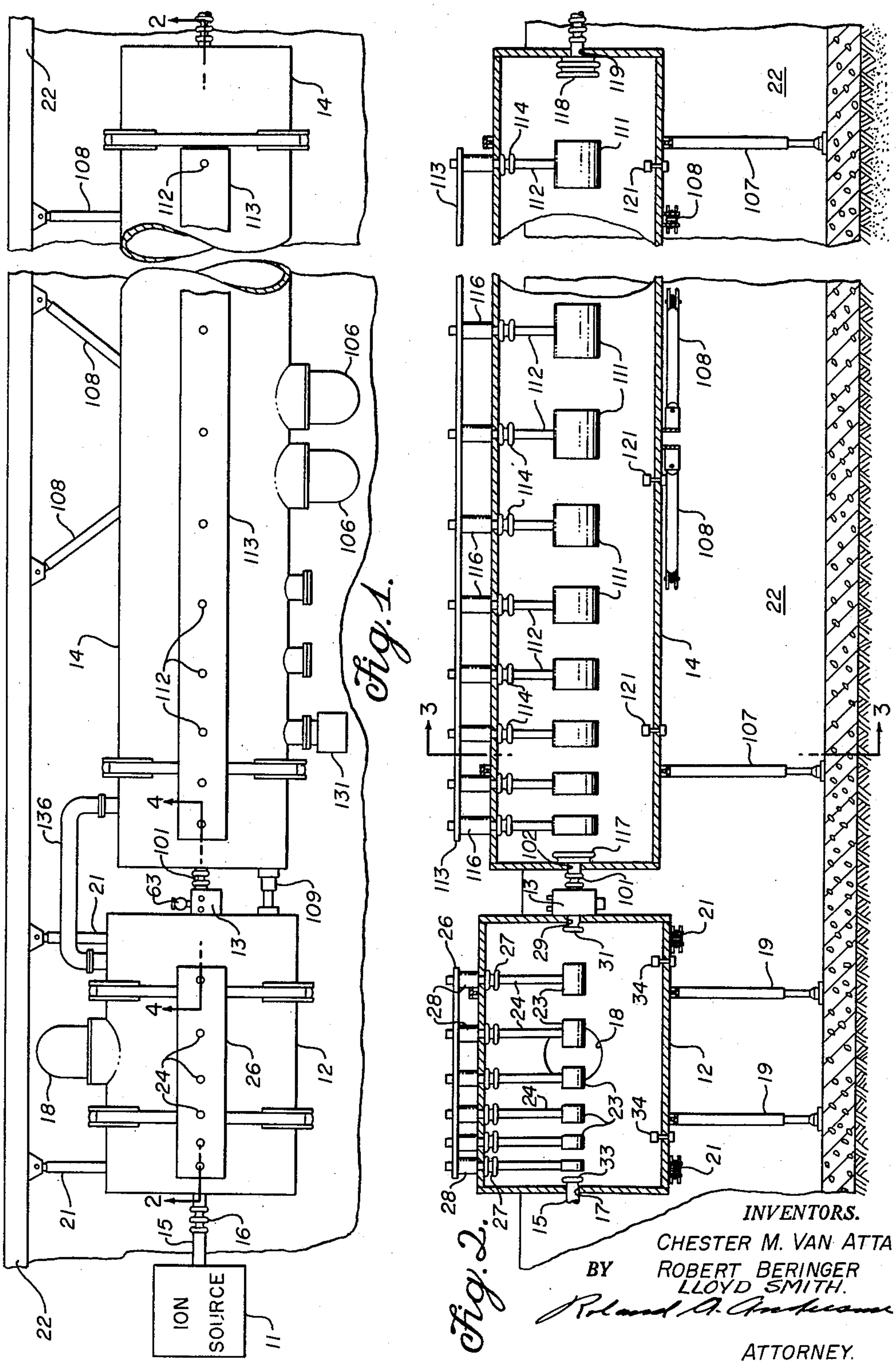
HEAVY ION LINEAR ACCELERATOR

Filed Oct. 10, 1957 3 Sheets-Sheet 1




INVENTORS.
CHESTER M. VAN ATTA
ROBERT BERINGER
LLOYD SMITH.

BY Roland A. Anderson

ATTORNEY.

Jan. 6, 1959 C. M. VAN ATTA ET AL 2,867,748

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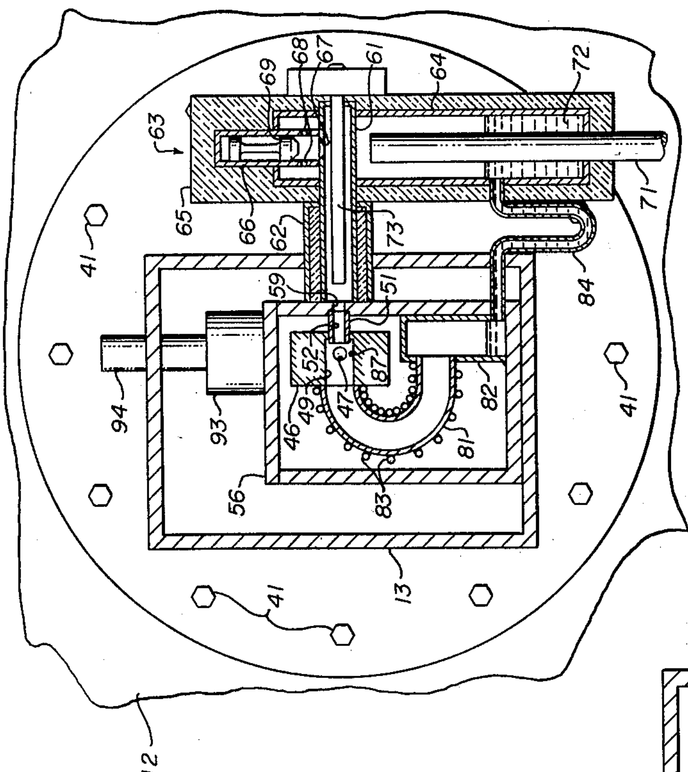

Fig. 6.

