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The ATLAS Positive-Ion Injector Proposal

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Introduction

The ATLAS facility will provide beams of heavy-ions through approximately mass 130. Energies provided will range from over 20 MeV/A for lighter ions down to approximately 5 MeV/A for mass 130. In discussions with our user group concerning future program needs, two major areas of focus emerged. The first was a desire to increase the beam intensities available by approximately a factor of ten beyond what is possible from our present negative-ion source and tandem injector for all ion species. The second was to obtain beams of at least 10 MeV/A energy for all possible masses through uranium. These features were desired without compromising the present qualities of the ATLAS facility: good beam quality, ease of operation, and continuous (D.C.) operation.

The facility which has been proposed [1] to address these goals consists of replacing the negative-ion injector and FN tandem with a positive-ion source and a superconducting linac of a new design which makes use of the high field gradients possible with superconducting structures. The positive-ion source proposed is an electron cyclotron resonance source mounted on a high-voltage platform, providing a 350-kv potential for preacceleration of the ions. This will produce, for example, uranium ions of 7 MeV with a velocity of .008c, assuming a charge state of 20+ . The ions will be bunched in a two stage bunching system providing a pulsed beam with a time width of better than 0.4 ns for injection into the linac.

The linac envisioned is a superconducting linac of independently-phased resonators. This approach is rather unusual in that a linac of this type has not been proposed previously due to the problems of resonator phase control and beam blowup in the early stages of acceleration. The first stages of acceleration will consist of short resonator structures followed by superconducting solenoids to refocus the beam before the beam size has grown to an extreme value. The proposed injector system will provide sufficient acceleration to inject the beams into the unmodified ATLAS facility for the remainder of the acceleration process.

A schematic representation of the proposed facility is shown in figure 1. The development of the facility is envisioned to occur in three major stages. The first stage will consist of the construction of a proof-of-principle prototype which may consist of the ECR positive-ion source and the first, low-beta acceleration sections of the linac. This phase would result in a machine which would only demonstrate the concept but would not be a useful accelerator in the ATLAS system. The second phase of the project is planned to increase the size of the linac to a total voltage of around 10 MV and provide beams as indicated in figure 2. THe third phase of the project, if approved, will expand the injector linac to allow proper matching into ATLAS of all heavy ions through uranium. The graph labeled '24 MV linac' in figure 2 indicates the performance which might be expected after completion of the third phase.

DISCLAIMER

The ECR positive ion source

The electron cyclotron resonance (ECR) positive ion source has been demonstrated to be an exciting new development in the quest for high charge state heavy ions. Much of the early development has come from the efforts of Geller [2]. The features of the ECR source which make it an attractive option for this application are: 1) high charge state heavy ions, 2) small energy spread (typically less than 10 ev), 3) good transverse emittance ($\beta\varepsilon = 0.2\text{-}0.6\ \pi$ mm-mr), 4) high operational reliability, and 5) large beam currents in comparison to a negative-ion source. Uncertain aspects of the ECR source is the production of ions from solid materials.

The small energy spread from such a source means that the longitudinal emittance for the system could be as low as 0.8 kev-ns for a pulse period of 82 ns. This small emittance value cannot be maintained when a stripping foil is used since energy straggling in the foil will dominate. Also nonlinear acceleration effects and resonator phase stability may make it difficult to deliver such a high quality beam to target, a substantial improvement in longitudinal emittance may be realizable over our existing system.

The transverse phase space for sources in which ions are produced in magnetic fields is constrained theoretically by the requirements of momentum conservation as the particles emerge into a field free region. Such considerations place a lower limit on the transverse phase space of 0.14 π mm-mr for uranium. This emittance limit scales as q/A which implies that the best possible emittance for the heavier ions with $q/A = 0.1$ is less than that for lighter ions where $q/A \simeq 0.5$. Recent measurements [3] on a Geller source show the transverse emittance to be approximately the theoretical limit. The present transverse emittance from the tandem system is determined by multiple scattering in the terminal strippper foil of the tandem and the beam size at that point. The ECR transverse emittance should be comparable to the tandem system if the theoretical ECR limit can be approached.

