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Résumé. — Le premier accélérateur Van de Graaff Tandem MP fut installé au Laboratoire Wright à la fin de 1966. Depuis, il a permis de développer un programme étendu de recherches à travers toute la table de classification périodique des éléments en utilisant aussi bien des particules incidentes légères que lourdes. Ce papier décrit les caractéristiques de l'accélérateur en fonctionnement et illustre son utilisation en faisant référence aux recherches en cours au laboratoire, telles que : étude spectroscopique des états analogues et leurs mécanismes de réaction dans la région du plomb, étude spectroscopique de noyaux légers, étude de l'excitation coulombienne induite par ions lourds (probabilité de transition et mécanisme de réaction). Quelques caractéristiques de l'instrumentation associée à ces types de recherches sont aussi discutées.

Abstract. — The first MP tandem Van de Graaff accelerator was installed in the Wright Laboratory late in 1966. Since that date it has been employed in an extensive research program utilizing both light and heavy projectiles on targets throughout the periodic table. This paper will present operating characteristics of the accelerator and will illustrate their utilization with reference to current research in the laboratory including isobaric analog studies of nuclear structure and reactions in the lead region, nuclear spectroscopic studies in light nuclei, Coulomb excitation of transition nuclei and heavy ion interaction mechanisms. Some characteristics of the associated research instrumentation will also be discussed.

The first of the MP series of tandem Van de Graaff accelerators, the Emperors, became operational on May 27, 1966 in the Wrigtht Nuclear Structure Laboratory at Yale University. Since that time it has been utilized, 24 hours per day, in a diverse program of nuclear physics research. For the first time these MP accelerators open all facets of a nuclear physics problem to attack in one laboratory ; for the first time they make all nuclei accessible to the precision study which has always characterized work with electrostatic accelerators.

The operating characteristics of the Yale accelerator are given in Table I :

TABLE I

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Terminal potential range utilized	0.9 ... 12 MV
Proton beam energy homogeneity	1 in 10^4
Long term beam energy stability	1 in 10^4
Beam energy reproducibility.........	$\pm$ 1 keV
Maximum hydrogenic beam current ..	30 μA
Maximum oxygen beam current (O^{5+}).	2 μA
Maximum helium beam current (He^{2+})	2 μA
Maximum sulfur beam current (S^{7+})..	1 μA
Beams accelerated :	
p, d, ^3He, ^4He, ^{12}C, ^{14}N, ^{16}O, ^{32}S, Br, I.	

Operation has been extremely reliable apart from as yet unexplained difficulties with charging belt lifetimes which thus far have averaged $\sim$ 3 000 hours of operation. On the other hand the original acceleration tubes have seen over 15 000 hours of service (perhaps over half at high voltages and with heavy ion beams) and show no evidence of any deterioration in physical appearance or performance. At present the tubes are the limiting factor in terminal voltage ; substantially higher terminal potentials than those of table I are anticipated as soon as it becomes possible to replace the current aluminium electrode tubes with an improved design utilizing stainless steel electrodes.

Both duoplasmatron and HVEC diode sourcess are mounted for use with the accelerator ; these include lithium vapor charge exchange facilities interchangeably with more standard gas exchange systems.

Major ancillary research instrumentation in the laboratory includes : an advanced computer based data acquisition system developed in a joint Yale-IBM study and based on a System 360/44 central processor ; a 24 gap magnetic spectrograph having a 80 cm pole radius and a maximum detectable proton energy of 97 MeV ; a 2 meter precision computer controlled goniometer for angular correlation studies on nuclear radiation ; a 80 cm ORTEC scattering chamber including azimuthal detector motions ;

an 8-port high speed target fabrication evaporator facility ; a 30 cm diameter × 30 cm deep NaI gamma spectrometer in an anticoincidence annulus and with automatic light pulse stabilization and control ; together with more specialized chambers and detector systems, electronic instrumentation and off-line computational facilities. Action has been initiated toward installation of a smaller buffer computer which will control either an automatic plate scanner for use with photographic plates exposed in the multigap spectrograph or an alternative series of multi spark chamber detectors which will replace the photographic plates when desired for instantaneous access to, and electronic manipulation of, the incoming data.

The laboratory staff currently includes 12 post-doctoral experimental physicists, 25 graduate students and some 40 engineering, technical and support staff.

The conference paper corresponding to this summary will draw on recent experimental work in the Wright Laboratory to illustrate a variety of new experimental approaches which the combination of the unique characteristics of the MP accelerator beam and the above mentioned instrumentation makes possible.

Preliminary work on neutron threshold reactions established the energy calibration of the Yale system up to equivalent proton energies of some 60 MeV. Subsequent cross checks have demonstrated that this independent calibration is in remarkable accord with that in use at the California Institute of Technology and that recently revised independently at the University of Wisconsin. At the higher energies accessible to the MP accelerators the older counter ratio methods are worthless and measurements have been made on positron activity associated with the neutron producing reactions at threshold and between bursts of a mechanically chopped accelerator beam. A new and much more precise, self consistent series of accelerator calibration points has been established covering the entire range accessible to electrostatic nuclear accelerators.

Isobaric analog studies have been carried out on both light and heavy nuclei using light projectiles. The beam energy resolution has permitted detailed delineation and study of a resonance having a width of only 1.22 keV occurring at an energy of 14 231 MeV in the scattering of protons from ^{12}C. In the lead region, accessible to precision spectroscopy for the first time, because of the higher available energies, extremely interesting and unexpected results have been obtained.

