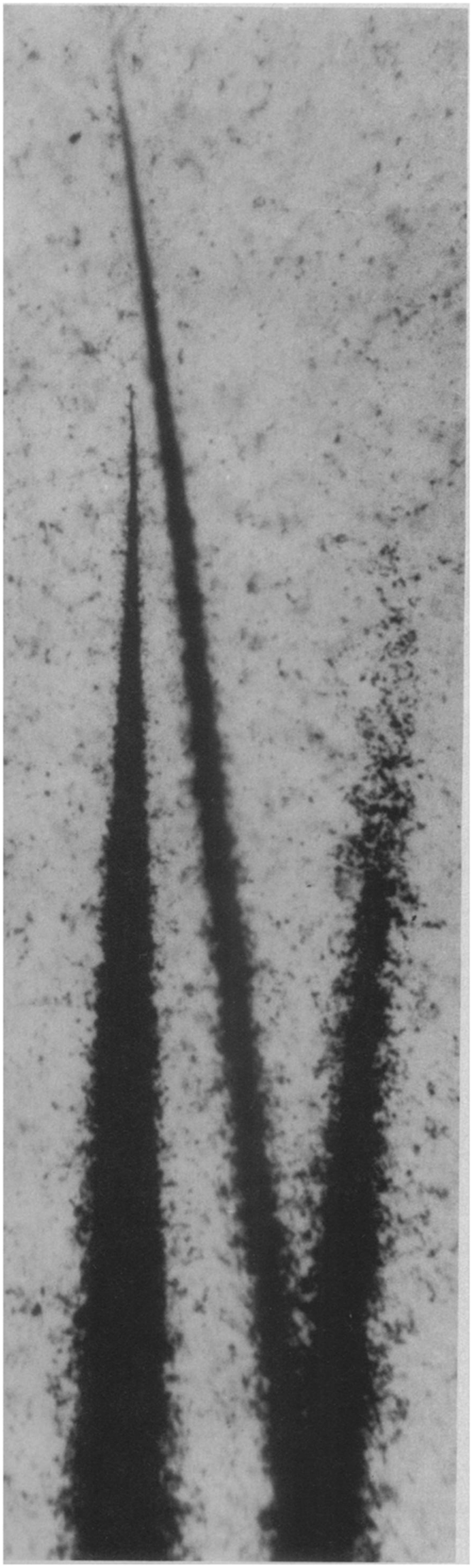

Two relativistic U^{68+} tracks. Fission at right.

Nuclear Physics at High Energy

At relativistic energies it promises to be a whole new game

By DIETRICK E. THOMSEN

Uranium is the heaviest chemical element naturally occurring on earth. As such it is both a goal and a boundary for the people engaged in accelerating heavy ions. If they can accelerate uranium to relativistic energies, to speeds near that of light, they can do the same for any lighter element they may wish to experiment with. For the first time ever, on May 11 at the Lawrence Berkeley Laboratory in Berkeley, Calif., a beam of uranium-238 ions was accelerated to an energy of 147.7 million electron-volts per nucleon. (In this field energies are quoted in electron-volts per nucleon, that is per nuclear particle, as it makes comparisons from element to element more meaningful. To get the total energy of the ion, multiply by 238.) At this energy the ions are traveling at close to half the speed of light.

LBL's announcement of the event spoke of jubilation and enthusiasm. Those emotions were still evident to a visitor more than a month later. The physicists involved are quite bullish about the prospect of finding out what high-energy nuclear physics is really like.

The achievement brings nuclear and atomic physics into domains not available for investigation before, and already there are indications that new and fascinating phenomena will appear. There are also possible technological applications. Accelerated heavy ions could be used to deliver the energy that ignites thermonuclear fusion in some target. Accelerated ions (though ones very much lighter than uranium) are used in biomedical research and therapy.

The uranium acceleration was accomplished in the apparatus known as the Bevalac. The name is a combination of the names of its two major components, the Bevatron and the SuperHILAC. The main acceleration is done in the 30-year-old Bevatron, which when built was one of the most advanced proton accelerators in the world — one of the first to take protons to energies of more than a billion electron-volts. Proton accelerators now exceed that by 400 or 500 times, and more than ten years ago the decision was made to convert the Bevatron to ion acceleration. The first stage accelerator is the SuperHILAC (originally just HILAC or Heavy Ion Linear Accelerator). To get beams of heavy ions with the density and quality necessary for this operation, a new ion source and injector had to be built for the SuperHILAC. This is called Abel, because in some ways it is the son of the previous two, Adam and Eve. LBL is located on a steep hill east of the University of California campus, and these items are stacked one above the other up the hill with the Bevatron at the lowest level.

Acceleration of uranium and other very heavy elements was made possible by two technological developments: a complete reconstruction of the Bevatron's vacuum chamber, in which the ions circulate, and a method of tuning the system on a lighter ion before letting the heavy ones through.

Ion accelerators generally need much rarer vacuums than proton or electron accelerators. An ion striking a gas atom can change its electric charge by taking or losing an electron. If it does that, the electromagnetic focusing and accelerating

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system, which is tuned to a particular charge-to-mass ratio, will not be able to recover it. (A bounced proton doesn't change its charge, and the focusing system can often recover it.)

