Nov. 14, 1967 R. J. VAN DE GRAAFF 3,353,107

HIGH VOLTAGE PARTICLE ACCELERATORS USING CHARGE TRANSFER PROCESSES

Filed Oct. 6, 1959 2 Sheets-Sheet 1

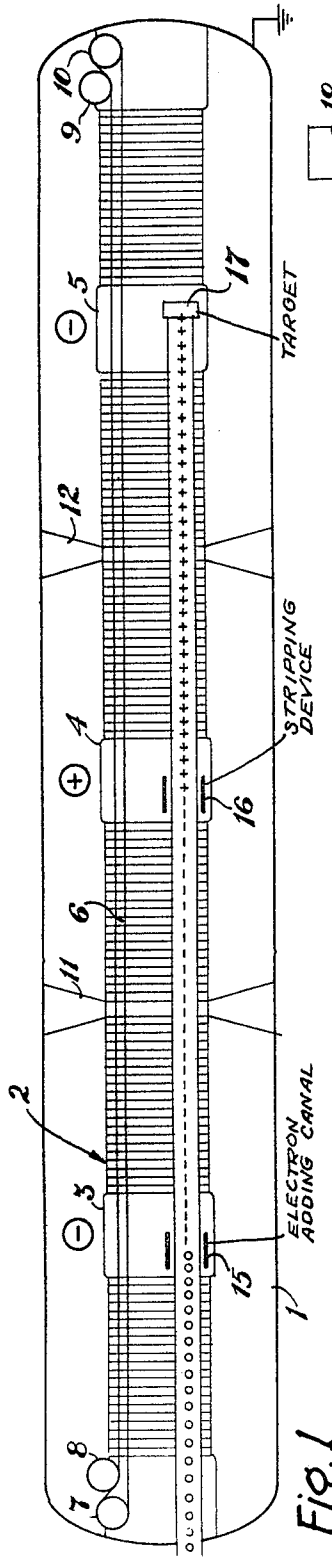


Fig. 1

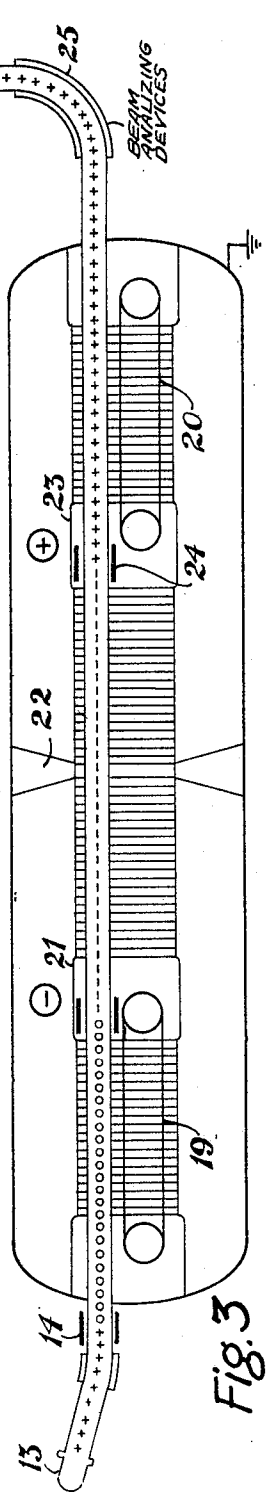


Fig. 3

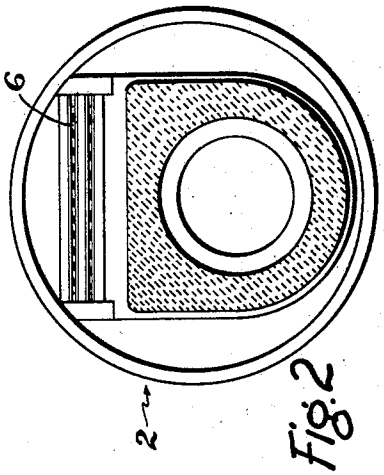


Fig. 2

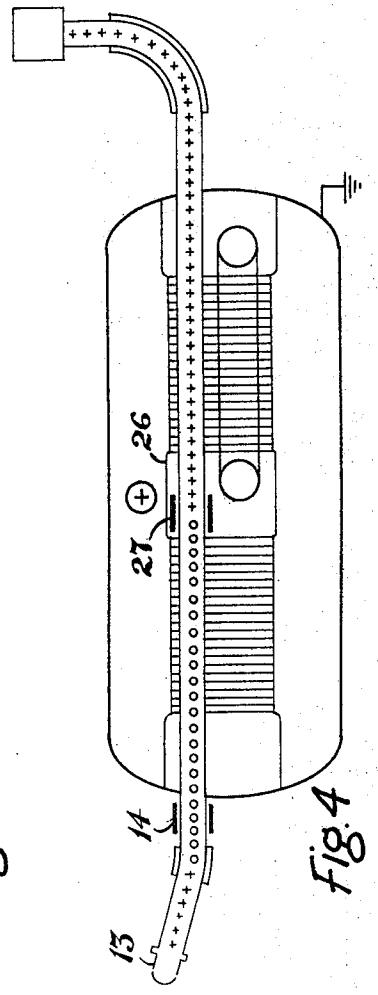


Fig. 4

Nov. 14, 1967 R. J. VAN DE GRAAFF 3,353,107

HIGH VOLTAGE PARTICLE ACCELERATORS USING CHARGE TRANSFER PROCESSES

Filed Oct. 6, 1959 2 Sheets-Sheet 2

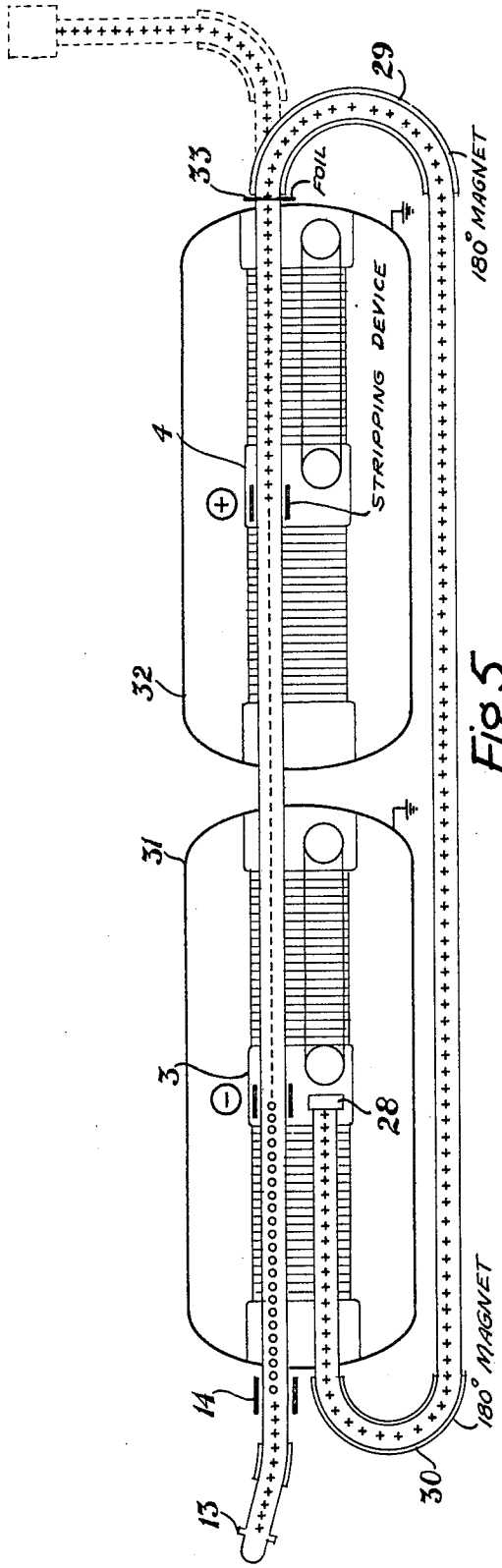


Fig. 5

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3,353,107

HIGH VOLTAGE PARTICLE ACCELERATORS USING CHARGE TRANSFER PROCESSES

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16 Claims. (Cl. 328—233)

This invention relates to new methods for the acceleration of charged particles to high velocity by means of high voltages and charge transfer processes. The invention comprehends tandem charge transfer processes wherein the charge state of the same beam of charged particles is changed more than once. In general there are three charge states, namely a particle may be negatively charged or positively charged or neutral. The invention also comprehends tandem acceleration in which the available voltage is applied more than twice to the same beam of charged particles so as to accelerate the same in at least three stages.