A most important question for our application of ECR sources is the possibility of obtaining ions from solid materials. ECR sources have historically operated only with gases. Recently Geller has reported on the production of ions from a number of solid materials [4]. This effort is in an early stage of development but the results are extremely encouraging and have revealed no significant problems in using solid materials.

The Linear Accelerator

The most important problem which must be addressed in the design of a linear accelerator for very slow particles is the problem of transverse defocusing and beam blow-up. When a linear accelerator operates in the 'phase focusing' mode the beam is continually rebunched in longitudinal phase space in order to preserve the beam quality, but this causes the beam to also experience defocusing forces in the radial dimension. These radial defocusing forces must be counteracted by some other focusing forces in order to maintain acceptable beam size. This problem is quite severe at low velocities because the beam emittance is relatively large and also the beam rigidity is small. The problem has been solved in most operating low-velocity linacs by using quadrupole focusing elements in alternate drift tubes in Wideröe linacs. The drift tubes containing these quadrupole must be $3\lambda/2$ in length rather than $\lambda/2$ which reduces the average accelerating field. Another approach, which has been receiving a great deal of attention recently, is the RFQ linac. In this approach, electric quarupole field terms are imposed of the accelerating electric field thereby combining the necessary focusing forces and accelerating forces in one system. The approach which we are proposing to use separates the acclerating regions and transverse focusing regions into physically discrete, alternating regions.

A qualitative picture of our proposed solution for the low velocity region of the positive-ion injector is shown in figure 3. Short, high field strength superconducting resonators are separated by superconducting solenoids which provide transverse focusing [1]. The first resonator, approximately 10 cm long, provides about 300 kv of accelerating potential and nearly doubles the beam energy. The radial defocusing effects produced by the first resonator are compensated by the superconducting solenoid which immediately follows. The large energy gain provided by these resonators also assists in the transverse dimension by reducing the phase space rapidly. This scenario is repeated four times in the low velocity section but each time the ratio of acclerating region to transverse focusing region can be allowed to increase as the divergence problem decreases in importance. At the end of the low-velocity accelerating region, the beam velocity is approximately .03c and the remainder of the accelerating process can be handled in a manner essentially the same as is presently employed in the existing ATLAS linac.

Low-Velocity Accelerating Structures

The requirements for accelerating low velocity ions which have been outlined above constrain the possible resonator designs [1]. In order to minimize the bunching requirements it is desirable for the resonator frequency to be as low as practicable. The low resonant frequency is also necessary in order that the transit time factor for these low-velocity (.008c) particles be large but at the same time maintain as long an accelerating structure as possible. Therefore the design frequency of 48.5 Mhz, one half the 97 Mhz frequency for the ATLAS low-beta (0.06c) and high-beta (0.105c) split-ring structures, has been chosen for these structures. This choice is also consistent with the requirement of drift tube aperture, > 15mm, and tube lengh ratio which is constrained by the beam emittance issues at low velocities. The length along the beam direction should be approximately 15 cm for the first resonator, but the following structures can increase in size in order to take advantage of the additional possible accelerating distance between solenoids and in order to better match the higher velocities.

The coaxial quarter-wave superconducting resonator appears to be a good candidate for these low velocity structures [5]. Two variations of the quarter-wave structure are being actively investigated at this time. One design which is being considered is a four-gap, three drift tube structure. Two of the drift tubes are driven by the quarter-wave line. A schematic view of such a unit is shown in figure 4. A second option which is also undergoing investigation is a two-gap single drift tube structure. Both approaches can be configured to obtain essentially similar overall linac performance. The four-gap option requires fewer resonators than the two-gap option, but requires that resonators matched to as many as three different velocities be designed. A two gap resonator approach whould require only two different matched velocity designs.

The fabrication of such resonators is not expected to present serious problems. This belief is based on the success of a 140 Mhz, .14c beta quarter-wave resonator model [5]. One possible problem is the phase stablilty of such a device. The length of a 48.5 Mhz quarter-wave resonator is 90 cm. The mechanical stability of such a long line must be considered because vibration affects the resonator phase stablilty. The mechanical stability can be improved by increasing the diameter of the quarter-wave line if necessary.

