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September 1967

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Summary

A novel guide-magnet configuration has been devised that makes possible the acceleration of all charge-to-mass ratios from 0.04 to 1. A concentric storage ring, with the associated beam-switching equipment, allows for the extension of beam duty factor to essentially 100%. The storage ring can also be used in a bootstrap acceleration of heavy ions in which the ions are injected at low e/m, accelerated to a moderate velocity, stored while the accelerating ring returns to minimum field, stripped to maximum e/m, and reinjected for further acceleration. With a pressurized 3.0-MV Cockcroft-Walton injector, the proposed system is capable of accelerating all ions from protons to uranium -- to energies up to 1.5 BeV for protons and 0.3 to 0.5 BeV/nucleon for the heavier ions. Intensities of 10^{12} to 10^{13} nucleons/sec. for the lighter ions ($M \leq 128$) are anticipated. The heavy-ion charge-exchange probabilities determine the vacuum requirements of this system. To minimize

these requirements and to increase beam intensity, a 60 cps cycling rate has been chosen. The vacuum requirements and the special rf resonator and beam-switching problems attendant with the high cycling rate are discussed.

Introduction

The energy range of primary interest for heavy ions used in nuclear chemistry is determined by the excitation required for the formation of compound nuclei, 5 to 7 MeV/nucleon. The principal source of these ions during the past 9 years at Berkeley has been the Heavy Ion Linear Accelerator (Hilac); this accelerator produces a maximum energy of 10 MeV/nucleon. With the completion of presently planned improvements to the Hilac, beams of argon (M=40) adequate for all needs will be available. It is also expected that significant beams of krypton (M=84) can be accelerated.

During the past few years, increased interest has developed in ultra-heavy ions ($M \leq 240$) in this energy range. The principal problem of producing these heavier ions is indicated in Fig. 1, which shows the relative abundance of krypton and xenon ions of various charge-to-mass ratios (ϵ) available from the cold-cathode PIG ion source used at the Hilac. Although extensive development of heavy-ion sources has been carried on over the past 10

years, at the Hilac and by a number of other investigators, significant improvement over this source has not been achieved, either in total current or in the enhancement of the higher charged states. The extremely small currents of ions with relative charge-to-mass ratio $\varepsilon = 0.125$, the minimum ratio for Hilac injection, precludes the possibility of using this accelerator for the production of ultra-heavy ions.

In addition to the nuclear chemistry demand for the extremely heavy ions in the low-energy range, biophysics studies at the Hilac, combined with the highly promising results achieved with medium-energy charged-particle medical therapy, have created a high degree of interest in the use of heavy (M=40) ions in this field. The general requirement for these ions is the ability to produce a precisely controlled dose in a precisely defined region of tissue at depth ranging up to 15 cm. These requirements, when transformed into beam specification, demand a high-quality beam with a continuously variable and precisely controlled energy. The maximum energy is determined as that required to produce a 10 cm range for argon ions, approximately 400 MeV/nucleon.

This latter requirement is particularly difficult for the heavier particles in that their efficient acceleration and containment in a magnet field of reasonable

dimensions demands the use of fully stripped ions. Present techniques (passage of the ions through a thin foil) require argon ion velocities of about 0.15 c (10 MeV/nucleon) for reasonable stripping efficiency. The accelerator system designed to produce these high-energy heavy ions must provide for stripping at an intermediate energy.

The magnetic field capable of containing a fully stripped 400 MeV/nucleon argon ion will also contain a 500 MeV alpha or a 1500 MeV proton. Since these energies fall well within the range of interest for medium-energy physics and light-ion medical physics, we have added as a basic accelerator design requirement modest intensities of these ions.

In addition to the variety of particles and the energies noted, all of the research programs demand a high beam duty factor ($\approx$ 50%), completely variable energy and, in some cases, a high energy resolution. A summary of the minimum requirements of the various research programs is given in Table I.

Table I. Omnitron beam requirements.

	Nuclear chemistry	Biophysics/ Medical	Physics
Mass number	40 - 240	1 - 40	1
Energy range	3 - 10	50 - 400	$\geq$ 1000 MeV/nucleon
Energy resolution	= 0.5%	$\leq$ 0.5%	$\leq$ 0.5%
Intensity	$\geq 10^{11}$	10^{12} M=1 10^{11} M=2 10^{10} M=40	$\geq 5 \times 10^{12}$ particles/sec
Duty factor	$\geq$ 50%	$\geq$ 50%	$\geq$ 50%

In designing an accelerator to satisfy these requirements the following general restrictions should be noted:

(1) Conventional PIG ion sources are capable of removing electrons with ionization potentials up to about 120 V. The injection charge-to-mass ratio in the low-energy section of the accelerator should not be such that any of the ions to be accelerated require charge states where this figure is exceeded. Since the nuclear chemistry groups require the acceleration of elements with mass up to 240, the accelerator injection charge-to-mass ratio is restricted to $0.04 \leq \varepsilon \leq 0.06$.

(2) The stripping of high-Z ions is extremely inefficient except for complete stripping at high velocities. If possible, the complete acceleration cycle of the ultra-heavy ions should be accomplished without stripping.

Figure 2 shows the magnetic guide field necessary to contain particles of various energies and various ε, over the entire range of interest. With a maximum guide field of 3×10^6 G-in., an ion with $\varepsilon = 0.05$ can be accelerated to approximately 7 MeV/nucleon. With this field the high-energy biophysics ions (alpha, carbon, nitrogen, oxygen, and neon) can be accelerated to 500 MeV/nucleon with $\varepsilon = 0.5$, and argon will reach 400 MeV/nucleon with $\varepsilon = 0.46$. Protons can be accelerated to a maximum of 1500 MeV.

The figure also indicates the minimum guide field,

9×10^4 G-in. (300 G in the magnets). Protons require an energy of 2.5 MeV to be injected into this ring and, since all other ε's can be injected with this voltage, this specifies the maximum injector potential.