In the case of the usual type of electrostatic accelerator, positive ions are produced inside a high-voltage terminal and then accelerated to ground in one stage of acceleration. In the case of the conventional type of tandem accelerator, negative ions are produced at ground, and then accelerated to a high-voltage positive terminal. Within the terminal the swiftly moving negative ions are stripped of electrons, thus becoming positive ions, which then receive an additional acceleration from the terminal to ground. Thus the particle beam receives two stages of acceleration instead of one.

The principles and techniques used in such conventional tandem accelerators have been originated and developed over many years and in various laboratories. It is regretted that lack of space prevents full acknowledgments here. However, reference should at least be made to the following names: Dempster, Bennett, Kallmann, Alvarez, Marshall, Woodyard, Herb, Stier, Danforth, and Rose. A number of two-stage tandem accelerators have been constructed by High Voltage Engineering Corporation in Burlington, Mass.

By utilizing charge transfer processes in accordance with the invention, three principal advantages are derived therefrom, namely, (1) multiple use of the available D.C. voltage, (2) an external and grounded ion injector and (3) the use of multiply charged positive ions.

The limitation on the D.C. voltage available is imposed by the surrounding atmosphere or other insulator between the high voltage portions of the apparatus and the surrounding grounded objects. Atmospheric air can insulate a given voltage, but if this voltage is exceeded one must take special precautions, and the difficulties encountered increase as the voltage desired increases. For example, one can enclose the apparatus in a tank filled with gas under pressure in order to increase the available voltage, but the size of the tank increases at least with the cube of the voltage. In accordance with the tandem acceleration principles of the invention, it is possible to apply the available voltage which is permitted by the insulation several times to the same beam of charged particles. In one example hereinafter given, the available voltage may be applied four times to the same beam of charged particles.

The second advantage which the invention provides through its use of charge transfer processes is that it permits the positioning of the ion injector outside the high voltage region and at approximately ground potential. In the conventional D.C. accelerator either the target and beam analysis apparatus must be at high voltage or else the ion source must be at high voltage. By using charge transfer processes if possible to have both the ion source (or particle injector with its associated focusing and analyzing apparatus) at earth as well as having the final beam analysis and target apparatus at ground potential. This will be of increasing importance because it enhances the possibility of utilizing new techniques such as multiple-ion sources, apparatus for the polarization of particle beams, and equipment for beam pulsing, which are of tremendous scientific interest.

By using the preferred embodiment of the invention, the ion source is at ground rather than within the negative terminal, and this results in numerous advantages. In the first place, no space limitations are imposed on the ion source; in the conventional accelerator, only .1% of the total space required is within the high-voltage terminal and available for the ion source. In the second place, more power can be delivered to the source and more heat can be dissipated by cooling apparatus. More information as to the nature of the ion beam is available. The ion beam controls can be adjusted more readily; stabilization problems are simplified and, since plenty of power is available, standard vacuum tubes can be used in the stabilization circuit, and great stability may be obtained using high power RF techniques; pulsing, beam-analyzing, and diaphragming to select particular ions are all rendered more simple. In particular, a very simple circuit using a photomultiplier may be employed to control the deflection of the beam so that the beam is always directed precisely at the canal for charge exchange; such a circuit can have the accuracy of a conventional television-tube cathode ray control. Higher beam currents may be obtained by using a plurality of ion sources with converging outputs. Moreover, a plurality of ion sources, each providing a different type of ion, may be used in succession without dismantling the entire accelerator; thus, one could do four different experiments with two generator units and two magnets. As a result of ease of alteration and replacement, the source can be continuoutly improved while in use; the source may be a "bench source" feeding into a standard high-voltage acceleration tube.

