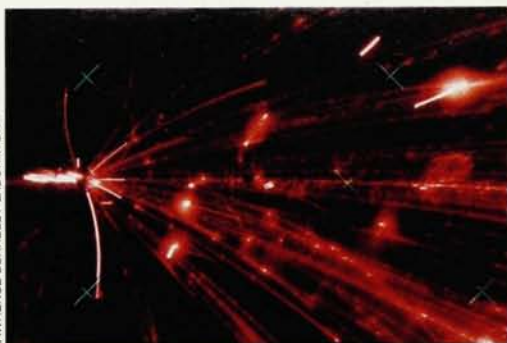


Relativistic La^{139} nucleus with an energy of 1.2 GeV per nucleon collides with a lanthanum target, resulting in a shower of high-energy debris.



Nuclear physics

In the 50 or so years between the discovery of the neutron and the meeting of the Panel on Nuclear Physics of the physics survey committee our understanding of the physical universe has been immeasurably expanded. In its report the panel first reviews the impressive achievements in nuclear physics of the decade passed, then goes on to make recommendations designed to insure continued achievement in the future.

The submicroscopic, swarming assemblies of neutrons and protons known as atomic nuclei are among the most experimentally and theoretically intractable systems ever studied by physicists. A vast array of tools and techniques have been applied to the study of the nucleus, revealing an unexpected richness of phenomena and pointing research in new directions.

Inelastic scattering of charged particles from target nuclei, for example, revealed in the 1970s several new modes of nuclear vibrations. Particularly important is the so-called giant monopole resonance, a vibrational

"breathing" mode that gave physicists their first glimpse of the previously unmeasured compressibility of nuclear matter. In other experiments pions were scattered off nuclei, giving clues to the relative importance in nuclear vibrations of protons, neutrons and the excited nucleon states known as deltas. In addition to vibrations involving the motion of nucleons, nucleon spins can also exhibit collective behavior. Researchers at the Indiana University Cyclotron Facility, using proton beams of 100–200 MeV, were recently able to flip the spins and isospins of nucleons in the nucleus without upsetting their spatial relationships.

High-energy electron scattering has revealed an unprecedented level of detail: Individual nucleons are resolved, as well as effects from the mesons whose exchange binds nuclei together and, to a rudimentary degree, the quarks that compose these particles. Understanding nuclei in terms of the fundamental interactions among quarks is one of the major goals of nuclear physics.

Subtle surgery performed with high-energy electrons is just one approach to understanding the properties of nuclei. Heavy-ion beams are proving to be particularly versatile probes of nuclear dynamics. Their often cataclysmic impacts on target nuclei cause a great variety of excitations and reactions. Heavy-ion collisions have also been indispensable in producing many exotic nuclear species, including recently four new chemical elements with atomic numbers 106 through 109.

Surgery of another sort is performed in the creation of hypernuclei. Hypernuclei are nuclei in which a hyperon—usually a lambda hyperon—is substituted for a nucleon. About two dozen distinct types of lambda hypernuclei have been produced, mainly from among the light elements. Analysis of the binding-energy data of the lambda in the nuclear ground state shows that

the spin-independent part of the lambda-nucleon interaction is only about two-thirds as strong as the nucleon-nucleon interaction and that the spin-dependent interaction is much weaker for the lambda. Sigma hypernuclei have also been studied to a small extent. Despite the sigma's rapid decay into the lambda, sigma hypernuclei seem to be quite long lived. The data are sparse, so it is not yet known if the long decay time of the sigma to the lambda in a nucleus represents a special inhibiting effect or a general property of nuclear matter.

Almost all nuclear physics to date has been done under conditions of normal nuclear density and low temperature. But many of the most interesting processes in the universe, such as those that occurred in the first microseconds of creation or that take place in collapsed stars, do not happen in this domain. Relativistic heavy-ion projectiles can be used to study the regime of extreme nuclear conditions, and this will be one of the important frontiers of nuclear physics in the remainder of this century.

The basic nature of nuclear physics guarantees that its techniques and results will have a considerable effect on other fields of science. The most obvious connection is to elementary-particle physics. The nucleus is an ideal laboratory for studying the relationships among the fundamental forces. Such basic issues as the existence of time-reversal invariance, the predictions of quantum chromodynamics and electroweak theory at low energies, and the question of whether or not the neutrino has a mass can be studied in nuclei. Nuclear astrophysics gives vital understanding of the origin and evolution of stars and of the universe itself. And the fruits of nuclear physics have many and often surprising applications to medicine and technology.

