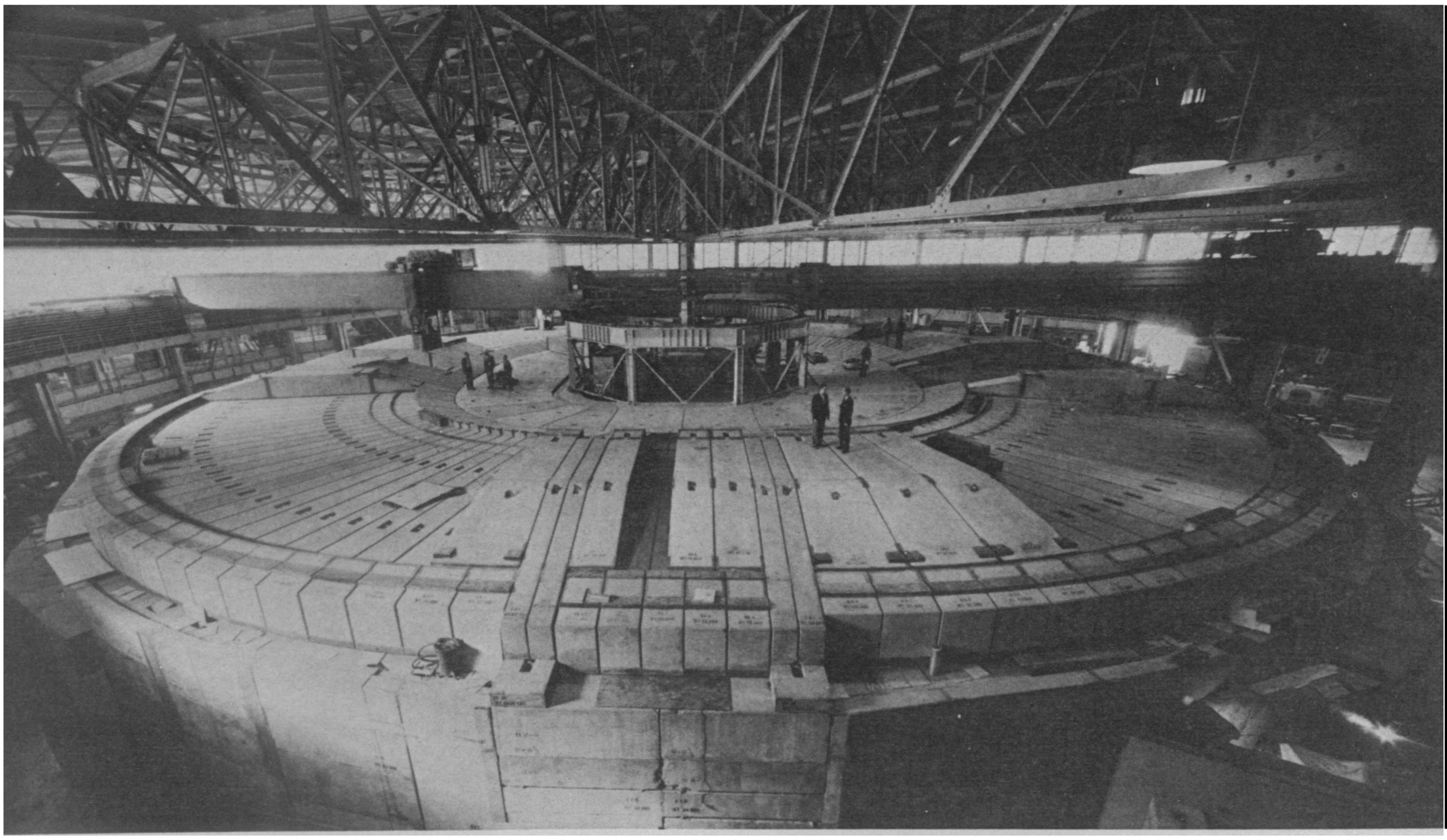


Accelerating heavy ions in the Bevatron

A beam of nitrogen ions opens up new applications in nuclear physics and biology for a veteran proton accelerator

by Dietrick E. Thomsen

Particle accelerators used to be limited mainly to energizing single particles: electrons and protons or at most deuterons or alpha particles. Now accelerator physicists are devising ways of accelerating heavy ions, nuclei of elements heavier than helium that have been stripped of many or all of their electrons.