The third principal advantage which the invention provides through use of charge transfer processes is that it permits more effective production and use of multiply charged positive ions. If the electron stripping devices are used in such a way that the positive ions that are created are multiply charged, the given D.C. voltage can produce many times the energy in electron volts than that available with singly charged positive ions which have been the rule in D.C. accelerators. With a three-stage or four-stage tandem accelerator it is possible to obtain a greater yield of stripping than with a two-stage tandem accelerator, so that greater intensities in the final beam may be obtained for a given intensity of the beam which is injected into the accelerator. Moreover, with the single stage tandem accelerator of the invention, it now becomes possible to produce doubly-charged helium ions or alpha particles. One example of the advantage of the neutral beam of the invention with regard to stripping in a single-stage tandem is the arrangement under construction for Chalk River in Canada. Here a 400 kilovolt accelerator is to be used as a neutral beam injector for helium particles for the large tandem accelerator now at Chalk River. The use of 400 kilovolts affords both a reasonable yield for producing the neutral beam and for stripping the neutral beam into doubly charged helium ions within the 5 megavolt terminal of the Chalk River accelerator. This 400 kilovolt injector with its power supplies, vacuum pumping system, controls and so forth would be far too large to install within the terminal of the high voltage accelerator so that the use of this source of alpha particles is made possible by the use of the neutral beam of helium particles.

In apparatus embodying the invention, the high-voltage terminals may derive their potential from any of a number of unidirectional voltage generators, such as an electrostatic belt-type generator or a transformer-rectifier set. In the following description thereof, the invention will be described as making use of an improved form of electrostatic belt-type generator; but the invention is not limited thereto, and the principles of the invention may be applied with equal success making use of other unidirectional voltage generators.

The invention may best be understood from the following detailed description thereof having reference to the accompanying drawings in which:

FIG. 1 is a diagrammatic view partly in side elevation and partly in longitudinal central section of a four-stage tandem accelerator constructed in accordance with the invention;

FIG. 2 is a transverse section of the column of the apparatus of FIG. 1 but showing greater detail and being to a larger scale than that of FIG. 1;

FIG. 3 is a diagrammatic view similar to that of FIG. 1 but showing a three-stage tandem accelerator constructed in accordance with the invention;

FIG. 4 is a diagrammatic view similar to that of FIG. 1 but showing a single stage tandem accelerator constructed in accordance with the invention; and

FIG. 5 is a diagrammatic view similar to that of FIG. 1 showing an alternative form of four-stage tandem accelerator constructed in accordance with the invention.

Referring to the drawings and first to FIG. 1 thereof, therein is shown a particle accelerator in which the available D.C. voltage may be used as many as four times over on the same charged particle beam. As has previously been noted, the available voltage is limited by the breakdown strength between the high voltage terminal and the surrounding tank. Thus while the length of the device in FIG. 1 is almost six times that of a single stage accelerator adapted to accelerate to the voltage available, the diameter of the device is no greater, so that four fold acceleration is obtained with less than a six fold increase in volume, as contrasted with an increase by four cubed.

Experience in the construction of electrostatic belt-type generators has shown that the volume of the tank enclosing the insulating gas surrounding the generator and the linear dimensions of the generator increase in proportion to more than the cube of the voltage. The increase is greater than the cube, due partly to increasing gradients and partly to the "total voltage" problem in vacuum tubes. In particular, the column length increases at a rate which is very much greater than the voltage. In accordance with the invention, on the other hand, the energy or equivalent voltage of the accelerated particles is increased over that obtainable by conventional D.C. accelerators by means of a linear increase in the dimensions of the apparatus.