The synchrotron ring with these parameters is thus capable of satisfying the energy requirements of all of the research groups, but unless flat-topping of the guide magnets is used, the duty-factor requirement cannot be met. In addition, an auxiliary medium-energy injection system is necessary to provide the high charge states required to achieve high-energy heavy ions for biomedical uses.

Both the intensity requirements and the problems of charge exchange for the multiply-charged beams indicate the necessity of cycling the system at the maximum possible rate. For the Omnitron the cycling rate has been chosen at 60 cps, limited primarily by the rf voltages required to achieve the high acceleration rate. The cost of providing a flat-topping power supply for a magnet system cycling at this rate, as compared with that of an auxiliary dc storage ring, is only slightly in favor of the flat-top supply. The storage ring has the significant advantage that it will not only provide for the high duty factor, but will also make possible the utilization of the synchrotron as its own injector for ions that must be

stripped at high velocities to achieve the maximum required energy. In this mode of operation the heavy ions are injected in a low charge state, accelerated to an intermediate energy, stored while the synchrotron magnetic field returns to minimum, completely stripped, reinjected into the synchrotron, and accelerated to high energy (see Fig. 3). Although the overall cycling rate of the system is decreased by a factor of 2 in this process, it is preferred to all other methods of injection, since the longitudinal distribution of the beam is maintained constant during the low-energy acceleration cycle and the entire beam can be transferred back into the synchrotron.

The storage ring must be capable of storing beam of the maximum $B\rho$, so that its parameters are essentially the same as those of the synchrotron. The diameters of the two rings have been chosen as nearly equal as possible, to avoid the problems of multi-turn injection in either ring during beam transfer.

The proposed accelerator consists of a 3.0 MV dc injector, an alternating-gradient synchrotron covering the range 9×10^4 to 3×10^6 G-in., a dc alternating-gradient storage ring concentric with the synchrotron, but with slightly larger diameter, and the necessary ring-to-ring beam-transfer equipment shown in Fig. 4. The various components of this system and the estimates of beam currents are discussed below.

Synchrotron and Storage Rings

Both the synchrotron and storage rings consist of 64 guide magnets arranged in 16 FOOFDOD cells, as shown in Fig. 4.

The synchrotron magnets have a profile parameter of 3.86/m, operate with guide fields between 0.3 and 10.0 kG, and provide a usable elliptical aperture with major and minor axes of 10 and 4 cm. Both focusing and defocusing magnets are approximately 0.7 m in length. In the chosen configuration these provide 3.25 radial and 4.25 vertical betatron oscillations in the 110 m circumference. The sixteen 2.2 m straight sections between focusing magnets contain the injection and extraction systems and the eight rf resonators. The 1.0 m separation between defocusing magnets contains correction lenses, beam monitoring equipment, etc.

The arrangement of the concentric storage ring is identical to that of the synchrotron except for slight adjustment of the magnetic gradient and magnet lengths and spacing necessary to produce similar betatron oscillations in the larger circumference (118 m). The usable aperture of this ring is a 4 by 8 cm ellipse.

In these rings, the particle motions produced by magnetic forces only are independent of ε, and are therefore identical for all particles. The synchrotron motion

produced by combined magnetic and electric forces, however, depends both on ε and on the rf harmonic number; the synchrotron frequencies and amplitudes, the injection bucket size, etc. all vary with ε and h. Studies of particle motion with the aid of SYNCH and APERT, IBM 7094 computer codes, indicate that for the configuration chosen, all of these parameters fall well within practical operating limits over the range $0.04 \leq \varepsilon \leq 1$. In addition, the 3.0 MV injection potential allows wide latitude in the choice of harmonic number for the lower ε, so that the synchrotron motion can easily be adjusted for optimum operation.

The design of the guide magnets has been facilitated by the use of the TRIM[1] computer program combined with PISA.[2] These programs will designate the steel profile necessary to produce a specified magnetic field configuration. The technique involves the introduction, by the computer, of perturbations of the steel profile, the calculation of their effects on the magnetic fields, and, subsequently, the calculation of the magnitude of perturbations necessary to produce the specified field configuration. Since TRIM will handle both finite and infinite permeabilities, the steel profile can be optimized to produce minimum deviation from the specified field configuration over the entire operating range. A prototype guide magnet has been constructed and the actual magnetic field is in excellent agreement with that predicted by PISA.

Accelerating System

The acceleration rate required for the synchrotron is

$$\text{Energy gain/turn} = V\varepsilon e \sin \Phi_s = 2\pi R \frac{d(p)}{dt} = 2\pi R \rho B \varepsilon e$$

where V is the total voltage per turn, $2\pi R$ is the mean orbit circumference, Φ_s is the synchronous phase angle, and p is the particle momentum. The total voltage per turn required for the particles to follow the change in magnetic field is thus independent of ε.

The accelerating frequency is

$$f_{rf} = hf_0 = \frac{h\varepsilon e\bar{B}}{2\pi m},$$

where $\bar{B}$ is the mean orbit magnetic field, h is the harmonic number, and e and m are the proton charge and mass. The accelerating frequency is therefore proportional to ε; however, by adjustment of the harmonic number the frequency program can be made identical for all ions, except for relativistic effects. With the 3.0 MV injection (Fig. 2) the maximum frequency swing of about 15.5:1 is required for alphas ($\varepsilon = 0.5$), with a 6.5:1 swing required for ions with $\varepsilon = 0.04$. A wide latitude in choice of the harmonic number is thus possible for the heavy ions.

The rf system chosen for the Omnitron is similar to that of the Princeton-Penn accelerator[3] and consists of two biased ferrite resonators, one tuned to cover the range 1.6 to 7.0 Mc/sec and the other 7.0 to 30 Mc/sec,

with a midrange crossover.