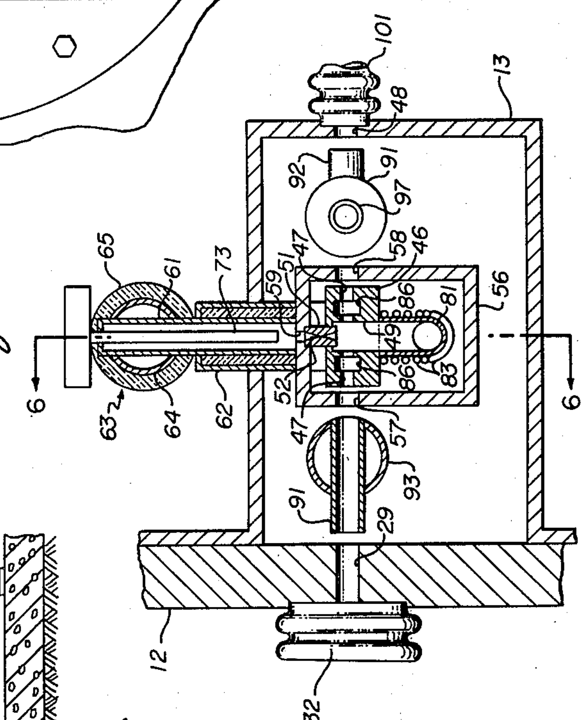

Fig. 5.

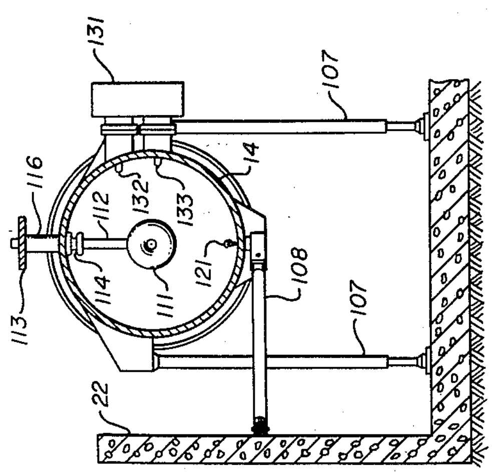

Fig. 3.

INVENTORS.
CHESTER M. VAN ATTA
BY ROBERT BERINGER
LLOYD SMITH.

Roland A. Anderson

ATTORNEY.

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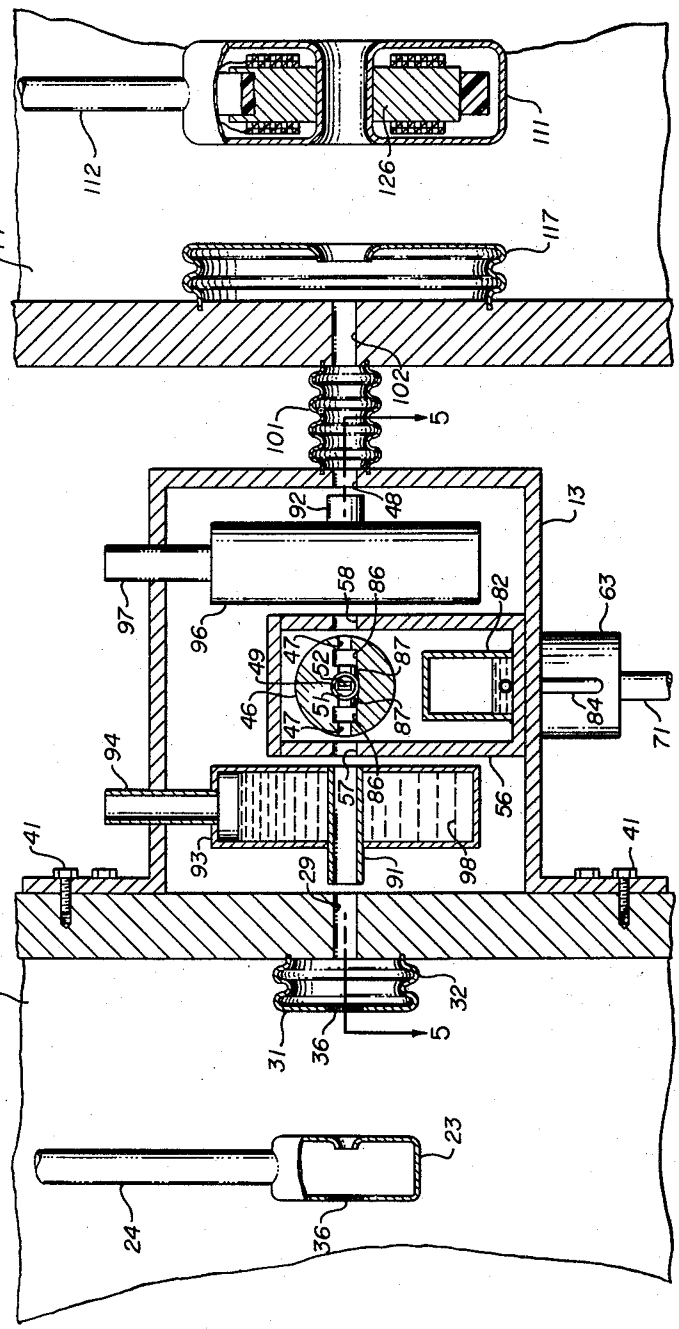
*Fig. 4.*




INVENTORS.
CHESTER M. VAN ATTA
ROBERT BERINGER
LLOYD SMITH

BY Roland A. Anderson

ATTORNEY.