Accelerated heavy ions promise to open up new territory in nuclear physics, biophysics and possibly medical therapy. Physicists in various parts of the world are busy designing and building accelerators especially for heavy ions. Others are attempting to add a heavy-ion capacity to existing proton accelerators. An important step in this direction was completed in August when the Bevatron at the Lawrence Berkeley Laboratory in Berkeley, Calif., accelerated nitrogen ions to an energy of 36 billion electron-volts (GeV) or 2.6 GeV per nucleon. (Most specially built heavy ion accelerators are aiming at several million electron-volts per nucleon.)

The alterations of the Bevatron were begun in March; the first nitrogen beam came through on Aug. 17. The work was done under the leadership of Hermann A. Grunder.

The Bevatron's heavy-ion capability promises to enable nuclear physicists to reverse a common experimental procedure and to do laboratory imitations of processes that take place in the cosmic rays. One of the traditional ways of studying nuclear physics is to bombard various nuclei with energetic protons or helium nuclei and see what happens as the target nuclei break up. Accelerating heavy ions allows the reverse process: Heavy nuclei are struck against proton or helium-nucleus targets.

The reverse process is what takes place in the cosmic rays. Astrophysical processes—probably in supernova explosions—produce a variety of heavy nuclei and inject them into interstellar space. As the nuclei travel through space, they strike nuclei of hydrogen or helium in the interstellar gas clouds and break into lighter nuclei. Laboratory determinations of the probabilities of a given nucleus breaking into given daughter nuclei under such conditions will aid in determining a picture of the history and origin of the cosmic rays.

To nuclear physicists generally the process of striking accelerated heavy ions against protons opens new ground because if a proton is shot against a stationary nucleus, the fragments sometimes don't come away with enough velocity to be recorded. In contrast, when the accelerated heavy ion strikes a proton target, the heavy-ion nucleus "is just tickled and falls apart," as Harry H. Heckman, a physicist on the Lawrence Berkeley staff puts it. The fragments continue on in about the same direction and with the same velocity as the original nucleus.

The advantage is that the products of this zero-energy breakup are more likely to represent what is present in the original nucleus when it is not being disturbed from the outside. One of the major current efforts in nuclear physics is to determine what subgroupings of neutrons and protons exist within heavy nuclei and how they relate to each other. Among the many possible combinations of neutrons and protons, some are more tightly bound than others, and some theorists suppose that within heavy nuclei such combinations form and interact with the rest of the nucleus more or less as a unit. If such combinations exist, they may show up as units in the debris when the nucleus breaks apart.

With their beam of accelerated nitrogen, Heckman and his collaborators set out to determine the break-up spectrum of the nitrogen nuclei by striking the nitrogen against hydrogen nuclei in a target of CH_2. They sorted out the different possible breakup products by making use of a property called magnetic rigidity.

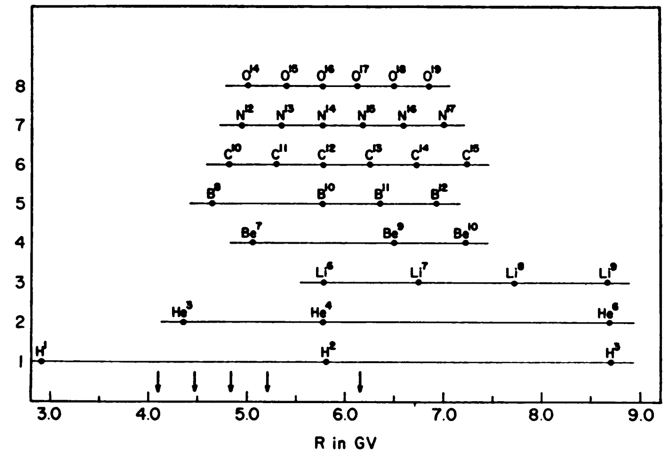
Magnetic rigidity is a combination of factors related to the response of the nuclei to a magnetic field. Magnetic rigidity for a given velocity depends on the ratio of the charge of the nucleus to its mass. By altering magnetic fields, the detecting apparatus can be tuned so that only nuclei of a given rigidity reach the counters. The charge of the recorded nuclei is also determined by the detectors.

