Tests of relativity (continued)

The most sensitive test so far of special relativity is claimed to show that Lorentz invariance is correct to within one part in 10^{21}. But the sceptics will no doubt shrug this off.

THERE are as many ways of testing special relativity as there are of designing distinct experiments, for at some level of sensitivity, the measurement of every phenomenon is a proof that Einstein was either right or wrong. But those who have made a profession of testing special relativity know that they cannot casually cite in their support the common knowledge that theories built around the assumption of Lorentz invariance are more satisfactory than other kinds of theories. Instead, there must be purpose-built experiments, no one of which will in general do more than test one aspect of special relativity. The latest experiment of this kind, a technically intricate comparison of the rates of precession of the nuclear magnetic moments of two mercury isotopes, has now been described by a group from the University of Washington (Lamoreaux, S.K., Jacobs, J.P., Heckel, B.R., Raab, F.J. & Forston, E.N. *Phys. Rev. Lett.* **57**, 3125; 1986).

The principle is simple enough. Nuclear magnetic resonance (NMR) is essentially a technique for measuring the rate of precession of an atomic nucleus with a net non-zero spin and thus magnetic moment about the direction of an applied magnetic field. Such measurements are made every day of the week, although not with particularly great accuracy. If, by some stretch of the imagination, special relativity should be false, then the results of these measurements should vary with the changing seasons or, more accurately, as the orientation of the precession axis changes relative to the fixed stars because of the rotation of the Earth. In reality, the chances of measuring such an effect (if there were one) with even the powerful NMR machines to be found in every other chemistry laboratory are negligible; these machines, which use powerful magnetic fields to make the precession frequencies accessible in the microwave region, are simply incapable of demonstrating departures from Lorentz invariance at the level of one part in 10^{20} or thereabouts — which is not to suggest that the machines do not have other uses.

That is why the measurements now reported from Seattle are based on the use of quite different parameters. The static magnetic field in which isotopes of ^{199}Hg and ^{201}Hg are made to precess is a mere 20 milligauss. The two isotopes have nuclear spins of 1/2 and 3/2 respectively, and their precession or Larmor frequencies in the conditions of the experiment are merely 5.5 Hz and 15 Hz. Plainly, frequencies of that magnitude are not directly measurable with anything like the accuracy needed, which is why the success of the experiment hangs on the design of a complicated servo-system that makes the precession frequency the basis for a stable oscillator from whose systematic phase shifts the frequency changes can be inferred with accuracy.

The centrepiece of the system is a 2-cm silica sphere filled with mercury at the vapour pressure corresponding to room temperature. The sphere is illuminated with circularly polarized light from a mercury-vapour discharge lamp chosen to exploit the fact that radiation from ^{204}Hg overlaps electronic transitions in each of ^{199}Hg and ^{201}Hg which, by absorption of the radiation, indirectly polarize the respective nuclei. The static magnetic field is at an angle of 45 degrees to the incident light, and these two axes are physically arranged so that the place which they define is parallel to the Earth's Equator.

The sample is at the centre of three pairs of Helmholtz coils at right angles to each other, with that at right angles to the equatorial plane producing a magnetic field that oscillates at a frequency close to the Larmor frequency. The light traversing the system is modulated by this frequency with a phase shift proportional to the mismatch. The trick, accomplished by means of four digital signal analysers, is by means of a suitable adjustment of the parameters of the system to fix the magnitude of the signal from ^{199}Hg at zero, when the magnitude of the signal from the other isotope is a sensitive measure of any relative shift of the frequences of the two.

The results are marvellous illustrations of the sensitivity that can be wrung from such experiments in which computers are used for logging on a continuing basis sets of data consisting of records of a dozen or so variables. The authors say that their equipment has been operated for six different periods each lasting 3.5 days. Although the direct measurement of the ^{201}Hg signal drifts in the course of one run (by a mere 100 microhertz), the drift is magically removed by taking account of correlations with other variables, among which the intensity of light from the mercury lamp is one of the worst offenders.

The end-product is a set of points on a graph of relative frequency shift against sidereal time which shows no significant pattern that would imply that the frequency shifts are determined by the time of day (relative to the fixed stars). Dutifully, the authors try to fit the data with a simpler Fourier series with components that have the periodicity of the Earth's rotation. They conclude that the dipole frequency-shift due to changes in the orientation of the equipment is less than 2.4 microhertz and that the corresponding quadrupole shift (in the language of NMR) is less than 0.48 microhertz. The smallness of the second upper limit is a consequence of the large quadrupole moment of the heavier isotope.

Elaborate though this technology may be, it does in the end have a bearing on special relativity. To put the point simply, if there were some means by which particular or preferred directions were distinguishable by local dynamics, the dynamical properties of atoms would vary with their orientation in space. In particular, the mass of, say, an atomic nucleus would be a function of its orientation. What the Seattle group has shown is that, for the nucleus of a mercury atom, any such variation must be less than the equivalent of 2×10^{-21} eV.

In the long run, the importance of this work is that it will suggest even more stringent tests of special relativity. The authors say that they could, for example, do even better if they had more stable mercury lamps. Even so, their present work is an improvement by a factor of 2,500 on the sensitivity of a test of the local isotropy of space done two years ago with beryllium ions in an electromagnetic trap.

Unfortunately, none of this sophistication will finally exorcise the belief of that small band of zealous but sceptical men (in *Nature's* experience, there are no women among them) who are persuaded that there is something radically wrong with special relativity. It may be true, of course, that tests like that carried out by the Seattle group are not tests bearing directly on the issues which the sceptics say are obstacles to belief — the constancy of the velocity of light (although these measurements bear on its local invariance with direction), the meaning to be given to the concept of time in moving frames of references and even the old twin paradox. The truth is a little like that in the running verbal with literal creationists; that belief and disbelief carry more weight than evidence, however extensive and skilfully acquired.

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