With the magnets operating with a 60 cps biased sine wave over the range 0.3 to 10.0 kG, a maximum energy gain per turn of 150 ε keV is required. With the synchronous phase angle at 40 deg, the total gap voltage must be 240 kV. This will be provided by four resonator systems (each with a gap voltage of 60 kV) situated symmetrically around the ring. Since these systems will be operated in phase, the allowable harmonic numbers will be restricted to those divisible by four.

The close spacing of the slow ions at high harmonic numbers requires that each resonator voltage be applied across a single gap, rather than the double-gap systems normally used with proton accelerators. With this exception, and that of the wide frequency range, the resonator and rf control system will closely follow present synchrotron practice.

Ion Source and Injection

The synchrotron space charge limit is given by the expression $Q = 6 \times 10^{-15} V$ coulombs, where V is the injection potential. If the system is operated for all ions at 3 MV, the single-turn injection time is $\tau = 4.5 \sqrt{\varepsilon}$ (μ sec). From these expressions it is apparent that the peak current from the ion source required to reach the space change

limit with single-turn injection is 3.6 $\sqrt{\varepsilon}$(mA), varying from 0.80 to 3.6 mA over the entire range of ions to be accelerated. These modest requirements are exceeded by the Hilac ions source for all gaseous elements up to xenon. A ten-turn injection system will be provided that will make possible the saturation of the synchrotron with ultra-heavy ions (ε = 0.05) for which the peak ion source current is as low as 80 μA. For all other ions the maximum intensity of the accelerated beam will be limited by the ion-source output.

Two 3 MV injectors will be provided to make possible the acceleration of different ions on alternate acceleration cycles. The high-voltage generators will be 100 kHz, shunt-fed Cockcroft-Walton supplies utilizing fast solid-state diodes. The stack construction and characteristics will be similar to the Hilac injector,[4] except that the entire high-voltage generator and terminal will be operated in an atmosphere of sulfur hexafluoride. Rapid access to the terminal will be provided to facilitate ion source servicing.

The calculated capacity of the terminal and the Cockcroft-Walton stack characteristics are such that ripple and terminal sag during the beam pulse will be negligible. Regulation will be about 1 kV (1:3000).

Ejection and Extraction

Extraction from the FOOFDOD magnet configuration is carried out in two adjacent long straight sections. Fast ejection from the synchrotron is accomplished with a ferrite kicker that rises in approximately 0.1 μsec to a maximum of 33 kG-cm, providing a 0.1 deg deflection. This small radial impulse in one straight section produces a pronounced radial displacement in the next adjacent straight section in which is located a thick (1.5 cm) septum magnet operated at 12 kG. The deflected beam is transferred to the storage ring through a 22.5 deg bending magnet located between the rings and a complementary fast injection system in the storage ring, shown in Fig. 5.

Fast transfer of the beam from the storage ring back to the synchrotron is accomplished through a similar system. The magnetic requirements of the synchrotron injection system's thick septum and fast kicker are considerably relaxed, however, since the beam charge-to-mass ratio will have been increased by stripping.

Slow extraction from the storage ring will be accomplished by a resonant system in which the beam will be expanded radially toward a thin (0.04 cm) septum magnet located at the center of one straight section. A thick septum magnet located in the next straight section deflects the beam from the ring. Magnetic properties of both the

thick and thin septums are approximately the same as those of the fast extraction system, and the beam characteristics through the extraction systems are essentially identical.

The beam is extracted from the synchrotron as indicated above. By slight adjustment of the bending magnet the beam can be directed either toward the entrance of the storage ring septum magnet, or directly through the center of the storage ring straight section. This straight section also contains the slow-extraction thick septum, so that the system allows the delivery of beam to the target area either by fast extraction from the synchrotron or by slow extraction from the storage ring. Two identical extraction systems are provided, one for the low-energy experimental area and the other for the high-energy area. In the case of the high-energy extractor, a cross-over transport system provides for the delivery of beam from either ring to either of two experimental areas, biomedical or physics. The use of two injectors allows the acceleration of two different ions to any desired energy on alternate cycles, one of which can be delivered by fast extraction from the synchrotron to one area and the other by slow extraction to either of the other two areas. This capability is particularly advantageous in that biomedical irradiations are generally of short duration or utilize low intensity.

Vacuum System

The investigation of beam losses due to interaction with residual gas in the vacuum chamber indicates that for all ions and charge states the most severe problem occurs in the low-energy heavy-ion acceleration cycle, and that scattering will be at least an order of magnitude less important than charge exchange. The losses to be anticipated from charge exchange have been estimated from data available in the literature[5,6] and from recent measurements at 1 and 10 MeV/nucleon at the Hilac. The beam attenuation due to charge exchange is

$$n/n_0 = \exp - (10^{27} P \int_0^t \sigma(\beta)\ \beta\ dt),$$

where P is the pressure in torr, $\sigma(\beta)$ is the total charge-exchange cross-section in cm^2, t is the acceleration period, and $\beta = v/c$.

The product $\sigma(\beta)\beta$ remains fairly constant at approximately 10^{-17} cm^2 over the range $0.01 \leq \beta \leq 0.07$. the low-energy cycle of the Omnitron. The attenuation for this case is thus

$$n/n_0 = \exp(-10^{10}\ Pt).$$

In order to achieve reasonable transmission the product Pt must be maintained at less than 10^{-10}. The presence of the accelerating period in this expression emphasizes the importance of the fast cycling of the accelerator. For the

60 cps rate chosen the vacuum must be maintained with an average pressure at less than 10^{-8} torr, helium equivalent.

The charge-exchange cross-sections are dependent on the charge state of the particle and its velocity and on the composition of the residual gas. The composition of the residual gas is in turn dependent on the outgassing characteristics of the chamber material, the system conductance for the various gas species, and on the pumping characteristics and history of the applied pumps. These factors complicate considerably the detailed analysis of the vacuum system requirements. Investigation has shown that no single pumping system can provide optimum vacuum conditions. Several combinations have been considered, all of which appear capable of providing beam transmission in excess of 0.9 for the low-energy cycle with ions up to mass 126 (xenon). Preliminary estimates for these systems indicate no particularly advantageous combination with regard to cost.

