Particle physics in slivers of mica

A heroic investigation at Berkeley has shown that mica of good quality can be used to search for evidence of one possible component of the missing mass required to close the Universe; none has been found so far.

ONCE upon a time (in 1986), when the search for magnetic monopoles was fashionable, P. B. Price at the University of California, Berkeley, had the grand idea of looking for evidence of the existence of monopoles by hunting through specimens of mica. For magnetic monopoles, whose existence is required by certain unifications of particle theories, should leave tracks a few micrometres long in minerals of all kinds. Mica is an ideal material in which to look for tracks of this kind because of the ease and precision with crystals of it can be cleaved. For a time, it seemed as if it would be possible to uncover a kind of fossil record of magnetic monopoles.

Even though there are still many people who speak fondly of grand unified theories (or GUTs), the hunt for free magnetic monopoles has fallen out of fashion. (The hunt for free quarks, which some even suggested might be found by taking vacuum cleaners to surfaces to which charged particles might adhere, has been abandoned for better reason — the recognition that quarks cannot, in the present condition of the Universe, exist in isolation from other quarks.)

But the potential usefulness of mica as a permanent record of past fluxes of particles of matter has not sunk without trace. The same P. B. Price has now described the use of mica to provide a limit — not a particularly stringent one — for the past flux of particles of what are called weakly interacting massive particles, or WIMPs, that may be one component of the "missing mass" that the cosmologists need to make the Universe gravitationally closed. It is central to what follows that WIMPs are massive objects, at least as massive as neutrons; on one view, they rejoice in the name "neutralino"; neutrinos that happen to have mass would not qualify.

Perhaps the most striking feature of Price's latest account of his work (D. P. Snowden-Ifft, E. S. Freeman and P. B. Price, *Phys. Rev. Lett.* **74**, 4133-4136; 1995) is its implicit demonstration of how techniques have improved in just under a decade. In 1986, looking for micrometre tracks in sheet of mica meant pushing optical microscopy to its limits, and not then succeeding very well. Now it seems to be much easier; simply etch the mica with hydrofluoric acid and use atomic force microscopy to measure the depth of etch pits in the surface. With careful calibration, it should be possible to tell which pits are what.

At this stage, it is probably fair to say that the group has gone little further than to define the magnitude of the background problem that must be taken into account by particle physicists who turn to mica to fill in time while waiting for the next particle accelerator to be commissioned. But that turns out to be intriguing. Although WIMPs carry no electric charge, their presence in minerals can in principle be detected by the recoil of nuclei with which they collide, and which in general will be ionized. These should leave tracks of lattice defects behind them in well ordered crystals, but stopping distances will usually be quite short.

What other generators of micrometre tracks in mica could there be? Atomic force microscopy has come into its own with what seems to be an unambiguous definition of the tracks left in mica by the decay of individual uranium and thorium atoms incorporated as impurities. Each emission of an α-particle creates a recoil nucleus, and there are eight α-decays in the uranium series before ^{238}U becomes lead, but the directions of successive nuclei are not correlated with each other. The result is that each radioactive atom generates a zig-zag of connected tracks so that the result after etching is quite a deep pit, reaching below the surface for 10 nm or more.

How in practice is it possible to distinguish between those messy and unwanted events and the simpler expulsion of a nucleus from an atom by a WIMP? That is now neatly dealt with. The first step is to cleave a crystal of mica, etch the two fresh surfaces and measure the depth of the pits in them both by atomic force microscopy. The pattern of the pits on the two surfaces can be used to put the mica sheets in proper register with each other. The general expectation is that the sum of the depths of opposing tracks in each of the two surfaces will be greater for α-recoil than for recoil of atomic nuclei caused by the collision of WIMPs.

Tracks that appear not to cross the interface or which fail to yield etch pits 2 nm deep in each of them are excluded from the measurements. And they are evidently rather time consuming. The team says with some pride that it has so far measured more than 80,000 μm^2 of surface, which is a small fraction (8 per cent) of a square millimetre.

That is the neat part of the investigation. Then comes the messy bit. To begin with, the mica (the group uses muscovite mica) must be chosen with care. Freedom from radioactive impurities is evidently a plus, so too is age (to integrate the recoils caused by WIMPs over as long as possible). Something of the geological history of the mica is also necessary, for annealing at a few hundred degrees Celsius is enough to get rid of many tracks. The calculations are that the search for WIMPs has been carried out with a specimen of muscovite mica roughly 500 million years old (measured by *in situ* fission tracks) and that it has never been exposed to temperatures greater than 200 Celsius.

The next step is to estimate the expected background of tracks caused by α-recoil, which can be done with a knowledge of the radioactive contamination and, of course, a Monte Carlo programme. The same goes for the spontaneous fission of uranium and thorium. But what is to be said of the spectrum of pits expected from the collision of WIMPs with nuclei in the mica? The way round that problem is to expose the mica to a fast neutron flux in a reactor, letting neutrons stand for WIMPs, and then to calculate the distribution of recoiling nuclei from the known composition of the mica. Even at 200 degrees Celsius, annealing is fast enough for roughly one in three putative WIMP tracks to have disappeared in 500 million years.

How does it all turn out? Nobody would yet expect the result to be compelling, but one interesting feature of the use of mica is that the material contains roughly 5 per cent of ^{39}K, the nuclear spin of which is likely to enhance the cross section of collisions with incoming WIMPs. Even so, the authors acknowledge that their result is an upper limit on the existence of WIMPs of particular mass that is an order of magnitude less stringent than previously obtained by other methods.

But optimism is not dimmed. Price and his colleagues say that their limits can be made more stringent; "we will simply analyze more mica". Careful selection of the mineral, from deep mines drilled into uranium-free rock, will help. So will the selection of a specimen of mica from the centre of a large block. Everybody, of course, will wish the enterprise good luck.

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