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R. S. Livingston
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ABSTRACT

The subject area of this bibliography is limited to published material concerning fixed-frequency and frequency-modulated cyclotrons, Articles appearing in scientific journals or in "project" literature during the years 1933 to 1955 are summarized or abstracted.

BIBLIOGRAPHY OF CYCLOTRON LITERATURE

Introduction

This preliminary review of cyclotron literature is limited to published articles concerning the various aspects of fixed-frequency and frequency-modulated cyclotrons. No attempt has been made to include work concerning synchrotrons, linear accelerators, or other types of machines. The period covered is from the publication of the original papers in 1930 until the present, mid-year 1955.

In the preparation of this bibliography the following cataloging and abstracting sources were checked:

Cumulative Book Catalog (or Index)

AEC Document Catalog

Chemical Abstracts, 1937 - 1954

Engineering Index, 1933 - 1954

Industrial Arts Index, 1933 - June, 1955

Guide to Published Research on Atomic Energy, 1946 - June, 1948
(This was superseded July, 1948, by Nuclear Science Abstracts.)

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Section A: Physics, 1933 - June, 1955

Section B: Electrical Engineering, 1933 - June, 1955

Journals (Indexes):

Nature, 1941 - 1954

The Physical Review, 1933 - 1954

The Review of Scientific Instruments, 1933 - 1954

An attempt was made to include all articles published in technical journals; some project reports are also included because the information is not available elsewhere. It is recognized that foreign publications have not been thoroughly covered, particularly those not published in the English language.

Considerable irregularity will be observed in the way the abstracts are written. In some cases the authors' original abstracts are used. Many abstracts are as prepared by the abstracting services referred to above. The present authors themselves have written a number of the abstracts and edited many of the others. When reading the abstracts the reader should keep in mind the date of publication, the evolution of terminology, and the changing reference points in scales of time and magnitude.

The abstracts are arranged by author and date. Both an author index and a subject index are included.

BIBLIOGRAPHY OF CYCLOTRON LITERATURE

A-1 Adams, J. B., and A. O. Edmunds, The Performance of the Harwell 110-Inch Synchrocyclotron, Report AERE-G/R-568 (1950).

The performance of the synchrocyclotron, in operation at AERE, Harwell since December, 1949, is assessed in light of current theory. General parameters, forced oscillations, free oscillations, mean beam intensity as a function of radius, nature of current pulse on internal target, and miscellaneous data are reviewed.

A-2 Adams, N. I., and H. L. Schultz, "Cyclotron Radiofrequency Power Unit," Rev. Sci. Instr. 11, 303-5 (1940).

An oscillator-amplifier unit, suitable for supplying r-f power to a cyclotron of medium size, is described. The power stage of the unit employs 4 RCA 833 air-cooled tubes operating at 80% efficiency with an input of 5 kw. Power is supplied to the dees through a resonant line; the peak radiofrequency voltage is about 45 kv. A 1-microampere beam of 3.1-Mev deuterons is obtained.

A-3 Abersold, P. C., "The Cyclotron: A Nuclear Transformer," Radiology 39, 513-40 (1942).

The significance and techniques of producing artificial radioelements with the cyclotron are discussed. The first cyclotrons, built by E. O. Lawrence, are described and illustrated. The principle of cyclotron conceived late in 1930, a 11-in. diameter apparatus was built in 1931, and in 1932 transmutations were achieved with it. In 1934 after deuterium became available, it was possible to accelerate deuterons, and by 1935 the 27-in. cyclotron was producing deuterons with energies of 4 Mev. The construction and performance of the 60-inch 16-Mev deuteron cyclotron and progress in the construction of the 184-in. 100-Mev deuteron cyclotron are then described.

A-4 Alkhazov, D. G., M. G. Meshcheryakov, and L. M. Kromchenko, "Radium Institute Cyclotron. I. Arc Type of Ion Source," J. Phys. (USSR) 8, 56-61 (1944).

The construction and operation of the cyclotron are described. Deuterons with energies up to 4 Mev can be obtained.

A-5 Allen, A. J., M. B. Sampson, and R. G. Franklin, "The Cyclotron of the Biochemical Research Foundation," J. Franklin Inst. 228, 543-61 (1939).

Many new features were incorporated in the cyclotron. The design of the magnetic circuit, vacuum chamber, the dees and the dee supports, ion source, high frequency system, and auxiliary apparatus are discussed. With an improved ion source, this cyclotron delivers a current of 30 μa of deuterons at 11 Mev on an external target. It is possible to produce radioactive material not only for indicator work but also for therapeutic purposes.

A-6 Allen, A. J., and R. G. Franklin, "A Constant Current Network for Supplying Power to a Cyclotron Oscillator," Phys. Rev. 57, 347 (1940).

A constant current network using 3 phase-4100 v from the power distribution system and supplying from 0.6 to 3.6 amp up to 12 kv to the plates of a cyclotron was developed. The network makes use of a simple resonant circuit for transforming constant voltage to constant current. The voltage, current, and protection requirements for the various parts are given.

A-7 Alvarez, L. W., Edwin McMillan, and A. H. Snell, "The Removal of the Ion Beam of the Cyclotron from the Magnetic Field," Phys. Rev. 51, 148-9 (1937).

The many obvious advantages of deflecting the cyclotron beam to an external target are noted. The first step in this direction was accomplished when the beam was made to emerge through the wall of the tank. Exploratory experiments showed that, at a distance of 40 cm from point of emergence, the beam was spread into a horizontal ribbon 10 cm wide and continued to diverge at greater distances. A partial refocusing was accomplished by applying an additional inhomogeneous field, provided by pieces of iron bolted to the magnet poles.

A-8 Alvarez, L. W., "High Energy Carbon Nuclei," Phys. Rev. 58, 192 (1940).

The 37-in. cyclotron chamber was filled with CH_4, and a beam of 50 Mev ${}_6C^{12}$ (6+) ions was detected with a linear amplifier. To resolve these ions from α-particles it was necessary to reduce dee voltage and to adjust magnetic field to the low side of α-particle peak. Under these conditions, about 500 carbon nuclei/min entered the ionization chamber. Pulses on oscillograph were about nine times as high as those from Po α-particles, showing that their charge was about 6e and range between 6 and 11 cm of air. Attempts to observe 100-Mev carbon ions in 60-in. cyclotron gave no conclusive results.

A-9 Anderson, H. L., and J. Marshall, The University of Chicago 170-Inch Synchrocyclotron Progress Report, July 1947-July 1948, Report NP-451.

Progress on the construction of this synchrocyclotron during first year is reported. The building, magnet, vacuum chamber, accelerating electrode, ion source, target arrangements, deflector, control system, and shielding are described.

A-10 Anderson, H. L., and J. Marshall, "170-Inch Synchrocyclotron at University of Chicago," Phys. Rev. 83, 232 (1951).

This synchrocyclotron, under construction for 3 1/2 years, is designed to accelerate protons to 450 Mev and deuterons and α-particles to 260 Mev and 520 Mev, respectively. In the initial operation deuterons were accelerated to radius of 77 in. and magnetic field of 17600 gauss.

A-11 Anderson, H. L., J. Marshall, L. Kornblith, Jr., R. H. Miller, and L. Schwarcz, University of Chicago 170-Inch Synchrocyclotron, July 1950-Jan. 1952, Report NP-3874

The 170-in. synchrocyclotron, which accelerates protons to energy of 450 Mev and provides beams of mesons of both signs over a wide range of energies, is described. Present beams range in energy from 66 Mev to 230 Mev for π^- mesons, and 66 Mev to 145 Mev for π^+ mesons.

A-12 Anderson, H. L., J. Marshall, L. Kornblith, Jr., L. Schwarcz, and R. H. Miller, "Synchrocyclotron for 450-Mev Protons," Rev. Sci. Instr. 23, 707-28 (1952).

A 170-in. synchrocyclotron completed at the Institute for Nuclear Studies, the University of Chicago, is described. The machine is capable of accelerating protons to energy of 450 Mev, deuterons to 256 Mev, and α-particles to 512 Mev. Magnet poles are contoured to give a field of 18,600 gauss in center and decreasing to 17,600 gauss at 76-in. radius. Circulating beam of about one microampere of 450Mev protons is normally obtained. Present beams range in energy from 66 Mev to 230 Mev for π^- mesons and from 66 to 145 Mev for π^+ mesons.

A-13 Andronov, A., and G. Gorelik, "Nonlinear Resonance of a Relativistic Particle in the Cyclotron," Compt. rend. 221, 696-8 (1945).

Simple equations are derived for periodic motion of relativistic particles in the cyclotron. An energy-loss term is added for each half cycle in the spiral path. This energy loss is attributed to radiation and collision processes. The equations are discussed.

A-14 Ashmore, A., and R. F. Raffle, "Magnetic Analysis of α-Particle Groups from (d,α) Reactions," Proc. Phys. Soc. (London)A, 64, 754-6 (1951).

A heavy-particle magnetic-focusing spectrometer was used to measure the energy spectrum of α-particles emitted during the bombardment of light elements with deuterons from the 39-in. cyclotron at University of Liverpool.

A-15 Atterling, H., and G. Lindstrom, "A High Frequency Cyclotron Generator with Demountable Tubes," Arkiv. Mat., Astron Fysik 35A, Paper 4 (1947).

An r-f generator using two 20-kw demountable triodes oscillating in push-pull, as used for the 32-in. cyclotron in Stockholm, is described. The system operates as a self-excited, tuned-anode, tuned-grid oscillator. An output efficiency of > 75% is obtained from the tubes at 9 kv; the ratio of dee r-f power to d-c input is nearly 25%.

A-16 Atterling, H., "Experiments with an Arc Ion Source for the Cyclotron," Arkiv. Mat., Astron. Fysik 35A, Paper 32 (1948).

An arc ion source used in connection with 32-in. cyclotron in Stockholm is described. The relation of ion output to electron emission and dee voltage was determined; the effects of various types of filaments, gas flows, and arc currents were investigated. A very concentrated beam of electrons was obtained by means of an indirectly heated tungsten point within the filament spiral. By the use of a hooded arc, 100-200 μa deuteron currents on an internal target were obtained.

A-17 Atterling, H., "Design of Acceleration Chamber and Dees for the 225-cm Cyclotron at the Nobel Institute for Physics, Stockholm," Arkiv. Fysik 2, 559-70 (1951).

This fixed-frequency cyclotron has a pole diameter of 225 cm; the chamber and dees are designed for accelerating ions to maximum radius of 90 cm.

A-18 Atterling, H., and G. Lindstrom, "A Fixed-Frequency Cyclotron with 225-cm Pole Diameter," Nature 169, 432-4 (1952).

A new machine put into operation in 1951 was designed to produce deuterons of 25-Mev energy. Dimensions of the magnet allow operations at higher energies either by applying higher voltages to dees, or by changing machine to f-m operation. A magnetic field of ~11,500 oersteds at center was obtained with a power input of ~60 kw. A negative bias of 500-700 v applied to dees proved to be sufficient to avoid discharges in acceleration chamber.

A-19 Atterling, H., and G. Lindstrom, "Notes on the 225-cm Cyclotron at the Nobel Institute for Physics, Stockholm," Arkiv. Fysik 4, 559-63 (1952).

The initial performance and additional design features of this cyclotron are presented. The fixed-frequency machine was designed to produce 25-Mev deuterons; in initial tests 21-Mev deuterons were obtained. Discussion of r-f system is given, since this seemed to have caused the greatest amount of trouble.

A-20 Atterling, H., "Acceleration of Heavy Ions in the 225-cm Cyclotron at the Nobel Institute of Physics, Preliminary Note," Arkiv. Fysik 7, 503-6 (1954).

The Stockholm deuteron cyclotron fixed frequency at 8.7 Mc/sec was used to accelerate C^{6+}, N^{6+}, and O^{6+}; useable ion currents were obtained at energies exceeding 50 Mev. The maximum energy attainable in Mev is 12.5 times the atomic weight. Doubly charged ions were preaccelerated; argon was introduced in the vacuum chamber to promote gas stripping; and the 6+ charged ions were accelerated on the "third harmonic". The article contains a brief review of the literature.

B-1 Backus, J., "Design of Cyclotron Oscillators," Rev. Sci. Instr. 22, 84-92 (1951).

The procedure used to design the oscillator for 60-in. cyclotron at Berkeley is described. It was assumed that the cyclotron and associated circuits would oscillate on one of the normal modes of vibration of electric circuit, and the circuit was adjusted to provide the proper voltage to drive the oscillator tube.

B-2 Baker, C. P., and M. S. Livingston, "A Discharge Tube Ion Source for the Cyclotron," Phys. Rev. 51, 1011-2 (1937).

A capillary discharge tube is designed to serve as a cyclotron ion source. The metal capillary (3/16 in. ID, 1/4 in. OD) is mounted vertically in center of cyclotron between parallel tubes for anode and filament. A small hole (1 mm) drilled through capillary wall provides an exit for ions and gives pressure differential between arc (H_2 at $\sim 10^{-2}$ mm) and cyclotron chamber ($\sim 10^{-5}$ mm). The chief advantages are in point source of ions and consequent improvement of energy distribution of high voltage ions, and elimination of heating effects from filament sources.

B-3 Baker, O. H., "Production of Forging for Carnegie Tech Cyclotron," Ind. Heating 15, 1654 (1948).

The article describes the design, construction, and method of production of the 1465-ton forged steel magnet used in the 145-in. synchrocyclotron, which is designed to accelerate protons to over 400 Mev.

B-4 Bakker, C. J., "The Amsterdam Cyclotron," Voord. Koninkl Inst. Ing. 2, 517-23 (May 1950).

The 72-in. synchrocyclotron built by Philips Works, operating with field strength of 14,000 oersteds, produced 30-Mev deuterons and 60-Mev α-particles.

B-5 Barden, S. E., "Regenerative Deflection as a Parametrically Excited Resonance Phenomenon," Rev. Sci. Instr. 25, 587-93 (1954).

The phenomenon, termed regenerative deflection, is treated as a resonance mechanism which is one of a larger class of similar mechanisms. Conditions of optimum coupling to promote growth of radial oscillations are described, and the results of some numerical calculations are given. An electrodynamic system for creating coupling inhomogeneities is also described.

B-6 Barnes, S. W., R. L. McCreary, A. Clark, W. Mortenson, H. Longemann, and C. Oxley, Construction Report; 130-Inch Rochester Cyclotron, July 1946-July 1949, Report NP-979.

A brief summary of research undertaken with 240-Mev protons is presented. Magnet, dee tank, vacuum system, dee and liner, rotating condenser, tank grids, power system, control system, cooling system, operating techniques, and proton-proton scattering experiments are described.

B-7 Barnes, S. W., A. Clark, G. B. Collins, C. Oxley, R. L. McCreary, J. B. Platt, and S. N. Van Voorhees, "Note on the Rochester Cyclotron," Phys. Rev. 75, 983 (1949).

The 130-in. cyclotron has accelerated protons out to radius of 58 1/2 in. or to estimated energy of 240 Mev since the first of the year. Measurement of C^{11} activity of carbon-tipped probe indicates average currents of about 0.1 μa at this radius. About 15 kw of r-f power for dee was furnished by grounded-grid oscillator with feedback through dee. Natural frequency of dee was varied from 26 to 18 Mc/sec by rotating condenser.

B-8 Baumgartner, H., C. R. Extermann, P. Gugelot, P. Preiswerk, and P. Scherrer, "Stabilization of Magnetic Field of the Cyclotron," Helv. Phys. Acta. 15, 330-1 (1942).

A method of stabilizing the magnetic field of a cyclotron is described. The variations of current in the electromagnet cause deflections of a sensitive galvanometer which brings about operation of series of relays through intermediate action of two photo-electric cells and two thyratrons.

B-9 Baumgartner, H., C. R. Extermann, P. Gugelot, P. Preiswerk, and P. Scherrer, "Oil Diffusion Pumps," Helv. Phys. Acta., 15, 332-3 (1942).

A number of oil diffusion pumps were examined as to suitability for use in cyclotron vacuum system. The effect of type of jet, diffusion column, heating effect, and particularly the dependence of the pumping performance on the temperature distribution in current of vapor, were studied. These studies resulted in an increase in pumping rate.

B-10 Baumgartner, H., C. R. Extermann, P. Gugelot, P. Scherrer, "Ion Source for the Cyclotron," Helv. Phys. Acta. 15, 333-4 (1942).

An ion source is described which provides a 1-ma stream of ions from a cathode emitting 50 ma with an accelerating potential of 250 v, and a gas pressure of 10^{-3} mm.

B-11 Beach, E. H., and W. C. Parkinson, "A Cathode-Type Arc Ion Source," Rev. Sci. Instr. 22, 697-9 (1951).

A brief description of an ion source with indirectly heated cathode originally designed for Michigan 42-in. cyclotron is given. No data on life is available.

B-12 Beach, E. H., W. J. Childs, P. V. C. Hough, J. S. King, and W. C. Parkinson, "Radial Oscillations in the Cyclotron - Experimental," Phys. Rev. 86, 582 (1952).

The order of the steps is: (1) central shimming to obtain proper magnetic focusing, (2) adjustment of median plane, (3) removal of first harmonic of any azimuthal asymmetries, (4) measurement and elimination of residual radial oscillations, and (5) controlled excitation of an oscillation desirable for extraction of the beam. The magnitude of the oscillation and the center of the orbit may be determined by the use of three internal probes, or with two probes, one of which carries a specially constructed head for determining the angle of the beam at a given radius.

