The neutron is exactly such a neutral particle and, as already mentioned, neutrons can exhibit pronounced wave-like interference phenomena — which may be conveniently observed in an interferometer cut from a single crystal of silicon[6]. Thus in the new experiment of Cimmino *et al.*[1] to check the Aharonov–Casher effect, the two beam paths 1 and 2 correspond to the two 'arms' of a neutron interferometer. Recall that, being topological in nature, the predicted phase shift depends on neither the geometry of the beam paths nor the detailed configuration of the charge; all that matters is the linkage of the electric charge line by the loop corresponding to the beam path. Thus Cimmino *et al.* enhanced the effect by using a series of line charges — in fact, an electrode system, contained within the two beam paths, and creating a horizontal electric field (Fig. 3). The effect is manifested, in principle, via a small change in the counting rate at the point C when the electric field is switched on, corresponding to a small shift in the intensity pattern.

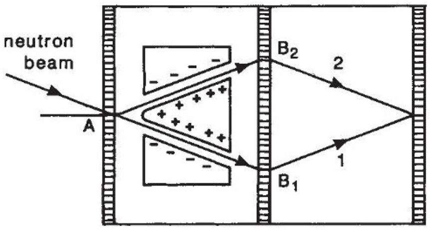

FIG. 3 Schematic of the crystalline-silicon neutron interferometer used by Cimmino *et al.* to demonstrate the Aharonov–Casher effect.

A significant problem in demonstrating the Aharonov–Casher effect is that the neutron's magnetic moment is very small, so that the phase shift is predicted to be only a few milliradians; the Aharonov–Bohm shift can easily be a thousand times larger. Furthermore, the magnetic moments of the beam neutrons should all be polarized parallel to the lines of charge. But the intensity of neutron beams is weaker than that of electron beams, and weaker still if only neutrons of a definite alignment are wanted. Very long exposure times would be needed to build up reliable statistics, but this would necessitate ensuring the mechanical rigidity of the interferometer to an extraordinary degree as the normal interference pattern is determined by the difference in path length of the two arms. In fact, Cimmino *et al.* state that an uncontrolled phase drift ϕ_0 can occur, of the order of 50 mrad a day, that would completely obscure the tiny Aharonov–Casher effect.

This problem has been overcome in a highly ingenious way. For polarized neutrons, the effect of the phase drift ϕ_0 can be cancelled by reversing the polarity of the electric field and measuring the corresponding difference in the neutron counting rates. Unfortunately, this cancellation does not occur for an unpolarized neutron beam, but Cimmino *et al.* surmounted this by exploiting the fact that a phase shift can be induced if the two beams pass through different gravitational potentials[7], which can easily be achieved by tilting the whole apparatus, and adjusting the phase shift, ϕ_g, so induced to cancel ϕ_0. A further refinement was the introduction of a magnetic field over part of one of the neutron paths; this induces yet another phase shift[8], which depends on the alignment of the neutron's magnetic moment and maximizes the sensitivity of the experiment. The measured Aharonov–Casher phase is 1.46±0.35 times the predicted value, where the error is purely statistical.

This demonstration of a subtle effect is an elegant example of the experimentalist's art. It turns out that the detailed theoretical interpretation is not without interest either. Recall that in the Aharonov–Bohm effect, the particle beams never penetrate the solenoid and thus 'feel' no classical force. Do the neutrons in the new effect feel a force or not? At first sight it would seem that they do, because, according to special relativity, a particle moving with uniform velocity through an electric field also experiences an apparent magnetic field — and this can act on the neutron's magnetic moment. Indeed, this force causes a differential slowing down between the neutrons travelling along the two paths, which generates a phase shift equal to Aharonov and Casher's prediction[9].

This interpretation has been challenged by Alfred Goldhaber, who points out[10] that the total force on a neutron must include a contribution from the change in the momentum carried by the electromagnetic field at the position of the neutron; when this is included, the total force is indeed zero, provided the dipole moment of the neutron is perpendicular to the electric field. Thus the Aharonov–Casher effect, as one would expect from its close analogy with the Aharonov–Bohm effect, does seem to be genuinely force-free and topological. All the same, we can expect to see further discussion of this point, and further exploration of the possibilities opened up by the new effect. □

I.J.R. Aitchison is in the Department of Theoretical Physics, University of Oxford, Oxford OX1 3NP, UK.

1. Cimmino, A. *et al. Phys. Rev. Lett.* **63**, 380–383 (1989).
2. Aharonov, Y. & Casher, A. *Phys. Rev. Lett.* **53**, 319–321 (1984).
3. Aharonov, Y. & Bohm, D. *Phys. Rev.* **115**, 485–491 (1959).
4. Chambers, R.G. *Phys. Rev. Lett.* **5**, 3–5 (1960).
5. Tonomura, A. *et al. Phys. Rev. Lett.* **56**, 792–795 (1986).
6. Rauch, H. *et al. Phys. Lett.* **47A**, 369–371 (1974).
7. Colella, R. *et al. Phys. Rev. Lett.* **34**, 1472–1474 (1975).
8. Werner, S.A. *et al. Phys. Rev. Lett.* **35**, 1053–1055 (1975).
9. Boyer, T.H. *Phys. Rev.* **A36**, 5083–5086 (1987).
10. Goldhaber, A.S. *Phys. Rev. Lett.* **62**, 482 (1989).

DAEDALUS

Shaking fever

Many health physicists suspect that microwaves are hazardous, even in doses too small to cause overt heating. Perhaps, says Daedalus, they set up molecular vibrations. A big protein molecule must have many fundamental vibrations at microwave frequencies. If by chance a lot of them lay in the output-band of a powerful microwave source, all those vibrational modes would be excited simultaneously.

This by itself would not be harmful. A molecule can take a lot of vibration without falling apart. But Daedalus recalls the 'freak wave' phenomenon: many small vibrations coinciding by chance to produce a huge and damaging momentary amplitude. If many of the molecular modes of the protein all happen to stretch a particular bond, then a freak-wave coincidence phasing them all together would probably break the bond and destroy the protein.

Daedalus sees a new therapy here. For viruses, too, are big enough to have many vibrational modes in the microwave region. But, whereas proteins come in innumerable varieties each with many molecular conformations, all the particles of a particular virus must be identical, with the same vibrational modes. So DREADCO biochemists are studying selected viruses by microwave spectroscopy, to identify every vibrational mode which contributes to stretching a particular bond or set of bonds.

The vibrational analysis of a complete virus particle will be daunting indeed; but the effort will be well worthwhile. For the DREADCO team will then be able to irradiate their viral cultures with all these crucial microwave frequencies simultaneously. They will even phase the frequencies for maximum freak-wave impact. The resulting 'targeted microwave radiation' will be a splendid, highly specific, antiviral therapy. Its heating effect need not be too great and, although it may zap the odd protein molecule by sheer chance, its general biological effect will be slight. But it will infallibly break up every virus particle of the targeted type.

The viral ills that flesh is heir to will thus be stopped in their tracks. For microwaves can penetrate the entire body. Even if the chosen virus hides inside the cells of its victim, where antibodies cannot reach, it will be swiftly shattered by microwave-induced freak-wave scission. Once the vibrational analysis of a given virus has been completed, DREADCO's programmable multifrequency microwave generator will be able to blast it out of the body on demand. Influenza, glandular fever, hepatitis, even the common cold, will surely succumb to this potent therapy. Even if the virus mutates in self-defence, a re-analysis of its new form will put it firmly back in DREADCO's sights. David Jones