At a rigidity of 4.84 units, a particularly high count of nuclei with a charge of 4 (4 protons) was recorded. They are attributed to beryllium 7 since that isotope has a charge-4 nucleus and the proper charge-to-mass ratio for this rigidity. It means, says Heckman, that beryllium 7 is moving around inside the nitrogen nucleus and likes to come out at this energy.

Beryllium is not the only thing that comes out. At a rigidity of 6.15 a peak occurs at charge 6. This is carbon 13.

Further experiments will attempt to complete the fragmentation spectrum of nitrogen.

Ultimately studies of this kind will amass a catalogue of fragmentation spectra for various elements. It will contain a large amount of data on low-energy nuclear physics for theorists of nuclear structure to feast on. For cosmic-ray physicists it will provide information on what isotopes come out of fragmentation processes at what abundances. It may be able to give them hypothetical histories for the various isotopes they discover in the cosmic rays. "Accelerator physics may lead the way in cosmology," says Heckman.



Magnetic rigidities of various nuclei. Vertical axis is charge; horizontal is rigidity. Arrows show rigidities at which searches for nitrogen fragments were made.

H. H. Heckman

Another project for the future is a connection between the Bevatron and the Superhilac, which is being built some distance up the hill from the Bevatron. The joint entity would be called Bevalac. The idea was suggested by the Superhilac group, which is under the leadership of Albert Ghiorso.

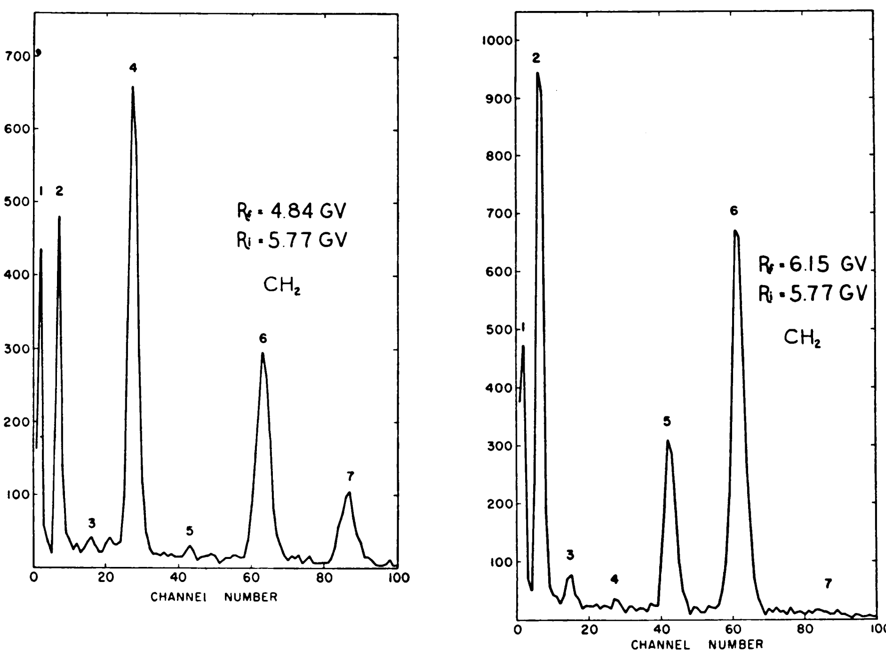
Superhilac is a heavy-ion accelerator. It is a reconstruction of the old Hilac (Heavy Ion Linear Accelerator) that substitutes for the planned Omnitron that the Berkeley Laboratory tried for years to get funded. The Omnitron would have been an entirely new machine at a cost of $30 million. The Superhilac is being built for one-tenth the cost of the Omnitron. Ghiorso says it will do better with the lighter ions than the Omnitron would have. If the connection to the Bevatron is made, an even more versatile and useful arrangement will result.