B-13 Bender, R. S., E. M. Reilley, A. J. Allen, R. L. Ely, J. S. Arthur, and H. J. Hausman, "The University of Pittsburgh Scattering Project," Rev. Sci. Instr. 23, 542-7 (1952).

The scattering program used charged particles from the University of Pittsburg 47-in. cyclotron (8-Mev protons, 16-Mev deuterons, and 31-Mev α-particles). A focusing magnet guides the beam through aperture in an 8-ft shielding wall into a scattering laboratory; a second magnet analyzes the beam in energy; a third magnet analyzes energy of charged particles produced in reactions. For 1/16-in. analyzing slits 1.0 μa of 8 ± 0.010-Mev protons are available at the target 31 ft distant from cyclotron. Reaction particle analyzer can be rotated about target. Energy dispersion for 5.298-Mev α-particles is 0.192 Mev/in. for each analyzer; momentum resolution is 1 part in 850.

B-14 Benson, W. K., Jr., R. L. L. Mather, B. J. Moyer, and Joseph Yater, "Radiation Field of the 184-Inch Cyclotron," Phys. Rev. 75, 1470 (1949).

Distribution and intensity of radiation field outside shielding is studied with various types of detectors.

B-15 Bethe, H. A., and M. E. Rose, "The Maximum Energy Obtainable from the Cyclotron," Phys. Rev. 52, 1254-5 (1937).

Calculations show that very serious difficulties arise when an attempt is made to accelerate ions in a fixed-frequency cyclotron to higher energies. The difficulty is due to relativistic change of mass which has the effect of destroying either resonance or focusing. A note is added later stating that it has been found possible to devise a magnetic field which gives (at 50-kv dee voltage) 12-Mev protons, 17-Mev deuterons, or 34-Mev α-particles, with small but measurable intensities.

B-16 Boch, A. L., and E. D. Hudson, "Cyclotron Efficiency and Power Distribution Measurements," Phys. Rev. 91, 224 (1953).

The high beam power obtained with the ORNL 86-Inch Cyclotron prompted an experimental study of the power distribution and the efficiency of the machine. As measured calorimetrically, the power transmitted to the internal target by 22-Mev protons exceeded 60 kw. For proton currents exceeding 1500 microamperes, the target power is over 10% of the power input to the oscillator, the ion transport efficiency approaches 15%, and the target power is over 50% of the total ion loading of the r-f system.

B-17 Bohm, D., and L. L. Foldy, "Theory of the Synchrocyclotron," Phys. Rev. 72, 649-61 (1947).

In the frequency-modulated cyclotron high energies are obtained at the expense of a decrease in ion current as compared with that available from the fixed-frequency cyclotron. This decrease results from the fact that during only a small fraction of the f-m cycle is it possible for ions to be captured in phase stable orbits.

B-18 Booth, E. T., M. W. Johnson, R. W. Schubert, H. C. Beck, W. E. Hovemeyer, and W. F. Goodell, Jr., Cyclotron Report: 1950-51, Report NP-3045 (1950).

Construction of the Nevis cyclotron is completed and the machine is now producing 385-Mev protons. Details of construction, site, building, and magnet are described. Performance of the cyclotron and the program of instrument construction are presented.

B-19 Boyd, G. A., "A Modified Arc Ion Source Filament for the Cyclotron," Rev. Sci. Instr. 15, 230 (1944).

A modification of the tungsten filament for the arc ion source of the cyclotron gives a considerable increase in life and insures the striking of the arc at the proper distance.

B-20 Boyd, G. A., "A Sliding Vacuum Gate for the Cyclotron," Rev. Sci. Instr. 18, 250 (1947).

A sliding vacuum gate is used to prevent loss of the vacuum in a cyclotron when the window is punctured. The advantages of the sliding gate over the swinging type of gate are the conservation of space in the target area and the reduction in weight of the housing. Description and illustrations are given.

B-21 Boyer, K., H. E. Gove, J. A. Harvey, M. Deutsch, and M. S. Livingston, "Instrumentation of the MIT Cyclotron for the Study of Nuclear Reactions," Rev. Sci. Instr. 22, 310-20 (1951).

An emergent beam was focused to bombard targets placed in evacuated chamber behind shielding walls. Heavy charged-particle products from targets can be counted and identified as to charge and mass with three proportional ionization chambers.

B-22 Brannigan, F. L., H. Blatz, and E. J. Kehoe, "Cyclotron Safeguards," Nucleonics 10, 20-4 (May 1952).

Specific dangers of cyclotron operation and methods of avoiding them are described. Fire and accident considerations discussed include cyclotron cooling media, flammable liquids, paraffin fire hazard, control room paneling, and radiation protection. Target handling and shielding are described.

B-23 Breit, G., M. H. Hull, Jr., and R. L. Gluckstern, "Possibilities of Heavy Ion Bombardment in Nuclear Studies," Phys. Rev. 87, 74-80 (1952).

Bombardment of nuclei by multiply charged ions of medium atomic weight such as C^{12} or O^{16} is considered as a possible means of studying nuclear structure. General design characteristics of a 60-in. cyclotron that should be capable of imparting the necessary energy to multiply charged ions are considered.

B-24 Brobeck, W. M., "The Cyclotron," Elec. Eng. 61, 348-53 (1942).

Possible relationships of the cyclotron to future engineering developments are considered. The development of atomic accelerating devices, the operating principles and construction of a typical cyclotron, and the uses to which it is now being put are discussed.

B-25 Brobeck, W. M., E. O. Lawrence, K. R. MacKenzie, E. M. McMillan, R. Serber, D. C. Sewell, K. M. Simpson, and R. L. Thornton, "Initial Performance of the 184-Inch Cyclotron of the University of California," Phys. Rev. 71, 449-50 (1947).

Successful application of the "principle of phase stability" to the 37-in. cyclotron led to the decision to complete the 184-in. cyclotron then under construction as a frequency-modulated machine. The article describes briefly the equipment and experiments by which deuteron and alpha-particle beams of approximately 200 and 400 Mev, respectively, were produced. Frequency modulation produced by rotating mechanical vacuum capacitor is similar in principle to one described in 1946 by F. H. Schmidt.

B-26 Brobeck, W. M., "Accelerating Atomic Particles," Phys. Today 1, 26-30 (1948).

The history of the development of accelerators of atomic particles is reviewed. Descriptions and diagrams of various types of accelerators are shown. Recent application of frequency modulation to cyclotrons to overcome relativistic limitations is described.

B-27 Brown, S. C., J. W. Irvine, Jr., and M. S. Livingston, "Cyclotron Targets: Preparation and Radiochemical Separation. II. Krypton," J. Chem. Phys. 12, 132-4 (1944).

Radioactive krypton ($T = 34h$, e^+, γ) is described as a very useful gas for tracer experiments. A brief description of methods used for preparation and separation is given.

B-28 Burgerjon, J. J., "New Deuterium Supply for Cyclotron Ion Sources," Rev. Sci. Instr. 25, 522-3 (1954).

An electrolysis cell and vacuum leak are described for supplying D_2 to the ion source of a cyclotron.

B-29 Burkig, J. W., E. L. Hubbard, and K. R. MacKenzie, "Pulsed Oscillator for F-M Cyclotron," Rev. Sci. Instr. 20, 135 (1949).

Pulsing was obtained by replacing the grid leak resistor of oscillator with a plate-to-cathode resistance (304-TH tube). Diagram of circuit for control tube is shown. Installation of pulse circuit allowed 50% increase in dee voltage with one-half previous plate dissipation. Present normal average power consumption, under pulse conditions, is $\sim$ 4 1/2 kw input for 12 kv on dee.

C-1 Carnegie Institute of Technology, Synchrocyclotron Progress Reports Covering the Period July 1947 through June 1950, Report TID-453 (1951).

Reports of progress on the CIT synchrocyclotron have been brought together; this provides an over-all concept of the design and development of synchrocyclotron to this date.

C-2 Cassels, J. M., and R. Latham, "Use of a Cyclotron to Detect Short-Period Activities," Nature 159, 367 (1947).

The cyclotron at Cambridge has a high-frequency set which can be readily modulated, allowing information to be obtained on activities of period varying roughly from 100 μsec to 1 sec. The apparatus consists of a master oscillator driving a ring-of-twelve scaling unit. Observations of tests are given.

C-3 Cassels, J. M., J. M. Dickson and J. Howlett, "Multiple Traversal of Cyclotron Targets," Proc. Phys. Soc. (London)B, 64, 590-4 (1951).

In high-energy cyclotrons the accelerated particles may pass through the target more than once. The average number of traversals is calculated theoretically and compared with experimental results. Good agreement is found.

C-4 Cassels, J. M., J. M. Dickson, and J. Howlett, "Multiple Traversal of Cyclotron Targets: An Extension to the Theory," Proc. Phys. Soc. (London)B, 64, 719 (1951).

Fourier transform techniques are used to extend previous results to the case of thin targets.

C-5 Chadwick, J., "The Cyclotron and its Applications," Nature 142, 630-4 (1938)

In the indirect methods of accelerating ions, a relatively small voltage is applied many times in succession. The most successful of these is that used in the cyclotron developed by Prof. E. O. Lawrence. The therapeutic application of cyclotron-produced isotopes and the use of these isotopes as tracers in biological investigations are discussed.

C-6 Chang, W. Y., and S. Rosenblum, "Two Simple Apparatus for Measuring the Cyclotron (Vertical) Magnetic Field with High Accuracy," Rev. Sci. Instr. 16, 75-8 (1945).

A magnetic balance and an indicating coil for measuring a strong vertical magnetic field are described. The magnetic balance is sensitive to about 1 gauss in 10,000 gauss. The indicating coil has such a nonlinearity that, when it is working in the vertical position, it will indicate a field of more than 10,000 gauss and, at this level, a variation smaller than 1 in 10,000.

C-7 Chem. Eng. News 26, 630 (1948), "Carnegie Tech Builds Synchrocyclotron."

Special development work with scale models predicts great saving in power and steel with new magnet design. New high-frequency oscillator designed by E. M. Williams produces a higher voltage in the dee but requires less power than other models in use.

C-8 Chou, C. N., W. F. Fry, and J. J. Lord, "Acceleration of Be and Carbon Ions in a Synchrocyclotron," Phys. Rev. 87, 671 (1952).

Carbon ion energies of up to 1.1 bev were obtained. Data obtained by δ-ray and scattering measurements in nuclear emulsion detectors were in agreement with theory.

C-9 Chu, E. L., and L. I. Schiff, "Recent Progress in Accelerators; Cyclotron," Ann. Rev. Nuc. Sci. 2, 82 (1953).

The principal advances in cyclotron design and construction during 1951 lie in the direction of increased energies and ion current. At the Oak Ridge National Laboratory an 86-in. fixed-frequency cyclotron was used to accelerate large currents of protons to 20 Mev; this corresponds to almost twice the relativistic mass increase of any other cyclotron. A high mass increase was also obtained with the Argonne 60-in. cyclotron; an external 100-μa beam of deuterons was produced at 24 Mev. Extremely high current at moderate voltage is the objective for the 18-in. cyclotron being completed at Brookhaven.

C-10 Chu, E. L., and L. I. Schiff, "Recent Progress in Accelerators; Synchrocyclotron," Ann. Rev. Nuc. Sci. 2, 83-4 (1953).

A synchrocyclotron with a 71-in. magnet which produced 28-Mev deuterons with an average internal current of 20 μa was installed in Institute for Nuclear Studies at Amsterdam. Since the magnet is the most expensive part of this machine, various attempts are being made to economize on magnet iron without a sacrifice in maximum orbit radius and field strength. In the Berkeley 184-in. synchrocyclotron an oscillator system was developed to accelerate both protons and deuterons with a minimum of change-over time.

C-11 Cockcroft, J. D., "The Cyclotron and its Applications," J. Sci. Instr. 16, 37-44 (1939).

First cyclotron was developed in Berkeley between 1929 and 1932. By 1932 the apparatus was producing beams of protons of the order of 10^{-9} amp and energies up to 1.2 Mev; with it Lawrence and Livingston confirmed the Cambridge results on transmutation of lithium by protons and later produced the first transmutations by deuterons. The following phases of the cyclotron are discussed: principle, construction, adjustment, outputs obtained, and application.

C-12 Cockcroft, J. D., "The Cyclotron and Betatron," J. Sci. Instr. 21, 189-93 (1944).

A description of the acceleration of particles in the cyclotron is given. The cyclotron is traced from the beginning through the various stages of improvement.

C-13 Cohen, B. L., "Motion of an Ion in a Fixed-Frequency Cyclotron," Phys. Rev. 83, 232 (1951).

A study is made of (1) phase shift per gap crossing, (2) energy gain per gap crossing, and (3) radius as a function of energy. Modifications of focusing formulas found in literature are presented. The complete vertical motion is computed. Formulas are derived for maximum energy obtainable in a f-f cyclotron as a function of the voltage.

C-14 Cohen, B. L., "The Theory of the Fixed-Frequency Cyclotron," Rev. Sci. Instr. 24, 589-601 (1953).

The theory of the f-f cyclotron is developed and illustrated at each step, with numerical results for an example. Conditions for ion transmission with respect to horizontal motion are derived, and it is shown that they are satisfied by all ions in most cyclotrons. A more correct and more complete focusing formula than that found in literature is derived and used to integrate the vertical motion. Proof is given that ions experience strong radial grouping. Effect of ion source "feelers" is discussed.

C-15 Cohen, B. L., and R. V. Neidigh, "Measurement of Angular Distributions of Nuclear Reaction Products with an Internal Cyclotron Beam," Rev. Sci. Instr. 25, 255-61 (1954).

Angular distributions of elastically-scattered protons, and of deuterons, tritons, and alpha particles from (p,d), (p,t), and (p,α) reactions are being measured with 22-Mev proton beam of the ORNL 86-Inch Cyclotron. The target designed for use in the internal beam is described. The particles are detected by observing the half lives of the activities induced by them.

C-16 Condit, R., "A Cloud-Chamber Study of Heavy Particles Accelerated in the Cyclotron," Phys. Rev. 62, 301 (1942)

It has been found possible to produce 85-Mev $^{12}C^{6+}$ and 113-Mev $^{16}O^{8+}$ ions with the 60-in. Berkeley Cyclotron. Very small beams of these high speed particles were led from the cyclotron through a thin window into a cloud chamber of conventional design. Range-velocity measurements were made for carbon at three new points; two new points for oxygen were obtained. Variation of heavy particle range with dee voltage was observed.

C-17 Cowie, D. B., and C. J. Ksanda, "Arc-Ion Source with Direct-Current Filament Supply for 60-Inch Cyclotron," Rev. Sci. Instr. 16, 224-5 (1945).

A capillary arc-ion source for a 60-in. cyclotron is described; it uses a d-c filament supply. This permitted 80-hr filament life with large deuteron beams. Stability of the arc and its operating conditions and construction are indicated.

C-18 Crane, H. R., and W. C. Parkinson, Excerpts from Final Report, University of Michigan Cyclotron, Report AECU-2037 (1952).

Engineering items necessary in rebuilding the 42-in. cyclotron are described. The cyclotron is operating with larger internal and external beams than at any time before; 5-Mev protons, 10-Mev deuterons, 20-Mev α-particles are available for research.

C-19 Crane, H. R., and P. V. C. Hough, University of Michigan Cyclotron, Annual Report, Report AECU-2847 (1953).

General operating characteristics of cyclotron, problem of long-term operation, design of scattering chamber, plans for improvement of cyclotron, and obtaining greater resolution in energy are discussed. Research completed and results published are reviewed.

C-20 Creutz, E. C., and R. R. Wilson, "Mono-Energetic Protons from Cyclotron," Rev. Sci. Instr. 17, 385-8 (1946).

The cyclotron beam does not lend itself to precise experiments requiring narrow energy band of well collimated particles. Energy spreads of several percent are not infrequent, and angular divergence is ordinarily several degrees. Apparatus is described which was used to obtain a monoenergetic beam whose energy was known to 1% and whose angular spread was less than 0.1 deg.

C-21 Creutz, E., M. Foss, G. Hinman, and E. M. Williams, Cyclotron Magnet and Oscillator Design; Annual Nuclear Physics Progress Report, Report NP-504.

Results of studies with 9-in. model magnet at Carnegie Tech are presented; 2-inch model magnet and a full-scale model oscillator were constructed.

C-22 Creutz, E., Design and Construction of Synchrocyclotron; Final Report, February 1, 1947 to September 1, 1950, Report NYO-780.

The magnet and coil design, engineering design, vacuum system, oscillator, rotary condenser, shielding, cooling system, research equipment and site at Saxonburg, Pennsylvania, are discussed and illustrated. (Carnegie Tech 142-in. f-m cyclotron).

C-23 Crewe, A. V., and K. J. Le Couteur, "Extracted Proton Beam of the Liverpool 156-Inch Cyclotron," Rev. Sci. Instr. 26, 625 (1955).

The proton beam of the Liverpool 156-in. f-m cyclotron was extracted by using a regenerative system of the type originally described by Tuck and Teng. The starting radius for extraction was chosen as 69 in. (380 Mev and n = 0.05). The expected radial oscillation amplitude increases by the ratio 1.5 per turn, so that when amplitude of oscillation reaches 2 in., the next orbit has an amplitude of 3 in. The beam travels down the magnetic channel, which is constructed in seven sections with a total length of about 6 ft. The energy of the beam was found to be 383 Mev.