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# HEAVY ION LINEAR ACCELERATOR

Chester M. Van Atta, Berkeley, Calif., Edward Robert Beringer, Hamden, Conn., and Lloyd Smith, Berkeley, Calif., assignors to the United States of America as represented by the United States Atomic Energy Commission

Application October 10, 1957, Serial No. 689,460

16 Claims. (Cl. 315—5.42)

The present invention relates to high-energy particle accelerators and, more particularly, to a linear accelerator of heavy ions.

High-energy particle accelerators are well known and have been highly developed in recent years, but are still limited to the acceleration of particles of substantially low mass, such as electrons, protons, deuterons, and alpha particles. In order to develop high energy in accelerated low-mass particles, to meet present day requirements, it is necessary to accelerate the particles to increasingly higher velocities. When the high-velocity particles are directed to bombard a target, the probability of incident particles giving up a portion, or all, of their energy to particles of the target decreases as the velocity increases. Thus the yield of desired results at the target also decreases as the velocity of the incident particles increases.

In addition to the effects of velocity of the accelerated particles, there is another disadvantage in the use of low-mass particles as projectiles. Particles, such as protons, deutrons, and alpha particles have a small number of nucleons, particularly neutrons, per particle and, while a single nucleon with an energy of about ten million electron volts produces single stage transmutations, such amount of energy is insufficient to ensure a high probability of penetration of the high potential barrier characteristic of the nuclei of high-mass target elements to produce multiple stage transmutations. With low-mass particles multiple stage transmutations are accomplished only by an improbable succession of single stage transmutations of a single nucleus of the target. Where the intervening stages result in unstable nuclei, the particular multiple stage transmutation reaction is even more improbable. Increasing the energy of the projectiles and the length of time during which the particles are incident upon the target tends to raise the probability, but at the same time introduces the aforementioned problem with respect to increased velocities.

To increase the probability of certain reactions at the target and the rate of production of such reactions, as well as possibly attaining results previously unobtainable, the present invention utilizes heavy ions as the projectile particles. The term "heavy ions" is defined, for present purposes, as charged particles formed from elements with atomic weight in the range from 12 (carbon) to 40 (argon).

Of the various types of high-energy accelerators it has been determined on the basis of cost, simplicity of construction, and convenience of operation that a linear accelerator is best adapted for heavy-ion acceleration. Such choice is also based upon the fact that multiply-charged heavy ions carry large amounts of energy when accelerated and at lower velocities than is possible for the low-mass projectiles. The foregoing is readily apparent from the expression for energy per nucleon as expressed in the following formula for the linear acceleration of charged particles:

$$U = k \cdot LE \cdot \frac{e}{m}$$

where U represents energy per nucleon for a particle having a charge, $e$, and a mass, $m$, L is the length of the accelerator, E is the value of the voltage gradient of the accelerating radio-frequency voltage, and $k$ is a constant of proportionality.

It is also to be seen from the above expression that, for a given value of energy per nucleon, an increase in the value of $m$ requires an increase in the value of the product LE. Further, it is apparent that an increase in the value of the charge, $e$, of the particle also satisfies the equation, as well as, would a more expensive increase in either L or E. Thus, the present invention provides a linear accelerator for heavy ions which are substantially the nuclei of one of the elements between carbon (12) and argon (40).

Since there are at present no known efficient sources of multiply-charged particles providing projectiles having a charge-to-mass ratio of 0.25 or greater, it is necessary to utilize a source of ions having a charge-to-mass ratio of about 0.15 and raise the ratio prior to final acceleration. The change in charge-to-mass ratio may be accomplished by a stripping foil, which removes additional orbital electrons from the ions; however, it has been found that such stripping foils are necessarily thin and are therefore limited to beams of ions having a very low density and also by the fact that an appreciable portion of the beam is lost at the foil. A more efficient stripper has been found to be a jet stream of a vapor, such as mercury vapor, directed transversely across the path of the beam.

It is therefore an object of the present invention to provide a new and improved linear accelerator.

Another object of the invention is to provide a method and apparatus for the acceleration of ions of elements of substantially heavy atomic weight to precisely uniform high energies.

Still another object of the invention is to provide a high-energy linear accelerator of heavy ions having a single source of accelerating energy at a fixed frequency.

A further object of the invention is to provide an efficient stripper of orbital electrons from partially-charged heavy ions.

A still further object of the invention is to provide a new and improved vapor type stripper of orbital electrons from partially-charged heavy ions for a linear accelerator.

Other objects and advantages of the invention will be apparent in the following description and claims considered together with the accompanying drawing, in which:

Figure 1 is a plan view of a linear accelerator of heavy ions;

Figure 2 is a sectional view of the accelerator, taken along the line 2—2 of Fig. 1;

Figure 3 is a cross-section of the accelerator, taken along the line 3—3 of Fig. 2;

Figure 4 is a sectional view of the ion stripper and a portion of the accelerator, taken along the line 4—4 of Fig. 1;

Figure 5 is a sectional view of the ion stripper, taken along the line 5—5 of Fig. 4; and

Figure 6 is a further sectional view of the ion stripper, taken along the line 6—6 of Fig. 5.

