Title
LINEAR ACCELERATOR FOR HEAVY IONS

Authors
Beringer, Robert
Gluckstern, Robert L.
Malkin, Myron S. (Yale U.)
et al.

Publication Date
1954-11-29

UCRL 2796

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

BERKELEY, CALIFORNIA

DISCLAIMER

UCRL-2796

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

LINEAR ACCELERATOR FOR HEAVY IONS

Robert Beringer, Robert L. Gluckstern, and Myron S. Malkin
Yale University

Edward L. Hubbard, Lloyd Smith, and Chester M. Van Atta
University of California Radiation Laboratory

November 29, 1954

Printed for the U. S. Atomic Energy Commission

LINEAR ACCELERATOR FOR HEAVY IONS

Robert Beringer, Robert L. Gluckstern, and Myron S. Malkin
Yale University

Edward L. Hubbard, Lloyd Smith, and Chester M. Van Atta
University of California Radiation Laboratory

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

November 29, 1954

ABSTRACT

Linear accelerators for the production of ions in the mass region up to that of neon with energies of 10 Mev per nucleon are to be constructed at the University of California Radiation Laboratory and at Yale University. Main features of the design as presently conceived are discussed.

LINEAR ACCELERATOR FOR HEAVY IONS

Robert Beringer, Robert L. Gluckstern, and Myron S. Malkin
Yale University

Edward L. Hubbard, Lloyd Smith, and Chester M. Van Atta
University of California Radiation Laboratory

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

November 29, 1954

INTRODUCTION

Production of high-energy, high-intensity beams of heavy ions (ions heavier than α-particles) would make possible many interesting experiments in nuclear physics,[1] nuclear chemistry, and biology. At present, heavy ions are being accelerated by two methods in cyclotrons about 60 inches in diameter. The investigation of transuranium nuclides[2] produced by heavy-ion bombardment has been in progress in Berkeley for several years. At Berkeley,[3] Birmingham,[4] and Stockholm[5] highly ionized ions are formed by stripping near the center of the cyclotron and are accelerated to energies up to 12 Mev per nucleon. The energy spread is large, however, and the beam currents are low. At Oak Ridge triply charged nitrogen ions from the ion source are accelerated without stripping. External beams of 2 μa are obtained,[6] but the energy of 29 Mev is too low for penetration of the Coulomb barrier of heavy nuclei. Production of ions with 10 Mev per nucleon in this way would require a magnet at least 160 inches in diameter.

GENERAL DESCRIPTION

A joint undertaking now in progress is the design of heavy-ion linear accelerators for construction at the University of California Radiation Labora-

[1] G. Breit, M. H. Hull, R. L. Gluckstern, Phys. Rev. 87, 74 (1952).

[2] A. Ghiorso, S. G. Thompson, K. Street, Jr., and G. T. Seaborg, Phys. Rev. 81, 154 (1951).

[3] G. B. Rossi, W. B. Jones, J. M. Hollander, and J. G. Hamilton, Phys. Rev. 93, 256 (1954).

[4] D. Walker, J. H. Fremlin, Nature 171, 189 (1953).

[5] H. Atterling, Arkiv Fysik 7, 503 (1954).

[6] H. L. Reynolds, D. W. Scott, A. Zucker, Phys. Rev. 95, 671 (1954).

tory and at Yale University. The objective is to produce ions in the mass region up to neon and possibly as high as argon with energies of 10 Mev per nucleon. The linac will consist of two 70-mc resonant cavities of the Alvarez type.[7] Stripping is to be used between the two cavities to increase the e/m of the ions from 0.15 to 0.30 and thus shorten the second cavity to 90 ft. The beam pulses will be about 2 milliseconds long. Figure 1 is a layout of the entire accelerator as planned.

Injector

Ions are to be injected into the linac by a 500-kv Cookroft-Walton accelerator. The ion source developed provides milliampere beams of ions with e/m = 0.15 and smaller currents of ions with higher specific ionizations. The ions are produced in a pulsed PIG discharge and extracted radially as in a cyclotron source. To reduce space-charge defocusing in the accelerating column the magnet for the ion source will also act as a 135° analyzing magnet for the elimination of unwanted ions. Since the different ions to be accelerated have slightly different values of e/m, it will be necessary to adjust the Cockcroft-Walton voltage to obtain the correct velocity at the input to the linear accelerator.

Prestripper

The ions will enter the prestripper cavity with an energy of 0.07 Mev per nucleon and be accelerated to 1 Mev per nucleon. The cavity is to be 15 ft long and 124 in. in diameter and will have thirty-seven 8-in.-diameter drift tubes with a bore of 3/4 in. The vacuum tank will be made of copper-clad steel and will also serve as the rf cavity.