C-24 Cross, W. G., L. L. Davenport, H. I. Ewen, R. J. Grenzeback, R. B. Holt, L. S. Lavatelli, R. A. Mack, A. J. Pote, N. F. Ramsey, L. G. Ritner, F. B. Robie, and P. J. VanHeerden, The Harvard University 95-Inch Cyclotron, Design, Construction, and Preliminary Operating Instructions, Report NP-1698 (1950).

Building and facilities, magnet, cyclotron orbits, radio frequency system, variable condenser, vacuum system, control circuit, cooling system, personnel protection, arc sources and probes are described.

C-25 Cunningham, B. B., H. H. Hopkins, M. Lindner, D. R. Miller, P. R. O'Conner, I. Perlman, G. T. Seaborg, and R. C. Thompson, "Transmutations with High-Energy Deuterons in the 184-Inch Cyclotron," Phys. Rev. 72, 739-40 (1947).

The successful operation of the Berkeley 184-in. cyclotron to produce useful beams of deuterons and helium ions of approximately 200 and 400 Mev, respectively, made possible the radiochemical identification of many of the transmutation products of nuclei excited to very high energies. With 200-Mev deuterons on As^{75}, activities were found representative of all elements from Se to Mn with lower elements not excluded. Both negative beta-particle and positron (or orbital electron capture) activities were noted.

C-26 Curtis, B. R., "A Cyclotron Ion Source with Retractable Filament," Phys. Rev. 57, 1070 (1940).

The difficulty resulting from the short life time of ion-source filaments was surmounted by making it possible to change filaments without losing the vacuum. An improved ion-source design provides for changing filaments through a commercial gate valve. Preliminary adjustments of ion source, with all other conditions the same and without feelers on the dees, increased the beam current from a maximum of 22 μa of deuterons at 11 Mev for the ordinary filament, to 35 μa for the new ion source.

C-27 Curtis, B. R., and R. S. Bender, "The Use of Elkonite for Cyclotron Ion Sources," Rev. Sci. Instr. 13, 266 (1942).

The intense ion bombardment to which the capillary of an ion source is subjected soon melts the copper used in its construction; the arc tip must frequently be replaced. At the suggestion of Dr. E. McMillan the arc capillary was constructed of Elkonite. The Elkonite 10W3, as used in the Harvard cyclotron in place of pure copper, has increased by at least a factor of three the useful life of the cyclotron ion source.

C-28 Curtis, B. R., J. L. Fowler, and L. Rosen, "Instrumentation for Nuclear Studies with Externally Focused Deuteron Beam from 10-Mev Cyclotron," Rev. Sci. Instr. 20, 388-93 (1949).

A 0.5-μa beam of 10-Mev deuterons was focused on an area 1/4 in. in diameter at the center of a 2-ft-dia reaction chamber 15 ft from the cyclotron. A gas target is supported in the center of the reaction chamber with side ports so constructed that nuclear reaction products from the gas can be counted by a proportional counter mounted at periphery of the chamber. Tests with charged particle detectors such as a proportional counter or photographic plates show the background to be sufficiently low to allow good resolution of products from the d-d reactions.

C-29 Cushman, Bonnie E., Bibliography of Particle Accelerators, July 1948 to December 1950, Report UCRL-1238 (1951).

This bibliography is a supplement to Report BNL-L-101. Information concerning accelerators in all parts of the world is listed as an appendix.

D-1 Danforth, W. E., and M. B. Sampson, "Measurement of the Radio-frequency Voltage in a Cyclotron," Rev. Sci. Instr. 9, 175-8 (1938).

Although the ultimate energy attained by particles in a cyclotron is independent of the radio-frequency voltage on the accelerating dees, knowledge of the magnitude of this voltage is of great practical usefulness. The following methods used for this purpose gave results in substantial agreement with each other: (1) by measurement of current to dees, (2) measurement of charging current to test electrode, and (3) to diode rectifier.

D-2 Danzer, H.,"A Study Model of the Cyclotron," Ann. Physik, Lpz. 41, 485-500 (1942).

A description is given of a simple mathematical model of the cyclotron suitable for demonstration purpose and with which the special features of cyclotron operation can be studied theoretically.

D-3 Davenport, L. L., L. S. Lavetelli, R. A. Mack, A. J. Pote, and N. F. Ramsey, "A Dee-Biasing System for a Frequency-Modulated Cyclotron," Rev. Sci. Instr. 22, 601-4 (1951).

The requirements that must be met by satisfactory dee-biasing system are outlined, and successful and simple means of meeting these are described.

D-4 Davenport, P. A., "A Radio-Frequency Power Supply System for High Voltage Accelerators," Brit. J. Appl. Phys. 3, 124-6 (1952).

A power supply system for operating an ion source is described. Multichannel link for r-f power is provided between ground and h-v terminal, each separate power requirement of ion source assembly having its own channel. Oscillators at ground potential provide power.

D-5 Debraine, P., Study of the Influence of the Form of the Magnetic Field on the Function of the Cyclotron, Report NP-2024 (1947).

The following items are included in this study: (1) variation of phase of particles in course of acceleration, (2) usable phase range, (3) optimum frequency of operation, (4) oscillations of particles about steady-state trajectory, (5) flow of particles through deflecting channel, and (6) effect of focusing on form of envelope of ion beam.

D-6 de Groot, W., "Cyclotron and Synchrocyclotron," Philips Tech. Rev. 12, 65 (1950).

The functioning of cyclotron up to energy limit set by relativity effect is described. It is explained how, by modulating the frequency of the accelerating field, resonance condition can, on an average, be fulfilled right up to edge of field.

D-7 Delano, V., and C. Goodman, "Shielding Properties of the Concrete Wall of the MIT Cyclotron," J. Appl. Phys. 21, 1040 (1950).

The shielding properties of 4-ft concrete wall were studied by using foils for neutrons and x-ray films for gamma rays. Measurements were made with cylindrical concrete blocks fitted into 4 1/2-in.-dia hole extending through concrete wall. Results indicate an attenuation factor of 8.3/ft for fast neutron component and 10/ft for thermal neutrons.

D-8 Delbecq, C. J., W. J. Ramler, S. R. Rocklin, and P. H. Yuster, "Crystal Techniques for Measuring Cyclotron Beam Energies," Rev. Sci. Instr. 26, 543-6 (1955).

A lithium fluoride crystal develops a yellow color when irradiated with deuterons from a cyclotron; if the deuterons are stopped within the crystal, there is a sharp demarcation in color between irradiated and unirradiated portions. It has been found that the depth of penetration of color into lithium fluoride can be used to determine accurately (±0.1 Mev at 20 Mev, ±0.2 Mev at 10 Mev) and rapidly the energy of deuterons in a cyclotron beam. A single exposure of a crystal to deuteron beam allows one to determine not only the energy of deuterons but also the angular orientation of beam trajectories.

D-9 Dickson, J. M., "Multiple Traversal of Cyclotron Targets," Proc. Phys. Soc. (London)B, 64, 615-6 (1951).

Effective target thickness is plotted against actual target thickness for 150-Mev protons in Harwell cyclotron, with results in agreement with the theory of Cassels, Dickson, and Howlett.

D-10 Dickson, J. M., and D. C. Salter, "Energy Spectrum Measurements of Protons in the Harwell Cyclotron," Brit. J. Appl. Phys. 4, 175-6 (1953).

The proton spectrum of the Harwell cyclotron was measured by a method which uses the cyclotron magnet as a momentum analyzer. For a maximum energy of 174 Mev, the width of the spectrum at half height was of the order of 10 Mev. A systematic variation of spectrum width with r-f accelerating voltage was found.

D-11 Dobbie, L. G., Cyclotron: Continuous Wave Fixed Frequency Excitation. Bibliography, Report NP-1230 (1948).

Sixty-nine references covering the period 1930-48 were compiled from Science Abstracts, Sections A and B, and from a few other sources.

D-12 Dodd, L. E., "The Reversed Cyclotron," Phys. Rev. 65, 353 (1944).

The backward operation of a cyclotron would permit the slowing down to some desired speed, perhaps zero, of an ionic particle having initially a high velocity. The principle is applicable theoretically for the stopping of a high speed cosmic-ray ion. Whether this is practicable for example in the case of a six-bev cosmic-ray electron appears to be a question of attaining experimentally the ultrahigh frequency of reversal of potential that would be necessary.

D-13 Donnelly, F. K., H. J. Engebretson, J. E. Henderson, T. J. Morgan, F. H. Schmidt, and J. F. Streib, "The University of Washington 60-Inch Cyclotron," Phys. Rev. 85, 767 (1952).

This machine is patterned after the Berkeley 60-in. cyclotron. Several new features are: grounded-grid oscillator with one ML-354 triode, 75-kw plate dissipation; plate at d-c ground; no insulated water supply needed; the system is stable and will "ride-thru" almost continuous sparking; and bake-out time is short.

D-14 Du Bridge, L. A., and S. W. Barnes, "The Rochester Cyclotron," Phys. Rev. 49, 865 (1936).

A magnetic resonance accelerator designed to produce 6-Mev protons was completed. The 17-ton magnet is designed to produce a field of 20,000 gauss, with pole faces 20 in. in diameter. The yoke is built of four Armco iron forgings 12 in. x 26 in. in cross section. The vacuum chamber follows closely the design of Lawrence and Livingston. High-frequency power is supplied by a 20-kw oscillator using commercial tubes.

D-15 Dunning, J. R., and H. L. Anderson, "High-Frequency Filament Supply for Ion Sources," Rev. Sci. Instr. 8, 158-9 (1937).

This paper describes the design of the oscillator built to supply power for the filament of the ion source of the Columbia 36-in. cyclotron and to indicate the extent of the modifications which can be tolerated in similar designs where it is desired to use the equipment on hand.

D-16 du Toit, S. J., "Cyclotron," S. African Mining Eng. J. 63, 761-3 (1953).

The general principles which were followed in designing a cyclotron at Council for Scientific and Industrial Research, Pretoria, South Africa, are discussed. The following are described: magnet design, radio-frequency supply, vacuum system, cyclotron building, and control system.

E-1 Edwards, R. F., and H. M. Owren, Instruction Notes for 184-Inch Cyclotron Deflector High Voltage Pulse Generator Model IV, Trigger Amplifier, Deflector Regulator, Regulator Delay, and Deflector Power Supply, Report AECU-350 (1949).

The theory of operation is outlined, and detailed circuit descriptions of the above auxiliary components of the 184-in. cyclotron are given. Maintenance notes are given for the pulse generator and trigger amplifier. A schematic diagram of basic pulse generator circuit and eight photographs of equipment are included.

E-2 Effat, K. E. A., "Dissociation of Molecular Hydrogen Ions in the Cyclotron," Proc. Phys. Soc. (London)A, 65, 433-6 (1952).

The losses produced by dissociation are discussed. Experiments are made on the H_2^+-ion current in a cyclotron. Vacuum conditions are shown to be important. At a pressure of 4×10^{-5} mm, some 70% of the H_2^+ ions reaching an energy of 1 Mev are later lost by dissociation.

E-3 Electronic Instruments 3, 86-9 (Oct. 1944). "Cyclotron - Atomic Research Instrument."

Illustrations and details of operation of cyclotron housed in the laboratory of Department of Terrestrial Magnetism of Carnegie Institute of Washington are presented. Construction details are given.

E-4 Engl. Elec. J. 11, 113-8 (June 1950), "Cyclotron Power Supplies."

Some of the power supplies for the 37-in. f-f cyclotron, Cavendish Laboratory, Cambridge, are described. A brief description of the cyclotron itself is given. The source of r-f power consists of a rectifier and its auxiliary equipment used in conjunction with a Marconi radio transmitter. The magnet supply and other auxiliary supplies are also considered.

E-5 Evans, R. D.,"Atom Smashing and Its Application to Medicine," Elec. Eng. 60, 250-60 (1941).

The elementary principles of atomic structure and atomic transmutation are concisely and clearly explained. Among examples of atom smashers the 2.5-Mev van de Graaff generator and the 42-in. cyclotron at MIT are briefly described with illustrations.

F-1 Foldy, L., and D. Bohm, "Efficiency of Frequency-Modulated Cyclotron," Phys. Rev. 70, 445 (1946).

In the f-m cyclotron the loss of resonance resulting from relativistic increase of mass is overcome by capture of particles in phase stable orbits, the energy of which is adiabatically increased by a slow decrease of dee voltage frequency. There is, however, only a small fraction of the cycle of frequency modulation during which ions can be captured into phase stable orbits with phase oscillations of amplitude small enough to prevent particles from being returned to origin. For conditions which may be realized in 184-in. cyclotron to be built at Berkeley, maximum efficiency is about 5%.

F-2 Foss, M. H., "The Pole Tips on the Carnegie Institute of Technology Cyclotron Magnet," Phys. Rev. 77, 758 (1950).

The pole tips on the above magnet have complex contours; the surfaces near the periphery have a series of ridges and valleys which rise above and below the average position. This structure enables the magnet to produce a higher energy proton beam than would be possible otherwise in a magnet with the same yoke, pole base, and coil.

F-3 Foss, M. H., J. G. Fox, R. B. Sutton, and E. C. Creutz, "Design of Cyclotron Magnet. I. Pole Design Using Half-Magnet," Rev. Sci. Instr. 22, 469-72 (1951).

A model half-magnet having 2-in.-diameter pole was constructed to measure effects of changes in design of pole and yoke for a large synchrocyclotron; design procedures are given.

F-4 Foss, M. H., Design of Cyclotron Magnets, Report NP-426.

This study is directed toward attaining increased particle at lower cyclotron magnet cost.

F-5 Fowler, R. H., "Professor Lawrence and the Development of the Cyclotron," Science 93, 74-6 (1941).

The author reviews his acquantance with Lawrence and the early work of Lawrence. The series of cyclotrons based on old Poulsen-arc magnet continued until its whole 37-in. pole pieces were utilized. At first Lawrence worked with pole pieces about 8 in. in diameter. The 37-in. was followed by the 60-in. Crocker Laboratory cyclotron capable of producing 100-μa beam of 16-Mev deuterons or 32-Mev alpha particles.

F-6 Fremlin, J. H., and J. S. Gooden, "Cyclic Accelerators," Repts. Progr. Phys. 13, 295-324 (1950).

The following discussions of the f-f cyclotron are presented: general principles, detailed consideration of different regions of acceleration, magnet, r-f system, and limitations of f-f cyclotron. The effect of frequency variation, early experimental work, and present position of the f-m cyclotron are discussed.

F-7 Fremlin, J. H., and V. M. Spiers, "The Break-Up of Negative Ions in the Cyclotron," Proc. Phys. Soc. (London)A, 68, 398-403 (May 1955).

A pinhole camera at the periphery of the cyclotron was used to record neutral products of dissociation of molecular ions accelerated to various radii. From the numbers of particles reaching different parts of a C 2 nuclear plate in the camera, the attenuation of accelerated ions due to collisions with residual air molecules could be deduced. This was compared with attenuation of H_2+ ions observed in a similar way.

F-8 Frost, F. E., and Jane M. Putnam, Particle Accelerators. I. Bibliography. II. List of High-Energy Installations, Report UCRL-2672 (November 1954).

This bibliography supplements Reports BNL-L-101, UCRL-1238, and UCRL-1951. The location of accelerators in all parts of the world is listed.

F-9 Fryer, E. M., and H. Staub, "Neutron Beam Monitor," Rev. Sci. Instr. 13, 187-8 (1942).

A modified BF_3 ionization chamber and an amplifier for controlling fluctuations in a cyclotron beam are described.

F-10 Fulbright, H. W., D. A. Bromley, J. A. Bruner, R. Hawrylak, and A. Hamann, Preliminary Report of the New 8-Mev Variable Energy Cyclotron of the University of Rochester, Report NYO-6541 (1954).

The small cyclotron (7.5-Mev protons) of University of Rochester was rebuilt in a new location within 3-ft thick shielding walls of limonite concrete. The new design allows for adjustment of oscillator frequency continuously from 2 to 7.5 Mev, and change to deuteron or α-particle operation is easily achieved. Of course it is necessary to retune the magnet to resonance after each oscillator frequency change. The external beam handling scheme employed was designed for modern low-energy nuclear scattering and reaction studies.

G-1 Gallop, J. W., London, Hammersmith Hospital, Notes on a Tour of American Fixed-Frequency Cyclotrons in the Autumn of 1950, Report NP-3537.

The design of principal components of the cyclotron is discussed, and various installations are quoted as examples. A considerable amount of information from the following laboratories is summarized: Carnegie Institute of Washington, Brookhaven, MIT, University of Pittsburgh, Argonne, University of Illinois, Washington University, University of California, and University of Washington.

G-2 Gardner, E., and C. M. G. Lattes, "Production of Mesons by the 184-Inch Berkeley Cyclotron," Science 107, 270-1 (1948).

Tracks believed to be due to mesons in photographic plates placed near a target bombarded by 380-Mev alpha particles are observed. These show the same type of scattering and variation of grain density with residual range found in cosmic-ray meson tracks by Lattes, Occhialini, and Powell; roughly two-thirds of them produce observable stars at the end of their range. The experimental arrangement is illustrated.

G-3 Garrison, W. M., H. R. Haymond, H. Powell, C. Corum, and J. G. Hamilton, "A Centrifugal Pump Target Assembly for Cyclotron Bombardment of Liquids," Rev. Sci. Instr. 24, 462-3 (1953).

This is a detailed description of apparatus for circulating liquids continuously during bombardment in the external beam of cyclotron. The temperature and rate of flow are controlled. The beam enters liquid through thin foil window.

