Lifetime of Compound Nucleus Is Measured by Crystal Blocking

In a time-of-flight experiment where the flight path is less than 0.01 nanometer and the time is 10^{-16} sec, the lifetime of a compound nucleus has been directly measured (probably for the first time). Combining solid-state physics with nuclear physics, Karl Ove Nielsen (Aarhus University, Denmark) and Walter M. Gibson (Bell Telephone Laboratories) determined the lifetime by measuring blocking patterns from single crystals. They reported their results at the Washington meeting of the American Physical Society.

Blocking occurs when a charged particle formed on a lattice site is prevented from leaving the crystal exactly along the crystal axes, and to a smaller extent, along the crystal planes. If you examine the angular distribution of particles, it shows a pattern of dips, which corresponds to the major crystal axes and planes. But, if the charged particle originates beyond the lattice site, the blocking disappears and you see no pattern.

Nielsen and Gibson bombarded crystals of uranium dioxide with protons of about 10 MeV. When you hit U^{238} with 10-MeV protons, the compound nucleus formed will recoil out of a lattice site with a velocity of about 10^7 cm/sec. If the compound nucleus lasts about 10^{-17} sec before fissioning it will have recoiled far enough to decrease the amount of blocking. So by examining the blocking pattern, you should be able to determine the lifetime of the compound nucleus.

The detectors, made of cellulose acetate, are sensitive to highly ionizing particles (such as fission fragments), but not to protons. By counting fission fragments as a function of position, you get an angular distribution.

Earlier blocking experiments, by Fred Brown, Donald Marsden and R. D. Werner (*Phys. Rev. Letters* **20**, 1449, 1968) of Chalk River Nuclear Laboratories, had set an upper limit on the lifetime for fast fission of U^{238} bombarded with 12-MeV protons; the limit was 2×10^{-17} sec.

Because the lifetime of the excited nucleus varies inversely as the difference between the excitation energy and the fission-threshold energy, if you hit the target with too much energy the compound nucleus decays too quickly to observe. Yet you must give the target enough energy to make the recoiling compound system move away from the atomic row, Gibson explains. The compound nucleus formed from 10-MeV protons has too high an excitation energy; it promptly decays either by fission or by neutron emission to Np^{238}. The new compound nucleus, Np^{238}, has just the right lifetime to be observable.

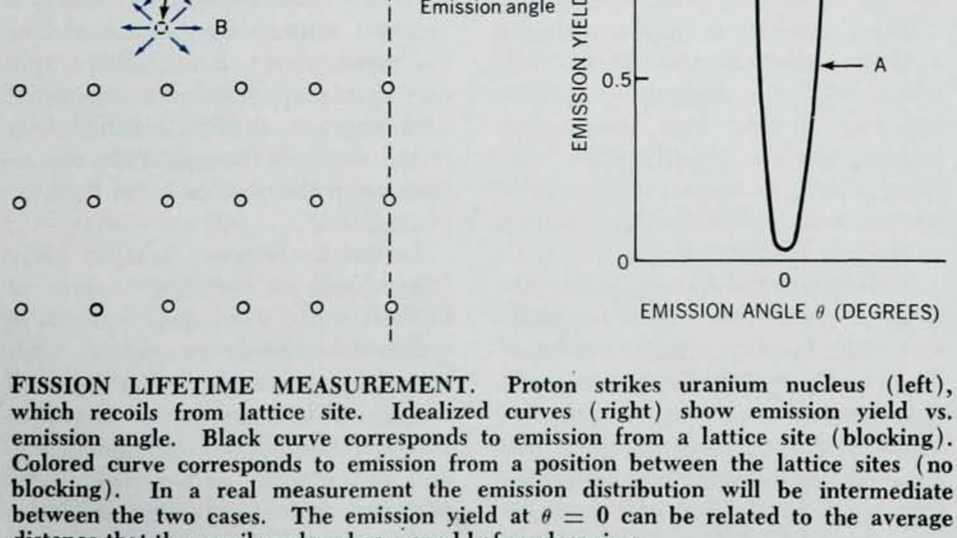
Knowing the velocity of the recoiling nucleus accurately and the distance it moves, Gibson and Nielsen can calculate the total lifetime of Np^{238}. They also did a control experiment to correct for multiple scattering in the crystal or at its surface. For 10-MeV proton fission of U^{238} they measure a lifetime of $(0.48 \pm 0.15) \times 10^{-16}$ sec; this corresponds to a partial fission lifetime of $(2.0 \pm 0.7) \times 10^{-16}$ sec for the excited Np^{238} nucleus at approximately 7.3 MeV average excitation. Calculating the Np^{238} lifetime from fission widths, you get $(2.4 \pm 1) \times 10^{-16}$ sec, in good agreement with the blocking results.