Referring to the drawing in detail, Fig. 1 in particular, there is provided a conventional ion source **11**, a preaccelerator tank **12**, an ion stripper housing **13**, and a post-stripper accelerator tank 14, with such elements linearly aligned in the order set forth. A suitable ion source 11 is described by Anderson et al. in U. S. Patent No. 2,839,706 entitled "Pulsed Ion Source," which issued on June 17, 1958, and is capable of providing a substantial output beam current of heavy ions (previously defined) having a light charge, such that the charge-to-mass ratio is about 0.15.

A tube 15 with a bellowed section 16 is extended from the output of the ion source 11 to an opening 17, in the preaccelerator tank 12, centered on the longitudinal axis of the tank so that the ion beam from the source is projected through the tank along the axis. The preaccelerator tank 12 is cylindrical and vacuum tight with a vacuum pump (not shown) suitably attached to a manifold 18 communicating with the interior of the tank. Vertical support for the tank 12 is provided by a plurality of extendible legs 19, suitably hinged at both ends. Stabilizer rods 21, similar to the legs 19, extend between a vertical wall 22 and the tank 12 to provide lateral support. The adjustability of the legs 19 and rods 21 provides for suitable alignment of the source 11 and tank 12.

Within the preaccelerator tank 12 there is disposed a plurality of drift tubes 23 (see Fig. 2), which are individually and suitably supported by stems 24 in spaced-apart relation and with the center line of each lying along the longitudinal axis of the tank. Such drift tubes 23 are of graduated length, increasing from the ion source end of the tank 12, and are spaced with the gaps between similarly increasing. The length of the drift tubes and the spacing are readily calculated from well-known formulae of the linear accelerator art. For positioning the drift tubes 23 coaxially within the tank 12, the stems 24 are suitably and adjustably secured to a plate 26 through vacuum sealing bellows 27 at the wall of the tank and through insulators 28. As an exit from the tank 12 for the beam accelerated along the axis, there is provided an opening 29 centered on the axis in the end opposite to the ion source end. An adjustable half drift tube 31, as by a section of bellows 32 (see Fig. 4), is suitably mounted on the end plate of the tank 12 about the exit opening 29 and a similar half drift tube 33 of smaller dimension is mounted about the entrance opening 17. Such half drift tubes 31, 33 are externally adjustable to provide alignment adjustments and tuning adjustments with respect to the resonant cavity established within the tank 12. Several inductance-capacitance tuning probes 34 are disposed within the preaccelerator tank 12 and are externally adjustable as a further aid in tuning the resonant cavity.

To overcome radial defocussing of the ions of the beam in an electric field between the drift tubes 23 in the preaccelerator tank 12, a focussing grid 36 (see Fig. 4) is mounted across the entrance opening (facing toward the ion source 11) of each of the drift tubes. A more efficient focussing principle is known in the art as alternating gradient focussing; however, at substantially low energy and velocity of the ions, the drift tube is not long enough to carry the required magnet structure and, further, it is not feasible to supply the required current to such magnet.

The ion stripper housing 13 is mounted, as by bolts 41, on the end of the preaccelerator tank 12 about the exit opening 29 (see Fig. 4). As has been set forth previously the desired ion stripping may be accomplished by a foil, but for reasons of efficiency of operation and the difficulty of maintaining a foil in a high value of beam current, the foil stripper has been discarded. A block 46 is disposed in the housing 13 with a beam passage 47 having a center line aligned with that of the exit opening 29 of the preaccelerator tank 12. Thus, the ion beam, as accelerated through the preaccelerator tank 12, enters the stripper housing 13 and proceeds through the passage 47 to emerge from the housing at an aligned opening 48.



A vapor passage 49 is also provided in the block 46 and is disposed transversely with respect to the beam passage 47 to intersect such passage. To provide a jet stream of vapor transversely across the path of the ion beam, a nozzle 51 is mounted within one end of the vapor passage 49. Such nozzle 51 has a narrow elongated slot 52 at the throat thereof which is disposed along a plane transverse to the center line of the beam passage 47. Also, from the slot 52 toward the beam passage 47 the nozzle 51 is provided with divergent walls. Thus, vapor forced through the nozzle 51 projects a wedge-shaped jet stream of vapor across the path of the ion beam to strip further orbital electrons from the ions.

A heat shield 56 is mounted within the housing 13 to surround the block 46 and is provided with oppositely disposed openings 57, 58 in alignment with the beam passage 47 and, also, with an opening 59 engaging one end of the nozzle 51 (see Figs. 5 and 6). A vapor tube 61 communicating with the opening 59 in the heat shield 56 is extended externally through the housing 13. Such tube 61 is provided with a heat jacket 62, which is coaxially disposed, and is terminated in a boiler 63. The boiler 63 comprises a tank 64 having a heat jacket 65 and a reentrant portion 66 extended to communicate with an opening 67 in the vapor tube 61. Several ports 68 are provided in the reentrant portion 66 to permit passage of vapor from the tank 64 into the vapor tube 61. To control the flow of vapor a piston type valve 69 is provided in the reentrant portion 66 and is externally controllable (not shown) to open and close the ports 68 and opening 67. A suitable heating element 71 is extended into the tank 64 to heat a material 72 to be vaporized. To prevent condensation in the vapor tube 61, as well as to control pressure of the vapor, a pressure regulated heating element 73 is extended coaxially into and for substantially the length thereof.