G-4 Grassel, E. E., "A Model Demonstrating the Cyclotron Principle," J. Chem. Ed. 20, 460-1 (1943).

This device demonstrates the movement of protons or deuterons between the dees of a cyclotron. The relative position of moving particles as the dees change in charge and the increase in speed of a projectile as it travels from center to the outer edge of the dees are shown. The device is illustrated.

G-5 Grace, C. H., Discriminator Design and Construction for the Carnegie Institute of Technology Synchrocyclotron, Report NP-1945 (1950).

The discriminator described determines time of operation of ion-beam deflector for the 142-in. f-m cyclotron. A simplified and detailed description of the operation and calibration of this discriminator is given.

G-6 Green, F. L., "Electromagnetic Shims for Focusing in a Fixed-Frequency Cyclotron," Phys. Rev. 91, 223 (1953).

The conventional iron shims, used for focusing in the ORNL 44-in. experimental cyclotron, were replaced with electromagnetic shims for studies of magnetic focusing of the beam. Various magnetic field configurations and gradients are easily examined with a great saving of time and labor. It was verified experimentally that magnetic focusing is of little effect at small radii but is very effective at large radii.

G-7 Green, F. L., and J. A. Martin, "High-Intensity Beam of Low-Energy Protons in ORNL 86-Inch Cyclotron," Phys. Rev. 95, 304 (1954).

Recent experiments in operating the ORNL 86-Inch Cyclotron produced 29.5 milliamperes of 1-Mev protons collected on an internal water-cooled aluminum target at a radius of 25 in. In order to accelerate these protons to 1 Mev the magnetic field was lowered to one-third of the normal value for 22 Mev protons so that the third half-cycles of the fixed r-f oscillator could be used. By adjusting the magnetic field to resonance, protons were also accelerated on fifth half-cycles and seventh half-cycles.

G-8 Grinberg, A. P.,"New Accelerators of Charged Particles. A Review of Published Data. II," Zhur. Tekh. Fiz. 19, 153-83 (1949).

In this part of a review on accelerators, theoretical and structural data are given concerning the "phasotron." Veksler gave this name to the machine known in American literature as the synchrocyclotron or f-m cyclotron. Veksler was the first, it is claimed, to discover the autophasing principle and the possibility of a cyclotron based on it. All 27 references cite American authors and publications.

H-1 Hamacher, E. A., "Cyclotron Beam Current Integrator and Recorder," Rev. Sci. Instr. 17, 364-8 (1946).

The instrument described is used to integrate and record the MIT cyclotron beam current both for probe and external target. The instrument has stable high sensitivity, linear a-c amplifier, with low impedance input, and mechanical inverter for d-c input signal. Integration is accomplished by standard a-c watthour meter, and recorded by means of 5-ma d-c pen recorder.

H-2 Hamilton, D. R., and H. J. Lipkin, On Deflection at n = 1 in the Synchrocyclotron, Report NYO-781 (1950).

The theory and a possible method for deflecting the beam of the Princeton f-m cyclotron is discussed. The orbits expand until the point of maximum Hp (n = 1) is reached; the ions then escape and spiral outward.

H-3 Hansell, C. W., J. J. Slattery, and J. M. Sanabria, Cyclotron Investigation, Heidelberg, Germany, Report NP-458 (1945).

This f-f cyclotron is similar to those most commonly used in the United States. A description of the component parts is given. The cyclotron was said to be capable of producing particles with 9 Mev.

H-4 Harkins, W. D., H. W. Newson, R. J. Moon, A. H. Snell, L. A. Slotin, L. P. Borst, S. L. Simon, B. Carpenter, and P. R. Bell, "University of Chicago Cyclotron," Phys. Rev. 55, 1110 (1939).

The accelerating chamber of the cyclotron is 32.5 in. in diameter, and the usable gap is 4.5 in. With an operating frequency of 10.8 Mc/sec, deuterons are accelerated to a final energy of about 6.5 Mev.

H-5 Harlow, F. H., "X-Ray Measurement of the Cyclotron R-F Dee Voltage," Rev. Sci. Instr. 23, 501 (1952).

A method is given for determining the peak dee-to-ground voltage in a cyclotron by measuring maximum energy of the x-rays coming from tank while oscillator is running. The value determined agrees with the voltage calculated from limiting radius of a beam as a function of dee voltage.

H-6 Harvard University, Progress Report: (a) Design and Construction of a 92-Inch Cyclotron. (b) Research on Properties of Nuclear Radiations by Deflection Methods, Report NP-107 (1947).

Nuclear laboratory, magnet, vacuum chamber, oscillator, control circuits, shielding, cooling, He^3 diffusion column, improvement of focus and resolving power in magnetic spectrometers are discussed.

H-7 Hausman, H. J., Description of the Modifications of the Ohio State University Cyclotron, Final Report, Part I, Report AECU-2607 (1953).

Modifications were made to increase the beam current and voltage output. The construction of vacuum tank, vacuum-pumping system, resonant dee lines, cyclotron dees, and ion sources, is described.

H-8 Hausman, H. J., Development of the Modified Ohio State University Cyclotron. Final Report. Part 2, Report AECU-2907 (1954).

Modifications of the 42 in. f-f cyclotron are described.

H-9 Henderson, M. C., and M. G. White, "A Cyclotron Electromagnet," Phys. Rev. 49, 641 (1936).

A brief description is given of the electromagnet being built at Princeton for use as a "Magnetic Resonance Ion Accelerator" as developed by Lawrence and Livingston. The final design should produce a field of 19,000 gauss in a 4-in. gap between 35-in. poles, with an excitation of 30,000 amp turns/cm of gap. The total weight of steel is 42 tons, a considerable saving over the amount used on converted Poulsen arc magnets.

H-10 Henderson, M. C., and M. G. White, "The Design and Operation of a Large Cyclotron," Rev. Sci. Instr. 9, 19 (1938).

The Princeton cyclotron is described with particular reference to magnet design, ion-source characteristics, r-f requirements, optimum shape of magnetic field, and distribution in range of high energy alpha-particle beam. Increasing ion-source electron current above 400 ma was found to lower efficiency of production of high speed ions. An investigation of r-f power losses showed anodes of oscillators absorbed 35% of total power while tank coil across dees and dees themselves took, respectively, 30% and 21%.

H-11 Henderson, W. J., L. D. P. King, and J. R. Risser, "The Purdue Cyclotron," Phys. Rev. 55, 1110 (1939).

Construction is completed and the machine is now adjusted to produce deuterons of 8 Mev energy or doubly charged helium ions of 16 Mev energy. Ion currents obtained with arc source are about 3 μa of deuterons and 1/30 μa of helium ions. Helium ions are being used to investigate production of artificial radioactivity in various elements.

H-12 Henrich, L. R., D. C. Sewell, and J. Vale, "Operation of the 184-Inch Cyclotron," Rev. Sci. Instr. 20, 887-98 (1949).

The operation of this f-m cyclotron is reviewed in terms of theory as developed by Bohm and Foldy. Certain relevant data on properties of magnet and rotating condenser are presented.

H-13 Henry, W. H., and J. D. Keys, "Pulser for Cyclotron Oscillator," Can. J. Phys. 29, 137-41 (1951).

In the direct exposure of photographic plates or studies of very short activities it is often necessary to operate the cyclotron for short periods. For this purpose an accurate pulser was built for controlling the r-f oscillator of a synchrocyclotron.

H-14 Heusinkveld, M., M.J.Jakobson, L. Ruby, and B. T. Wright, "A Report on the Three-Dee, Three-Phase, 20-Inch Cyclotron," Report UCRL-1889 (Rev) (March 1955).

A 20-in. three-dee, three-phase, f-f cyclotron was constructed as a test model for determining the conditions that might be encountered in the initial orbits of a large magnetically phase-compensated cyclotron for accelerating ions to energies far beyond the normal range of f-f cyclotrons. The Thomas-type clover-leaf pole tips were used. A steady proton beam of 6 ma at 1 Mev was obtained with a dee voltage of 28 kv. By changing the sequence of the three-phase system, 6 ma of deuterons was accelerated to the full radius of 8 1/2 in. (0.5 Mev). (More briefly covered in UCRL-3187.)

H-15 Heyn, F. A., "The Synchrocyclotron at Amsterdam, I. General Description of the Installation. II. The Oscillator and the Modulator," Philips Tech. Rev. 12, 241-56 (1951).

The cyclotron operates steadily with a 20-μa deuteron current at 28 Mev. The major parts of installation are mentioned; an idea of the extent of accessory apparatus is given. A peak dee voltage of only about 15 kv is needed; the frequency is 10.7 Mc/sec.

H-16 Heyn, F. A., "The Synchrocyclotron at Amsterdam, III. The Electromagnet," Philips Tech. Rev. 12, 349-64 (1951).

The machine is designed for accelerating deuterons to an energy of 25 Mev; the air gap is 36 cm. It is known that power for excitation could be about 80 kw; and a steel with certain magnetization curve is available.

H-17 Heyn, F. A., and J. J. Burgerjon, "The Synchrocyclotron at Amsterdam, IV. Details of Construction and Ancillary Equipment," Philips Tech. Rev. 14, 263-79 (1953).

The Philips synchrocyclotron has been in continual use for three years as a tool for nuclear-physics research and the production of radioactive isotopes. Special features are a very high beam current (and hence high yield of radioactive substances) and a high degree of reliability in service. A description is given of the acceleration chamber, dees, ion source, target, vacuum pump, and some controls and protective devices.

H-18 Hintz, N. M., "Excitation Functions with an Internal Cyclotron Beam," Phys. Rev. 83, 185-6 (1951).

The stacked foil method for obtaining nuclear excitation functions can be used with internal cyclotron beam if the beam is deflected by multiple Coulomb scattering in a thin foil placed in median plane. Measurements are made on the proton beam of the maximum of 12 Mev at 110 Mev. The arrangement being used at Harvard is shown and described.

H-19 Honig, R. E., "The Technique of Bombarding Organic Compounds with Deuterons," Rev. Sci. Instr. 18, 389-94 (1947).

To study the chemical effects of heavy charged particles, a number of organic compounds - gases, liquids, and solids were bombarded with deuterons from the MIT cyclotron. Target materials included paraffins, organic acids, salts, and some complex mixtures. To prevent chemical reactions of the compounds with the metal parts, the chamber and target holders were gold plated.

H-20 Hough, P. V. C., "Radial Oscillations in the Cyclotron," Rev. Sci. Instr. 24, 42-8 (1953).

The excitation and evolution of the radial oscillations of ions in the cyclotron were studied theoretically and experimentally. A simple method for calculating the pattern of oscillations leads to detailed criteria for preparation of the magnetic field and a systematic theory of shimming. A new method for measuring the pattern of oscillations is used to check the theory.

H-21 Howe, J. D., and I. Walerstein, "Effects of Fringing Flux in Large Magnets," Rev. Sci. Instr. 9, 53-4 (1938).

The Purdue f-f cyclotron was designed to produce 20-Mev protons. It has tapered pole pieces. This design has the advantages of allowing considerable saving in the amount of iron and copper used in the cyclotron.

H-22 Hoynaux, M., "The Focusing Principles of High Energy Particle Accelerators. II. Magnetic Field Accelerators," Atomics, London, 2, 310-19 (1951).

A summary of the theory of vertical, radial, and phase focusing is given with application to each type of accelerator.

H-23 Hubbard, E. L., and E. L. Kelly, Alternating-Gradient Focusing of of the 20-Inch Cyclotron External Beam, Report UCRL-2181 (1953).

A description of the 20-in. cyclotron which was used as the injector for one-quarter scale model bevatron is given. The machine, later modified to operate with a deflector system and electrostatic focusing, produces 700/μa of 0.73-Mev protons.

H-24 Hubbard, E. L., and E. L. Kelly, "Alternating-Gradient Focusing of Cyclotron External Beam," Rev. Sci. Instr. 25, 737-9 (1954).

The 3/4-Mev external proton beam from the 20-in. cyclotron appeared to diverge horizontally from one point and vertically from another. With a series of three alternately converging and diverging electrostatic lens elements of hyperbolic cross section, it was possible to focus external beam to a point or to make it parallel.

I-1 Irvine, J. W., Jr., "The Production by the Cyclotron of Some Useful Radionuclides," J. Chem. Soc. (London) 1949, Suppl. No. 2, 350-60.

The author points out the inadequacy of the chain reactor for the production of many radionuclides, i. e., those which decay by positron emission or orbital electron capture, and those which are isotopically pure activities. Ten-to 20-Mev deuterons produced in a cyclotron were used to obtain sodium, manganese, iron, and zinc radionuclides.

I-2 Ise, J., R. V. Pyle, D. H. Hicks, and R. M. Main, "Production of 320-Mev Deuterons by He^3 Stripping," Rev. Sci. Instr. 25, 437-42 (1954).

Deuterons can be accelerated in 184-in. cyclotron to 190 Mev. To produce higher energy deuterons, doubly charged He^3 ions are accelerated to 493 Mev, and a fraction of them are stripped in internal target, yielding deuterons with average energy of 330 Mev. A current of 5×10^{-13} amp is obtained in experimental "cave" external to cyclotron shielding. Deuterons have average energy of about 330 Mev.

J-1 Jacques, R. B., "Automatic Frequency Control for a Cyclotron," Rev. Sci. Instr. 12, 442-4 (1941).

This paper describes a discriminator circuit which automatically compensates for changes due to thermal effects in the capacitive and inductive reactances as a quarter-wavelength dee line of a cyclotron. The unit thereby contributes to smoother power input.

J-2 Jakobson, M. J., and F. H. Schmidt, "Characteristics of a Proposed Double-Mode Cyclotron," Phys. Rev. 93, 303-5 (1954).

It is proposed to accelerate ions in a f-f cyclotron, either with dee voltage 180 deg out-of-phase, or with dee voltages in-phase. This is possible if angular extent of dee electrodes is made less than customary 180 deg. Formulaes have been derived for energy gain per turn of ions with various charge-to-mass ratios as function of angle of dees. The principal advantage of double-mode cyclotron for purpose of heavy-ion acceleration would be that it permits the harmonic acceleration of a larger variety of ions.

J-3 Johnson, R. D., and A. B. Martin, "The Effect of Cyclotron Bombardment on Self-Diffusion in Silver," J. Appl. Phys. 23, 1245-54 (1952).

Radioactive tracer techniques were employed to measure the rate of self-diffusion in silver in polycrystalline and single crystal solvents over a wide range of temperature, and to investigate the effect of bombarment with 10-Mev protons on this diffusion process. Cyclotron techniques and apparatus are described in some detail.

J-4 Jones, R. J., "The Oak Ridge 44-Inch Cyclotron," Phys. Rev. 91, 223 (1953).

A description of the ORNL 44-in. experimental cyclotron is presented. This proton accelerator is being used in the study of the transmission of ions in a f-f cyclotron. A discussion of beam composition and beam attenuation is presented. The use of focusing grids at the entering edges of the dees increases the ion beam current at small radii, but has little effect at the maximum radius.

J-5 Jones, R. J., and A. Zucker, "Two Ion Sources for Production of Multiply Charged Nitrogen Ions," Rev. Sci. Instr. 25, 562-6 (1954).

Two ion sources were developed for production of milliamperes of N^{+}, N^{2+}, N^{3+}, and N^{4+} ions. Under good operating conditions, 28 ma of N^{3+} and 10 ma of N^{4+} produced. Details of source construction are given, and the method for analyzing source output is presented. Characteristics of both sources as function of arc current and arc voltage were investigated.

J-6 Judd, D. L., "Theoretical Study of Relativistic Constant Frequency Cyclotrons," Bull. Am. Phys. Soc., 30(8), 20 (1955).

The principle of magnetic phase compensation was first proposed by Thomas in 1938 as a way to circumvent the relativistic effects which limit the energy attainable in a f-f cyclotron; the principle was independently arrived at by McMillan in 1949. Judd describes his extensive program of theoretical studies performed during 1950 to 1952. This work served as a basis for the experimental program with three-phase clover-leaf cyclotrons at Berkeley. The theoretical work is related to the more recent developments in cyclotron development.

K-1 Kerns, Q. A., W. R. Baker, R. F. Edwards, and G. M. Farly, "High Voltage Pulser for 184-Inch Cyclotron Electric Deflector," Rev. Sci. Instr. 19, 899-904 (1948).

This is a description of a high voltage pulse generator for use at UCRL. It develops deflecting potential of 200 kv that rises from 10% to 90% of peak value of 0.1 microsecond.

K-2 Kerst, D. W., K. M. Terwilliger, K. R. Symon, and L. W. Jones, "Fixed-Field Alternating-Gradient Accelerator with Spirally Ridged Poles," Phys. Rev. 98, 1153 (1955).

The spirally ridged pole magnet described is an attempt to retain desirable features of Symon's design (d-c magnet excitation, high momentum content, large injection aperture) and at same time to reduce the size of the magnet by eliminating regions of reverse field.

K-3 Kerst, D. W., Constant Frequency Cyclotrons with Spirally Ridged Poles, Report MURA-DWK-9 (Rev) (March 29, 1955).

This revision is due to Laslett's determination of influence of scalloped orbit on focusing. The possibility of overcoming vertical (axial) defocusing by addition of alternating gradient effects is considered here. The spirally ridged (Mark V) type of pole is tried. The course of trying to avoid integral, half integral, and sum resonances regardless of structural difficulties to exhibit the problems is followed. The scalloping of the orbit makes the construction of a cyclotron easier than was originally expected because the amount of alternating-gradient focusing can be less.