The idea is to use the Superhilac as an injector for the Bevatron. This will permit the Bevatron to accelerate species of ions that its own ion injection system cannot accommodate. The Bevalac combination would give high-energy beams of nuclei as heavy as argon (atomic weight 40) and possibly krypton (atomic weight 84). (The Superhilac is designed to accelerate all species up to uranium, but to energies of 8.5 *million,* not billion, electron-volts per nucleon.) A bare-bones connection could be built for $500,000, says Ghiorso, but a more sophisticated one, including a booster section, would be preferred and the cost could go up to 10 times that figure. Money has been requested from the Atomic Energy Commission.

One of the things that is sure to be done with the combination is an attempt to manufacture superheavy nuclei by striking heavy ions against heavy-nucleus targets. Ghiorso suggests trying for element 114 by using a plutonium target and impinging calcium nuclei. Plutonium 244 plus calcium 48 could yield 114–288 plus four neutrons or possibly 114–290 plus two neutrons.

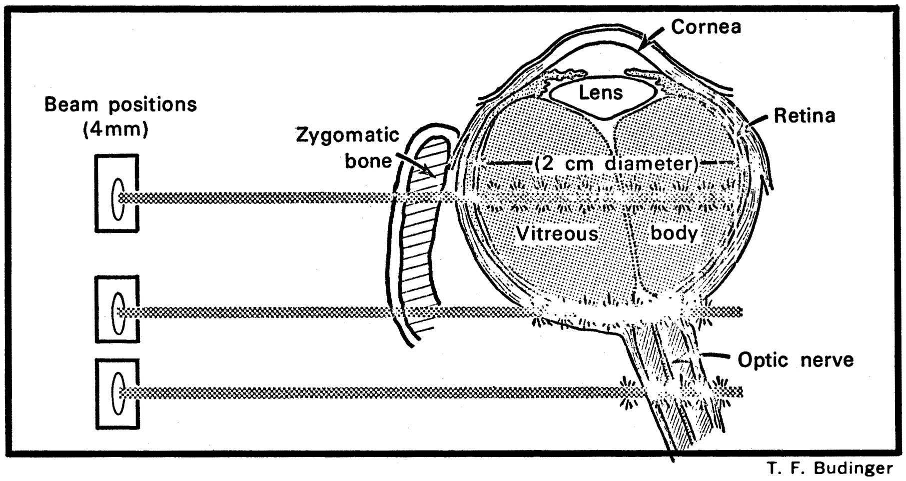
A long-shot possibility is plutonium 244 plus calcium 56 to make 114–298 plus two neutrons. Calcium 56 is an unusual isotope, but it might be made from krypton at high energies. It is not known what energy range would be required to accomplish this: 30, 300 or 3,000 MeV per nucleon. "The Bevatron itself might produce superheavies," says Ghiorso.

The other major branches of science in which accelerated heavy ions will open new directions of research are bi-



H. H. Heckman

Nitrogen fragments (charges 1 to 7) recorded at rigidities of 4.84 and 6.15.



Ion-beam trajectories used to find the cause of the astronaut light flashes.

ology and medicine. Experiments at LBL have already determined the cause of the strange light flashes seen by astronauts on space flights. Heavy ions from the cosmic rays were suspected as the cause, but it was uncertain whether the flashes represented Cerenkov light emitted as the ions passed through the vitreous humor of the eye or whether the flashes resulted from direct stimulation of tissue by the ions. Experiment found that human subjects saw the flashes only when the ion beams struck their retinas, indicating that impact of ions on retinal cells is the cause.