Now the experimenters are trying monoenergetic neutrons, which should enable them to define the excitation energy of the compound system somewhat better. —GBL

US Fusion Experimenters Want to Try Tokomaks Now

The recent visit of Lev Artsimovich to the US, in which he reported significant plasma confinement at thermonuclear temperatures in the Tokomak T-3 (PHYSICS TODAY, June, page 54), has generated a wave of US proposals to build Tokomaks or Tokomak-like devices. Among the laboratories proposing Tokomak experiments are Princeton, Oak Ridge, MIT, University of Texas and Gulf General Atomic.

Meanwhile, at the Kurchatov Institute, Moscow, plans for a much larger Tokomak are already well advanced. The new device is expected to produce ion temperatures of 3 keV and



FISSION LIFETIME MEASUREMENT. Proton strikes uranium nucleus (left), which recoils from lattice site. Idealized curves (right) show emission yield vs. emission angle. Black curve corresponds to emission from a lattice site (blocking). Colored curve corresponds to emission from a position between the lattice sites (no blocking). In a real measurement the emission distribution will be intermediate between the two cases. The emission yield at $\theta = 0$ can be related to the average distance that the recoil nucleus has moved before decaying.

densities of about 5×10^{13} particles/cm^3. (Tokomak T-3, Artsimovich reported, has 5×10^{13} particles/cm^3 at 0.5 keV.) If the device worked, it could be just a step away from a full-scale pilot model of a fusion reactor. The T-3 is a large toroid with 25-cm minor radius and 100-cm major radius. Magnetic field is about 25 kG.

Princeton plans to modify its Model-C stellarator to resemble the T-3. By ripping most of the straight sections out of the Model-C racetrack, they will be left with a toroid having a 15-cm minor radius and a 1-meter major radius. Maximal toroidal field will be 50 kG. Melvin Gottlieb told us that the Tokomak modification will employ mostly existing components, although it will require a new vacuum system and some more coils. Cost should be around $200 000, he said.

Oak Ridge has built a small Tokomak model with 5-cm minor radius and 35-cm major radius. Herman Postma says that they would like to build a bigger version with the same parameters as the Tokomak TM-3: 12-cm minor radius, 40-cm major radius, maximal field of 50 kG. Later, by replacing a shell, they could make a version of T-3 size but with a smaller aspect ratio. These models would use an existing building and motor-generator sets; total hardware cost would be $400 000.

At MIT a new type of device called TokaMIT has been designed. Bruno Coppi told us that the device combines a relatively large aspect ratio with high (150-kG) field while maintaining the simplest configuration. The device opens a new range of plasma parameters, which can test existing scaling laws and exhibit new physical effects, he said. Cost will be about $200 000.

The University of Texas is planning a device slightly larger than the T-3, which will have separate control of turbulent heating and confinement currents (unlike the Kurchatov devices, which use the same current for heating and confinement), according to William Drummond.

At Gulf General Atomic, Tihiro Ohkawa proposed (just before Artsimovich's visit) building a larger version of his recently tested Doublet; it is a current-carrying multipole that requires no floating ring. The new machine would have plasma characteristics similar to T-3 but with a smaller magnetic field. Like a Tokomak, the Doublet uses plasma current for heating. At the same time these currents produce quadrupole-like fields, which have greater stability. Hence, Ohkawa says, larger energy densities can be contained than in the conventional Tokomak.