K-4 Kitagaki, T., "A Focusing Method for Large Accelerators," Phys. Rev. 89, 1161-2 (1953).

The use of alternate guiding magnets (having $n \sim 0$) and focusing magnets (having n large) is proposed. The latter magnets, which may be of quadrupole or solenoid construction and of relatively short length, are placed in linear portions of orbit.

K-5 Knox, W. J., "Multiple Traversals of High Energy Particles in a Cyclotron Beam through Thin Targets," Phys. Rev. 81, 693-7 (1951).

An experimental determination was made of the average number of times that 340-Mev protons traverse various targets in the Berkeley 184-in. cyclotron. The numbers range from slightly above 1 for a 1-in. thick copper target to about 15 for an aluminum target 0.0015 in. thick. Results are compared with calculated values based on multiple scattering in target and oscillations of particles in the cyclotron.

K-6 Kornblith, L., Jr., "An R-F Generator for Nuclear Energy Studies," Electronics 27, 142-5 (1954).

Parts of the frequency-modulated r-f system of the 170-in. University of Chicago cyclotron are described. The frequency cycle is 28.4 to 18.2 Mc/sec, and protons reach a final energy of 450 Mev at 76-in. radius with a 17,600 gauss field. Details are given of rotary condenser, oscillator tube, and pulsing system for switching the oscillator.

K-7 Kornblith, L., Jr., "Electronic Power for a Synchrocyclotron," Tele-Tech. 13, 98-100, 186-94, 197-8 (1954).

To maintain synchronism when the effect of relativistic increase in mass becomes important, the r-f energy supplied to the dees is pulsed, and the frequency is lowered toward the end of each cycle. The pulse repetition rate is 50-60 sec, the cycle duration $\sim$3 milliseconds and the r-f ranges from 28.8 to 17 Mc/sec. The "holding-off" biasing supply, the provisions for insulating and cooling, the method of stabilizing the 1000-kw magnet supply within 0.1%, and the monitoring arrangements are all described in detail.

K-8 Kruger, P. G., G. K. Green and F. W. Stallmann, "Cyclotron Operation Without Filaments," Phys. Rev. 51, 291 (1937).

With use of a transmission line to supply high-frequency power to the dees of a cyclotron, it is possible to operate with a continuous glow discharge in the vacuum chamber; it is unnecessary to use filaments to create ions for acceleration. In this way a steady ion beam current of 5 μa was obtained. Operating conditions with a continuous glow discharge in vacuum chamber are much more stable than with no glow discharge, since a small change in gas pressure does not affect tuning of dee circuit appreciably.

K-9 Kruger, P. G., and G. K. Green, "The Construction and Operation of a Cyclotron to Produce One Million Volt Deuterons," Phys. Rev. 51, 699-705 (1937).

Describes a small 16-in. cyclotron built at the University of Illinois. General magnetic field characteristics, and effect of shims on magnetic field are examined. The production of ions for acceleration with and without filament is discussed. This cyclotron found very reliable in operation, a maximum ion beam of 11 μa was maintained for long periods of time.

K-10 Kruger, P. G., G. K. Groetzinger, J. R. Richardson, E. M. Lyman, W. E. Ogle, M. E. Nelson, G. Schwarz, J. B. Greene, N. C. Colby, R. W. Lee, C. E. McClellan, D. Scag, L. Smith, and F. K. Tallmadge, "A Cyclotron Which Allows the Accelerated Particles to Emerge in a Direction Parallel to the Dee Interface," Rev. Sci. Instr. 15, 333-9 (1944).

The construction of the dees, deflection channel, and vacuum chamber of the University of Illinois cyclotron is described. The design allows the accelerated ions to pass through an electrostatic deflecting field for a quarter revolution and then to proceed through the magnetic fringing field for another quarter of a revolution before they leave the cyclotron vacuum chamber. Several curves showing typical operational characteristics of cyclotrons are included.

K-11 Kruse, U. E., R. A. Mack, and N. F. Ramsey, "Trochoidal Orbits in Synchrocyclotrons," Rev. Sci. Instr. 22, 839 (1951).

Various experimental effects due to low energy protons following trochoidal orbits are described.

K-12 Kundu, D. N., T. W. Donaven, M. L. Pool, and J. K. Long, "Nuclear Reactions with 21-Mev He^3 in a Cyclotron," Phys. Rev. 89, 1200-2 (1953).

He^3 ions were accelerated to a maximum energy of 21 Mev in the Ohio 42-in. cyclotron. Bombardment of Be, C, O, and Ni led to numerous known activities. The relative cross sections of the He^3 reactions involving O and Ni nuclei are evaluated. The half-lives of C^{11} and Zn^{62} were found to be 20.74 ± 0.10 min and 7.4 ± 0.2 hr, respectively.

K-13 Kurie, F. N. D., "Present-Day Design and Technique of the Cyclotron," J. Appl. Phys. 9, 691-701 (1938).

Of several methods of multiple acceleration which Lawrence and associates tried, the one which is now embodied in the cyclotron has been most successful. The preeminence of the cyclotron over other methods investigated is due to its flexibility and compactness, as well as the very high energies it can produce. The constructional and design details are discussed.

K-14 Kurie, F. N. D., "The Technique of High Intensity Bombardment with Fast Particles," Rev. Sci. Instr. 10, 199-205 (1939).

Improvements in cyclotron technique led to the utilization of beams of such intensity that nearly a kilowatt of power must be dissipated in the target. To maintain high operating efficiency it is desirable that targets should be bombarded in elementary form rather than as compounds, and that the cyclotron vacuum chamber should be protected from the debris of bombardment at all times. A bombarding chamber (a "bell-jar window") developed to meet this situation is described.

L-1 Lawrence, E. O., and N. E. Edelfsen, "On the Production of High Speed Protons," Science 72, 376-7 (1930).

This is a summary of a paper, presented by Lawrence at the September 1930, meeting of the National Academy of Science; it constitutes the first published description of a system for using magnetic resonance in the acceleration of protons. An experimental system with plates (dees) of 10-cm radius was then being constructed at the physics laboratory in Berkeley.

L-2 Lawrence, E. O., and M. S. Livingston, "A Method for Producing High Speed Hydrogen Ions without the Use of High Voltage," Phys. Rev. 37, 1707 (1931).

A method for producing high speed hydrogen ions without the use of high voltage was described at the September 1930, meeting of National Academy of Science. With a 10-cm magnet giving a field of 12,700 gauss, 80-kev hydrogen molecule ions were produced by using only 2-kv high-frequency oscillations on the plates. A larger magnet is under construction for producing one million volt ions.

L-3 Lawrence, E. O., and D. H. Sloan, "The Production of High Speed Canal Rays without the Use of High Voltages," Proc. Nat. Acad. Sci. 17, 64-70 (1931).

Describes earlier experiments in accelerating ions which later led to the development of the cyclotron. A linear-type accelerator with 21 drift tubes was used in accelerating mercury ions to over 200 kv; the maximum applied voltage was about 10 kv.

L-4 Lawrence, E. O., and M. S. Livingston, "The Production of High Speed Protons without the Use of High Voltage," Phys. Rev. 38, 834 (1931).

The practicability of a method for accelerating ions to high energies, as described at the meeting of the National Academy of Sciences, September 1930, and later before American Physical Society (Lawrence and Livingston, Phys. Rev. 37, 1707, 1931) has now been confirmed. A magnet with pole faces nine in. in diameter and producing a field of 15,000 gauss was used to accelerate protons to over 0.5 Mev. Modifications are being made to make it possible to achieve over 1 Mev.

L-5 Lawrence, E. O., and M. S. Livingston, "The Production of High Speed Light Ions without the Use of High Voltage," Phys. Rev. 40, 19-35 (1932).

With a magnet 11 in. in diameter, a current of 10^{-9} ampere of 1.2 Mev-protons was produced in a tube to which the maximum applied voltage was only 4000 volts.

L-6 Lawrence, E. O., and M. S. Livingston, "The Multiple Acceleration of Ions to Very High Speeds," Phys. Rev. 45, 608-12 (1934).

A larger model of apparatus for multiple acceleration of light ions, described earlier, is capable of generating hydrogen ions with energies up to 5 Mev. At 3 Mev, ion currents of 1/3 μa are readily obtainable. Construction of even larger apparatus, designed for generation of hydrogen ions of about 10 Mev energy is under way. The magnet is of double yoke design with pole face diameter of 27 1/2 in.

L-7 Lawrence, E. O., and D. Cooksey, "On the Apparatus for the Multiple Acceleration of Light Ions to High Speeds," Phys. Rev. 50, 1131-40 (1936).

Significant improvements of the apparatus for multiple acceleration of light ions, now called the "cyclotron", have been made. The apparatus produces many microamperes of deuterons having energies up to 6.3 Mev and a few tenths of microampere of 11-Mev doubly charged helium ions. Detailed description of the cyclotron, including discussion of adjustment, operation, and advances in design are given. With 5-Mev deuterons, it was found possible to produce radioactive isotopes of many of the elements throughout the periodic table.

L-8 Lawrence, E. O., L. W. Alvarez, W. M. Brobeck, D. Cooksey, D. R. Corsen, E. W. McMillan, W. W. Salisbury, and R. L. Thornton, "Initial Performance of the 60-Inch Cyclotron of the William H. Crocker Radiation Laboratory, University of California," Phys. Rev. 56, 124 (1939).

The proton resonance was found close to the expected value for the magnet current. The intensity of the resonance effect was built up by adjusting magnetic field with shims. A target current was then observed, and further shimming yielded 25 μa of protons at 8-Mev. No difficulty in producing 25-Mev deuterons and 50-Mev α-particles with present equipment is seen; it is evident that much higher energies could be obtained from cyclotron of larger dimensions.

L-9 Lawson, J. L., and A. W. Tyler, "A Magnet Current Stabilizer," Rev. Sci. Instr. 10, 304-7 (1939).

A precision current stabilizer which is suitable for controlling an electromagnet is described. The circuit is adaptable to a wide range of current values. Applications to a cyclotron and to a beta-ray spectrometer are discussed. Currents were stabilized over a period of several hours to better than 1 part in 50,000.

L-10 Le Couteur, K. J., "The Regenerative Deflector for Synchrocyclotrons," Proc. Phys. Soc., (London) B, 64, 1073-84 (1951).

Tuck and Teng have proposed extracting the beam from synchrocyclotron by modifying the normal magnetic field so that the amplitude of radial oscillations is built up until protons can escape from magnet. In this paper the method is studied analytically, and formulas are derived which express performance in terms of magnetic field perturbations.

L-11 Le Couteur, K. J., "Perturbations in the Magnetic Deflector for Synchrocyclotrons," Proc. Phys. Soc. (London) B, 66, 25-32 (1953).

In an earlier article, the linearized equation of motion of particles in the deflector was solved exactly; now the effect of non-linear terms, proportional to d^2H/dr^2, is evaluated approximately. The results indicate the tolerances on field shape and desirable radial position of deflector.

L-12 Lindstrom, G., "An Equipment for Automatic Resonance Control," Ark. Mat. Astr. Fysik 35A, Paper 5 (1947).

Equipment is described for maintaining resonance between the magnetic field and the oscillator frequency in a cyclotron.

L-13 Lindstrom, G., "Some High Frequency Measurements on a Cyclotron Model," Ark. Mat. Astr. Fysik 35A, Paper 15 (1948).

Experiments on a $\frac{1}{10}$ -scale model of the 225-cm cyclotron under construction at the Nobel Institute of Physics in Stockholm are described. The appropriate coaxial-line equations are established to confirm the reliability of model measurements.

L-14 Livingood, J. J., "The Fixed-Frequency Cyclotron," Elec. Eng. 67, 587-8 (1948).

The purpose of a cyclotron is described. Cyclotrons are generally operated with field strength equal to about 15,000 gauss, and when accelerating deuterons the frequency is about 11 Mc/sec. If intense currents of ions at moderate energy (20 Mev) are wanted, the f-f cyclotron is adequate, provided high dee-to-dee r-f voltages are used. Then the desired energy can be attained with comparatively few revolutions before ions can slip too far out of phase with dee voltage.

L-15 Livingston, M. S., "High-Speed Hydrogen Ions," Phys. Rev. 42, 441-2 (1932).

An apparatus was developed which produced hydrogen ions with energies equivalent to 3.6 Mev. The essential part is a 27.5-in. electromagnet which gives uniform fields over considerable areas; the field is in excess of 15,000 gauss and the gap 3.5 in. With a 28.5-meter wave length and a magnetic field of 14,000 gauss, hydrogen molecules were produced with energies of 3 Mev and with current approximately 10^{-9} amp. At 25.8 meters and 15,250 gauss, 3.6 Mev ions were produced.

L-16 Livingston, M. S., and E. O. Lawrence, "The Production of 4,800,000 Volt Hydrogen Ions," Phys. Rev. 43, 212 (1933).

Improvements in method recently described for multiple acceleration of ions to high speeds resulted in much higher energies. Enlargements in physical size of apparatus led to production of hydrogen ions of 3.6 Mev. Now, by using two insulated electrodes instead of one, the capacity in the oscillating circuit is reduced to half. This makes it possible to use shorter wave-lengths and larger magnetic fields for the resonance condition.

L-17 Livingston, M. S., "The Magnetic Resonance Accelerator," Rev. Sci. Instr. 7, 55-68 (1936).

The magnetic resonance accelerator or "cyclotron" described in this paper produces resonance by the application of a large and uniform magnetic field. The construction and operation of the Cornell cyclotron to produce 1 to 2 Mev ions is described. Proton and deuterons are accelerated. First practical installation used a magnet of 11-in. pole diameter and produced 1.2 Mev.

L-18 Livingston, M. S., M. G. Holloway, and C. P. Baker, "A Capillary Ion Source for the Cyclotron," Rev. Sci. Instr. 10, 63-7 (1939).

A new type of ion source for the cyclotron gives a concentrated beam of ions of high intensity and is effectually isolated from the cyclotron chamber. Among the several advantages of the source described are the high intensities achieved and the essentially point source of the ions.

L-19 Livingston, M. S., J.H. Buck, and R. D. Evans, "The MIT Cyclotron," Phys. Rev. 55, 1110 (1939).

A 42-in. cyclotron under construction at MIT is described. It will be used to produce radioactive materials to be used primarily in a medical research program.

L-20 Livingston, M. S., "Cyclotronics," Rept. New Engl. Assoc. Chem. Teachers 42, 60-4 (1940).

A description of the cyclotron, nuclear disintegration, induced radioactivities, and the use of radioactive isotopes as indicators is given. Promising applications in researches in chemistry, biology, medicine, metallurgy, and many other sciences are indicated.

L-21 Livingston, M. S., "The Cyclotron I," J. Appl. Phys. 15, 2-19 (1944). "The Cyclotron II," J. Appl. Phys. 15, 128-47 (1944).

This paper evaluates available information which may aid in improving the efficiency, reliability, and output, and in determining most economical sizes and designs of cyclotrons for large scale production. Topics discussed include: physical principles, electric and magnetic focusing, maximum energy, resonant circuit and chamber, ion source, laboratory design, cyclotron costs, yields of nuclear reactions, and optimum size.

L-22 Livingston, M. S., "Ion Sources for Cyclotrons," Revs. Mod. Phys. 18, 293-9 (1946).

The source of ions in the modern cyclotron is an exposed column of ionization from a low-voltage arc discharge. The development of the ion source, the modifications in use in various cyclotrons, and certain important features such as the cathode, cones, gas pressure, filament stem, and arc operation are discussed.

L-23 Livingston, M. S., "Particle Accelerators," Advances in Electronics 1, 269-316 (1948).

This article includes the following sections: (1) resonance accelerators: the cyclotron, (2) principles of acceleration to high energies, (3) the synchrocyclotron. It traces briefly the development of the cyclotron from the proposal first made by Lawrence in 1930.

L-24 Livingston, M. S., "Synchrocyclotron," Ann. Rev. Nucl. Sci. 1, 163-8 (1952).

The history of the development of f-m cyclotrons and their present status in U. S. and Europe are discussed. The first test of the frequency modulation principle was made at the University of California with the 37-inch cyclotron. Success of this model led to modification of the 184-inch machine which originally was intended to be a f-f cyclotron. This machine was completed in November 1946; designed originally to produce deuterons of 200 Mev it was later modified to accelerate protons to 350 Mev. The important new application to meson work is discussed.

L-25 Livingston, M. S., "Standard Cyclotron," Ann. Rev. Nucl.Sci. 1, 157-62 (1952).

The history of f-f cyclotron development is reviewed. Certain advantages of this machine, such as the high beam current available and its application to the production of neutron-deficient isotopes and to the direct irradiation of materials and organisms, have resulted in renewed interest in the f-f machine. Recent applications and related instrumentation are discussed.

L-26 Livingston, M. S., High-Energy Accelerators, Interscience Tracts on Physics and Astronomy; No. 2, Interscience Publishers, 1954.

The emphasis in this book is on physical principles of operation, properties of particle orbits, and design principles of basic components. There are chapters concerning: (1) high-energy accelerators as tools for nuclear research, (2) principles of acceleration to high energies, (3) electron synchrotron, (4) synchrocyclotron, (5) linear accelerators, (6) proton synchrotron, and (7) alternating gradient focusing.

L-27 Livingston, Robert S., "The Oak Ridge 86-Inch Cyclotron," Nature 170, 221-3 (Aug. 9, 1952).