A proposed pumping system consists of 4.5°K cryopumps located between each magnet, cooled by a tube carrying 4°K helium completely around the rings. In operation the system will be raised to 20°K periodically (weekly) to purge the cryosurfaces of accumulated gases which will be pumped from the system by an oil diffusion pump equipped with a chilled porous meter baffle. This pump will also be used for roughing the system.

In the vicinity of the rapidly varying magnetic fields, the chamber must be of an insulating material; an investigation of the vacuum properties and strengths of available materials has indicated the superiority of α-alumina for this purpose. These will be elliptical cylinders, lightly metallized on the inner surface to prevent the build-up of charge, and metal-bonded to stainless steel flanges. These sections will be heliarc-welded in place to the stainless steel tube comprising the remainder of the vacuum chamber.

Prototype segments of this system have been fabricated and measurement of the outgassing rates of the various surfaces have been made. These measurements indicate that mean effective pressures in the low 10^{-10} torr (helium equivalent) can be expected in both rings. Total beam losses due to charge exchange will thus be limited to a few percent for both the acceleration and storage cycles of the low ε beams.

With a vacuum system of this complexity, <u>in situ</u> baking is impossible. Preprocessing, including high-temperature vacuum degassing, of all chamber components, and extreme care in the assembly of the system will be necessary. Rapid-closing valves, supplemented by acoustic delay tubes, will be used between the accelerator and the cave areas, to prevent disaster in the event of experimenter error.

Shielding and Cave Facilities

At the pressures required for the acceleration of particles of low charge-to-mass ratios, gas scattering losses will be negligible for the high-energy, fully stripped ions. In addition, for those ions with $\beta \geq 0.2$, the charge exchange becomes negligible. The loss of high-energy beams in the fast transfer from the synchrotron to a storage ring can be eliminated by emptying a series of buckets at low energy, or by rebunching the fully accelerated beam at a low harmonic number, to accommodate the ejection-magnet rise time. Thus extreme radiation problems in the rings can be eliminated except in the region of the slow-extraction system on the storage ring.

A maximum beam of approximately 10^{13} particles/sec can be accelerated, with an expected 10% loss on extraction. The modest cost of increasing the proton injection energy by a factor of 10 or more with a linear accelerator, and the probable increased demand for mesons for both medical therapy and medium-energy physics research, make it mandatory that the permanent shielding around the accelerator be designed in such a manner as not to preclude eventual increase in proton currents to 10 to 15 μA.

The high-energy cave system consists of a long central alley parallel to an existing hill that can serve as a beam dump. Beams can be deflected into a series of caves along

its entire length. Alteration of this system to accommodate increased beam currents will consist primarily of the addition of shielding to the caves.

The low-energy cave system is located approximately 180 deg around the ring, opposite the high-energy extraction system. This area consists of a central alley from which the beam can be deflected in both directions into the caves which require only 1-2 ft of concrete.

The magnetic transport equipment is identical for both experimental areas, since they are both required to handle full-momentum beam (3×10^6 G-in.).

Beam Estimates

In estimating the beam intensities that can be produced by the Omnitron the following assumptions have been made:

1) The calculation of space charge limits as compared with the Hilac ion source output indicate that, over the range $1 \leq M \leq 132$ for gaseous elements and for injection at 3 MV, space charge will limit the accepted beam to $1.2/n \times 10^{13}$ particles/sec (n = charge number).

2) For the operating pressures considered feasible, total beam losses due to charge exchange during the acceleration and storage cycle will not exceed 10%.

3) Ring-to-ring transfer efficiency is $(1 - \tau f_o)$,

where τ is the fast kicker rise time, here assumed to be 80 nsec, and f_o is the ion orbit frequency.

4) Fifty percent of an argon beam can be fully stripped at 10 MeV/nucleon,[7] and this figure is used in estimating all beams requiring multiple acceleration. In addition to this loss, it should be noted that for multiple acceleration the system operates at a repetition rate of 30 cps.

5) A slow extraction efficiency of 90% is estimated on the basis of calculated radial gain per turn and thin septum dimensions, through comparison with the performance of similar operating systems.

Various beam intensities estimated by using these assumptions are shown in Table II.

Estimates of intensities of ions heavier than xenon or non-gaseous elements are problematical in that ion source output of the required charge states are unknown. It should be emphasized, however, that for ions for which the space charge limit exceeds the ion source output, multiple-turn injection can be utilized up to a total of 10 turns. For the very heavy ions, stripping at 3 MV before injection can be used to achieve the necessary charge states.

Table II. Omnitron beam intensity.[a]

Energy (MeV/nucleon)	5 - 10	50 - 100	100 - 500	500 - 1500
Protons	1.0	10	10	10
Alpha	5	5	5	--
Carbon	5	5	1	--
Neon	5	5	1	--
Argon	3	3	0.9	--
Krypton	2	0.8	0.2	--
Xenon	1.5	0.3	0.1	--

[a]All values times 10^{12}/sec.

Figure Captions

Fig. 1. Hilac ion-source output.

Fig. 2. $B\rho$ vs energy per nucleon.

Fig. 3. Omnitron acceleration cycle.

Fig. 4. Omnitron layout.

Fig. 5. Omnitron beam transfer and extraction.

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**Now at the National Accelerator Laboratory, Chicago, Ill.