Development Plans

The development of these plans will be undertaken in four phases. The first phase is the design and development of resonators for the low velocity end of the linac. Computer modeling of the options mentioned above is in progress and construction of a prototype four-gap quarter wave resonator is expected to begin before the end of November, 1984. The second phase of the effort will be the construction of a prototype positive-ion source and linac system which will demonstrate the design concepts. These stages would then be followed by the construction of a useful linac with characteristics similar to the curve for the '10-MV linac' shown in figure 2. The last phase of the project would be to expand the prototype linac to provide a total voltage of 24 MV which would allow acceleration of uranium ions to approximately 10 MeV/A.

This project is the joint effort of many people. The project leader is L. Bollinger and K. Shepard is responsible for resonator development.

References

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2. R. Geller, I.E.E.E. Trans. on Nucl. Sci., NS-23, 904(1976).

3. R. Geller and B. Jacquot, Proc. of the 1984 Linear Accel. Conf. (to be published).

4. P. Spadtke, K.D. Leible, and B.H. Wolf, Proc. of the 1984 Linear Accel. Conf. (to be published).

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Figure Captions

Figure 1: Schematic representation of the proposed positive-ion injector.

Figure 2: Beam energies expected from the positive ion injector at an intermediate development stage and after completion of the project. The performance of the existing tandem is shown for comparison.

Figure 3: Schematic representation of the low-velocity region of the positive ion injector.

Figure 4: Schematic view of a very-low beta quarter wave resonator for the positive-ion injector.

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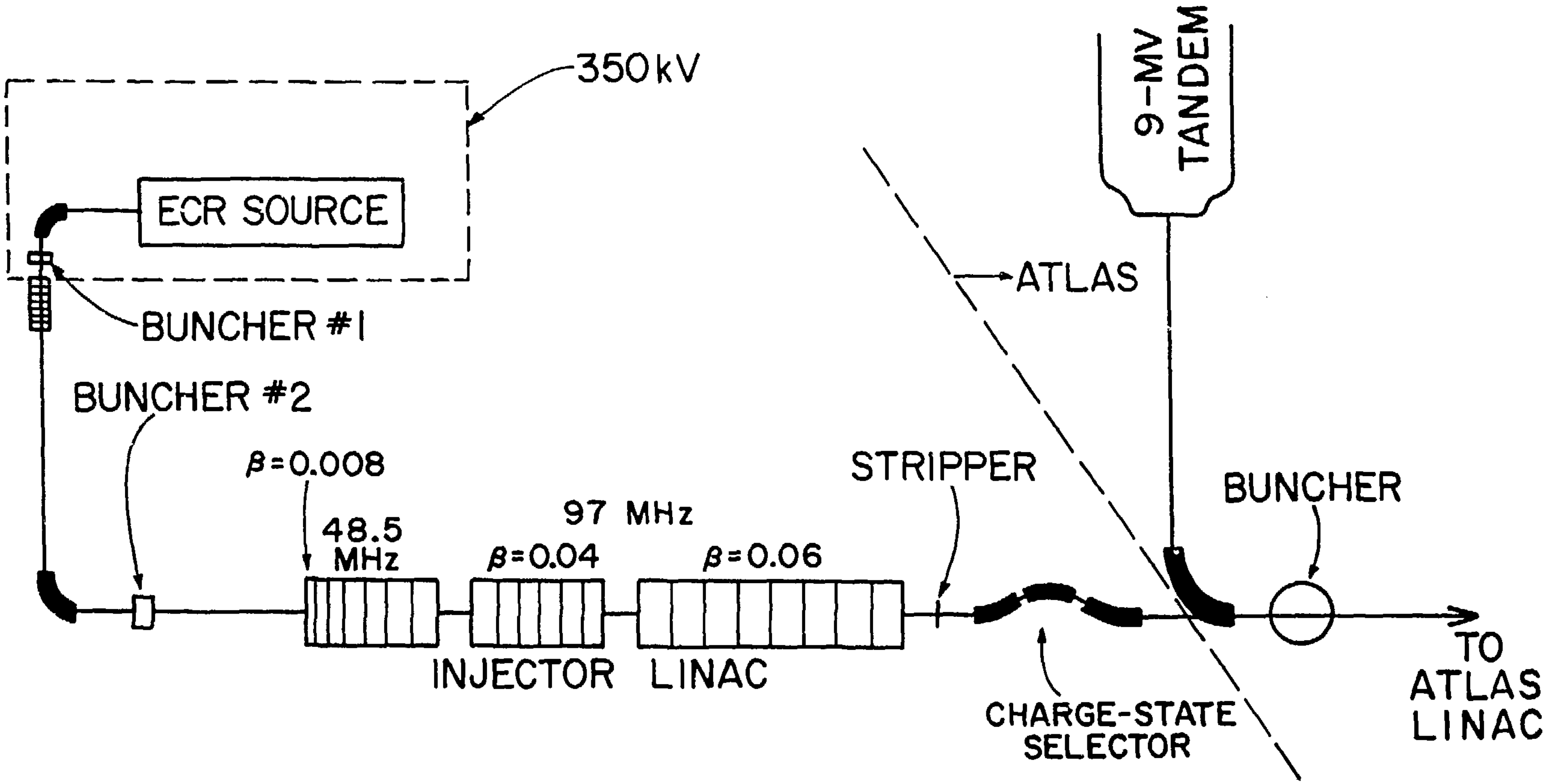