To collect and condense the vapor after traversal of the ion beam a curved tube 81 (see Fig. 6) is extended from the vapor passage 49 in the block 46 to a reservoir 82 with both the curved tube and reservoir disposed within the heat shield 56. To cool the curved tube 81 and provide condensation of the vapor, a coil of tubing 83 is disposed about the tube and suitably connected to a source of coolant (not shown). Thus the vapor condenses in the tube 81 and the condensate flows into the reservoir 82. A tube 84 having a conventional U-shaped trap extends from the reservoir 82 to the tank 64 of the boiler 63 where the condensate is re-vaporized.

To minimize the amount of the stripping vapor escaping from the housing 13 into the preaccelerator tank 12 and the post-stripper accelerator tank 14, trapping chambers 86 are provided along the beam passage 47 with one disposed on either side of the intersection with the vapor passage 49 (see Figs. 4 and 5). Such chambers 86 are merely enlargements of the beam passage 47, the walls of which are cooled sufficiently by thermal contact with the curved condensing tube 81. Drainage of the trapping chambers 86 is provided by small bores 87 extended from the chambers to the vapor passage 49.

In order to further minimize the effect of escaping vapor particles into the accelerator tanks 12, 14, the beam passage 47 is lengthened by disposing a condensing tube 91 in alignment between the exit opening 29 of the tank 12 and the opening 57 of the heat shield 56, and a second condensing tube 92 in alignment between the opening 58 of the shield and the opening 48 of the housing 13. To prevent heat transfer between the condensing tubes 91, 92 and the heat shield 56, such elements are suitably spaced apart. A coolant vessel 93 is disposed to encase a portion of the condensing tube 91 with a tube 94 extended through the housing 13. Similarly, a coolant vessel 96 is disposed to encase a portion of the condensing tube 92 with a tube 97 extended through the housing 13. The tubes 94, 97 provide inlets for the introduction of a coolant 98, such as liquid nitrogen, into the vessels **93**, **96**, respectively. Thus, those vapor particles, which escape through the beam passage **47**, are cooled to a condensate in the condensing tubes **91**, **92** and frozen in the tubes to prevent entrance into the accelerator tanks **12**, **14**.

The ion beam leaving the ion stripper housing **13** is channeled through a tubular bellows **101** extended from the opening **48** of the housing to an entrance opening **102** of the post-stripper accelerator tank **14**. Such opening **102** is centered about the longitudinal axis of the tank **14** and, therefore, the axis of each of the accelerator tanks **12**, **14** is a continuation of the other. In the illustrated embodiment of the invention of the drawing, the post-stripper accelerator tank **14** is longer and has a smaller diameter than the preaccelerator tank **12**, for a reason which will be apparent in the following description. In other respects the tank **14** is similar to the other tank **12** and is provided with manifolds **106** which are connected to vacuum pumps (not shown) for evacuation of the tank. Vertical support is provided by adjustable legs **107**, lateral support is provided by adjustable stabilizer rods **108**, and the spacing between the accelerator tanks **12**, **14** is provided by an adjustable jack type rod **109** extended therebetween (see Figs. 1 and 2).

A second plurality of drift tubes **111** is disposed coaxially within the post-stripper accelerator tank **14** by stems **112** which are adjustably secured to a plate **113** through vacuum-sealing bellows **114** at the wall of the tank and through insulators **116**. Again, the drift tubes **111** are of graduated lengths, increasing from the stripper housing end of the tank **14**, and are spaced apart with the gaps similarly increasing. Also, an adjustable half drift tube **117** is disposed at the entrance opening **102** of the tank **14** and a second adjustable half drift tube **118** is disposed at an axially positioned exit opening **119** which leads to a target chamber (not shown).

Within the post-stripper accelerator tank **14**, a plurality of externally adjustable inductance-capacitance tuning probes **121** are provided to adjust an accelerating electric field in the tank **14** to a substantially constant value for the length of the tank. Since the ions of the beam in the post-stripper accelerator tank **14** have a substantial energy and velocity, the length of the drift tubes **111** is sufficiently large to permit use of alternating gradient focussing and magnet currents for such focussing are feasible; therefore, each of the drift tubes **111** is suitably provided with strong focussing electromagnets **126** (see Fig. 4). Such magnets are suitably excited by leads (not shown) extended through the stems **112** to an externally positioned source (not shown) of electrical power.

To excite the post-stripper accelerator tank **14** with an axial electric field, in the manner well known in the accelerator art, at least one high frequency oscillator **131** is provided with the output suitably coupled to the tank, as by a drive loop **132** and a feedback grip loop **133** (see Fig. 3). The frequency of oscillation of the oscillator **131** is the natural resonant frequency of the post-stripper accelerator tank **14** and, as has been set forth above, the tuning loops are adjusted to provide a substantially constant value of the excitation for the length of the tank.

A coaxial transmission line **136** (see Fig. 1) having a length equal to one wavelength of the excitation frequency (or an integral multiple thereof) is extended between the two accelerator tanks **12**, **14** with the ends of the line, respectively and suitably, coupled to the tanks, as by coupling loops (not shown). In such manner the preaccelerator tank **12** is excited with an axial electric field, which is at the same frequency and in phase with that of the post-stripper accelerator tank **14**. Thus, both accelerator tanks **12**, **14** are excited by a single oscillator **131** (or bank of parallel operated oscillators) and the problem of phasing and frequency control between separate oscillators for each tank is eliminated. It is to be recalled that adjustable tuning probes **34** are provided in the preaccelerator tank **12** to establish the same resonant frequency for both of the accelerator tanks **12**, **14**.

