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RADIOACTIVE BEAMS (NONTECHNICAL SUMMARY)

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The state of matter we observe on earth is not very characteristic of the universe. In contrast to our rather arbitrary reference point, "extreme" conditions seem to be prevalent in the past as well as in the present universe. These extremes of temperatures, densities, forces, time scales, and mixtures of nuclear particles under which the building blocks of all living and nonliving things on earth were created, can, in some cases, be imitated and approximated in the laboratory through experiments with particle accelerators. In recent years, two trends in these experiments are distinguishable, one is towards ever higher energies of "simple" projectiles like protons and electrons, and the other is towards moderate energies of more complex projectiles including beams of heavy ions like uranium. While in the first case we are looking further and further back in time at conditions similar to those a fraction of a second after the big bang, the second type of experiments explores states of matter that may be found in present day astrophysical objects. There has, however, been an important experimental limitation: all available beams from heavy ion accelerators are comprised of *stable* nuclei, while under astrophysical conditions at high temperatures *radioactive nuclei* are essential reaction partners. Only very recently has it become conceivable to produce radioactive beams of sufficient intensity for experiments in the laboratory.

There are two promising methods to generate such beams; the first method was pioneered at the Bevalac in Berkeley. Projectiles of stable heavy nuclei accelerated to high energy in a synchrotron are fragmented in collisions with light target nuclei like beryllium. The heavy nuclei break up into pieces, some of which have unusual neutron to proton ratios and are therefore radioactive. After purification in a set of magnetic devices the "secondary beams" can be used for experiments or injected into storage rings. One such combination of a high intensity heavy ion synchrotron coupled with a storage ring is presently under construction at GSI in Darmstadt, West Germany. An important feature of the storage ring is its ability to cool and decelerate the radioactive beams to low energies near the Coulomb barrier where conventional nuclear reactions can be carried out.

A prototype accelerator using a different method is being built in Leuven, Belgium. It will produce radioactive isotopes with a small cyclotron, and then inject the radioactive species into a second cyclotron which subsequently accelerates them to the desired energies. Some variations of this basic scheme are, replacing the cyclotron with a high-intensity, high-energy proton accelerator like TRIUMF or replacing the second cyclotron with a radio frequency quadrupole.

The research that can be carried out with radioactive beams falls into three categories: (1) studies of the properties of the radioactive beams themselves, (2) nuclear reactions with such beams, and (3) applied research in biology, medicine, and solid state physics. Experiments of the first category have already been carried out at the Bevalac where interaction cross sections, nuclear radii and magnetic moments of highly unstable light nuclei have been measured. The second category of experiments has great significance for astrophysics where important nuclear reactions can be simulated in which the radioactive beams collide with light particles, and gamma rays or protons are emitted. (This can, for example, be achieved by placing a gas jet target in the storage ring.)

In the future, having radioactive beams circulate in storage rings will provide unprecedented experimental opportunities; for example, the search for a new mode of beta decay, studies of the effects of high internal electric and magnetic fields on nuclear properties, and the interactions between radioactive beams and high intensity photon and electron beams. Due to the altered neutron to proton ratios of the radioactive projectiles, compound nuclei with extreme neutron or proton excess can be created in nuclear reactions; including such key nuclei as ^{78}Ni, ^{80}Zn, ^{100}Sn, ^{130}Cd, and perhaps even super heavy nuclei.

An example of the *applied* use of radioactive beams is their potential role in cancer research and treatment. Beams of heavy ions generally, have an advantage over other charged particle beams, neutrons, or gamma rays in that their peak energy deposition can be precisely localized in the tumor volume. The difficulty is, however, to measure the exact path length of the beam in living tissue of varying composition and density. Using radioactive heavy ion beams of ^{19}Ne for example, an elegant solution to this problem can be found since this projectile decays by emitting positrons. When the positrons annihilate with ordinary electrons in the tissue two gamma rays separated by 180° are emitted and can be recorded by a special camera, similar to a CAT scanner. Thus, each beam particle reveals its location in the tumor.

These are only a few examples of the exciting new dimension that radioactive beams open up in experimental nuclear physics, astrophysics and several applied fields.

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