The beam will be focused with grids similar to those used in the 40-ft linac at Berkeley. Strong focusing cannot be used because the fields required are too high. Ions with an e/m of 0.15 will require an rf electric field gradient of 0.5 Mv/ft, and ions with higher values of e/m can be accelerated at lower gradients. The rf power is to be supplied by a full-wave transmission line, which will couple power from the poststripper cavity. Proper phasing of the beam bunches as they enter the poststripper will be achieved by mechanical

[7] Alvarez, Bradner, Franck, Gordon, Gow, Marshall, Oppenheimer, Panofsky, Richman, and Woodyard, "Berkeley Proton Linear Accelerator," University of California Radiation Laboratory Report No. UCRL-236 (rev.), Oct. 1953; also this issue Rev. Sci. Instr.

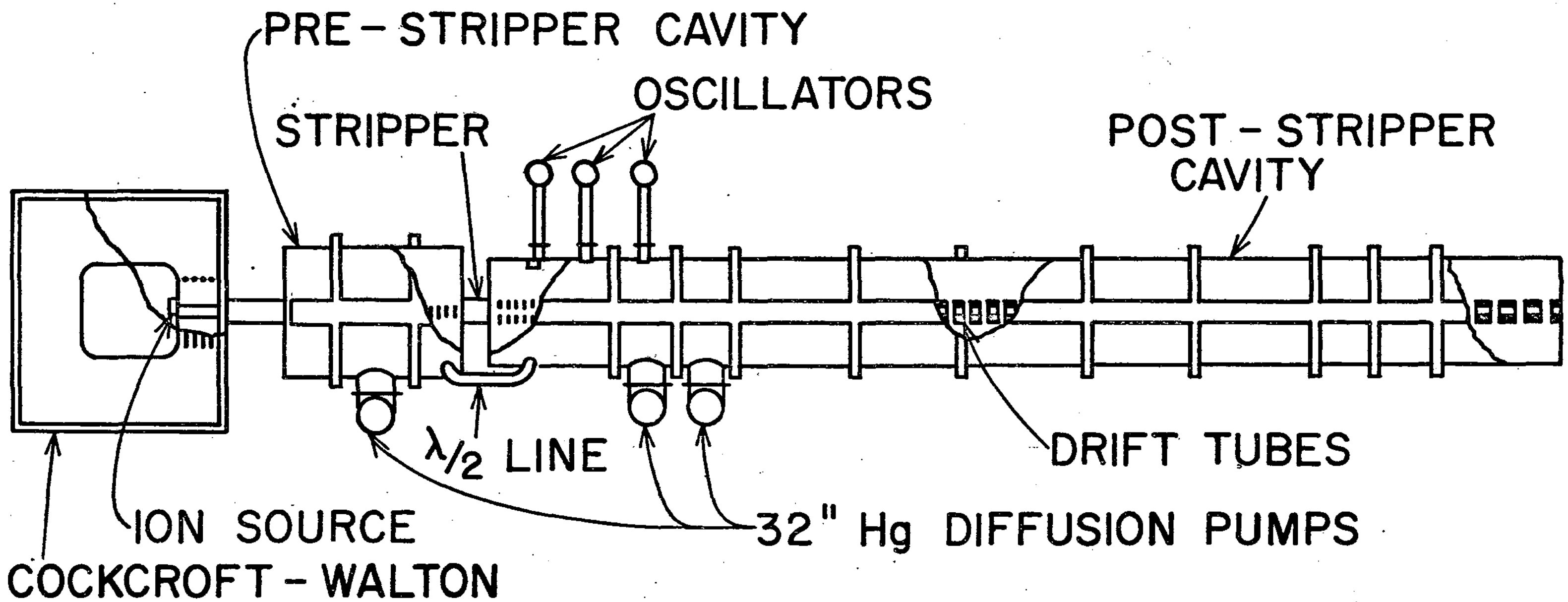

Fig. 1 Plan view of heavy ion linear accelerator

22834-1

adjustment of the position of the prestripper cavity.

Stripper

Between the two linac cavities, electrons are to be stripped from the ions by passing them through matter. To keep the energy loss and the multiple scattering small it is desirable to use only as much matter as is needed to do the stripping. Experiments with oxygen and neon ions accelerated in the 4-Mv Van de Graaff indicate that only a few $\mu g/cm^2$ are required. Since foils of this thickness undoubtedly would not last in the beam, a gas stripper is planned. The required amount of gas can be obtained with either a differential pumping system or with a jet of vapor that flows transverse to the beam. The yield of highly stripped ions increases with the velocity at the stripping point, but making the prestripper longer would increase the amount of beam intercepted by focusing grids. The choice of 1 Mev per nucleon is a compromise between these two effects.