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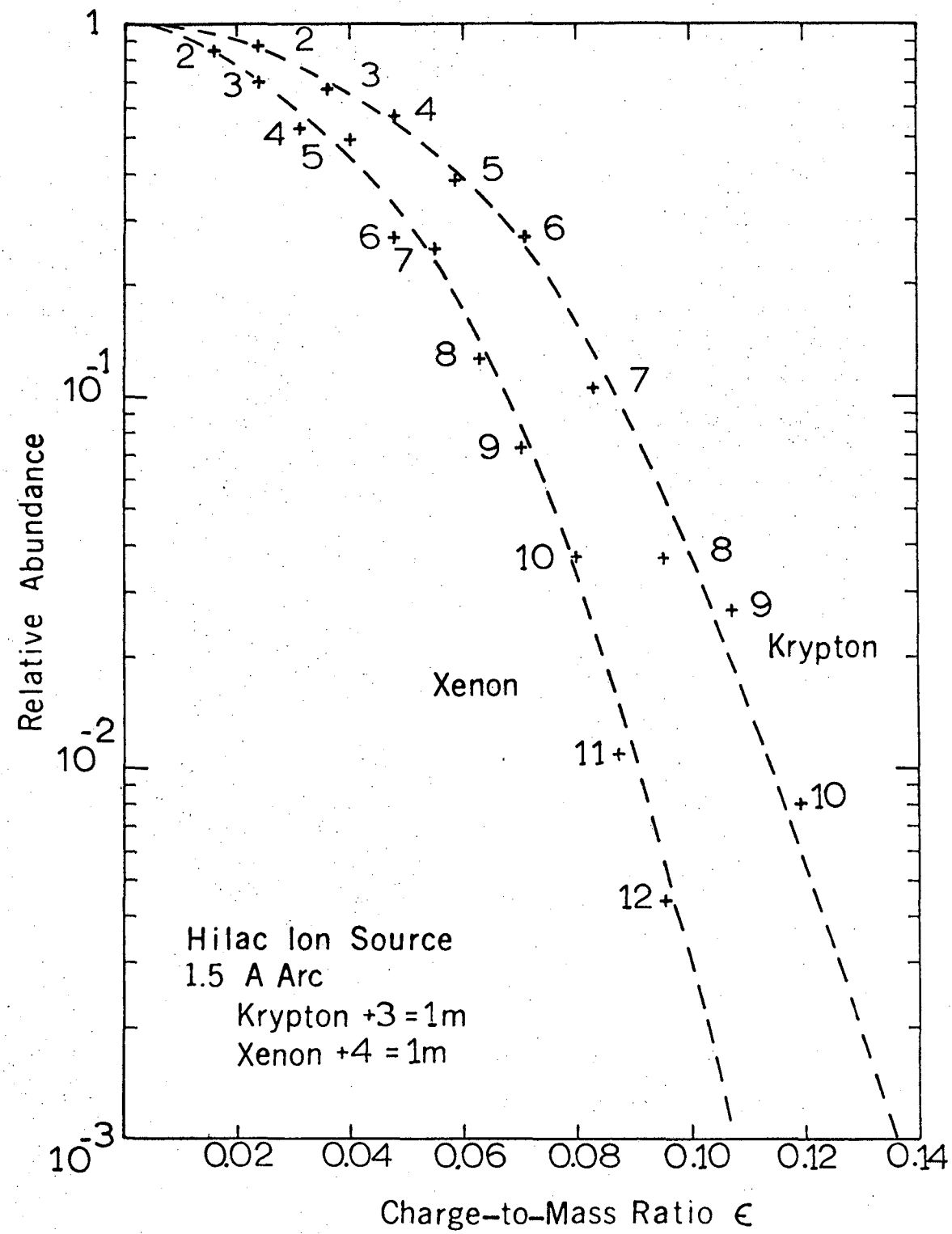
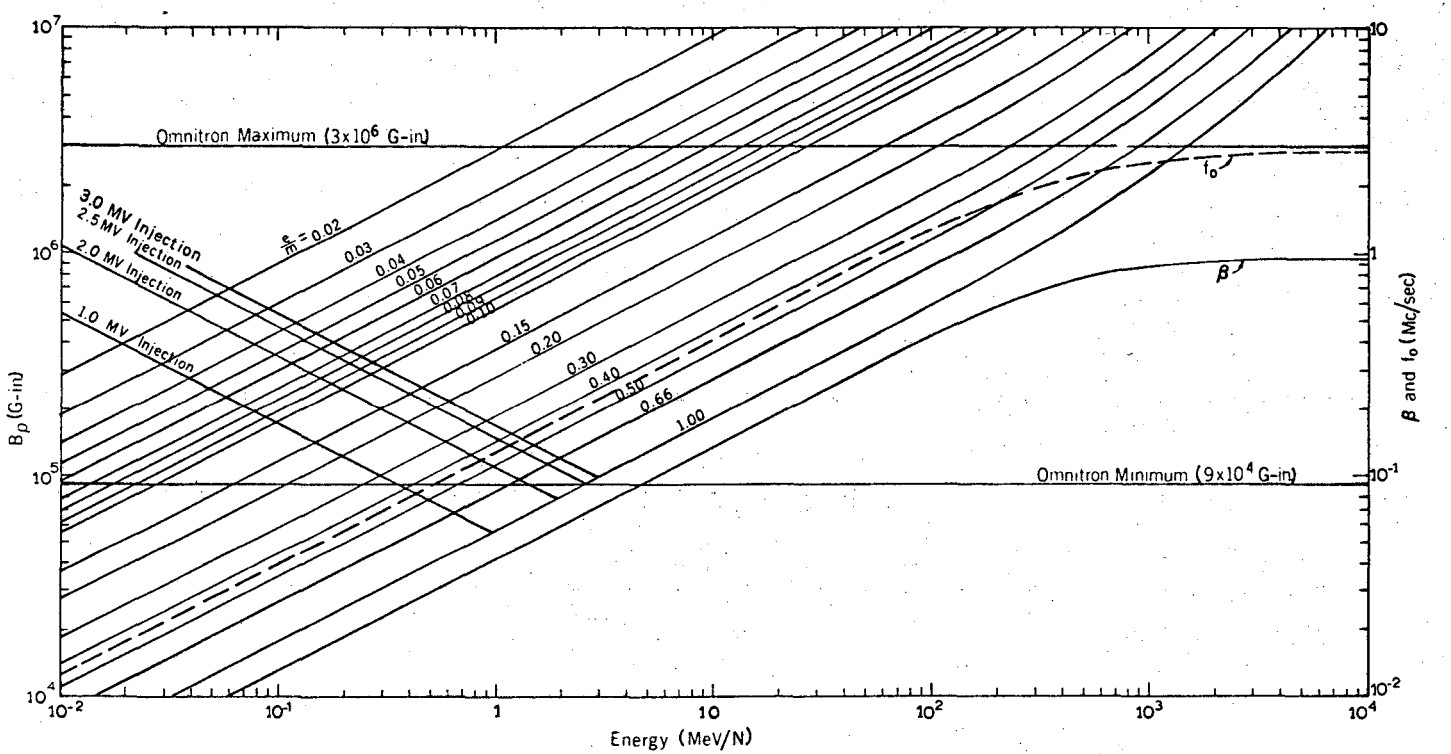