Fig. 1

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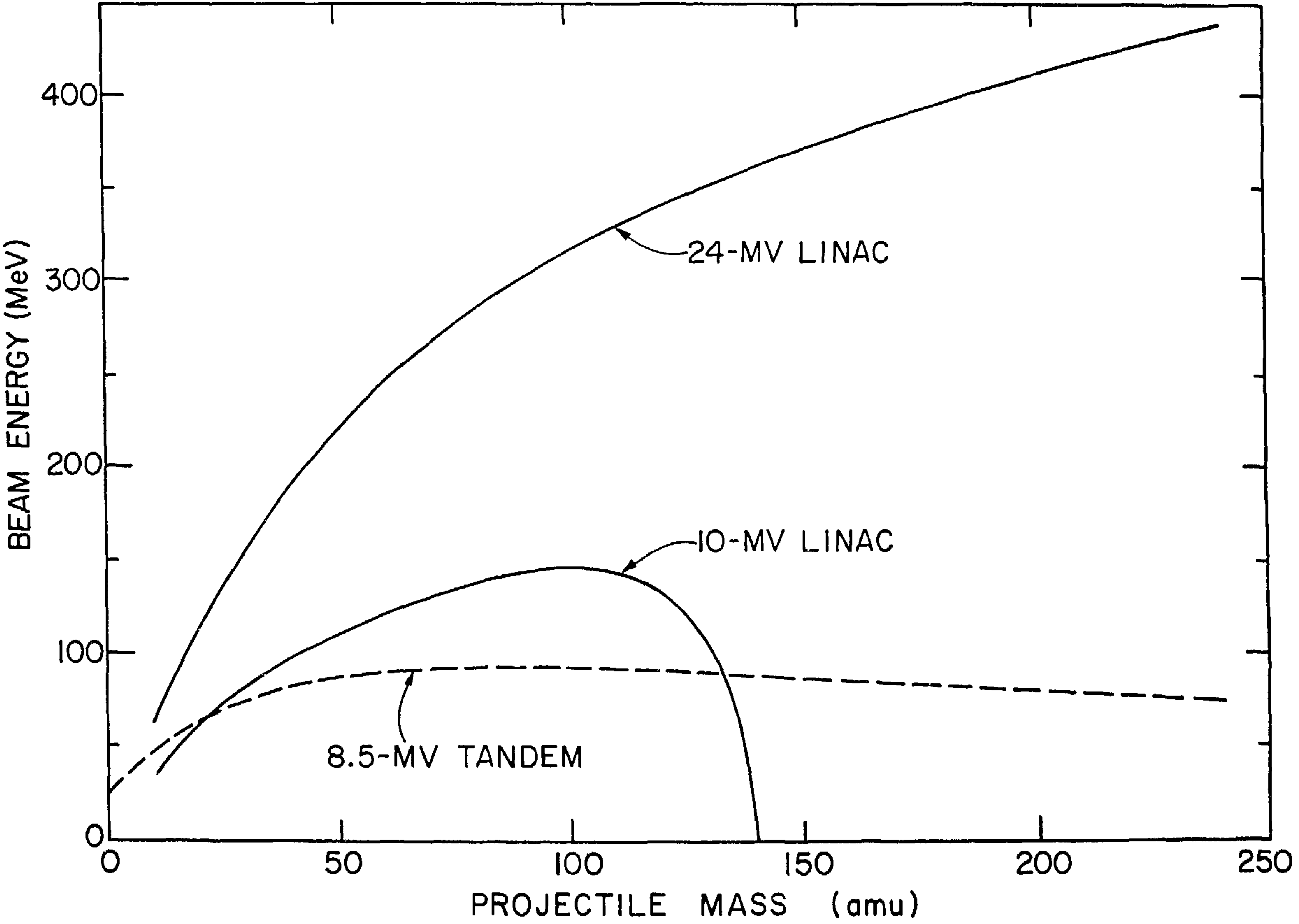