Poststripper

The poststripper cavity will be 108 inches in diameter and 90 feet long and will also be of copper-clad steel construction. It will have 68 drift tubes 20 inches in diameter with a quadrupole strong focusing magnet inside each one. It is planned to initially connect the magnets in pairs so that the polarity reverses after each pair of drift tubes. With this NNSS connection the focusing-magnet power required for the whole machine will be about 80 kw. Operation with the polarity of the magnets reversing after each drift tube (NSNS) improves the radial focusing, but would require about 280 kw. Provision will be made for future addition of power supplies for NSNS operation.

An increase in bore is required at the transition between the grid-focused prestripper and the strong-focused poststripper. The bore will be 2 in. in the first drift tube of the poststripper and will increase to 3.5 in. at the output end to allow for expansion of the beam caused by misalignment of the magnets. With this taper in the bore, calculations indicate that the axes of the focusing magnets must be located within 0.025 in. of the axis of the accelerator and that the magnets must be aligned azimuthally to 0.5°.

With strong focusing, particles with a wide range of synchronous phases are radially stable. As a result, ions in several charge states can be simultaneously accelerated to the same energy, and therefore the distribution of stripped ions over several charge states will not appreciably lower the beam current.

The electric field gradient required to accelerate particles of e/m = 0.30 in the poststripper is 0.5 Mv/ft. The three megawatts of peak rf power required to drive both cavities will be supplied by three RCA A2332 triodes coupled to the poststripper cavity. The rf pulse length will be 3 milliseconds with an initial duty factor of 3 percent.

Status

Beam dynamics studies have been completed, and general features of the accelerators are fairly well determined. Detailed design is now under way, and construction of the machines is expected to start in the spring of 1955.

ACKNOWLEDGMENTS

The authors listed are not the only ones who have made major contributions to the design of the heavy-ion accelerator. The incentive for undertaking the design and construction of a heavy-ion accelerator was largely provided by Gregory Breit[*] and Glenn T. Seaborg.[†] Important work on specific components has been done by the following people: ion source, Carl E. Anderson,[*] Kenneth W. Ehlers,[†] W. D. Kilpatrick;[†] mechanical engineering, Hayden S. Gordon,[†] Luther R. Lucas,[†] Ralph Peters,[†] D. Theodore Scalise,[†] Leroy Schwarz,[*] Robert W. Young;[†] electrical engineering, Warren L. Dexter,[†] Carl Stern,[†] Ferdinand Voelker;[†] oscillator development, William R. Baker,[†] Nathaniel Feldman,[†] Neil J. Norris,[†] David A. Vance,[†] George W. Wheeler;[*] stripping, Eugene J. Lauer,[†] Waldo Rall;[*] rf cavity modeling, Robert M. Main;[†] beam dynamics, Fred N. Holmquist, Jr.;[†] shielding, William J. Knox.[*]

---

*Yale University
†UCRL

DESIGN PARAMETERS FOR THE HEAVY ION ACCELERATOR

Frequency = 70 Megacycles/second
Total Exciting Power = 3000 kw

λ = 14.05 feet = 4.29 meters
Duty Cycle = 0.03

PRE-STRIPPER CAVITY
(Grid Focusing)

$e/m = 0.15\ (e/m)_{proton}$
Injection Voltage = 472 KV
Injection Energy = 0.071 Mev/nucleon
Output Energy = 0.97 Mev/nucleon
RF Gradient = 0.51 MV/ft

Cavity -- Diameter = 124.1 inches
Length = 14.93 feet
Drift Tubes -- Bore = 3/4 inch
Diameter = 8 inches
Number = 1/2 + 36 + 1/2

POST-STRIPPER CAVITY
(Magnetic Alternative Gradient Focusing)

$e/m = 0.30\ (e/m)_{proton}$
Output Energy = 10.14 Mev/nucleon
RF Gradient = 0.44 MV/ft (input end)
= 0.58 MV/ft (output end)
Focusing Power -- NNSS = 80 kw
NSNS = 280 kw

Cavity -- Diameter = 108.2 inches
Length = 89.7 feet
Drift Tubes -- Bore = 2 inches (input)
= 3.5 inches (output)
Diameter = 20 inches
Number = 1/2 + 67 + 1/2

Accelerating conditions for various ions available from the arc ion source

Isotope	Cockcroft-Walton KV	Pre-Stripper Charge*	Pre-Stripper e/m	Post-Stripper Charge*	Post-Stripper e/m
C^{12}	425	2	0.167	4	0.333
N^{14}	331	3	0.214	5	0.357
O^{16}	379	3	0.187	5	0.312
O^{18}	425	3	0.167	6	0.333
Ne^{20}	472	3	0.150	6	0.300
Ne^{22}	389	4	0.182	7	0.350
S^{32}	454	5	0.156	10	0.313
A^{40}	472	6	0.150	12	0.300

* Minimum charge values acceptable for cavity gradient $\lesssim 0.5$ MV/ft