The construction of an 86-in. high-current, f-f proton cyclotron was started at Oak Ridge in August 1949. The first beam was obtained in November 1950. This cyclotron produces an internal beam of protons in excess of one milliampere at 24 Mev; the relativistic increase in mass is 2.6%. Major specifications of the cyclotron are listed, and parts are described. The cyclotron is unique in that the median plane of magnetic field is vertical. Targets for utilizing large currents are discussed.

L-28 Livingston, Robert S., "Acceleration of Partially Stripped Heavy Ions," Nature 173, 54-7 (Jan. 9, 1954).

In an effort to obtain larger currents of heavy ions with a more uniform energy distribution, the acceleration of partially stripped ions (N^{3+}) was undertaken with a new 63-in. f-f cyclotron at Oak Ridge National Laboratory. It is possible to obtain more than 50 μa of 25-Mev N^{3+}. A brief description is given of this heavy-particle cyclotron, its ion source, and some of the nuclear results. Potentialities of this new approach for long-range research in nuclear physics and nuclear chemistry are suggested.

L-29 Livingston, Robert S., and R. J. Jones, "High-Intensity Ion Source for Cyclotron," Rev. Sci. Instr. 25, 522-7 (1954).

The mechanical design features and operating characteristics of a hot-cathode arc-discharge type ion source are described. Proton currents of 500 ma are obtained under d-c test conditions. A maximum current of 3 ma of 22-Mev protons is obtained with source installed in the ORNL 86-Inch Cyclotron. Distinguishing features of ion source are: arc chamber of carbon, heavy tantalum filament heated with direct current, and use of a specially shaped accelerating electrode.

L-30 Lofgren, E. J., "A High Intensity Cyclotron," Phys. Rev. 76, 587 (1949).

Preliminary experiments were performed on the use of a cyclotron as an injector for the Bevatron at Berkeley. It was possible to deflect 7 ma and by the use of a wedge-shaped magnetic field to bring 2/3 ma to a focal spot about 1/2 in. x 1 1/2 in. eight ft from the cyclotron. The source is a cold-cathode arc inside a 1/2-in. dia tube whose axis is parallel to the field.

L-31 Lofgren, E. J., and B. Peters, "Description of a Frequency-Modulated Cyclotron and a Discussion of the Deflector Problem," Phys. Rev. 70, 444 (1946).

To verify the theory of frequency modulation as applied to the cyclotron, a prototype was built to operate with the 37-in. magnet at Berkeley. Variation of resonant frequency due to mass increase at large energies was simulated by a radial decrease in magnetic field. It was shown that processional motion of orbits could greatly increase the change of radius per turn and would thus be helpful in beam deflection. A d-c deflector was used successfully to deflect up to 10% of circulating beam of 8-Mev deuterons.

L-32 Lofgren, E. J., "Negative Ions and Charge Neutralization in the Cyclotrons," Rev. Sci. Instr. 22, 321-3 (1951).

Evidence is given for the presence of negative H ions in the synchrocyclotron. They are lost by charge neutralization before they reach an energy of about 3 Mev. Protons have been made to circulate in the cyclotron without acceleration after they have reached an energy of 5 - 22 Mev and are found to be lost with a half-life of 1/3 to 2 sec.

M-1 MacKenzie, K. R., and V. B. Waitham, "R-F System for Frequency-Modulated Cyclotron," Rev. Sci. Instr. 18, 900-7 (1947).

A grounded-grid oscillator and a single dee resonant system for use with a f-m cyclotron at Berkeley are described. A deuteron energy of 7.5 Mev was obtained with dee voltages up to 15 kv and frequency range from 9.5 - 12 Mc/sec. Coupling constants, phase correction, amplitude modulation, and discharge phenomena are discussed.

M-2 MacKenzie, K. R., "Wide Range Frequency Modulation," Phys. Rev. 74, 104-5 (1948).

The cyclotron frequency-modulation systems so far proposed utilize mechanical variation of capacity. The capacity is most effective when placed at the leading edge of the dee but many difficulties are introduced. A system was developed in which the variable capacitor is outside the magnetic field. Tests made with a one-half scale model of the proposed system for the 184-in. cyclotron show that a frequency range of 2.4 to 1 can be covered continuously. A schematic diagram is shown and discussed.

M-3 MacKenzie, K. R., F. H. Schmidt, J. R. Woodagard, and L. F. Wouters, "Design of the Radiofrequency System for the 184-Inch Cyclotron," Rev. Sci. Instr. 20, 126-33 (1949).

The f-m oscillator and its associated r-f circuits, as used in the 184-in. cyclotron for accelerating deuterons to 190 Mev or alpha particles to 380 Mev, are described. During normal operation the oscillator delivers $\sim$20 kw of r-f power to dee system at 60% efficiency. History of design, and reasons for choices made are given.

M-4 MacKenzie, K. R., "Proton Deuteron R-F System for Berkeley Synchrocyclotron," Rev. Sci. Instr. 22, 302-9 (1951).

The system for accelerating 190-Mev deuteron or 350-Mev protons in 184-in. cyclotron is discussed. The dee is connected to a large cross-section line, then connected, through rotating condenser, to a short section of grounded line of about same cross section.

M-5 McMillan, E. M., and W. W. Salisbury, "A Modified Arc Source for the Cyclotron," Phys. Rev. 56, 836 (1939).

Encouraged by the success of Livingston and others with arc ion sources in cyclotrons, a similar source was tried in the 60-in. cyclotron at Berkeley. A description is given.

M-6 McMillan, E. M., "The Synchrotron - A Proposed High Energy Particle Accelerator," Phys. Rev. 68, 143-4 (1945).

The device proposed here makes use of the "phase stability" possessed by certain orbits in a cyclotron. To accelerate the particles it is necessary to change the equilibrium energy; this can be done by varying either the magnetic field or the radio frequency. Equations describing phase and energy variations derived by taking into account time variation of both magnetic field and frequency are given.

M-7 McMillan, E. M., "The Origin of the Synchrotron," Phys. Rev. 69, 534 (1946).

The author explains why he failed to refer to Veksler's work in the previously published letter on synchrotron. Since McMillan's thoughts on the synchrotron occurred near July, 1945, it is apparent that Veksler's discovery of the principle was earlier.

M-8 Manley, J. H., and M. J. Jakobson, "Cyclotron Beam Energy Determination by a Time-of-Flight Method," Rev. Sci. Instr. 25, 368-9 (1954).

Through use of both movable and fixed stilbene scintillation detectors, a phase delay measured in terms of the cyclotron frequency is introduced by flight time of beam particles. Measurements of energy were good to 2%.

M-9 Mann, W. B., "The Cyclotron and Some of Its Applications," Repts. Progr. Phys. 61, 125-36 (1939).

Subjects discussed are magnetic resonance acceleration, energy of emergent ion beam, effect of relativity, magnetic and electrostatic focusing, radio-frequency dee-voltage supply, ion source, and some applications.

M-10 Mann, W. B., The Cyclotron, 4th Ed., Wiley, New York, 1953.

The following chapters comprise this book: introduction; magnetic resonance acceleration; cyclotron vacuum chamber and magnet; high-frequency supply and ion source; electrostatic and magnetic focusing; the adjustment of the cyclotron; application of the cyclotron; and epilogue, 1953.

M-11 Martin, J. A., "Radioisotopes Production in the ORNL 86-Inch Cyclotron," Phys. Rev. 91, 224 (1953).

A proton current in excess of one milliampere at an energy of 22 Mev is available on internal targets in the ORNL 86-Inch Cyclotron. Currents of this magnitude and at this energy make possible the relatively large-scale production of a number of radioisotopes which cannot be produced in nuclear reactors. The yields for several radioisotopes are given.

M-12 Mates, J., Magnet Report, Report TID-5118 (1953).

Model-magnet studies for Carnegie Institute of Technology synchro-cyclotron are described, together with results of measurements made on full-scale magnet. Full-scale field shape duplicated that of model prototype very closely.

M-13 Mather, R. L., Cerenkov Radiation from Protons, Report AECU-451 (UCRL-409) (1949).

Cerenkov radiation was observed for the first time from 345-Mev protons in the deflected beam of the 184-in. cyclotron. Two types of medium were used: extra dense flint glass, and amorphous silver chloride. The directional character of the radiation was verified as well as its dependence on proton energy.

M-14 Miller, J. F., J. G. Hamilton, T. M. Purnam, H. R. Haymond, and G. B. Rossi, "Acceleration of Stripped C^{12} and C^{13} Nuclei in the Cyclotron," Phys. Rev. 80, 486 (1950).

A program to increase intensities of accelerated heavy ions was under way at Crocker Laboratory using 60-in. cyclotron. This program included attempts to accelerate B^{10}, B^{11}, C^{12}, C^{13}, N^{14}, O^{16}, O^{17}, O^{18}, and F^{19}. To date, detectable intensities of completely stripped C^{12} and C^{13} ions have been observed. A hooded capillary ion source gave best results. Maximum intensity of external deflected beam of C^{12} ions obtained to date is of order of 10^5 C^{12} nuclei per second, and 10^4 C^{13} nuclei.

M-15 Miller, J. F., "Stars Produced in Nuclear Emulsions by Carbon Ions from the Cyclotron," Phys. Rev. 83, 1261-2 (1951).

Nuclear emulsions were exposed to carbon ions accelerated in the 60-in. cyclotron at the Crocker Laboratory. Early results on observation of inelastic nuclear events with atoms of the emulsions are reported.

M-16 Mills, C. B., and C. F. Barnett, "High-Intensity Ion Source," Rev. Sci. Instr. 25, 1200-2 (1954).

An ion source that does not require a filament was developed for use in the cyclotron. Positive ions, from an oscillatory region within a hollow anode, bombard the cathodes at both ends and maintain them at emission temperatures. The source aperture is a lateral slit, 3/32 in. x 2-1/4 in., in the wall of the anode.

M-17 Moak, C. D., H. Reese, Jr., and W. M. Good, "Design and Operation of Radio-Frequency Ion Source for Particle Accelerators," Nucleonics 9, 18-23 (1951).

R-f excitation is used to produce intense atomic hydrogen discharge in a Pyrex vessel. An extraction potential of 0-5 kev is applied to tungsten anode set in a short capillary at top of tube, and ion beam emerges through 1/16-in. canal in aluminum cathode. Under typical conditions the source gave 1.15 ma of H^+, 0.08 ma of H^+2, and 0.02 ma of H^+3, with a gas consumption of 6 cc/hr (at atmospheric pressure). Source can be operated 30 hr without attention.

M-18 Moore, M. J., "The 156-Inch Cyclotron at Liverpool," Nature 175, 1012 (1955).

The frequency-modulated cyclotron and building are described. The 156-in. magnet of the cyclotron has a maximum gap of 15.5 in. near center and minimum of 11.5 in. at edge. It is designed for a proton energy of 410 Mev. The modulation frequency is 110 c/sec. With a circulating beam of 1 μa an extracted beam of 383-Mev protons is available. Neutrons having energies from 200 to 400 Mev are produced. Provision is made for the extraction of pion beams of 150 Mev and 96 Mev.

M-19 Moyer, B. J., R. Hildebrand, N. Knable, T. J. Parmley, and H. York, "Character of Radiation Field and Shielding at 184-Inch Cyclotron," Phys. Rev. 72, 744-5 (1947).

Absorption experiments with ionization chamber detection with various absorbing materials in fast neutron beam show transition effects followed by approximately exponential reduction in ionization with increasing absorber thickness.

M-20 Murray, R. L., and L. T. Ratner, "Electric Fields within Cyclotron Dees," J. Appl. Phys. 24, 67-9 (1953).

Formulas for the electric field strength parallel to and perpendicular to the magnetic field are derived for idealized cyclotron dee system by use of Schwarz-Christoffel transformation.

N-1 Nahmias, M. E., Le Cyclotron, Theorique et Instrumentale, Paris, 1945.

The book is devoted to a discussion of the design details and the uses of the cyclotron. Other high voltage devices are discussed briefly for the sake of comparison.

N-2 Nature 169, 476-7 (1952), "The University of Birmingham Cyclotron."

The design is based largely on the 60-in. UCRL machine with adjustments to accelerate deuterons to 20 Mev. An external beam was obtained July 1950. The operating frequency at time of article was 10-24 Mc/sec; peak voltage between dees is 150 kev.

O-1 Oliphant, M. L., "The Cyclosynchrotron. Acceleration of Heavy Particles to Energies above 1,000 Mev and Homopolar Generator as a Source of Very Large Current Pulses," Nature 165, 466-8 (1950).

The model is to be installed at Australian National University. Pole diameter is 136 in. with 14-in. gap, magnetic field $\sim$ 15,000 gauss, and produces protons with energy of 200 Mev in final orbit 150 cm in radius. The machine is valuable for studies in energy-region up to 200 Mev; operation is described.

P-1 Panofsky, W. K. H., and E. A. Martinelli, "Magnetic Deflector for Mesons Produced in the 184-Inch Cyclotron," Rev. Sci. Instr. 20, 286-8 (1949).

Mesons artificially produced in 184-in. cyclotron by α-particle bombardment are available outside cyclotron tank. Deflector consists of magnetic shield especially designed to operate in very high external magnetic fields. The total meson flux is $\sim$500 mesons/min.

P-2 Panofsky, W. K. H., and W. R. Baker, "A Focusing Device for the External 350-Mev Proton Beam of the 184-Inch Cyclotron at Berkeley," Rev. Sci. Instr. 21, 445-7 (1950).

The device consists of a cylindrical tube 4 ft in length and 3 in. in diameter, and contains longitudinal arc of nearly uniform current density. It will focus any beam of cylindrical symmetry. Because of large power requirements, the device is applicable to only very short pulsed beams.

P-3 Parkins, W. E., and E. C. Crittenden, Jr., "A Graphical Method for Determining Particle Trajectories," J. Appl. Phys. 17, 447-9 (1946).

A graphical ray tracing scheme, which gives improved accuracy for tracing particle orbits of the type encountered in cyclotron, betatron, and synchrotron, is described. The motion of the particle deduced from motion of a working point is related to instantaneous center of curvature of particle orbit.

P-4 Perry, T., "A Cyclotron Magnet-Current Stabilizer," Phys. Rev. 53, 943 (1938).

A circuit developed at the University of Rochester utilizes commercial radio receiving tubes for maintaining the constancy of the cyclotron magnet current within 0.02%. It is essentially a two-stage direct coupled amplifier.

P-5 Pickavance, T. G., J. B. Adams, and M. Snowden, "The Harwell Cyclotron," Nature 165, 90-1 (1950).

This f-m type cyclotron has been operated since December 1949; it produces 180-Mev protons. The magnet has straight-sided poles, 110 in. in diameter, 12 in. apart. Yoke and poles are built of 670 tons of low-carbon steel in 10-ton plates. The 70-ton windings are copper strip, oil-cooled, and use 355 kw for a center field 16,500 gauss. It is operated with peak "dee" potential $\sim$5.5 kv and average acceleration per traversal $\sim$3 kv.

P-6 Pickavance, T. G., "Cyclotrons," Prog. in Nuc. Phys., 1-20 (1950).

In a review for non-specialists the conventional cyclotron is briefly explained, but most of the article is devoted to the f-m cyclotron. Practical considerations of magnet, magnetic pole design, r-f system, vacuum system, ion source, extraction of beam, and shielding are given.

P-7 Pollard, E., "Regulated Filament Emission for Cyclotron," Rev. Sci. Instr. 12, 37 (1941).

A filament regulator circuit for the Yale cyclotron is described. The emission current can be kept quite steady, and it is easily possible to hold the cyclotron beam free from fluctuations greater than 2% while a count of protons is being taken.

P-8 Pote, A. J., "Radio Frequency for a Synchrocyclotron," Electronics 24, 100-5 (1951).

General problems of design and construction of oscillators and modulators for synchrocyclotrons are described.

P-9 Powell, W. M., L. R. Henrich, Q. A. Kerns, D. C. Sewell, and R. L. Thornton, "Electromagnetic Deflector for the Beam of the 184-Inch Cyclotron," Rev. Sci. Instr. 19, 506-12 (1948).

A pulsed electric deflector was designed that would produce additional radial oscillation,up to 7 cm, in ion orbits.

P-10 Powell, W. M., A 22-Inch Wilson Cloud Chamber in a Magnetic Field of 21,700 Gauss, Report AECU-431 (1949).

The large cloud chamber is described. The magnet is pulsed in synchronism with the 184-in. Berkeley cyclotron and can be operated with a steady field of 10,000 gauss. Protons, α-particles, and deuterons can be distinguished with little ambiguity near the end of their range.

P-11 Purcell, E. M., "Automatic Tuning for the Cyclotron," Phys. Rev. 57, 1070 (1940).

The Harvard cyclotron was equipped with a device which automatically maintains maximum beam current. A brief description is given.

P-12 Pyle, R. V., "An Electron Model Phase-Compensated C-W Cyclotron," Report UCRL-2344 (Rev) (March 1955).

A 33-in. diameter f-f test cyclotron was constructed to test the phase-compensation principle proposed by Thomas; clover-leaf pole pieces produced a three-fold azimuthally varying magnetic field. With a peak potential of 59 volts on the three-dee system, electrons were accelerated to $v/c = 0.46$; the frequency was 61 Mc/sec. Experimental results were promising enough to justify construction of a second and somewhat larger machine, described below by the same author.