Amasa Bishop, who heads the AEC controlled thermonuclear research program, told us that proposals for all five facilities have been submitted and were scheduled for review by the CTR standing committee at the end of June. Bishop said that under present budget restrictions it would be very difficult to initiate a strong Tokomak effort in the US in fiscal 1970. Because of recent CTR progress, however, he feels there is still hope for financial relief.

Theorists Offer Explanation For Pulsar Speeding Up

Why did the 89-millisec period of the Vela pulsar, PSR 0833-45, abruptly decrease by 208 nanosec (sometime between 24 February and 3 March)? Theorists have risen to the challenge of explaining the observation made by Philip Reichley and George Downs (Jet Propulsion Laboratory) and independently by V. Radhakrishnan and R. N. Manchester (CSIRO).

At the Washington American Physical Society Meeting A. G. W. Cameron (Yeshiva University) described a hypothesis originated by George Greenstein (Yeshiva) and himself. Like most astrophysicists, they consider that pulsars are rotating, highly magnetized neutron stars, and that the slowing down of the frequency of pulses (already detected for eleven pulsars, including PSR-0833-45, for which $dP/dt = 4000$ nanosec/year) is due to torques applied to the surface through the external magnetic field.

Cameron and Greenstein envision a nonrigid neutron star, whose surface has been braked to a much slower spin rate than that of its core, somewhat analogous to Robert Dicke's solar model, in which the core of the sun rotates about thirty times faster than the photosphere.

In the neutron-star interior, instabilities lead to the displacement of fluid elements; when displacements of sufficient amplitude are attained, weak interactions alter the composition of the gas. The net effect is to reduce suddenly the radial composition gradients of neutrons, protons and other particles. Peter Goldreich (Cal Tech) and Gerald Schubert (UCLA) (*Astrophys. J.* **150,** 571, 1967) have shown that when the angular momentum per unit mass decreases with increasing stellar radius, concentration gradients are required to stabilize the gas against convective mixing. Cameron and Greenstein believe that the sudden adjustment in concentration gradients inside the neutron star leads to such mixing, which transfers angular momentum outwards; so the neutron-star (pulsar?) surface speeds up.

The next day, Kip Thorne (Cal Tech) described a different explanation, due to Malvin Ruderman (New York University), for the abrupt period change of PSR 0833-45. Speaking at the Symposium on Pulsars of the National Academy of Sciences, he reviewed Ruderman's suggestion last year (*Nature* **218,** 1128, 1968) that when the temperature of the outer layers of a neutron star is less than 10^8 K, those regions may become crystallized, and the surface may show deviations from smooth topography, perhaps with "mountains" several meters tall. On the other hand, the interior should still be highly nonviscous, and perhaps may even be a superfluid. So one could imagine discontinuous changes in the stellar structure that would be adequate to explain the speeding up. In fact, the adjustment in moment of inertia necessary to explain the measured period change of PSR 0833-45 is equivalent to a compression of only one centimeter in the radius of the neutron star (a mini-starquake).

X Rays from Crab Have Period of Radio Signals

The Crab Nebula is emitting x rays that pulse with the same frequency as the radio signals from the pulsar NP 0532, according to recent observations by several groups. Earlier, NP 0532 had been found to pulse optically with the same frequency as the radio signals (PHYSICS TODAY, March, page 60).

Gilbert Fritz, Richard Henry, John Meekins, Talbot Chubb and Herbert Friedman of the Naval Research Laboratory reported (*Science*, 9 May, page 709) that the pulsed radiation is about 5% of the total x-ray power being emitted by the nebula (in the energy range 0.8–4 keV).

In 1964 the NRL group had observed a lunar occultation of the Crab x-ray emission. Because the flux dropped off gradually during the covering of the nebula, the group believed that the x-ray emission was neb-