400
300
200
100
0
BEAM ENERGY (MeV)
0
50
100
150
200
250
PROJECTILE MASS (amu)
24-MV LINAC
10-MV LINAC
8.5-MV TANDEM

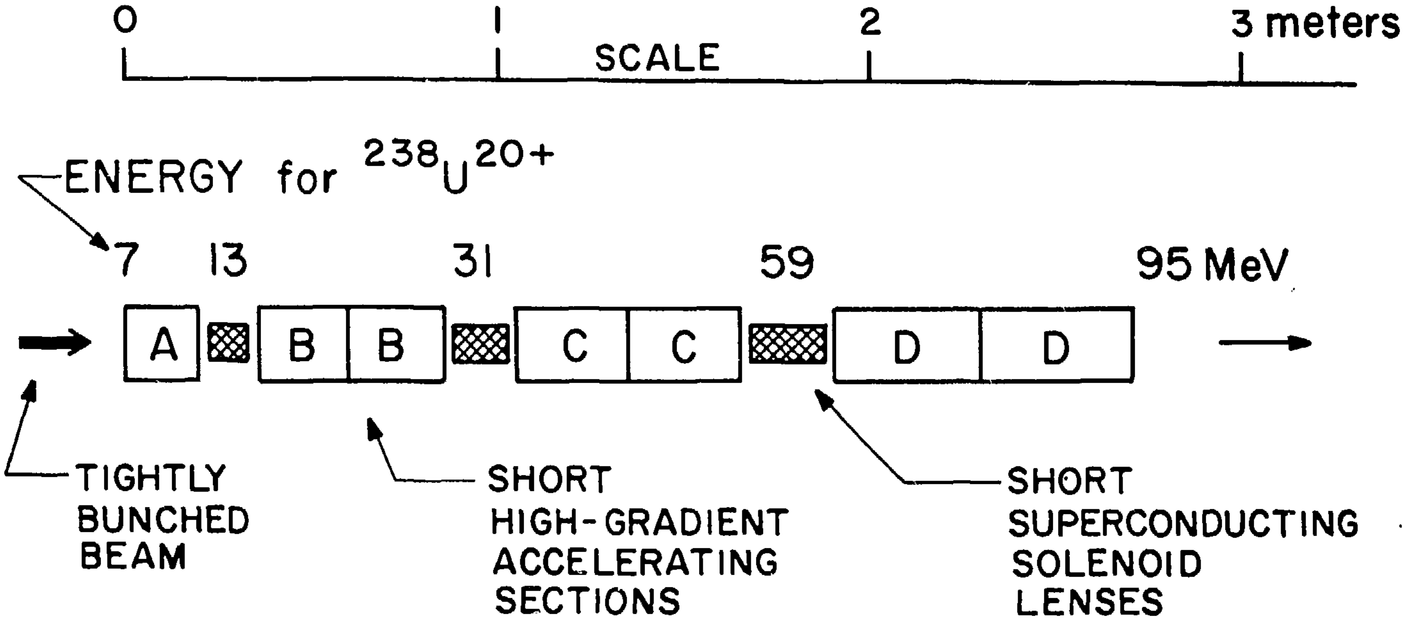
0
1
2
3 meters
SCALE
ENERGY for $^{238}U^{20+}$
7
13
31
59
95 MeV
A
B
B
C
C
D
D
TIGHTLY BUNCHED BEAM
SHORT HIGH-GRADIENT ACCELERATING SECTIONS
SHORT SUPERCONDUCTING SOLENOID LENSES