P-13 Pyle, R. V., The Second Electron Model Phase-Compensated C-W Cyclotron, Report UCRL-2435 (Rev) (March 1955).

A 40.5-in. diameter f-f cyclotron was built in which electrons were accelerated to $v/c = 0.51$. Azimuthal variations in the magnetic field (suggested by Thomas) make the periods of revolution the same in all stable orbits, and provide suitable axial and radial focusing properties. The phase-compensating field contained three "hills" and three "valleys". The three-electrode r-f accelerating system operated at 54.1 Mc/sec. The threshold voltage was 23 volts; by extrapolation, it would be less than 100 kv for a 300-Mev deuteron machine.

R-1 Reid, A. F., "Internal Cyclotron Targets," Rev. Sci. Inst. 18, 501-3 (1947).

Preparation of cyclotron targets to be used within the dee enclosure for production of radio elements is discussed from both theoretical and application angles. Both general and quantitative considerations are advanced in target design.

R-2 Reilley, E. M., and R. L. Ely, Precision Scattering Project; Equipment Design, Report NP-1537 (1950).

The Precision Scattering Program is designed to make use of the cyclotron beam for precision scattering measurements of nuclear particles in the medium energy range from 10 to 30 Mev. The general method is outlined, and the design of the more pertinent equipment is shown.

R-3 Relf, K. E., The Radio-Frequency System of the 60-Inch Cyclotron at Berkeley, Report BP-42, 3rd Ed. (1950).

The detailed description of the r-f system given includes oscillator tube and circuit, electrical behavior of dee circuits, characteristic curves of oscillator tube, metering circuits, and booster oscillator.

R-4 Reynolds, H. L., and A. Zucker, "Excitation Function for Nitrogen-Induced Nuclear Reactions in Carbon," Phys. Rev. 96, 1615-20 (1954).

Excitation functions for reactions $C^{12}(N^{14}, 2p)Na^{24}$, $C^{12}(N^{14}, \alpha)Na^{22}$, and $C^{12}(N^{14}, 2\alpha)F^{18}$ were measured with external 20-Mev nitrogen beam of 63-in. cyclotron. Thick-target yields as function of energy were differentiated to obtain absolute cross sections from 16 to 29 Mev. Similarity to excitation functions for reactions produced by protons on Mg^{25} is suggested.

R-5 Richardson, J. R., K. R. MacKenzie, E. J. Lofgren, and B. T. Wright, "Frequency-Modulated Cyclotron," Phys. Rev. 69, 669-70 (1946).

Application of synchrotron phase stability principle to f-m cyclotron is investigated experimentally on the 37-in. Berkeley cyclotron. (probably first reported test of f-m principle.)

R-6 Richardson, J. R., B. T. Wright, E. J. Lofgren, and B. Peters, "Development of the Frequency-Modulated Cyclotron," Phys. Rev. 73, 424-36 (1948).

Experimental development of phase stability principle as applied to 37-in. f-m cyclotron is discussed. Ions were required to pass through an over-all radial decrease in magnetic field of 13%. Some theoretical estimates of yield vs modulation frequency are given; these were found to be in satisfactory agreement with experimental results. It was found that some of ions emerge as late as four or five modulation cycles after their initial acceleration.

R-7 Riddiford, L., "An Air-Cored Synchrocyclotron for 400-Mev Protons," Proc. Phys. Soc. (London)B, 64, 218 (1951).

An investigation of energies available was based on the limit set by mechanical forces exerted on coil. Power requirements are comparable with those of large iron-cored accelerators at present under construction. In machine with useful orbit of radius 11.8 cm, it is possible to provide a field of 2.7×10^5 gauss over circle enclosed by that orbit, so protons can be accelerated to an energy of 400 Mev.

R-8 Rose, M. E., "Focusing and Maximum Energy of Ions in the Cyclotron," Phys. Rev. 53, 392-408 (1938).

The effect of inhomogeneities of electric and magnetic fields on motion of ions in cyclotron was investigated. It is shown that both fields exert focusing action on ions, electric focusing predominating over first part of path and magnetic focusing over remaining part. Magnetic fields are described which give greatest energy with measurable beam intensities. Main feature is that they are greater than field required for exact resonance near center, and become smaller than resonance field near exit slit.

R-9 Rose, M. E., "Magnetic Field Corrections in the Cyclotron," Phys. Rev. 53, 715-9 (1938).

It is pointed out that in order to obtain magnetic fields which will allow the ions in the cyclotron to attain high energies it is first necessary to render the field homogeneous within an accuracy of about 1 part in 1000. The corrections (insertions of "shims") for the most important source of inhomogeneity - namely, the decrease in field near the edge of pole pieces, is considered. A general method is given for determining dimensions for any shape of these shims. Results are given for dimensions of shims in form of a ring of rectangular cross section placed at the edge of cyclotron chamber.

R-10 Rose, M. E., On Electric Focusing in the Fixed-Frequency Cyclotron, Report ORNL-849 (1950).

The theory of electric focusing in the f-f cyclotron is discussed quite completely. The report presents an alternative method of obtaining the orbit equation in which the nature of the approximations is brought out more clearly.

R-11 Rossi, G. B., W. B. Jones, J. M. Hollander, and J. G. Hamilton, "The Acceleration of Nitrogen-14 (+6) Ions in a 60-Inch Cyclotron," Phys. Rev. 93, 256-7 (1954).

Techniques are described for accelerating $C^{12}(+6)$ ions by changing ion source gas from CO_2 to N_2 and increasing the magnetic field. To verify existence of these high-energy nitrogen ions in the 60-in. cyclotron, several experiments were performed in which isotopes of elements with atomic number Z +7 were produced and isolated by chemical procedures.

R-12 Rotblat, J., "The Cyclotron," in The Acceleration of Particles to High Energies, H. R. Lang, ed., Institute of Physics, London, 1950.

The book is composed of papers presented at The Institute of Physics 1949 Convention. In the first chapter recent developments of the fixed-frequency and frequency-modulated cyclotrons are discussed by J. Rotblat.

R-13 Rukavichnikov, V. N., "The First USSR Cyclotron," Phys. Rev. 52, 1077 (1937).

The initial operation of the cyclotron of the State Radium Institute is described; beams of protons (0.5-2.1 Mev) and of hydrogen ions (0.1-1.0 Mev) were obtained. The chamber's internal diameter is 60 cm, proton exit radius is 25.6 cm. In the first experiments it appeared that the chamber had an accessory ion source besides that of glowing filaments. This pheonomenon is attributed to hydrogen ionization by the high frequency at maximum voltages, approximately equal to those required for a glow discharge. Other features of this cyclotron are discussed.

S-1 Sachs, D. C., and J. R. Richardson, "The Absolute Energy Loss of 18-Mev Protons in Various Materials," Phys. Rev. 83, 834-7 (1951).

The absolute energy loss of 17.77 ± 0.03-Mev protons passing through various materials was measured with the UCLA 41-Inch F-M Cyclotron. A ribbon foil of thorium, mounted inside the dee, was used to deflect the circulating proton beam above the median plane of cyclotron magnetic field. Some information was obtained concerning the corrections to be applied to the stopping-power formula.

S-2 Salisbury, W. W., Accelerators for Heavy Particles, McGraw-Hill, New York, 1947.

This survey article traces briefly the development of heavy particle accelerators from Goldstein's canal-ray apparatus to the early discussion of the principle of the proton synchrotron. Some details are given on the early development of the cyclotron.

S-3 Savel, P., "Use of the Cyclotron at the College de France," J. Phys. Radium 6, 121-5 (1945).

The cyclotron was used only for the acceleration of deuterons to energies up to 7 Mev. Beryllium or lithium targets were used for neutron production, other target materials were irradiated directly. Data are given as to the neutron distribution outside the cyclotron, the optimum thickness of paraffin for greatest intensity of slow neutrons, and the radium equivalent of the instrument.

S-4 Schiff, L. I., "On the Paths of Ions in the Cyclotron," Phys. Rev. 54, 1114-5 (1938).

Thomas has shown that a variation of the magnetic field of a cyclotron with polar angle, together with a radial increase in the field, can produce a focusing effect on the beam while maintaining resonance. For polar angle variations of period 2π or π, the orbits are unstable, while for $\pi/2$ they are stable. The calculations were extended to polar angle variations of period $2\pi/3$; orbits in such a field are stable. The results for the most interesting cases of period $2\pi/3$ and $\pi/2$ are compared.

S-5 Schmidt, F. H., "Mechanical Frequency-Modulation System as Applied to the Cyclotron," Rev. Sci. Instr. 17, 301-6 (1946).

A high speed variable capacitor operating in a vacuum is described. The capacitor is coupled to the cyclotron dee by means of a transmission line whose length is such that the voltage node occurs nears its center. The frequency change obtained is greater than 13%.

S-6 Schmidt, F. H., and M. J. Jakobson, "Cyclotron Oscillators and the Shifting Inter-Dee Ground Surface," Rev. Sci. Instr. 25, 136-9 (1954).

It is shown that the push-pull mode of oscillation of a conventional two-dee cyclotron can be described in terms of a ground-potential surface between the dees. Unbalance in dee voltages arising from changes in capacitance or inductance of one dee system can be interpreted as a shift of position of the ground surface. The predictions of the theory were checked experimentally. The effects on a self-excited type of cyclotron oscillator are discussed.

S-7 Schmidt, F. H., G. W. Farwell, J. E. Henderson, T. J. Morgan, and J. F. Streib, "The University of Washington 60-Inch Cyclotron," Rev. Sci. Instr. 25, 499-509 (1954).

The new 60-inch f-f cyclotron is described, and its principal mechanical features are listed. An account is given of major troubles encountered and steps taken to achieve satisfactory operation. The cyclotron produces external beams of 125 to 200 μa at a nominal deuteron energy of 21 Mev with an oscillator power output of 100-125 kw.

S-8 Schmitz, W., and W. Wiebe, "The Bonn Cyclotron," Z Tech Phys, 24, 195-206 (1943).

The University of Bonn f-f cyclotron is described; problems encountered in its construction and operation are enumerated.

S-9 Schrank, G., "Energy Control for External Cyclotron Beams," Rev. Sci. Instr. 26, 677-80 (1955).

A device is described which stabilizes the mean energy of the external beam of the Princeton f-m cyclotron to better than 0.1%. This control is achieved by inspecting the end of the range of a sample of scattered particles; the signal produced by protons passing through a variable absorber is used to regulate the cyclotron magnet current. The device is also used to measure the mean energy to within 0.3%.

S-10 Schulke, A. A., and R. E. Nuelle, "Note on Removing the Deuteron-Induced Color from Quartz Target Plates," Rev. Sci. Instr. 20, 623-4 (1949).

A method is described for restoring quartz plates, which had been used as a visual aid in alignment of various cyclotron assemblies, to their original transparent state. Heating experiments were conducted, and it was found that at 280°F a fluorescence was observed accompanied by an increase in transparency; at 600-700°F the plates become perfectly clear.

S-11 Schwarz, W. M., "A Voltage Stabilizer for a Direct-Current Generator," Rev. Sci. Instr. 13, 213-4 (1942).

A simple stabilizer is described, which stabilizers the voltage across a cyclotron magnet to within 1 part in 2000. It acts as a variable resistance in parallel with the generator field, which remains shunt connected to the armature.

S-12 Sewell, D. C., L. Henrich, and J. Vale, "Some Operating Phenomena Associated with 184-Inch Cyclotron," Phys. Rev. 72, 739 (1947).

Two experiments are described: radio autographs of special probes were used to explain the disappearance of the beam at the 82-in. radius, and a synchroscope was used to examine the time structure of the beam current to the probe.

S-13 Shewchuck, S., Bibliography of Particle Accelerators, January to Dec. 1951, Report UCRL-1951 (1952).

This bibliography is a supplement to previous reports BNL-L-101 and UCRL-1238. It includes information on all types of accelerators. In addition, a complete list of accelerators both in the United States and outside the United States is given.

S-14 Shoemaker, F. C., R. J. Britten, and B. C. Carlson, "A New Method for Focusing Ion Beams," Phys. Rev. 86, 582 (1952).

An arrangement of small magnetic lenses was developed for obtaining double focusing of high energy ion beams without the expense of a magnet sufficiently powerful to produce large-angle deflections. This arrangement was applied to the focusing of the 18.5-Mev external proton beam from the Princeton cyclotron. Two 400-lb magnetic lenses, (400 w each) focus 25% of the internal deflected beam on a 3/8-in. spot 15 ft from the cyclotron.

S-15 Shull, F. B., C. E. MacFarland, and M. M. Bretscher, "Concentration of a Cyclotron Beam by Strong Focusing Lenses," Rev. Sci. Instr. 25, 364-7 (1954).

A pair of strong focusing magnetic lenses is used to concentrate a part of the external beam from the Washington University cyclotron. The lenses focus the beam at distances up to more than four meters beyond the cyclotron. This system produces approximately an eightfold improvement in beam intensity.

S-16 Siegel, B. V., and R. C. Sinott, "The El Cerrito Cyclotron," Phys. Today 1, 10-13 (Aug. 1948).

The construction and performance of a 6-in. cyclotron with a peak output of 2000 w are described. The cyclotron was built at the El Cerrito High School.

S-17 Sloan, D. H., and E. O. Lawrence, "The Production of Heavy High Speed Ions without the Use of High Voltage," Phys. Rev. 38, 2021-32 (1931).

A method is described for the multiple acceleration of ions to high speeds without the use of high voltage. The present experiments show that ions having kinetic energies in excess of 1 Mev can be produced with modest laboratory equipment, and that the production of 10 Mev ions is an entirely practicable matter.

S-18 Smith, A. W., and M. L. Pool, "The Ohio State University Cyclotron," Phys. Rev. 57, 347 (1940).

The 42-in. f-f cyclotron under construction is briefly described. The salient features discussed include the magnet frame, glass-insulated and water-cooled magnet coils, vacuum chamber and system, r-f oscillator system, and the quarter wave-length transmission line.

S-19 Smith, B. H., A 90-Inch Cyclotron with an Adjustable-Energy External Beam, Report UCRL-2620 (1954).

This cyclotron under construction at Livermore is intended to produce a large external beam which can be tuned through the following ranges: protons - 4 to 15 Mev, deuterons - 4 to 12.5 Mev, and tritons - 7.5 to 8.5 Mev. The report is a survey of the design of the dee and resonator, magnet, electronic equipment, and plant layout.

S-20 Smith, B. H., "36-Inch Cyclotron Phase Servo-Control System," Report UCRL-1484 (Rev) (March 1955).

A servo-control system was developed to provide automatic control of the phase relationship of the three dees in the three-phase r-f system used in the electron model phase-compensated f-f cyclotron described elsewhere by R. Pyle. The control system is described, with details of circuitry.

S-21 Smith, B. H., "The Clover-Leaf Three-Phase Radiofrequency System," Report UCRL-1884 (Rev) (March 1955).

A three-dee r-f system was designed with the dees fitting in the valleys produced by the clover-leaf shims of the 20-in. cyclotron described elsewhere by Heusinkveld et al. The design and performance of the r-f system are described.

S-22 Spear, F. G., "Medical Uses of the Cyclotron," J. Sci. Instr. 22, 21-7 (1945).

The direct application of a cyclotron as a neutron generator and its use for preparing artificial substances are discussed.

S-23 Stubbins, W. F., An Ion Source for the 184-Inch Synchrocyclotron, Report UCRL-2078 (1953).

Performance of the ion source was analyzed on a differential analyzer with which electrolytic-tank measurements were used to obtain electric-field inputs. Protons can be accelerated from the source into orbits having small radial oscillations by using the close spacings proposed and 20 kv applied to the dee. The source is suitable for heavier particles.

S-24 Stubbins, W. F., "Beam Escape from Synchrocyclotrons," Phys. Rev. 96, 856 (1954).

A study of the large synchrocyclotrons reveals that only in three is a small part (from 0.5 to 10%) of the circulating beam accelerated to the limit of radial stability and then spiraled out of the cyclotron. The analysis of the conditions at the end of the acceleration cycle shows the following requirements for particles to escape: (a) a rapid rate of expansion of the synchronous orbit, (b) a small first harmonic in azimuthal variation of the magnetic field at the outer radii, and (c) a small amplitude of radial oscillation about the synchronous orbit.

S-25 Stubbins, W. F., An Experimental Ion Source for the 184-Inch Cyclotron, Report UCRL-2698 (1955).

A PIG-type ion source was mounted in the center of the 184-in. cyclotron with extension lips placed on dees to reduce dee gap and aperture in the source region according to calculated requirements. The operation of source and the nature of cyclotron beam were observed for various conditions of dee voltage, dee bias, source position, and time sequence of ion injection.

S-26 Sturm, W. J., and R. J. Jones, "Application of Thermocouples to Target Temperature Measurement in the Internal Beam of a Cyclotron," Rev. Sci. Instr. 25, 392 (1954).

The calibration of chromel-alumel thermocouples used under the unusual conditions encountered in internal targets in a cyclotron was checked against the melting points of pure samples of lead, aluminum, and silver exposed to the 22-Mev proton beam of the ORNL 86-Inch Cyclotron. In each case the apparent melting point was within ± 3.7°C of accepted value which was well within accuracy of equipment used.

S-27 Symon, K. R., "Fixed-Field Alternating-Gradient Accelerators," Phys. Rev. 98, 1152-3 (1955).

