

subsonic and transsonic (but not supersonic) airflows. A longer-range prospect, he mentioned, is that of using liquid hydrogen first to cool the exterior surfaces for drag reduction, and then as the fuel for propulsion. (Its high impulse per unit mass makes hydrogen a very desirable aircraft fuel.)

While the basic theory of drag reduction by polymers is still in question, a lot is already known about how to control and apply it.

► In trials in New York City, it was found possible to reduce the diameter of a fire-hose when polymer was added to the water, and still deliver the same volume of water; large hoses are extremely difficult to handle.

► In irrigation systems the addition of polymers substantially increases the area that can be served by a given pump, with a longer throw as well as increased pipe flow. Poly(ethylene oxide) is nontoxic and readily biodegradable.

► The US Navy is studying its application to surface shipping and submarines. However, Lumley has found no clear economic benefit in using polymers to reduce the drag of supertankers.

► A report by Shell indicates that they are using a specially developed polymer (with molecular weight about  $10^7$ ) for addition to petroleum pipelines.

A misuse related as an anecdote illustrates an interesting property of polymer solutions. The story has it that a group was using the method to hose off insulators. However, polymer solutions do not break up into sprays, thus providing a continuous electrical path—and a shock.

—HRL

## Reference

1. Proceedings of the IUTAM Symposium on Structure of Turbulence and Drag Reduction (F. Frenkiel, M. Landahl, J. Lumley, eds.), *Phys. Fluids* **20**, No. 10, part II (1977); also available as a bound volume published by the American Institute of Physics.

## New limit on constancy of velocity of light

Among today's physicists, it is doubtful that many would claim that the speed of light depends on the velocity of the source. But it is pleasing to know just how right Einstein's second postulate in the special theory of relativity is. Recently, by analyzing observations of pulsating x-ray sources in binary star systems, Kenneth Brecher of MIT has calculated<sup>1</sup> a limit he believes is five orders of magnitude better than past verifications.

The question of whether or not the velocity of the source adds to the velocity of light dates back at least to physicists like Augustin Fresnel and Armand Fizeau, who worked in the early and mid-19th century. In 1905, when Albert Einstein

formulated special relativity, he based it on two postulates. The first says that a law of physics that holds in one coordinate system holds in any other coordinate system moving uniformly with respect to the first. Limits on this postulate were established in the original Michelson-Morley experiment and more recently at MIT by T. S. Jasega, Ali Javan, J. Murray and Charles Townes in 1964, who obtained a limit of one part in  $10^4$ .

The second postulate says that the speed of electromagnetic radiation is independent of the velocity of the source.

In 1908 W. Ritz developed a theory of electromagnetism that involved a speed of light that was relative to the source. Such an emission theory says that radiation emitted by a source moving with velocity  $v$  with respect to the stationary observer propagates with velocity  $c' = c + v$  in the rest frame of the stationary observer. One can test this hypothesis by assuming  $c' = c + kv$  where  $k$  is a constant that is 1 for the Ritz theory and 0 for the Einstein theory.

A few years later W. de Sitter said Ritz was wrong because astronomers would have seen ghost images in binary sources. He set a limit on  $k$  of  $1 \times 10^{-3}$ . In the early 1960's, J. G. Fox (Carnegie-Mellon University) pointed out that the radiation at optical wavelengths would be scattered by the interstellar medium, and the original wave would be replaced by a reradiated wave, which would have a phase velocity characteristic of the medium (according to the so-called "extinction theorem" of Paul Ewald and C. W. Oseen). The characteristic "extinction" length for visible light is about two light years.

But the extinction length varies inversely as the wavelength. So Brecher studied sources of 70-keV x rays, where the extinction length is larger than the size of the galaxy (10 kiloparsec). Brecher considered three binary sources of x-ray pulses. From the pulse arrival time, he calculated the orbital motion of the source and determined the angular position of the x-ray source in its orbit with respect to the line of sight from the binary star system to the observer. He independently determined the angular position of the source from the eclipse observations. In special relativity, the two positions coincide. For the source in the Small Magellanic Clouds (SMC X-1), Brecher found a limit on  $k$  of  $4 \times 10^{-10}$ . However, Brecher feels a more reliable limit is the one obtained from Her X-1, "a clean system." From Her X-1 he finds a limit on  $k$  of  $2 \times 10^{-9}$ .

A less stringent limit was obtained in 1964 by Torsten Alvager (then at CERN) and his collaborators, who studied relativistic  $\pi^0$  decay into gammas. If the velocity of the pions is added to the velocity of light, the gammas would have a velocity of almost  $2c$ . If not, the gamma velocity would be  $c$ . By time-of-flight measure-

ments, the CERN group verified the second postulate to one part in  $10^4$ . —GBL

## Reference

1. K. Brecher, *Phys. Rev. Lett.* **39**, 1051 (1977).

## Positrons

*continued from page 17*

effective  $Z$  of 184), theoretical calculations indicated that a positron would be created spontaneously, without the expenditure of any energy. In this process an electron would fill the empty innermost bound resonant state associated with the K shell of subcritical systems, and the positron would be emitted with a kinetic energy  $B - 2m_e c^2$ , where  $B$  is the binding energy of the resonant state.  $Z_{cr}$  is that value of  $Z$  that causes  $B = 2m_e c^2 = 1.02$  MeV.

For values of  $Z$  greater than  $Z_{cr}$ , one can think of the electric field of the nucleus as being so strong that the "neutral vacuum breaks down" and ceases to be the ground state. Instead of an uncharged vacuum, one will have a charged vacuum. The group at GSI is trying to learn if there are unforeseen effects such as nonlinear terms that prevent this.

Interest in strong-field behavior in finite nuclei has had a long history.<sup>3,4,5</sup> More recently, in 1969, papers by W. Pieper and Walter Greiner (University of Frankfurt) and by S. S. Gershtein and Ya. B. Zeldovich (Moscow) have examined atomic levels for finite-size nuclei in overcritical fields. In 1972 Berndt Muller, Johann Rafelski (now at CERN) and Greiner described how effects characteristic of  $Z$  greater than  $Z_{cr}$  would appear in a realistic heavy-ion experiment. Since then the Moscow group, led by V. S. Popov and Zeldovich, has produced a number of papers expanding these ideas. Meanwhile the group at Frankfurt, led by Greiner, has been extremely active and has inspired much of the present activity.

In a series of experiments, the group at GSI is searching for this fundamentally new phenomenon by attempting to observe spontaneously emitted positrons in overcritical quasimolecular systems. Heavy ions are accelerated to about 5 MeV/nucleon; for uranium this amounts to about 1.2 GeV. Nuclear reactions with target nuclei and contaminants are excluded from the positron events recorded. Two instruments are used to transport the positrons being emitted from the target to a region where they are counted and identified by their distinctive annihilation radiation. One device is a solenoidal transport system. The other is called an "orange spectrometer;" it has 60 coils (the orange sections) that produce a toroidal focussing magnetic field.

One of the major factors to be considered in interpreting these measurements is the background positron emission from