More tests of special relativity

Yet another experiment has provided a novel test of special relativity, one that duplicates in the laboratory phenomena for which people usually look to astrophysics.

GIVEN the zeal with which those who disbelieve the special theory of relativity go about their business, it is a comfort that experimental tests of relativity are also flourishing. One of the latest, an experiment carried out at Los Alamos by D.W. MacArthur *et al.*, has the special virtue of providing a test, successful as it happens, of the relativistic Doppler effect at velocities as great as 0.84 of that of light (see *Phys. Rev. Lett.* **56**, 282; 1986). Moreover, this laboratory experiment has all the promise of being generically novel.

The principle of the experiment is straightforward enough, as most convincing designs must be. The essential phenomenon is the excitation of quickly moving neutral hydrogen atoms by an ultraviolet laser. The atoms of the hydrogen beam have essentially a constant velocity, as does the laser. But by varying the angle at which the laser beam intercepts the moving hydrogen atoms, the interaction energy — as seen from a frame of reference in which the atoms are at rest — can be varied over a wide range.

The experiment has been made possible by the meson factory at Los Alamos, formally known as the Clinton P. Anderson Meson Physics Facility (LAMPF) and, as such, an enduring memorial of the time when members of the US Congress were among the strongest supporters of the nuclear industry in the United States. Among other things, the machine can produce a beam of negative hydrogen ions with an energy of 800 MeV, corresponding to 0.84 of the velocity of light.

Magnet

The beam is processed in three successive steps. First, a proportion of the negative hydrogen ions is converted into neutral atoms by means of an infrared laser at a frequency corresponding to that needed to shake loose one of the two electrons. The second and crucial step is the interaction with the beam of a pulsed ultraviolet laser, an yttrium aluminium garnet device doped with neodymium and yielding photons with an energy of 4.66 eV. The effect of the interaction is, naturally, to excite some of the neutral hydrogen atoms or even to ionize them completely. The final step is the separation of the three species of hydrogen atoms, the neutrals and the negatively and positively ionized atoms, by a magnet. The trick is to use a magnet whose field is strong enough to convert into protons any neutral hydrogens that have been excited above the second excited state (with principal quantum number three). Both the neutral hydrogens and the protons are counted by means of scintillators.

The cumbersome part of the equipment is the turntable that allows the laser beam to intercept the atomic beam at various angles. (There is a system of mirrors to ensure that the laser itself does not move.) The result is that the energy of the ultraviolet photons appears, from the rest-frame of the hydrogen beam, to vary by an order of magnitude between 1.4 eV and 15.8 eV. For practical purposes, the arrangement is one for allowing the measurement of the energy of the successive excitations of neutral hydrogen atoms. The authors of the experiment show convincingly that the excitation curves that they obtain (essentially the production of protons in the detection system as a function of the angle of their turntable) are indistinguishable from a gaussian curve (which is what would be expected). They have been able to record resonances corresponding to excitations from the ground state to between the fourth and the eleventh quantum level inclusive. The interpretation of the data hangs on the accuracy with which the position of the turntable can be measured, with a precision of 30 microradians, it is claimed.

Reconciling these results with what special relativity predicts requires a little subtlety. The familar Lorentz transformation between one coordinate frame and another has the time T in one frame of reference related to that, t, in the other by means of a linear relationship of the form $T = at + bx$, where x is a spatial coordinate and the factors a and b are coefficients depending on the relative velocity of the two frames, v. In practice, the prediction of special relativity is that the quantity a is the time-dilation factor given by the square root of $1/(1 - v^2/c^2)$. MacArthur and his colleagues allow the possibility that this relationship may not be exact, that the coefficient a may be a function of velocity other than the time-dilation factor, and set out to determine from their resonance measurements just what it may be. Because of the way in which the measurements are carried out, by the interaction of atoms and photons at positions that are well-defined in both frames, the experiment cannot provide information bearing on the second coefficient, b.

Unsurprisingly, the outcome of the experiment is that the time-dilation factor is sufficient to account for the variation of the energy of the ultraviolet photons as seen from the frame in which the hydrogen atoms are at rest. That energy is the energy of the photons in the rest-frame of the laser multiplied by the time-dilation factor and by the factor that represents the influence of the strictly classical Doppler effect. This, by involving the cosine of the angle between the two beams, allows for the way in which the experiment spans a whole order of magnitude in the excitation energy of the neutral hydrogen atoms. The precision of the result is given as 27 parts in 100,000. With what would obviously be a great deal of hard work, the authors believe they could improve the precision of the experiment by a factor of as much as 1,000.

Velocity

The arresting feature of the experiment now described is not, however, its precision but the large fraction of the velocity of light at which the two frames are moving relatively to each other. It is true, of course, that most people are sufficiently persuaded of the accuracy of what has now been demonstrated about the accuracy of the time dilation factor of special relativity by the increase of the lifetime of quickly moving particles, as in cosmic rays, while the behaviour of charged particles in accelerating machines is another line of related evidence. Another novel feature of the Los Alamos experiment is that it provides a demonstration of how a laser beam, with a frequency defined in one frame of reference, can be translated into a tunable but defined frequency in another. That should be suggestive of all kinds of other measurements.

In the long run, efforts in that direction may be less rewarding than would be a successful experiment to verify that the other factors in the Lorentz transformation of coordinates behave as predicted. The obvious difficulty is that of constructing experiments in which events seen as if from two relatively moving frames are separated from each other in time and/or distance. The obvious measurements to make are those of the signals from Earth satellites and spacecraft. Much has been done already, but further efforts are needed, and not merely to keep the army of sceptics of the special theory at bay.

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