Although it is possible, without departing from the spirit and scope of the invention, to mount a conventional negative ion source within the negative terminal, in the device shown in FIG. 1 both the original particle injector as well as the target and analyzing apparatus are at ground potential so that no limitation is imposed on their size. As a consequence the high voltage terminals may also be smaller since there is no need to handle the beam source and injection problems. In the device shown in FIG. 1 pulleys customarily present in the high voltage terminal have been eliminated and the single belt goes straight through all the high voltage terminals. Moreover, since the charge particles are not accelerated in a single long column but rather in a number of columns, the individual columns can be shorter and much smaller in diameter. The columns are shorter because since the total voltage is less, higher voltage gradients can be supported. Since the columns can be shorter, it follows that they can be smaller in diameter owing to mechanical support considerations. Referring now to FIG. 2 of the drawing, adjacent equipotential planes of the column and tube are electrically separated and mechanically supported by only one piece of glass, whereas in the conventional tandem design, there are five. The single piece of glass or other insulator in practical in the new design of the invention because the acceleration tube occupies a considerable part of the cross sectional area of the column. All the foregoing shows that the new electrostatic design of the invention provides a simpler and cheaper construction of the column and terminal.

A further advantage of the electrostatic design of the invention is the fact that in this design a smaller fraction of the radial insulating length available for a given tank is lost. That is to say, for a given inside diameter of the tank there is a certain terminal and column diameter which provides maximum voltage insulation across the gap. In conventional devices where the ion source and other apparatus must be stored within the terminal, the diameter of the terminal must be made greater than the value required simply for high voltage insulation. Thus, for example, the optimum diameter might be 15 inches, and the various apparatus required in the high voltage terminal might require that its diameter be thirty inches so that one would lose fifteen inches of insulating region. In fact, in principle the terminal diameter might be made even smaller than the calculated optimum for prevention of high voltage breakdown provided that intermediate shells are used between the terminal and the tank in accordance with my Patent No. 2,230,473, issued Feb. 4, 1941.

Referring now more specifically to FIGS. 1 and 2, the device therein shown comprises a tank **1** which is filled with an insulating gas under pressure. Within this tank there is supported a long column **2** which is similar to that of the conventional electrostatic belt-type generator, except that three high voltage terminals **3**, **4**, **5** are provided instead of one. The central high voltage terminal **4** is raised to a high positive voltage and the other two terminals **3**, **5** are raised to a high negative voltage. Electric charge is deposited and maintained on the high voltage terminals by means of a single insulating belt **6**, each end of which is supported on two pulleys **7**, **8**, **9**, **10** rather than one in order that the two runs of the belt may be as close together as possible despite the size of the pulley. The charge transfer is effected by well known charge transfer devices such as corona discharge and, if desired, both runs of the belt may participate in the charge transfer. Thus, for example, if the lower run of the belt is travelling from left to right, negative charge is deposited thereon at ground, and within the first high negative voltage terminal **3** an appropriate charge transfer device can be provided which not only removes the negative charge but also sprays positive charge onto the belt **6** so that in travelling from the first high voltage terminal **3** to the second high voltage terminal **4** the belt bears positive charges. Within the second high voltage terminal the positive charges are removed and negative charges sprayed on the belt, and these negative charges are then carried by the belt to the third high voltage terminal **5** where, if desired, positive charge may be sprayed on the belt in addition to the removal of the negative charge. This positive charge would then be removed at the grounded pulley. Similar arrangements may be provided on the reverse run of the belt.

It will be observed from FIG. 1 that, in addition to being supported at its ends, the long column **2** is also supported at the two ground planes **11**, **12** which are located mid-way between the high voltage terminals **3**, **4**, **5**.

At first glance it might be thought that it would be possible to inject positive ions at the left hand extremity or injection end of the apparatus and accelerate them to the first negative high voltage terminal **3** where they would be converted to negative ions and then further accelerated. Unfortunately the cross section of negative ion formation in this manner falls off rapidly with increasing energy of the positive ion source above a hundred kilovolts. Such an arrangement is thus inefficient. However,