Relative Abundance of Krypton and Xenon Charge States from the Hilac Ion Source

MUB 11740

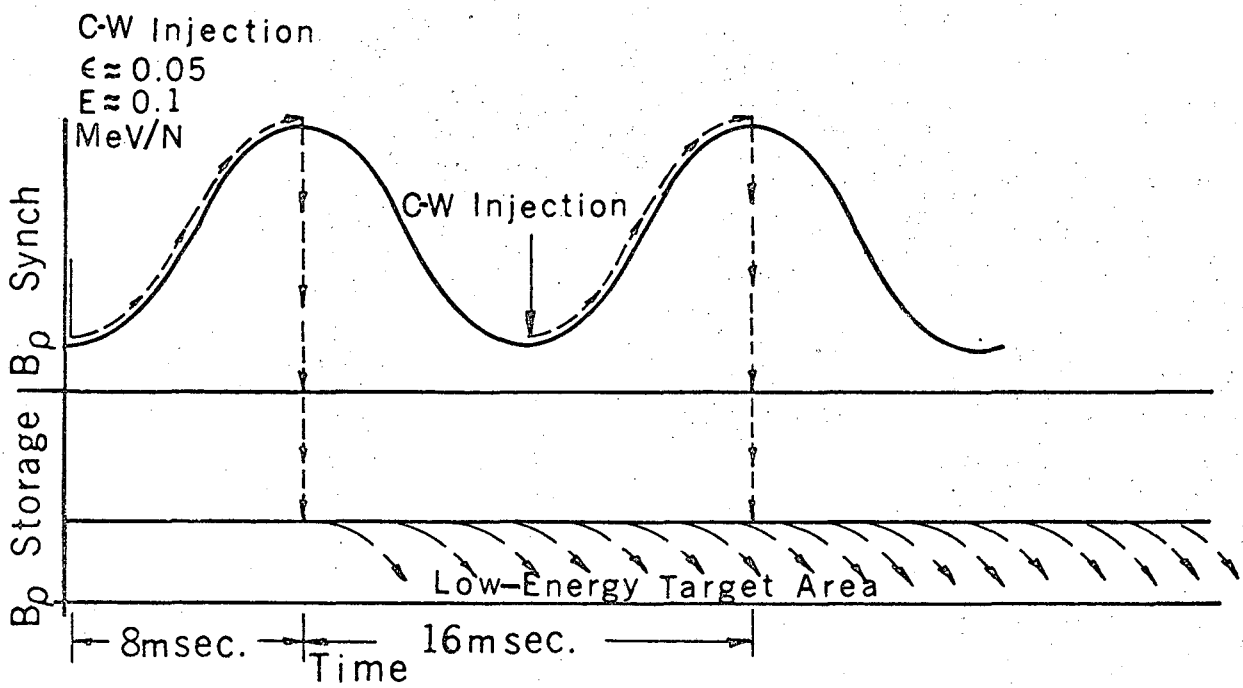
Fig. 1



Magnetic Rigidity and Velocity vs. Energy for Various ϵ

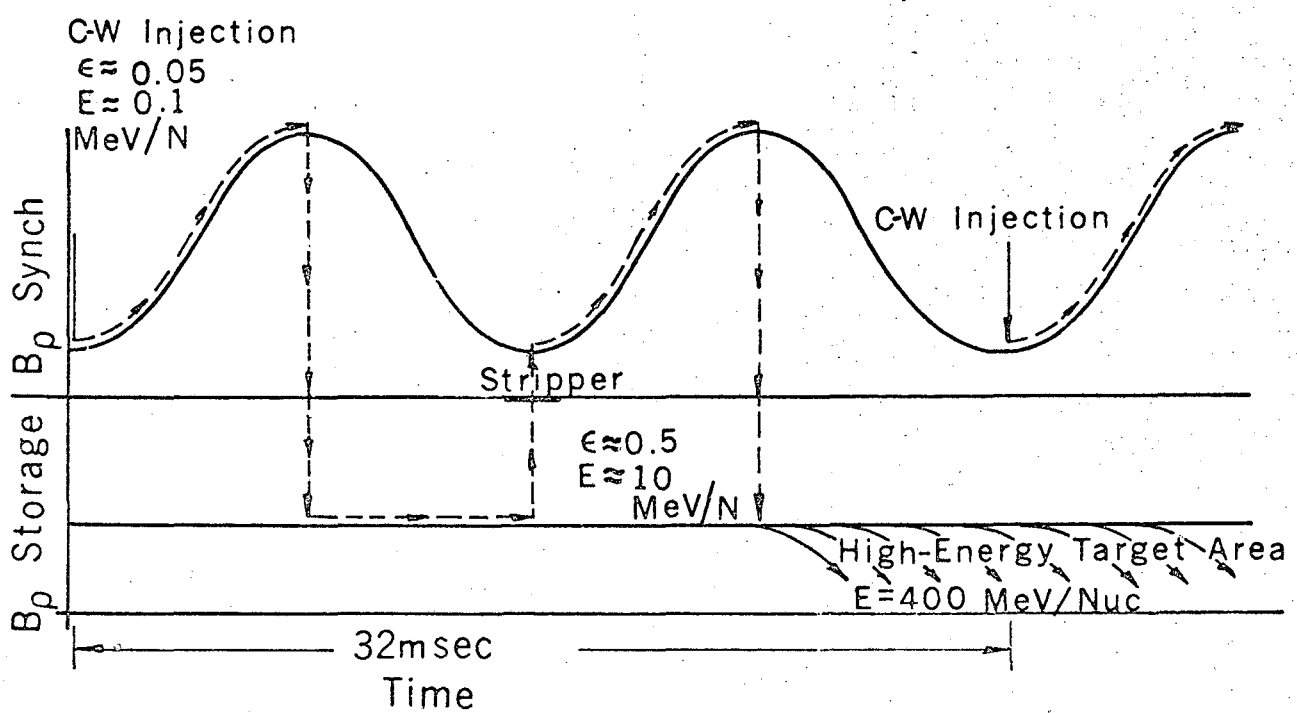
MUB 11759A

Fig. 2



(a)

Single Cycle (Low Energy)



