Nuclear physics

Widening scope for new heavy-ion accelerators

from Shigeru Kubono

A NEW generation of heavy-ion accelerators is opening up fresh fields of research in the natural sciences — including astrophysics, solid state physics, medicine and geology — as well as finding more conventional application in nuclear physics. One of their biggest successes so far has been the production of new elements, heavier than ever seen before in nuclear reactions. An element of atomic number (Z) = 108 has recently been synthesized at GSI Darmstadt in West Germany following the discovery of $Z = 106$ and $Z = 109$ elements, and experiments have been planned to search for elements of $Z = 110$ and heavier. These and other new findings in nuclear physics, along with applications of heavy-ion beams in other areas, were the theme of a two-part symposium* held in Japan.

Since the Second World War, light-ion and electron beams have been used extensively to investigate nuclear structure and reaction mechanisms. Heavy-ion beams, with energies up to 10 MeV per nucleon, made their appearance in the 1960s. Several new generation machines, now with energies of ten to a few hundred MeV per nucleon, have already been completed — principally at Michigan State University, Caen in France (GANIL), and Darmstadt (GSI) — and several more are on their way, including RIKEN in Japan and at Lanzhou in China.

The new heavy-ion beams have a wide range of application in the natural sciences. They are highly effective in cancer radiotherapy, as shown in a recent joint US-Japan cooperative research project (K. Sakamoto, Tohoku University). The main advantages of such beams over other particle beams are the higher efficiency with which they kill cells, the independence of their cell-killing from the stage of the cell cycle and their selectivity for killing tumour cells rather than normal cells. So far, only the Lawrence Berkeley Laboratory has radiotherapy facilities; experiments with carbon, neon and silicon ions have been tried.

Transfer of energy from heavy ions causes a variety of effects at solid surfaces and interfaces. These are the basis of a number of applications that are likely to be of great commercial value, including the reduction of surface reflectivity in scintillators, improvement of thin film adhesion and the establishment of electrical con-

tacts, and the implantation of ions into semiconductors (T. Tombrello, California Institute of Technology).

Heavy-ion beams can also be used in mass spectrometry, allowing detection of isotope ratios as small as 10^{-14} . In addition to various archaeological applications, this will make it possible to use neutrino detectors such as ^{71}Ge or ^{205}Tl rather than conventionally used ^{37}Cl . These detectors would provide a good sensitivity for neutrinos from the earliest stage of the pp chain in stellar evolution.

Several quite new problems in nuclear physics can also be tackled with the aid of the new accelerators. One proposal (E. Adelberger, University of Washington, Seattle) is to look for charge symmetry breakdown in the very high excitation energy region of nuclei by comparing heavy ion- and light ion-induced reactions. Adelberger also suggests a search for breakdown of the time-reversal symmetry by using the elastic scattering of polarized neutrons from certain heavy nuclei. Other important topics that can now be tackled experimentally are the production of high-density nuclear matter in relativistic heavy-ion scattering (S. Nagamiya, University of Tokyo) and the important role that may be played by very neutron-rich nuclei in the early stage of the Universe (K. Sato, University of Tokyo).

Quantum electrodynamics has been tested by looking at the decay of the vacuum by the spontaneous positron emission in the supercritical fields of a giant nuclear system of high atomic number. In the presence of the very strong electric fields produced by such systems the vacuum is predicted to decay by positron emission. Such a phenomenon has been observed experimentally at GSI and the result shown to be compatible with theory (B. Müller, J. Goethe University, Frankfurt). The phenomenon appears to follow the production of a giant nuclear system of $Z = 173$ –188.

Conventional nuclear physics has also received a boost from the new heavy-ion accelerators. In addition to the discovery of the $Z = 108$ element and plans for the search for even heavier elements and nuclei that are far off the stability line on the nuclear chart (G. Münzerberg and O. Klepper, GSI), giant resonances — particularly high energy octupole resonances — have been shown to be better excited by heavy ions (D. Youngblood, Texas A. & M. University). Some remarkable new detectors were also described. One is a 'crystal ball' that covers almost all the space around the target where the nuclear

reaction takes place with a NaI or BGO crystal. Studies of very high spin states and structure have made tremendous progress with the help of such a detector (J. Garrett, Niels Bohr Institute), as have studies of the decay property of giant resonances (J. Beene, ORNL, USA) and of quasi-molecular resonances (V. Metag, University of Giessen, FRG).

Quasi-molecular states seem to have gained recognition as one of the general features of nuclei. A rotational band based on the quasi-molecular configuration now seems quite likely to exist below the threshold energy (S. Kubono, University of Tokyo) and even in very heavy nuclei (M. Gai, Yale University). A new reaction mechanism has been proposed in which fission does not go through compound nucleus formation; this process becomes more prominent as the incident energy of the heavy-ion beam increases (B. B. Back, Argonne National Laboratory). A time-dependent Hartree-Fock calculation for heavy-ion scattering has been used to predict that two colliding nuclei with low angular momenta will not fuse under some conditions. Possible evidence of such a low angular momentum cut-off has been measured (T. Nomura, RIKEN).

One of the most controversial subjects discussed at the symposia concerned absolute fusion cross-sections below the Coulomb barrier — a subject related to the proton-proton chain in stellar evolution (T. Kajino, Tokyo Metropolitan University). According to some reports, a contribution from quasi-elastic scattering processes is very important in reproducing the absolute values (T. Tamura, University of Texas; C. Signorini, Padova; N. Taki-gawa, Tohoku University); but an alternative explanation involves a process of neck formation (A. Iwamoto, JAERI).

As the incident energy increases, the reaction mechanism of heavy-ion scattering seems to evolve dramatically (C. Détraz, GANIL; R. G. Stokstad, Lawrence Berkeley Laboratory). The cross-sections of fusion reactions decrease in a systematic manner (S. M. Lee, University of Tsukuba; S. Harar, SACLAY) and new reaction mechanisms, such as break-up/fusion and fragmentation processes (H. Utsunomiya, Michigan State University; D. Gross, HMI; E. Rehm, Argonne National Laboratory), and a pre-equilibrium process (C. K. Gelbke, Michigan State University), start to play an important role. Another interesting subject in nucleus-nucleus scattering at an intermediate incident energy is the absolute cross-sections for pion production near the absolute threshold energy. The existing theories underestimate the π^0 production cross-sections by more than an order of magnitude. Why they do so remains an open question. □

*The 1984 INS-ROKEN International Symposium on Heavy Ion Physics was held in two parts: 'New Scope of Heavy Ion Science', Tokyo, 24–25 August, 1984, and 'Heavy Ion Nuclear Physics', Mt Fuji, 27–31 August, 1984. The proceedings will be published in Supplements to the *Journal of the Physical Society of Japan*.

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