Alternating-gradient focusing makes it possible to design fixed-field cyclotrons having almost any desired radial dependence of energy. A static magnetic field distribution in which stable proton orbits between 0.5 Mev and 20 bev will all lie inside a single doughnut of 1-meter radial aperture can be constructed. In the simplest designs, with some reverse field sectors, the over-all orbit radius is greater by a factor of 3 to 5 than for the conventional alternating-gradient synchrotron.

T-1 Tape, G. F., University of Illinois Cyclotron Oscillator, Report NP-1582 (1950).

The design, construction, and operation of the tuned-plate, tuned-grid r-f power oscillator are described. The grounded-grid oscillator, tried with the cyclotron in 1947, was found unsuccessful due to ion loading in vacuum chamber. Circuit diagrams and drawings are included.

T-2 Teichmann, T., "Beam Oscillation in F-M Cyclotron," J. Appl. Phys. 21, 1251-7 (1950).

A study was made of radial and axial oscillations of synchrocyclotron beam. Conditions for various oscillations and their behavior are discussed.

T-3 Thomas, E., P. Mittelman, and H. H. Goldsmith, Particle Accelerators. Bibliography and List of High Energy Installations, Report BNL-L-101 (July 1948).

This bibliography, covering the period 1930 through June 1948, is divided into the following sections: general, betatron, cyclotron, electrostatic accelerator, proton synchrotron, synchrotron, ion sources and miscellaneous. Accelerators in all parts of the world are listed.

T-4 Thomas, L. H., "The Paths of Ions in the Cyclotron, I. Orbits in the Magnetic Field. II. Paths in the Combined Electric and Magnetic Fields," Phys. Rev. 54, 580-98 (1938).

It is shown that the energy limitation, imposed by the relativistic mass increase, holds for a radially symmetrical magnetic field, but it is not necessarily true in general. For a field varying with polar angle there is an additional focusing effect. If relative variation of field with polar angle is of the order of ratio of velocity of ion to velocity of light, this focusing effect will compensate the defocusing effect of a radially decreasing magnetic field.

T-5 Thornton, R. L., "Recent Experiments with the 184-Inch Cyclotron," Science 106, 508-9 (1947).

This cyclotron had been in operation for about a year at time of publication of this article. It produced deuteron and alpha-particle beams of 190 and 300 Mev, respectively.

T-6 Timoshenko, G., "Characteristics of a Strong Ion Source," Rev. Sci. Instr. 9, 187-94 (1938).

The construction and operating characteristics of an ion source of capillary-arc type are described.

T-7 Tobias, C., and E. Segre, "High Energy Carbon Nuclei," Phys. Rev. 70, 89 (1946).

Early experiments in heavy particle acceleration are described.

T-8 Tuck, J. L., and L. C. Teng, "Regenerative Deflector for Synchrocyclotron," Phys. Rev. 81, 305 (1951).

The deflection of a synchrocyclotron beam can be obtained through the increasing radial oscillation induced by repeated passage through a locally increased magnetic field at one point on the stable orbit and a similarly reduced field at another. Azimuthal separation between these two pertubations is made about 90 deg. Graphical plotting shows that by suitably shaping field pertubations, separation between consecutive orbits can reach about 1.5 in. after $\sim$25 revolutions for a 45-Mev proton beam at 76 in. stable radius, while at the same time the growth of the vertical oscillation can be suppressed.

T-9 Tyren, H., and P. A. Tove, "Short-Lived Radio-Nuclides Produced by a Synchrocyclotron," Phys. Rev. 96, 773-4 (1954).

A method of studying short-lived radio-nuclides produced by the internal beam in a synchrocyclotron is described. Preliminary results on a number of proton-produced activities in the mass range below 70 are given.

U-1 University of California Radiation Laboratory, Index to Information Available on the 60-Inch Crocker Cyclotron, Report UCRL-1651 Rev. (July 1954).

U-2 University of Washington, University of Washington 60-Inch Cyclotron, Progress and Status Report of Design and Construction, Report AECU-1951 (June 1951).

The cyclotron is reported to be assembled and ready for initial testing. Photographs illustrating steps in construction are included.

V-1 Veksler, V., "A New Method for Acceleration of Relativistic Particles," Acad. Sci. USSR, Compt. rend. 43, 329-31 (1944).

It is believed that the method of resonance acceleration carried into effect by Lawrence for heavy particles (cyclotron) cannot be used for acceleration of electrons, because mass of particles is relativistically variable with velocity. A new possibility, based upon simple generalization of resonance method, is pointed out. Very fast relativistic particles can be obtained by this method if the simplest case, where a charge relativistic particle is moving in resonance accelerator, is considered. In physical terms this will mean that after every acceleration the time of travel of particle along circumference increases just by value of period. Acceleration is obtained by applying constant magnetic field. (This is the first proposal of frequency modulation.)

V-2 Veksler, V., "On a New Method of Acceleration of Relativistic Particles," Acad. Sci. USSR, Compt. rend. 44, 365-8 (1944).

This paper attempts to prove that, due to automatic phasing, resonance acceleration is possible not only in constant magnetic field, but also in those in which intensity increases with time. Advantage of resonance accelerator over solenoidal is that the effect of radiation (due to motion of particle in magnetic field) on acceleration does not exist in former; another advantage is that magnet can be constructed in form of thin ring, which is a very profitable feature. As magnetic field increases, any deviation of period of revolution from resonance period decreases.

V-3 Veksler, V., "A New Method of Acceleration of Relativistic Particles," J. Phys.(USSR) 9, 153-8 (1945).

It is shown that by application of resonance method, acceleration of relativistic particles can be effected in two different ways - by method of multiple resonance in constant magnetic field, and by method of adiabatic variation of parameters of accelerator. In accelerators with constant magnetic field, stability of acceleration process can easily be attained. It is proved that in method of adiabatic variation, acceleration of particles is possible for any law of variation of magnetic field (or frequency). It is established that in an adiabatic accelerator, electromagnetic radiation does not violate stability and, therefore, very high energies can be attained, in principle, in this type of accelerator.

V-4 Veksler, V., "Concerning Some New Methods of Acceleration of Relativistic Particles," Phys. Rev. 69, 244 (1946).

In two papers appearing in 1944 under the above title, the author of this letter pointed out two new principles of acceleration of relativistic particles which generalize the resonance method. New possibilities for resonance acceleration of particles in a constant magnetic field are described in the first of these papers, and possibility of resonance acceleration in magnetic fields which increase with time is also noted. This latter case is specially examined in the second paper. It is shown that phase stability automatically sets in if time variation of field is sufficiently small; relation between amplitude of variable electric fields and rate of variation of magnetic field is established.

V-5 Von Dardel, G., E. Hellstrand, and C. Taylor, "Two Systems for Synchronization of Pulsed High-Energy Ion Beams," Appl. Sci. Research B, 3, 35-46 (1952).

Two links are described, one using r-f system at 450 Mc/sec and the other using a pulsed beam of light. Both systems provide control over pulse width as well as pulse spacing. The r-f system transmits pulses to 1 microsecond. The optical system transmits pulses down to 4 μsec.

W-1 Walker, D., and J. H. Fremlin, "Acceleration of Heavy Ions to High Energies," Nature 171, 189-91 (1953).

Pioneering work at Berkeley on the acceleration of ions heavier than ^{4}He was reported by Alvarez in 1940. The f-f cyclotron was used, with methane filling the cyclotron chamber. Recently, Chou and others, using the Chicago 170-inch f-m cyclotron, accelerated carbon ions to energies as hgih as 1,100 Mev. They mentioned acceleration of $^{12}C^{5+}$ ions as well as completely stripped carbon ions, and also accelerated $^{9}Be^{4+}$ ions. A recent study was made of heavy ion resonances over a wide range of magnetic fields with the 60-inch f-f cyclotron at Berkeley. Resonances due to the following ions, listed in order of increasing mass-to-charge ratio, were studied: $^{13}C^{6+}$, $^{20}Ne^{9+}$, $^{9}Be^{4+}$, $^{14}N^{6+}$, $^{12}C^{5+}$, $^{15}N^{6+}$, $^{13}C^{5+}$, and $^{16}O^{6+}$.

W-2 Walker, D., J. H. Fremlin, W. T. Link, and K. G. Stephens, "The Acceleration of Heavy Ions in a Fixed-Frequency Cyclotron," Brit. J. Appl. Phys. 5, 157-64 (1954).

The following ions were accelerated in the Berkeley 60-inch cyclotron: $^{9}Be^{4+}$, $^{12}C^{5+}$, $^{13}C^{5+}$, $^{13}C^{6+}$, $^{14}N^{6+}$, $^{15}N^{6+}$, $^{16}O^{6+}$, and $^{20}Ne^{9+}$. Ions originating in the ion source appear to be stripped by collisions with tank gases and then accelerated on the "third harmonic". The beam current of high energy ions can be increased by increasing the pressure of gas in cyclotron tank to increase the probability of stripping.

W-3 Wall, N. S., and J. W. Irvine, Jr., "Preparation of Unusual Targets for Cyclotron Studies," Rev. Sci. Instr. 24, 1146-7 (1953).

For the study of (d,p) reactions on elements which are not readily available as thin foils, a technique was developed for preparing thin self-supporting samples containing the desired element. The technique yields a polystyrene film containing the element to be studied in a finely divided state.

W-4 Wall, T. F., "The Cyclotron," Elec. Rev. 123, 45-46 (July 1938).

A brief description of the principle of operation and the construction features is given.

W-5 Wall, T. F., "Cyclotron," Engineering 156, 201-3, 223-5 (1943).

This is a discussion of the principles and application of the cyclotron, and its early development.

W-6 Watts, R. J., "Millimicroampere Current Integrator for a Cyclotron," Rev. Sci. Instr. 22, 356-9 (1951).

A low-current integrator that successfully avoids the problem of current leakage by the use of electrometer tubes is described. An electronic master switch is used to operate the charging cycle of integrator.

W-7 Watzlawek, H., "The Cyclotron," Elektrotechn. Z. 63, 319-26 (1942).

This is a comprehensive review of the development of the cyclotron, based on American, British, and Continental literature. Nomograms are given for the dependence of wave length, frequency, and angular velocity on field strength; and of wave length, energy, and range on the radius of the ion path with various field strengths, for protons, deuterons, and α-particles.

W-8 Weil, A. S., A. F. Reid, and J. R. Dunning, "Metaborate Compounds for Internal Cyclotron Targets," Rev. Sci. Instr. 18, 556-8 (1947).

The use of $NaBO_2$ as target material for preparation of radioactive Na^{24} through deuteron-bombardment reaction is discussed. The general advantages of $NaBO_2$ as target material is compared to metallic sodium or other sodium-containing compounds. Procedure for target preparation and details of chemical treatment used for purification of Na^{24} are given.

W-9 Westcott, C. H., H. I. S. Allwood, J. N. Dodd, D. H. Simmons, and C. J. Baker, "Instrument for Measuring Energies and Angular Distributions of Charged Reaction Products," J. Sci. Instr. 31, 371-4 (1954).

Equipment for studying reactions induced by the external beam of the University of Birmingham f-f cyclotron is discussed. An arrangement of proportional counters with absorbing foils is used for measuring angular and range distribution for protons and other emergent charged particles.

W-10 White, M. G., M. C. Henderson, W. J. Henderson, and L. N. Ridenour, "The Production of High Energy Alpha-Particles by the Princeton Cyclotron," Phys. Rev. 51, 1012-3 (1937).

Doubly charged helium ions were accelerated to 9 Mev at a current of 0.05 μa. The difference between the m/e for helium ions and for hydrogen mass two ions is sufficient to permit almost complete separation of helium beam from possible deuteron contamination.

W-11 White, M. G., H. W. Fulbright, P. Gugelot, and R. R. Bush, "Redesign of the Princeton Cyclotron to Yield 18-Mev Protons," Phys. Rev. 74, 1242-3 (1948).

The 35-in. cyclotron magnet operates at 19,500 gauss with a maximum $H\rho$ of 6.5×10^5 at $n = 0.2$. When redesigned for f-m operation it yielded an average internal current of 1 - 1.5 μa at 18 Mev, with only 10 kev on the single dee.

W-12 White, M. G., Final Report of Nuclear Research Performed at Princeton under the Joint Program of the Office of Naval Research and the Atomic Energy Commission, Report NP-3018.

Reconstruction of the cyclotron, which was destroyed by fire on February 22, 1950, and changes in its design are described briefly. A few illustrations of the cyclotron after the fire and after reconstruction are given. A brief summary of project work is presented.

W-13 Whitmer, R. M., "A Simple Cyclotron Dee Voltmeter," Rev. Sci. Instr. 10, 165 (1939).

A simple diode rectifier arrangment, illustrated and described, was used on the Purdue cyclotron; it proved entirely satisfactory. The only unusual feature is that the tube is mounted in a vertical position only three inches from the chamber wall, in a very strong magnetic field. A similar arrangement was used on the University of Michigan cyclotron.

W-14 Wiebe, W., "The Problem of Focusing in a Cyclotron," Z. Tech. Phys. 122, 451-64 (1944).

Focusing of ion beams in cyclotrons is investigated mathematically. The effects of the r-f voltage and magnetic field are considered. Axial oscillations of ions and the required focusing forces are discussed. The theory is applied in calculating the physical data for an 80-Mev cyclotron.

W-15 Williams, E. M., C. H. Grace, and L. W. Johnson, "Timing Unit and Pulse Deflector Generator for 145-Inch Synchrocyclotron," Proc. I. R. E. 39, 309 (1951).

The 145-in. Carnegie Institute of Technology f-f cyclotron employs an electrostatic beam deflector. Details of the timing circuits, a novel cascade cavity-enclosed hydrogen-thyratron pulser, and test results are described. Factors affecting timing accuracy are discussed in detail.

W-16 Wilson, R. R., and M. D. Kamen, "Internal Targets in the Cyclotron," Phys. Rev. 54, 103-36 (1938).

The large circulating ion current in the cyclotron, which ordinarily does not reach the target chamber, was utilized in the preparation of extremely active samples of radioiron and radiophosphorus. The construction of the probe, nature of circulating current, and the manner in which target material is applied to probe are discussed.

W-17 Wilson, R. R., "Theory of the Cyclotron," J. Appl. Phys. 11, 781-96 (1940).

The processes of formation of initial ions in the cyclotron are reviewed, after which various processes by which ions are lost from resonance are considered. A theory of loss of ions by collision or by electron capture is given and compared with measurements made on variation of high energy beam current with gas pressure; satisfactory agreement is found.

W-18 Wilson, R. R., "Magnetic and Electrostatic Focusing in the Cyclotron," Phys. Rev. 53, 408-20 (1938).

A quantitative study of magnetic and electrostatic focusing of ions accelerated in the cyclotron was made on the basis of the electric and magnetic field measurements. The relative importance of the two effects was found to depend on energy or beam radius. Initially, the electrostatic action is defocusing; then it becomes a focusing action but decreases with energy and, if it were not for the magnetic field effect, would cause particles to oscillate back and forth across central plane with increasing amplitude.

W-19 Wouters, L., General Recommendations for Design of Small Cyclotrons, Report UCRL-476 (1949).

A description of the steps necessary in the design and fabrication of small f-f cyclotrons is given. Magnet design and supply, tank design, the oscillator, and early operational details are discussed, and schematic drawings are given.

W-20 Wright, B. T., and J. R. Richardson, "Frequency-Modulated Cyclotron Characteristics," Phys. Rev. 70, 445-6 (1946).

The dependence of beam current on various operational parameter is compared with theory. Those investigated include the following: modulation frequency, pressure, and dee voltage. Structure of individual beam pulses is mentioned. Some ions start on one modulation cycle and arrive at final radius as many as three modulation cycles later.

W-21 Wyly, L. D., and A. Zucker, "Activities in Light Nuclei from Nitrogen Ion Bombardment," Phys. Rev. 89, 524-5 (1953).

The 63-in. cyclotron was constructed at Oak Ridge National Laboratory to accelerate triply ionized nitrogen ions to energy of $\sim$ 25 Mev. The targets bombarded and activities observed are given. The beam energy, corresponding to the $H\rho$ at the target radius of 24.25 in., is 25 Mev for N^{3+} ions. Target is mounted on a water-cooled brass probe which is inserted into the upper dee. Bombardments are from 2-30 min. Nitrogen was bombarded in form of tantalum nitride, prepared by passing nitrogen over clean tantalum at 1000°C. Upon bombardment, target showed 2-min, 10-min, and 112-min activities.

Y-1 Yockey, H. P., A. Andrew, F. L. Fillmore, L. E. Glasgow, C. Hunt, and J. H. Pepper, "Cyclotron Techniques for Radiation Damage Studies," Rev. Sci. Instr. 25, 1011-9 (1954).

The methods and equipment developed for irradiation of materials under controlled conditions in the 60-in. Berkeley cyclotron are described. Descriptions of the components of equipment for use in the temperature range from -195°C to 2000°C are given. Typical targets are described along with conditions of irradiation. The method of determining spatial distribution of irradiation intensity is also given.

Y-2 York, H., R. Hildebrand, T. Putnam, and J. G. Hamilton, "Acceleration of Stripped Light Nuclei in the Cyclotron," Phys. Rev. 70, 446 (1946).

Stripped light nuclei were accelerated with the 60-in. Berkeley cyclotron for use in nuclear experiments. Two types of sources were investigated: an arc source such as normally used in cyclotrons, and a spark source similar to that used in spectroscopic investigations of highly ionized atoms. Typical yields from an arc source are 1000 $C^{13,+6}$ 146-Mev ions/sec and 100,000 $C^{13,+6}$ 135-Mev ions/sec.

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