Now consider the operation of the linear accelerator as described in structural detail in the foregoing paragraphs. With the two accelerator tanks **12**, **14** and the stripper housing **13** suitably evacuated, the oscillator **131** is started in operation to provide a high value of voltage at a constant high value of frequency. The value of the frequency is equal to the natural resonant frequency of the resonant cavity provided by the post-stripper accelerator tank **14**. The tuning probes **121** of such tank **14** are adjusted so that the axial electric field in the tank is a substantially constant value throughout the length thereof. Under such condition of the post-stripper accelerator tank **14**, electrical energy is coupled by the transmission line **136** to the preaccelerator tank **12**. Now, since the preaccelerator tank **12** has different dimensions than the post-stripper accelerator tank **14**, the natural resonant frequency is different and it is necessary to tune the preaccelerator tank, by adjustment of the inductance-capacitance tuning probes **34**, to the resonant frequency of the post-stripper accelerator tank and, necessarily, to the frequency of the oscillator **131**.

Now, with the axial accelerating electric fields suitably established in the tanks **12**, **14**, in accordance with the foregoing, operation of the ion source **11** is initiated to project a beam of partially-charged particles of a substantially heavy element (from carbon 12 to argon 40) along the axis of the preaccelerator tank **12**. As stated previously, the ions injected by the ion source **11** have a charge-to-mass ratio of substantially 0.15 and a substantially low value of velocity. Several considerations influence the selection of the final energy of the partially-charged ions at the exit end of the preaccelerator tank **12**. Among such considerations is that value of energy at which alternate gradient focussing is feasible and, also, that value of energy at which the removal of additional orbital electrons from the ions is efficiently feasible. It has been determined by theory and by practice that such value of energy for heavy ions, as defined, is substantially one m. e. v. per nucleon. From the determination of the energy per nucleon to be imparted to the partially-charged ions, the exact structural dimensions and electrical details of the preaccelerator tank **12**, including drift tubes, are determined from the formula previously set forth and from well-known formulae of the linear accelerator field (see High-Energy Accelerators by M. Stanley Livingston, Interscience Publishers, Inc., New York, 1954) when, for example, an accelerating electric field of about 0.5 million volts per foot is established in the tanks **12**, **14**. Thus, partially-charged heavy ions having a charge-to-mass ratio of 0.15 are accelerated through the preaccelerator tank **12** to an energy of about one m. e. v. per nucleon with radial defocussing forces counteracted by the grids **36** installed at the entrance ends of the drift tubes **23**.

The preaccelerated beam then passes into the stripper housing **13** through the passages provided. The liquid material **72**, such as mercury, is heated in the boiler **63** and the resulting vapor is controllably channeled to the nozzle **51** disposed in the transverse vapor passage **49** of the block **46**. A jet stream of mercury vapor in a thin curtain is projected transversely of the preaccelerated beam proceeding along the beam passage **47** of the block **46**. For suitable electron stripping the thickness of the vapor curtain is diverging in the direction away from the nozzle **51**. By the use of the vapor curtain a substantially small value of micrograms of mercury per square centimeter is exposed to the beam, as required for efficient electron stripping, which also provides a minimum amount of scattering from collisions. The reaction between the ions of the beam and the particles of the controlled mercury vapor (both as to density and velocity) is to provide an emergent beam of ions having a charge-to-mass ratio of substantially 0.30 with a slight loss of energy because of such reaction.

Those particles of the mercury vapor that escape from the vapor passage **49** because of scattering due to collisions or because of the vacuum system disposed on either side, first encounter the trapping chambers **86**. Any of such escaping vapor particles, which are not caught in the trapping chambers **86**, are condensed and frozen within the condensing tubes **91, 92**. In such manner the vapor particles are prevented from entering the accelerating tanks **12, 14** where destructive sparking readily occurs with the presence of a gas or vapor. After traversing the beam passage **47** the majority of the vapor is condensed in the curved tube **81** and is eventually returned in liquid form to the boiler **63**.

The highly stripped ions (having a charge-to-mass ratio of 0.30) then enter the post-stripper accelerator tank **14** with an initial energy of substantially one m. e. v. per nucleon. Again the exact structural and electrical details, including the drift tubes, are determined from the above-referenced formulae (as for the preaccelerator) when the final energy per nucleon is known. Thus, the more highly charged ions entering the post-stripper accelerator tank **14** are further accelerated to a higher value of energy per nucleon with the radial defocussing forces counteracted by the alternate gradient strong focussing magnets **126** disposed within the drift tubes **111**. For a majority of the foreseeable uses of the output beam of the accelerator a minimum final energy of about ten m. e. v. per nucleon is required which means that the final energy is 120 m. e. v. for nuclei of carbon up to 400 m. e. v. for nuclei of argon. The foregoing is merely an example of the energies for certain uses and is not to be considered limiting upon the invention.

While the salient features of the present invention have been described in detail with respect to one embodiment it will be apparent that numerous modifications may be made within the spirit and scope of the invention and it is therefore not desired to limit the invention to the exact details shown except insofar as they may be defined in the following claims.

What is claimed is:

1. In a method of accelerating ions, the steps comprising ionizing atoms of an element to a first charge-to-mass ratio, accelerating the resultant ions to an energy substantially equal to one m. e. v. per nucleon, stripping orbital electrons from such accelerated ions to provide a second charge-to-mass ratio, and finally accelerating the resultant stripped ions to a final energy of at least ten m. e. v. per nucleon.

2. In a method of accelerating ions, the steps comprising ionizing atoms of a relatively heavy element to a first charge-to-mass ratio, linearly accelerating the resultant ions to an energy substantially equal to one m. e. v. per nucleon, interposing a transversely flowing thin curtain of an elemental vapor in the path of such accelerated ions to increase the charge-to-mass ratio of ions, and finally linearly accelerating the ions of increased charge to a final energy of at least ten m. e. v. per nucleon.