The Bevatron's new vacuum system maintains a pressure (or better, absence of pressure) of 10^{-10} torr. (One torr is 1/760 of normal atmospheric pressure; this is one ten-billionth of that.) The chamber is three nested boxes. The inner two are made of printed circuit board material (that is, the board that forms the base of printed electronic circuits) etched in a way that inhibits the induction of electric eddy currents in it. Eddy currents generate heat and other interference. The design is attributed to J. Meneghetti of the Bevalac's mechanical staff. The outermost of the three boxes is at room temperature, the middle one is cooled to 77 kelvins, the inner one to 12 K. An organic "superinsulation" separates them from each other. The extreme cold not only makes pumping more efficient, it also induces residual atoms to precipitate themselves on the walls of the chamber.

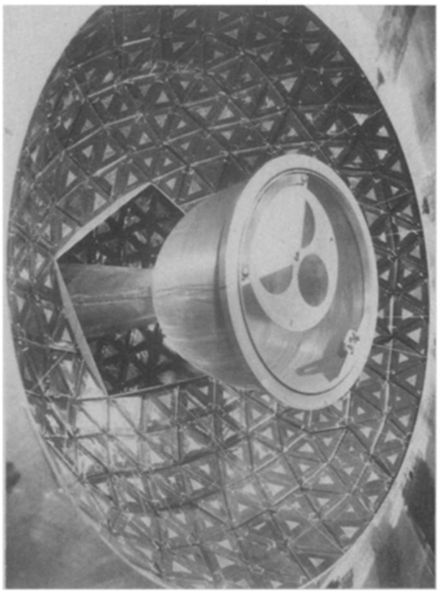
In the Bevalac it is not possible to strip all the electrons from atoms as heavy as uranium and come out with a bare nucleus. The ions used in the actual first beam had positive charge 68 (out of a possible 92). The electrons are stripped by passing the atoms through a metal foil, but they do not all come out of the foil with the same charge. There is thus a range of charge-to-mass ratios. For example, it might be 67/238, 68/238, 69/238, etc. The focusing and bending magnets must be tuned to just one of those fractions, and as close together as they are, it is difficult to do. So the system was pretuned using iron with charge 16 and mass 56. The charge-to-mass ratio 16/56 is the same as 68/238, but the lighter element is easier to tune the system to. They could have used something else, but iron happened to be in the system, says José Alonso, one of the physicists involved in the operation of the Bevalac, so they used it. The apparatus is tuned to charge 16 iron, and then the uranium is let in. "The technique works very well," Alonso says. They are extending it to other pairs of elements, xenon and neon, for example.

Cross section of the improved Bevatron vacuum chamber.

Photos: LBL

Although the physicists are eager to enter the new domain, they are not rushing into an experimental program, Alonso says. First they want to improve the Bevalac's performance. Particularly, they hope to get the number of uranium ions per pulse up from the present 1,000 to about a million.

There are already two large detectors in place ready for experimentation, the "plastic ball," which fills almost the whole volume around a target with plastic detectors, and the Heavy Ion Superconducting Spectrometer. These items look as big as the detectors used in particle physics. Nuclear physics is getting like particle physics in another way, Alonso points out: The numbers of people working together on one of these experiments approaches those customary on a single particle physics experiment.



Each triangle on the inner surface of the plastic ball is the surface of a particle detector. Accelerated ions strike a target in the middle of the smaller sphere.

At last, says Harry Heckman, another of the physicists in the group, physicists will be able to study *nuclear* fission. The kind of fission that occurs in a reactor, or even a bomb, is considered by physicists to be a Coulomb process ("Coulomb fission") because it is dominated by the Coulomb or electrostatic force. Two kinds of forces are at work in every atomic nucleus, the strong or nuclear forces, which act between neutrons and protons alike and hold the nucleus together, and electrostatic forces, which act between protons and tend to spring it apart. If the nuclear force is the stronger, the nucleus is stable. It might seem to be possible to make any size nucleus stable by adding more and more neutrons, as they contribute to the nuclear forces but not to the electrostatic forces, but actually that is not possible. The nuclear force has a very short range; its strength falls off very rapidly with distance, much faster than the strength of the electrostatic force does. There is a limiting size beyond which a nucleus can hold no more neutrons. They start to drip off.

The fissile species of uranium lie just on the knife edge of balance between the nuclear and electrostatic forces. Tickle them just a little, and they fall apart. Then the electrostatic force takes over and impels the fragments apart from one another. In a reactor or a bomb the uranium nuclei are just tickled by incoming low-energy neutrons.

When these relativistic uranium nuclei out of the Bevalac slam into a target or a piece of detecting material, what happens can be dominated by the nuclear force, which comes into its own in high-energy, short-range interactions, and if fissions occur — and they do — they may go according to its characteristics.

What the physicists have been doing up to now is studying the tracks that are made as the accelerated uranium stops in various detectors made of plastic or photographic emulsion. In emulsion Heckman, Y. J. Karant and E. M. Friedlander of LBL find that about 70 percent of the hits involve binary fission (that is, into two roughly equal fragments) with or without the emission of some much lighter fragments by the side. One-third of the hits result in binary fission only. Two-thirds show emission of light particles (with or without fission), a signature for nuclear-force events. Three hits show light particles only, but they come in the highest energy range, which may indicate that at higher and higher energies more events will occur that "totally obliterate" the incoming nucleus. S. P. Ahlen, G. Tarlé and P. B. Price of LBL studied binary fission in a plastic detector (they found one ternary fission) and concluded that theory does not accurately predict the probabilities. This is typical of the history of nuclear physics. In particle physics theorists describe in detail what experimenters should find, and, lo, the experimenters find it. In nuclear physics experiment tends to lead theory. ☐