Strong evidence for validity of a simple shell model, beyond anything anticipated, was found as was compelling evidence for the existence of well defined doorway states and for extremely simple core-particle coupling situations. The original measurements here were carried out using cooled silicon surface barrier detectors, 2 mm in depth, a counter telescope system and analog particle identifiers — both double and triple — fabricated in this laboratory after Goulding designs at Berkeley. This permitted simultaneous collection of data on reactions leading to protons, deuterons and tritons and vastly increased the effectiveness of data collection. Currently measurements have also been initiated with the large multigap spectrograph to permit detailed study of particle-hole structure in the lead region which cannot be resolved with semi-conductor detectors.

The on-line computer controlled goniometer system has been used in extensive nuclear structure studies in the low end of the s-d shell. Both correlation and lifetime measurements have been carried out with high efficiency and have led to the surprising result that nuclei such as ^{21}Ne may well be the most rigid of all nuclei. Complementary inelastic scattering studies using high energy deuteron and alpha particle beams have permitted detailed studies on the upper end of the s-d shell so that a comprehensive picture of the behaviour of the nuclear shape and collectivity throughout the shell has been obtained for the first time.

For the first time, the quadrupole giant resonance in carbon has been studied using the higher proton energies from the MP accelerator in the $^{11}B(p, \gamma)\,^{12}C$ reaction. Since photons of energy up to over 40 MeV are involved, a 30 cm × 30 cm dia NaI spectrometer is used in these studies. Since the capture gamma radiation of interest is between 4 and 5 orders of magnitude less intense than lower energy radiations from the targets, it has been necessary to develop an entirely new fast counting system which avoids both pile-up and counting loss problems. A completely automatic computer control loop has been developed which stabilizes both the system gain and resolution through control of both photomultiplier voltages and the incident beam intensities. Similar measurements are now in progress in many heavier nuclear systems.

The ready availability of heavy ion beams from the accelerator and of both Li-Ge and NaI spectrometers has provided great impetus to studies on Coulomb excitation of transition nuclei at either end of the rare earth region. This work has included the first detailed experimental test of the new microscopic nuclear models of Kumar and Baranger, study of the possible magnetic dipole component of electromagnetic transitions between collective rotational bands, and elucidation of the behaviour of centrifugal stretching throughout this mass region.

Extensive studies on inelastic alpha particle scattering on selected rare earth nuclei has been complementary to this work in focussing on the interference between Coulomb excitation and nuclear quadrupole terms in the excitation of 2^+ states and of the interference between nuclear quadrupole and hexadecapole terms in the excitation of the 4^+ states. Only the lithium vapor, atomic resonance charge exchange source makes possible adequate alpha particle beams for these low cross section studies.

Following on earlier work on nuclear molecular interactions carried out with the first tandem accelerator at Chalk River several years ago, studies on heavy ion interactions *per se* are in progress. Totally unexpected structure has been found in excitation functions for scattering of identical light nuclei in the energy range up to about 80 MeV. It has been possible to interpret this structure to gain unique new insight into the interaction potentials involved and through them to the fundamental nuclear matter considerations which underly them. Brueckner and his collaborators have shown that the heavy ion data are sensitive to repulsive cores in the nuclear interaction potentials and thus to the basic nucleon-nucleon forces. Greiner has shown that these data may be analyzed to yield an experimental determination of the effective compressibility of nuclear matter — an important quantity which has thus far eluded measurement. These studies are continuing and are only made possible through the high energies and *simultaneously* high energy resolution of the heavy ion beams from the accelerator. Without beams of this quality and geometric definition it would be impossible to resolve the structure of interest.

The availability of a broad range of heavy ion projectiles makes possible the creation of a very broad range of new nuclear species-isotopes lying far removed from the valley of beta stability, and utilizing Li-Ge spectrometers it becomes possible to test current nuclear structure calculations in a most sensitive way. The Yale gaseous diffusion isotope separation program has just produced significant quantities of the light xenon isotope ^{124}Xe (normally 0.1 % abundant) and this will be used as target material in moving well off to the proton rich side of the valley.

In summary, it has been possible to exploit many of the unique features of the MP accelerator during the past two years ; we have been well pleased with its performance. In the near future we anticipate extension of both its energy range and the variety of accelerated species ; both will open new and challenging areas for attack. Although in the part it has often been assumed that precise energy resolution was of decreasing importance with increasing energy beyond say 10 MeV for protons, work thus far in this laboratory has demonstrated conclusively that maintenance of the characteristic Van de Graaff resolution to the higher energies now available has led to just as many new and unexpected phenomenon as was the case at lower energies. We may confidently predict that this trend will continue.

References

[1] BROMLEY (D. A.), Proceedings of the Tokyo Conference ed. by J. Sanada. Tokyo 1968.

[2] BROMLEY (D. A.), OVERLEY (J. C.) and PARKER (P. D.), *Phys. Rev. Letters*, 1966, **17**, 705.

[3] OVERLEY (J. C.), PARKER (P. D.) and BROEMLY (D. A.), *Nucl. Instr. Methods*, 1967, **53**, 56.

[4] SIEMSSEN (R. H.), MAHER (J. V.), WEIDINGER (A.) and BROMLEY (D. A.), *Phys. Rev. Letters*, 1967, **19**, 369.

[5] STEIN (N.), WHITTEN (C. A.), BROMLEY (D. A.), *Phys. Rev. Letters*, 1968, **20**, 113.

[6] CASTEN (R. F.), GREENBERG (J. S.), BURGINYON (G. A.), and BROMLEY (D. A.), *Phys. Rev. Letters*, 1967, **18**, 912.

[7] STEIN (N.), COTTON (J. P.) and BROMLEY (D. A.), *Phys. Rev. Letters*, 1968, **21**, 1456.

[8] BROMLEY (D. A.) : Proceedings of the Dedication of the University of Rochester Nuclear Structure Research Laboratory June, 1967.