Fig. 3

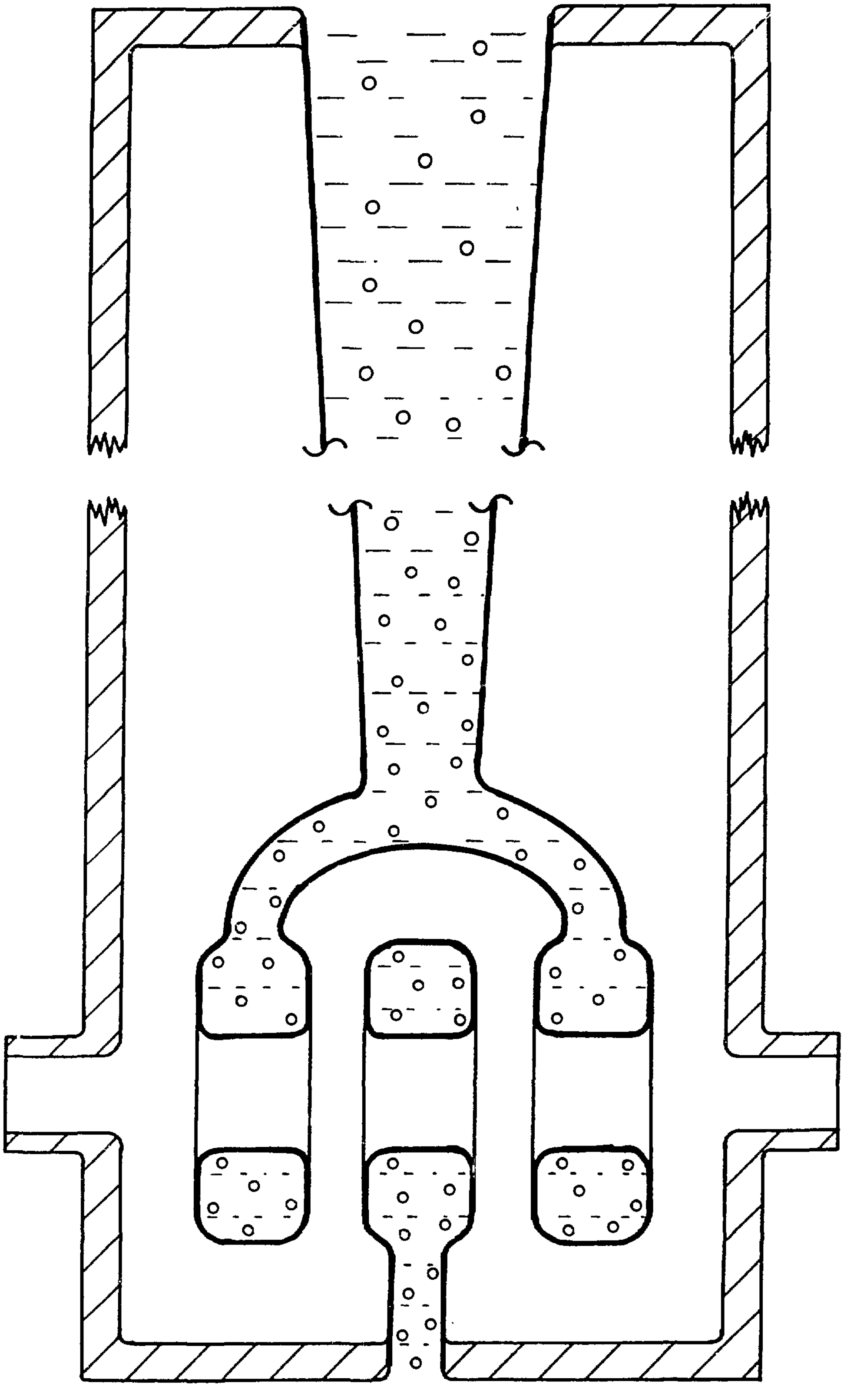

Fig. 4