one can still avoid the necessity of having the original positive ion source within a high voltage terminal by performing the electron adding process in two stages. Accordingly the positive ion source **13** (see FIG. 3) is located at ground, but before injection into the accelerator many of the positive ions are neutralized by the addition to each of a single electron. This is accomplished through use of a neutralizing canal **14** into which an appropriate gas is introduced for charge-transfer purposes. Although the neutralized beam which emerges from the neutralizing canal has no charge, it nevertheless still has the energy of the positive ion beam, which was given a certain amount of acceleration upon extraction from the positive ion source **13**. As a result, the neutral beam proceeds at constant velocity up the acceleration tube and into the negative high voltage terminal **3** (FIG. 1). Within this high voltage terminal **3** an electron adding canal **15** is provided. The charge transfer process which take place in this canal is similar to that which took place in the neutralizing canal **14**, except that since the injected particles are already neutral, some of the emergent particles are negatively charged due to having acquired an additional electron. These negatively charged particles are then accelerated from the negative high voltage terminal **3** through the ground plane **11** and into the positive high voltage terminal **4**. Electron removal is relatively simple and may be accomplished either by a stripping canal containing gas or by a metal foil or other means. Such a stripping device **16** is provided within the positive high voltage terminal **4** and converts the incoming negative ions into outgoing positive ions. Because of the ease of electron removal, it is possible at this point in the case of certain ions to produce multiply charged positive ions by the removal of several electrons. It is apparent that multiple charges provide multiple acceleration for a given voltage drop. The positive ions which are thus formed are accelerated from the positive high voltage terminal **4** through the second ground plane **12** and into the second negative high voltage terminal **4**.

One can then put an appropriate target **17** within this high voltage terminal for bombardment thereof by the positive ions. In this way the accelerator could be used for the production of artificial radioactivity or in other applications where sufficient detection apparatus of special design could be operated within the high voltage terminal surrounding the target.

Referring now to FIG. 3 of the drawings, therein is shown another embodiment of the invention which although providing few stages of acceleration than that shown in FIG. 1, has the important advantage of the target **18** being at ground. The device of FIG. 3 is identical to that of FIG. 1, except that there are only two high voltage terminals, the second negative high voltage terminal having been eliminated. For simplicity of discussion, the single belt **6** has been replaced by two conventional belts **19**, **20**; but, of course, the single belt arrangement of FIG. 1 may also be used in the device shown in FIG. 3. In the device of FIG. 3, the charged particle injection into the negative high voltage terminal **21** is the same as that in FIG. 1. The negative ions produced in the negative high voltage terminal are then accelerated through the ground plane **22** to the positive high voltage terminal **23** where a stripping device **24** is provided for conversion of the negative ions into positive ions. Here again multiple charging is possible. The positive ions thus created are accelerated to ground and thence into the appropriate beam analyzing devices **25** onto the target **18**. The device shown in FIG. 3 has three acceleration stages and thus may be called a three-stage tandem accelerator, and it will be observed that the device is rendered possible by use of a neutral beam. The formation of the neutral beam is an important part of the invention and plays a part in another embodiment to be described hereinafter. The neutral beam will enhance the possibility of injecting and acceleration polarized particles. It is the use of the neutral beam that permits the ion source apparatus to be removed to ground despite the fact that the actual main acceleration process must start with the production of negative ions within a high voltage negative terminal.

Referring now to FIG. 4, therein is shown a device which is essentially a single stage device. The device therein shown is similar to a conventional electrostatic belt-type generator, except that the positive ion source has been removed to earth. This is accomplished by producing a neutral beam such as that produced in the previous drawings and directing it into a positive high voltage terminal **26** where a stripping device **27** would produce positive ions. One purpose of the device shown in FIG. 4 would be to produce positive ion beams of tremendous intensities—that is to say, much greater than possible with the present belt generator, where a representative 3 mev. machine produces a maximum of 100 to 200 microamperes of positive ions. The device of FIG. 4, is, of course, not limited to use with an electrostatic belt-type generator, and much more powerful voltage sources could be used. At the present time more power than the electrostatic belt-type generator can provide is not required since the ion source itself provides a limitation. However, using the neutral beam as shown it would be possible to get ion beams of tens of milliamperes or possibly even hundreds of milliamperes without the necessity of enlarging the weight to accommodate the considerable amount of ion source equipment which would otherwise be necessary. Such intense ion beams could provide, for example, a monoenergetic neutron source of great power. The fact that a beam of neutral particles has no space charge will be of increasing advantage as higher particle beam intensities are attempted.

