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Recent applications of nuclear tracks in solids

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Abstract

With partial support from an NSF US–China exchange program, five Chinese scientists collaborated with me for one or more years during the 1980s and 1990s. This review begins with a discussion of some of the research they did while at Berkeley. That is followed by brief reviews of recent applications of the nuclear track technique to nuclear fusion; molecular identification with nanopores; ion track filters for imaging X-ray astronomy; magnetic studies with nanowires; polymeric nanowires; microbiology with Nuclepore filters; radon and neutron dosimetry; and thermochronology with ^{238}U and ^{244}Pu fission tracks. My review provides a small sample of the interesting topics to which nuclear track techniques are now being applied.

Keywords: Magnetic monopoles; High-energy fragmentation reactions; Barium phosphate glass detectors; Cluster radioactivities; Fractional charge states; Gene sequencing; Imaging soft X-ray astronomy; Nanowires; Polymeric nanowires; Radon dosimetry; Fission track dating; Thermochronology

1. Introduction

At the 22nd International Conference on Nuclear Tracks in Solids (ICNTS) in Barcelona I reviewed recent scientific and technological advances made possible by nuclear track-recording solids (Price, 2005). The present review is a written version of the talk I gave at the 23rd ICNTS, held in Beijing. The number of practitioners and the breadth of applications of nuclear tracks in solids continue to grow, especially in China, the host country for this conference. The application of fission track dating to thermochronology is more vital and important now than ever before. Nanotechnological applications, especially in molecular biology, represent the most exciting advance since the Barcelona conference. Nuclepore filters are a prominent tool in practically all microbiological and biomedical research.

I have had the pleasure of collaborating with five outstanding Chinese scientists, who spent extended periods working in my laboratory. In the next five Sections 1 review some of the research we did during their stays in Berkeley.

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2. Collaboration with Guo Shilun

Guo Shilun (Chinese Institute of Atomic Energy, Beijing) and I have been friends for 25 years. I first met him when he attended the 11th ICNTS at Bristol in 1981. He was then already recognized in China for having determined the fission track age of Peking Man by analyzing tracks in grains of sphene that had been accidentally heated in their fires in a cave in Zhoukoudian. His result, 0.462 ± 0.0045 Myr, showed that Peking Man was nearly as old as the oldest European hominids known at that time (Guo, 1982).

During his stay in my laboratory in 1984, we published a search for supermassive magnetic monopoles, which Grand Unification Theories had predicted to exist and to have velocities no greater than $\sim 10^{-3}c$ relative to Earth. We used hydrofluoric acid to etch tracks in large natural mica crystals with track-retention age ~ 460 Myr. To exclude tracks of spontaneous fission of ^{238}U in the mica, we required coincidence of etched tracks on the top and bottom surfaces of three layers of mica cleaved from the same sheet and aligned in an optical microscope. Our null result for tracks that are longer than fission tracks, shown in Fig. 1, allowed us to set the world's most stringent flux limit, $\sim 10^{-17}\,cm^{-2}\,sr^{-1}\,s^{-1}$, on supermassive monopoles reaching the Earth (Price et al., 1984). That paper is one of the most frequently cited to come from my group.