Most of the research in nuclear

Panel on Nuclear Physics

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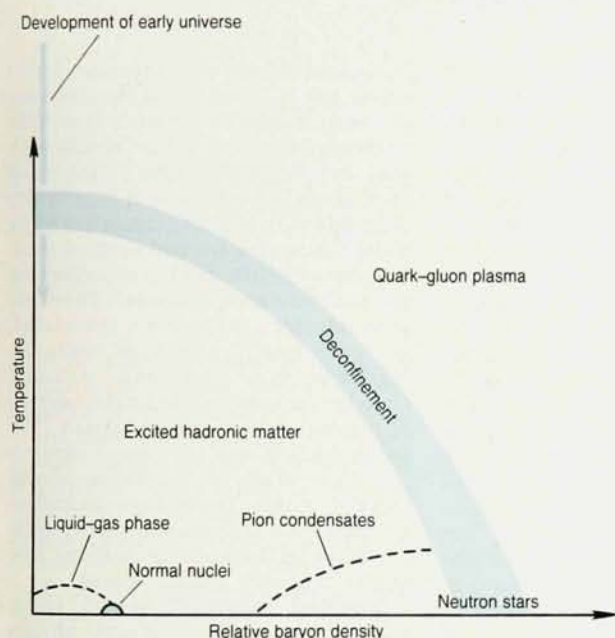
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Phases of nuclear matter expected to exist at high temperatures and a range of baryon densities. The colored band represents the transition region beyond which lies the quark-gluon plasma.

second or so after the Big Bang. The formation of a quark-gluon plasma will provide rare insights into the origin and nature of matter.

The only currently conceivable way of achieving the temperatures and densities required to form a quark-gluon plasma is by colliding together beams of very heavy ions—uranium is the natural choice. To this end NSAC proposed and the panel endorses a large, \$250 million accelerator facility called the Relativistic Nuclear Collider, which will be capable of achieving an energy of 30 GeV per nucleon in each beam. Head-on collisions of such beams will be so intense that the nuclei will exhibit nuclear transparency: They will interpenetrate explosively, creating two baryon-rich regions—vestiges of the original nuclei—and a central region of high energy density.

It is in this central region that one expects the quark-gluon plasma to be formed. Detecting it will be another, very difficult problem. At such extreme energies the production of particles will be copious: If all the energy of a collision of 30 GeV/nucleon were converted to matter, as many as 100 000 pions could result. A more realistic estimate numbers the final pions in the thousands. Detecting and recording these will require innovations in detector design.

The path to a quark-gluon plasma will require a state-of-the-art accelerator and large detector arrays. With these tools physicists will be able to look back across the ages to the moment of creation and to a new (or, depending on how these things are reckoned, extremely old) state of matter. The panel believes that confirming the existence of a quark-gluon plasma would have a major impact on fundamental questions common to nuclear physics, particle physics, astrophysics and cosmology. Such confirmation would be a very exciting achievement.

—BRUCE SCHECHTER □

physics is done with particle accelerators of various kinds. There are currently nine large, multi-user national accelerator facilities, spanning the entire experimental spectrum; the two largest are the Los Alamos Meson Physics Facility, a proton linear accelerator at Los Alamos National Laboratory, and the Bevalac Complex, a relativistic heavy-ion accelerator at Lawrence Berkeley Laboratory. In addition, 13 university accelerators are supported primarily for nuclear-physics research. While much vital research can still be carried out at these accelerators, whose usefulness can be extended by planned upgrades, the panel, in full agreement with the Nuclear Science Advisory Committee of the Department of Energy and the National Science Foundation, supports the construction of two major new accelerator facilities.

Investigations of the microscopic quark-gluon structure of the nucleus require intense, continuous beams of high-energy electrons. To provide such

beams NSAC recommended in April 1983 the construction of the 100%-duty-factor, 4-GeV linear accelerator-stretcher ring complex now known as the Continuous Electron Beam Accelerator Facility, which will cost approximately \$225 million. The beam energy will be variable from 0.5 to 4.0 GeV, allowing the study of nuclear structure from the level of nucleon-nucleon interactions through the intermediate regime of baryon resonances to the behavior of quarks and gluons describable by quantum chromodynamics.

Unquestionably the most exciting possibility faced by nuclear physics is the creation of the quark-gluon plasma. Recent lattice gauge theoretical calculations indicate that at extremely high but experimentally accessible collision energies the quarks and gluons that compose nucleons will become deconfined. Theorists predict that in extremely relativistic collisions between heavy ions, the nucleus dissolves into a quark-gluon plasma like that which might have existed a micro-