The general trend of biological experiments with heavy-ion beams will be to study the damage they do to cells, says Thomas F. Budinger, a physician on the LBL staff. Heavy ions cause a qualitatively different type of damage from other forms of radiation. Cells repair some of the damage, but what can be repaired and what cannot is not clear.

An important question is whether the repair mechanism returns the cell to the status quo or whether some genetic change occurs. In observing what happens one might see chromosome changes "like putting pink fenders on a black car," he says. If there are genetic changes, a knowledge of them could help interpret the past as well as predict the future.

One of the interesting questions in paleontology today is the relation of geomagnetic reversals to the evolution of biological species. A number of times in geological history the magnetic field of the earth has reversed its polarity. In the midst of each such change there was probably a period when the strength of the field was zero. It is the geomagnetic field and the atmosphere that prevent most of the cosmic rays—especially the heavy ions—from reaching the earth's surface. If the field was turned off, some of the heavy ions may have gotten through. The question is: Could they have been responsible for increased rates of mutation that may have happened at those times?

The question whether the cells can repair the damage at all will have important repercussions in space biology and space flight. Some of the heavy cosmic-ray ions get through the shielding of space capsules and strike the bodies of the astronauts. One of the questions is how many of them go through the middle of the brain and how much damage do they do there. Up to ten percent of brain-cell nuclei could be hit by cosmic-ray particles during a three-year flight. The extent of damage is unknown but can be learned by research with beams of heavy ions.

Finally, heavy ions have a therapeutic promise. If they damage useful cells, they will also damage tumorous ones, and they do it in a qualitatively different way from the X-rays that are commonly used in radiation therapy. X-rays deposit energy in sizable amounts all along their path through tissue, but the heavy ions deposit most of their energy at the ends of their paths. (How far a heavy-ion beam penetrates depends on its energy.) Thus the heavy ions may prove useful in treating deep-seated tumors where the use of X-rays might cause unacceptable damage to overlying tissue.

Budinger stresses that here is no potential cure-all for cancer. Such therapy would be useful only for the class of tumors for which radiation therapy is now used: compact, localized growths. "You couldn't hit leukemia this way," he emphasizes. Furthermore this class of tumors is also susceptible to surgical excision, and in current practice radiation therapy is usually resorted to only when surgery is not indicated—for example when large blood vessels are present that might bleed too much if they had to be cut.

Budinger points out that all these questions are still early in the basic research stage. It will be years before therapeutic applications are worked out and patients can be treated. □

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IMPLEMENTING ORGANIZATIONAL INNOVATIONS: A Sociological Analysis of Planned Educational Change—Neal Gross, Joseph B. Giacquinta and Marilyn Bernstein —Basic Bks., 1971, 309 p., $8.95. Using the case history of the failure of an elementary school to implement a major educational innovation it had accepted on paper, the study focuses on the crucial aspect in the process of organizational change—the extent to which the innovation is in fact in operation.

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THE RADIO UNIVERSE—J. S. Hey—Pergamon Press, 1971, 248 p., photographs, diagrams, $7. Covers the whole field of radio astronomy including radar astronomy, waves, telescopes, radio emission from moon and planets, the radio sun, galactic emissions, radio galaxies and quasars.

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SCIENTIFIC, TECHNICAL AND RELATED SOCIETIES OF THE UNITED STATES—National Academy of Sciences—NAS, 1971, 9th ed., 213 p., $13.50. Lists 531 organizations with up-to-date information about principal officers, history, purpose, memberships, meetings, professional activities and publications. Includes cross-referencing of former names and mergers.

SOVIET PLANNING TODAY: Proposals for an Optimally Functioning Economic System—Michael Ellman—Cambridge Univ. Press, 1971, 219 p., diagrams, $10; paper, $4.45. Explains the proposals put forward by the Central Economic Mathematical Institute of the USSR Academy of Sciences, proposals for improving the Soviet economic mechanism and the methods of economic calculation.