3. In a method of accelerating ions, the steps comprising ionizing atoms of a relatively heavy element to a charge-to-mass ratio of substantially 0.15, accelerating the resultant ions to an energy substantially equal to one m. e. v. per nucleon, stripping orbital electrons from such accelerated ions to increase the charge-to-mass ratio to substantially 0.30, and finally accelerating the ions of increased charge to a final energy of at least ten m. e. v. per nucleon.

4. In a method of accelerating ion, the steps comprising ionizing atoms of an element between carbon and argon on the atomic scale to a charge-to-mass ratio of substantially 0.15, accelerating the resultant ions along a linear path to an energy substantially equal to one m. e. v. per nucleon, interposing a transversely flowing thin curtain of mercury vapor across the path of such accelerated ions to increase the charge-to-mass ratio to substantially 0.30, and finally accelerating the ions of increased charge along a linear path aligned with the first-mentioned path to a final energy of at least ten m. e. v. per nucleon.

5. In a method of accelerating ions, the steps comprising ionizing atoms of an element between carbon and argon on the atomic scale to a charge-to-mass ratio of substantially 0.15, accelerating the resultant ions along a linear path to an energy substantially equal to one m. e. v. per nucleon, overcoming radial defocussing of such ions during acceleration by eliminating diverging electric accelerating fields, interposing a transversely flowing thin curtain of mercury vapor across the path of such accelerated ions in increase the charge-to-mass ratio to substantially 0.30, finally accelerating the ions of increased charge along a linear path aligned with the first-mentioned path to a final energy of at least ten m. e. v. per nucleon, and compensating radial defocussing of the ions of increased charge during final acceleration by alternate gradient strong focussing fields.

6. In a high-energy accelerator, the combination comprising a source of multiply-charged ions disposed to direct said ions along a linear path, a first linear accelerator disposed along said path to increase the energy of said multiply-charged ions to an intermediate value, a curtain of an elemental vapor disposed transversely of said path at the exit end of said first linear accelerator to increase the charge of said ions by electron stripping, and a second linear accelerator disposed adjacent to said curtain and aligned along said path to further increase the energy of the ions of increased charge to a final high value.

7. In a high-energy accelerator, the combination comprising a source of multiply-charged ions disposed to direct said ions along a linear path, a first linear accelerator disposed along said path to increase the energy of said multiply-charged ions to an intermediate value, a curtain of an elemental vapor disposed transversely of said path at the exit end of said first linear accelerator to increase the charge of said ions by electron stripping, a first vapor trapping means disposed between said curtain and said first linear accelerator, a second linear accelerator disposed adjacent to said curtain and aligned along said path to further increase the energy of the ions of increased charge to a final high value, and second vapor trapping means disposed between said curtain and said second linear accelerator.

8. In a high-energy accelerator, the combination comprising a source of multiply-charged ions disposed to direct said ions along a linear path, a first linear accelerator disposed along said path to increase the energy of said multiply-charged ions to an intermediate value, means projecting a thin continuously flowing curtain of mercury vapor transversely of said path at an exit opening of said first linear accelerator to increase the charge of said ions by electron stripping, a first vapor trap disposed between said means and said first linear accelerator, a second linear accelerator disposed adjacent to said means and aligned along said path to further increase the energy of the ions of increased charge to a final high value, and a second vapor trap disposed between said means and said second linear accelerator.

9. In a high-energy accelerator, the combination comprising a source of ions having a charge-to-mass ratio of substantially 0.15, said source directing said ions along a linear path, a first linear accelerator disposed along said path to increase the energy of said ions to substantially one m. e. v. per nucleon, mercury vapor means disposed adjacent said first linear accelerator to project a thin jet curtain of such vapor transversely of said path to increase the charge-to-mass ratio of said ions to at least 0.30, a first vapor trapping means disposed between said

curtain and said first linear accelerator, a second linear accelerator disposed adjacent to said mercury vapor means and aligned along said path to further increase the energy of the ions of greater charge-to-mass ratio to a final energy of at least ten m. e. v. per nucleon, and second vapor trapping means disposed between said curtain and said second linear accelerator.

10. In a stripper of orbital electrons from lightly-charged ions for a high energy accelerator, the combination comprising a vacuum-tight housing, a block disposed in said housing and having a beam passage for ions and a transversely intersecting vapor passage, a nozzle mounted at one end of said vapor passage, a source of vapor under pressure connected to said nozzle to provide a stream of vapor across said beam passage, a vapor condenser disposed at the other end of said vapor passage, and vapor traps disposed along said beam passage on either side of said vapor passage to prevent escape of said vapor.

11. In a high-energy accelerator, the combination comprising a source of multiply-charged ions disposed to direct said ions along a linear path, a first linear accelerator disposed along said path to receive said multiply-charged ions and to increase the energy thereof to an intermediate value, said first linear accelerator having a plurality of drift tubes with a focusing grid disposed across the entrance end of each drift tube, a vacuum-tight housing having axially aligned inlet and outlet openings with said inlet opening in axially aligned pressure sealed communication with an exit opening of said first linear accelerator, a block disposed within said housing having a beam passage for said multiply-charged ions of intermediate energy in alignment with said openings and a transversely intersecting vapor passage, a nozzle mounted at one end of said vapor passage, a source of elemental vapor under pressure connected to said nozzle to provide a thin stream of vapor across said beam passage to increase the charge-to-mass ratio of said ions passing therethrough, a vapor condenser disposed at the other end of said vapor passage, vapor traps disposed along said beam passage on either side of said vapor passage to prevent escape of said vapor, and a second linear accelerator disposed adjacent to said housing in axially aligned communication with said outlet opening to accelerate said ions of increased charge to a final high energy, said second linear accelerator having a plurality of drift tubes with alternate gradient strong focusing magnets disposed in each of said drift tubes.