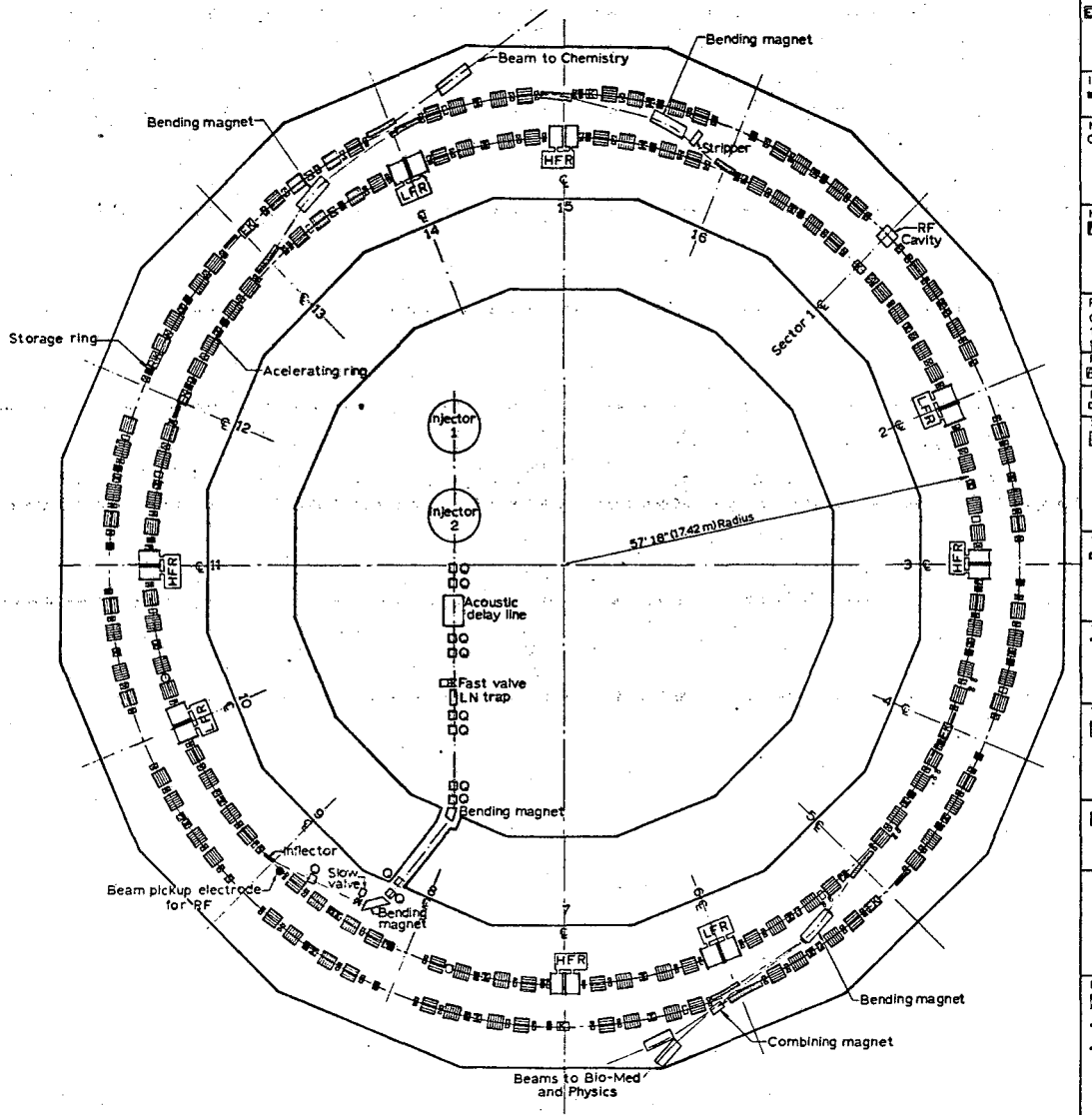
(b)

Double Cycle (High Energy)

Acceleration Cycles

MUB-11753

Fig. 3



ACCELERATING RING PARAMETERS

EXTRACTION KICKER 2 Required
EK Ferrite magnet
Aperture = 10 x 4 cm
Length = 25 in.
Peak field = 650 gauss
Rise time A.S.A.P.