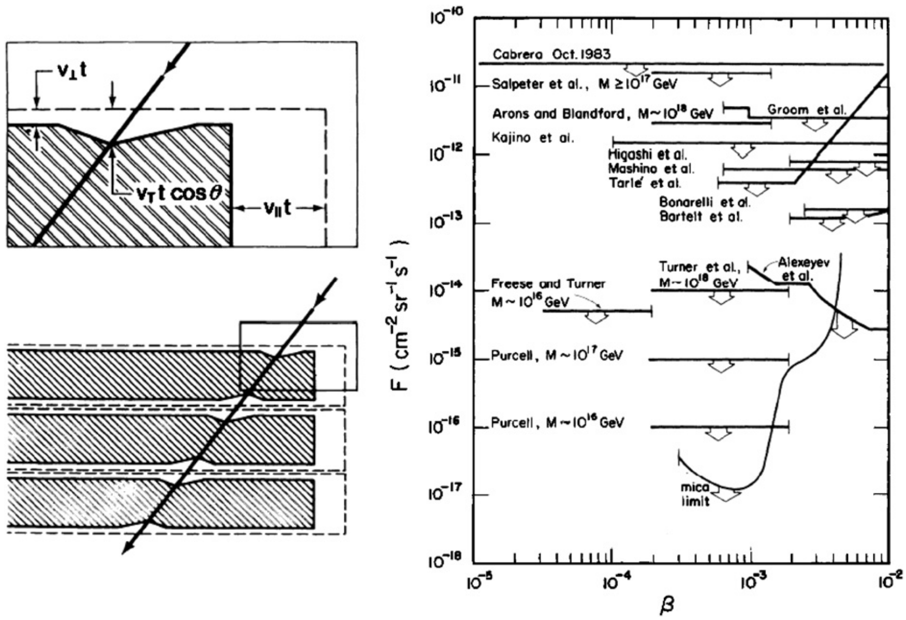

Fig. 1. (Left) Coincidence method for searching for shallow etchpits made by supermassive magnetic monopoles in mica; (right) limit on flux of monopoles as a function of velocity (Price et al., 1984).

Many years later Guo et al. (1997) used the fission-track method to date tektites that had been found in the same stratum as stone tools of ancient man in the Baise region of Guangxi province. Their result, corrected for fading, was 0.732 ± 0.039 Myr, about the same age as the Australian–Indochina tektite fall. This age is also similar to the reversal time of the geomagnetic field from the Matuyama epoch to the Brunhes epoch (0.789 ± 0.008 Myr), which led Guo and co-workers to conjecture that impacts of space objects on the Earth might cause at least some reversals of the geomagnetic field (see also Durrani and Khan, 1971).

3. Collaboration with Ren Guoxiao

With support from an NSF US–China exchange program, in 1987–1988, Ren Guoxiao (Chinese Institute of High Energy Physics, Beijing) collaborated with my students and me, using stacks of track-recording CR-39 plastic sheets with good charge resolution to study high-energy fragmentation reactions. Fig. 2 shows one of the results of her very productive visit (Guoxiao et al., 1989). The histogram on the left gives the distribution of etchpit radii and the nuclear charges of projectile fragments formed during interactions of 1.28 GeV/N ^{139}La nuclei in a stack of sheets of the CR-39 polymeric detector. The largest peak is for uninteracted beam particles, $Z = 57$. The peak at $Z = 58$ is due to interactions in which one unit of nuclear charge is transferred from the target to the projectile in the interaction. The right side of Fig. 2 shows signals in the individual plastic sheets before and after pickup of one charge (a, d), pickup of two charges (b), and fragmentation with loss of several charges (c). An unexpected result of their study was that the charge pickup cross section for $\sim$ GeV/A projectiles increases steeply with A_P, the projectile mass: $\sigma_{\Delta Z=+1} \approx \text{const } A_P^2$.

4. Collaboration with Wang Shicheng

While working in our group in 1988, Wang Shicheng (Chinese Institute of High Energy Physics, Beijing) used her training as a chemist to develop the track-recording glass BP-1 (molar composition 5% SiO_2, 4.5% Na_2O, 25% BaO, and 65.5% P_2O_5), which has the highest track-etch sensitivity of any glass yet made (Wang et al., 1988). Using a stack of plates of BP-1 attached outside the Mir Station for 5 years, Westphal et al. (1998) measured the composition of ultraheavy cosmic rays with the highest charge resolution yet obtained.

Wang also collaborated with our group in studies of cluster radioactivity of a number of actinide nuclides. One of our most challenging projects was our successful search for two rare decay modes of ^{238}Pu (Wang et al., 1989). Spontaneous fission created a serious background, which we were able to eliminate by filtering out the fission fragments, which had somewhat shorter ranges than the Mg and Si products. We used a very insensitive phosphate glass detector, LG750 (Price et al., 1987), to resist the intense radiation damage from alpha particles. The branching ratios for cluster radioactivities relative to alpha decay are the lowest yet observed: 6×10^{-17} for Mg emission and 1.4×10^{-16} for Si emission. The data are shown in Fig. 3.

5. Collaboration with Jing Guiru

During her stay in our group in 1989, Jing Guiru (Chinese Institute of High Energy Physics, Beijing) carried out a search for magnetic monopoles and other hypothetical highly ionizing particles at a luminosity (a measure of collision rate of two colliding beams) of 10^{34} cm^{-2} at the Fermilab Collider (Price et al., 1990). They surrounded the D0 collision region with stacks of both polycarbonate (Rodyne) and CR-39 covering 70% of 4π