That's why AM and FM radio shows fade as you get farther from their origins. It's also why baseball fans in the balcony have to scream louder than fans in box seats if they want the players to hear them. Even needle-thin laser beams get wider and less energy-packed as they travel. Not so for ADEPTs.

Unlike typical acoustic or electromagnetic waves that radiate from, say, vibrating vocal cords or oscillating electrons in an antenna, ADEPTs emerge from a complex interplay of acoustic waves made by an underwater "array" of electronically driven crystals that vibrate at ultrasonic frequencies. The researchers drive each element of the array so that it creates a somewhat different pulse, but these sum into a pencil-like ultrasonic beam, Ziolkowski says. Since ADEPTs remain confined to small regions, the energy they contain also remains concentrated.

So far, the researchers have launched ADEPTs that travel only a few feet before they die out. The challenge now is to build arrays that can launch them much farther, Ziolkowski says. *– I. Amato*

High-precision tests in particle physics

As high-energy particle accelerators grow more difficult and expensive to build and operate, and the collisions they generate become more complex to monitor and interpret, physicists are turning to alternative ways of probing the fundamental laws of matter. Such novel approaches, which rely on advanced lasers and other sophisticated instruments, are now yielding remarkably precise measurements of the properties of electrons and other particles. Moreover, these relatively inexpensive, "tabletop" experiments furnish extremely sensitive tests of theories predicting the behavior of atoms and subatomic particles. In many cases, their precision far surpasses that of present-day accelerators.

The contrast between the atom-smashing approach to physics and its alternatives is striking. Using a high-energy accelerator is like trying to figure out how a watch works by smashing it with a sledgehammer, then examining the fragments. On the other hand, instead of destroying the watch, researchers can try to deduce what's happening inside the watch simply by observing subtle vibrations of its casing. Both approaches are indirect, but the gentler techniques are proving superior for certain kinds of determinations. Such methods for making high-precision measurements were the subject of a session at this week's meeting in San Francisco of the American Association for the Advancement of Science and the American Physical Society.

To compare the properties of electrons and positrons (the antimatter equivalent of electrons), Hans G. Dehmelt and his colleagues at the University of Washington in Seattle isolate a single electron or positron in an electromagnetic trap, holding the same particle for hours or even days at a time. Such a trap, in which the particle is virtually stationary, recently allowed the researchers to show that electrons and positrons have the same magnetic moment to within a few parts in 10^{12}.

"This work severely tests the fundamental theory of quantum electrodynamics and the mirror symmetry of electrons and positrons," Dehmelt says.

Similar experiments also indicate that the electron's radius must be less than 10^{-20} centimeters, less than one-thousandth the value of the previously accepted upper limit on the electron's radius (determined by smashing electrons together). In addition, by using traps holding individual, singly charged ions, researchers have managed to detect quantum jumps, in which an electron shifts from one energy level to another.

To test the "standard electroweak model," a remarkably successful theory uniting electromagnetism and the weak nuclear interaction, researchers are using advanced laser technology to detect tiny distortions in heavy atoms such as cesium. Electrons in atoms "feel" not only the electromagnetic force between an electron and a positively charged nucleus, but also the much smaller influence due to the weak nuclear interaction. According to the standard electroweak theory, that additional effect distorts an atom about as much as a single hair added to Earth's surface changes the planet's shape. By measuring the distortion precisely, physicists can determine whether the strength of the weak nuclear force deviates at all from the strength predicted by the standard model.

To date, the most precise measurements of this distortion come from Carl E. Wieman and his colleagues at the University of Colorado in Boulder. Using cesium atoms, they obtained values in agreement with the standard model and with previous, less precise measurements.

"While the results are now in excellent agreement with the standard model, it makes sense to continue these experiments, provided they can be done with sufficient precision in atoms amenable to unambiguous theoretical analysis," says Eugene D. Commins of the University of California, Berkeley. Such experiments demonstrate that the model holds precisely over a wide range of conditions. Furthermore, physicists hope to uncover the precise nature of subtle, previously unmeasurable contributions to the efects observed. *– I. Peterson*