INFLECTOR 1 Required
Electrostatic
Radius of curvature = 2.3 m

MULTI-TURN INJECTION ELECTRODE 2 Required
Inside pumpouts
Electrode separation = 10 cm
Electrode length = 4 cm
Peak voltage = 46 kV
Fall time 50-500 μsec adjustable

HORIZ CLOSED-ORBIT DEFLECTORS 16 Required
Inside pumpouts in F-F space
Length = 4 cm
Electrode separation = 10 cm
Height = 6 cm
Peak voltage = 2 kV dc

PICKUP ELECTRODES, (horiz & vert) AND VERTICAL CLOSED ORBIT DEFLECTOR IN PUMPOUTS
16 Required in D-D spaces

REINJECTION KICKER 1 Required
RIK Same as Extraction kicker, but with ½ field

REINJECTION THICK SEPTUM 1 Required
Same as Thick septum except 52 in. long

STEERING MAGNET 4 Required
Replaces Pumpout chambers in F-D space in sectors 3, 5, 11, & 13
Flat field
Aperture 10 x 4 cm
Length 10 cm
Peak field 2 kG
Rise time 500 μsec

THICK SEPTUM 2 Required
1 inch Septum
Field = 11.2 kG
Length = 54 in.
Vertical aperture 2 cm
Radial aperture 5 cm

THIN SEPTUM 2 Required
1 mm Septum
Field = 1000 gauss
Length 24 in.
Vertical aperture = 2 cm
Radial aperture = 5 cm

TUNING SEXTUPOLES 8 Required
Aperture = 10 cm (round)
Poletip field 400 gauss = 33 G/cm²
Iron length = 6 in.
Rise time = 1 msec
Includes extra DC windows for skew Quadrupole.

TUNING QUADRUPOLE 16 Required
Gradient = 500 G/cm
Iron lenghts = 6 in.
Rise time = 1 msec
Aperture = 10 cm (round)

L_{F-F}	= 2.2 m	=	86.61 in.
L_F	= 700.88 m	=	27.59 in.
L_{F-D}	= 4 m	=	15.75 in.
L_D	= 720.49 m	=	28.37 in.
L_{D-D}	= 1.0 m	=	39.37 in.
Radius	= 17.42 m	=	685.8 in.
Diameter	= 34.84 m	=	1371.6 in.
Circumference	= 109.44 m	=	4308.65 in.

PUMPOUT CHAMBER
May also include other components as indicated.
• ACCELERATOR MAGNET ELECTRICAL CONNECTIONS.
• ACCELERATOR MAGNET COOLING WATER CONNECTIONS
(The location of electrical and water connections shown in sectors 4 & 5 is typical for accelerator.)

scale
0 5 10 15 20 feet

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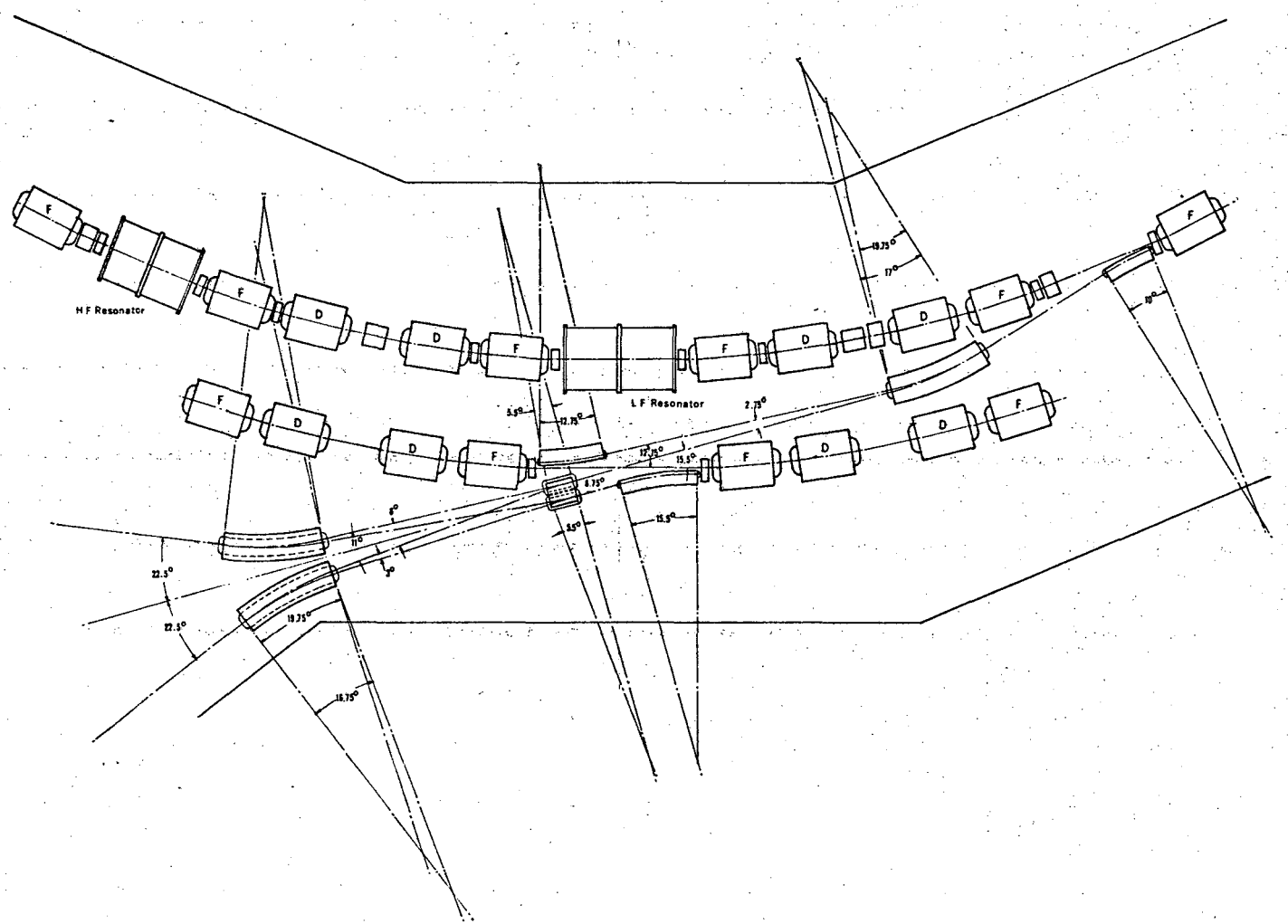
Fig. 4



Combined Beam Transfer and Extraction

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Fig. 5

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