12. In a heavy ion accelerator, the combination comprising a source of multiply-charged ions of an element between carbon and argon on the atomic scale, said source directing said ions along a linear path, a first linear accelerator disposed along said path to receive said ions and to increase the energy thereof to an intermediate value, an ion stripper housing having axially aligned inlet and outlet openings disposed along said path, said inlet opening communicating in pressure sealed relationship with an accelerated ion exit opening of said first linear accelerator, a block disposed within said housing having an ion beam passage in alignment with said openings for receiving said multiply-charged ions of intermediate energy and a transversely intersecting vapor passage, said beam passage including enlarged chambers on either side of said vapor passage, a nozzle mounted within one end of said vapor passage and having a narrow elongated slot disposed at the throat thereof along a plane transverse to the center line of said beam passage, said nozzle having walls diverging from said slot toward said beam passage, a heat shield encompassing said block with oppositely disposed openings in alignment with said beam passage and an opening engaging said nozzle, a boiler containing mercury connected to said nozzle to supply mercury vapor under pressure thereto and thereby provide a continuously moving thin curtain of mercury vapor across said beam passage to increase the charge-to-mass ratio of said ions passing therethrough, a reservoir disposed within said housing at a level below said block, a cooled condensing tube extending from the other end of said vapor passage to said reservoir, a condensate return tube connected between said reservoir and said boiler for returning condensate thereto for re-vaporization, a pair of cooled condensing tubes respectively disposed in axial alignment with said beam passage between the inlet and outlet openings of said housing and the corresponding beam passage openings of said heat shield, and a second linear accelerator disposed along said path in axially aligned communication with the outlet opening of said stripper housing to accelerate said ions of increased charge to a final high energy.

13. Apparatus for providing a jet stream of vapor transverse to an ion beam comprising a vacuum-tight housing, a block disposed in said housing and having a beam passage for receiving said ion beam and a transversely intersecting vapor passage, a nozzle mounted within one end of said vapor passage and having a narrow elongated slot at the throat thereof disposed along a plane transverse to the center line of said beam passage, a source of vapor under pressure connected to said nozzle to provide a stream of vapor across said beam passage, a vapor condenser disposed at the other end of said vapor passage, and vapor condensing means disposed along said beam passage on either side of said vapor passage for condensing and trapping vapor escaping from said vapor passage.

14. Apparatus as defined by claim 13 but wherein said vapor condenser comprises a reservoir disposed within said vacuum housing at a level below said block, a cooled condensing tube extending from said vapor passage to said reservoir, and a condensate return tube connected between said reservoir and said source for returning condensate thereto for re-vaporization.

15. Apparatus for providing a jet stream of vapor transverse to an ion beam comprising a vacuum housing having axially aligned inlet and outlet openings to facilitate traversal of the housing by an ion beam, a block disposed within said housing having a beam passage in alignment with said openings and a transversely intersecting vapor passage, said beam passage including enlarged chambers on either side of said vapor passage, a nozzle mounted within one end of said vapor passage and having a narrow elongated slot disposed at the throat thereof along a plane transverse to the center line of said beam passage, said nozzle having walls diverging from said slot toward said beam passage, a heat shield encompassing said block with oppositely disposed openings in alignment with said beam passage and an opening engaging said nozzle, a boiler connected to said nozzle to supply vapor under pressure thereto and thereby provide a stream of vapor across said beam passage, a vapor condenser disposed within said heat shield and connected to the other end of said vapor passage, and condensing tubes respectively disposed in axial alignment between the inlet and outlet openings of said housing and the corresponding beam passage openings of said heat shield.

16. A heavy ion accelerator comprising a source of multiply-charged heavy ions disposed to direct said ions along a linear path, a pre-accelerating tank disposed along said path in receiving relationship to said ions and having a first natural resonant frequency, a plurality of drift tubes disposed in spaced-apart relation within said tank with the center line of each drift tube lying along said path, a focusing grid disposed across the entrance end of each drift tube, an ion stripper housing having axially aligned inlet and outlet openings disposed along said path with the inlet opening communicating with an axial exit opening of said pre-accelerating tank, means disposed within said housing projecting a thin continuously flowing curtain of mercury vapor transversely of said path to increase the charge of ions by electron stripping, a first vapor trap disposed within said housing along said path

between said means and said inlet opening, a second vapor trap disposed within said housing along said path between said means and said outlet opening, a post-stripper accelerating tank disposed along said path in axially aligned communication with said outlet opening and having a second natural resonant frequency, a second plurality of drift tubes disposed in spaced-apart relation within said post-stripper tank with the center line of each drift tube lying along said path, an alternate gradient strong focusing magnet disposed in each of said second plurality of drift tubes, an oscillator coupled to said post-stripper tank and having a frequency equal to said second natural resonant frequency for exciting said post-stripper tank with an axial electrical field, adjustable tuning means disposed in said post-stripper tank to provide a substantially constant excitation along the length thereof, a transmission line coupled between said post-stripper and pre-accelerating tanks and having a length equal to one wavelength at the frequency of said oscillator, and adjustable tuning means disposed within said pre-accelerating tank to alter said first natural resonant frequency to the frequency of said oscillator and thereby excite the pre-accelerating tank with an axial electric field at the same frequency and in phase with that of said post-stripper tank whereby said ions are accelerated to an intermediate energy in said pre-accelerating tank and increased in charge in passing through said curtain of vapor to be thereafter accelerated to a final high energy in said post-stripper tank.

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