Referring now to FIG. 5 of the drawings, therein is shown what might be termed a four-stage tandem accelerator. It is basically similar to the device shown in FIG. 1, except that instead of directing the positive ions from the high positive voltage terminal **4** to a second negative high voltage terminal **5**, they are redirected so that the beam enters the first negative high voltage terminal **3** and impinges upon a target enclosed **28** within it. For this purpose, two 180° magnets **29**, **30** or magnetic mirrors are provided. As can be seen from consideration of the particle optics involved, this particular magnet configuration is extremely well adapted for the purpose of redirecting the beam of positive ions as shown. For example, even with small variations in the energy of the positive ions, the beam will remain parallel to the position shown.

As is shown by FIG. 5, it is not necessary to have the entire apparatus in a single tank, and indeed the multiple acceleration may be provided by the use of several tanks **31**, **32**. It will be observed that the two tanks in the device shown in FIG. 5 are virtually identical and each in turn is virtually identical to the single stage device shown in FIG. 4. Thus the device of FIG. 4 may readily be converted to the device of FIG. 5 by the addition of the appropriate apparatus. Conversely a plural-stage device may be converted to a device of fewer stages through the use of appropriate switching arrangements.

It has already been pointed out hereinbefore that by stripping so as to produce multiply charged positive ions one obtains multiple acceleration for a given voltage drop. The number of electrons which are removed by the stripping process increases with increasing energy of the particles being stripped. The increased particle energy which the invention affords for an available voltage thus enhances the possibility of multiple stripping. Moreover, in some cases where the stripping device within the high positive voltage terminal can only partially strip the particles travelling therethrough, it is possible in accordance with the invention to provide another stripping device in the path of the particle beam after the particles have acquired additional energy. For example, referring to FIG. 5, a foil **33** may be interposed in the path of the

beam as shown for the purpose of stripping additional electrons with resultant increase in energy gain during the fourth stage of acceleration.

In the following claims when reference is made to the location of a source of negative ions or to the place at which negative ions are produced, the location in question is always the point at which the last step is taken in the production of the negative ions. Thus, the words "producing negative ions in a region" or the words "a source of negative ions within a region" includes each one of the following three situations: (1) direct extraction of negative ions from a discharge which takes place within the region; (2) the production of positive ions within the region and conversion thereof into negative ions within the region or (3) the production of a neutral beam outside the region with the conversion of said neutral beam into negative ions within the region.

Having thus described the principles of the invention together with several illustrative embodiments thereof, it is to be understood that although specific terms are employed they are used in a generic and descriptive sense and not for purposes of limitation, the scope of the invention being set forth in the following claims.

I claim:

1. Apparatus for the acceleration of charged particles comprising a source of low velocity positive ions and a charge neutralizing device associated therewith, a high (with respect to said charge neutralizing device) negative voltage terminal having within it an electron adding device, a high positive voltage terminal having an electron stripping device within it, and means for causing particles originating in said positive ion source successively to travel through said charge neutralizing device, said electron adding device, and said electron stripping device, whereby said particles originating in said positive ion source are neutralized to permit them to reach the high negative voltage terminal at low velocity, whereby electrons are added to said neutrals within said high negative voltage terminal so as to form negative ions which are then accelerated from said high negative voltage terminal to said high positive voltage terminal, and whereby electrons are stripped from said negative ions within said high positive voltage terminal so as to form positive ions which are then accelerated away from said high positive voltage terminal.

2. A method of producing high velocity charged particles, which method comprises producing and directing low velocity positive ions, neutralizing some of said positive ions to form low velocity neutrals of approximately the same velocity and direction, said positive ions having been directed so that said neutrals travel across a potential difference which is large relative to the potential difference used to give said positive ions their low velocity into a region at high (with respect to the region in which said positive ions are neutralized) negative potential, adding electrons to some of said neutrals so as to form negative ions, directing said negative ions towards a region of high positive potential, within this region removing electrons from some of said negative ions so as to form positive ions, and directing said positive ions away from said region of high positive potential.

3. Apparatus for the acceleration of charged particles comprising a negative voltage terminal having within it a source of negative ions, a positive voltage terminal having an electron stripping device within it, each of said terminals being supported within a grounded tank and maintained at a voltage with respect to ground which is high relative to the potential difference used to give said negative ions their velocity at the formation thereof, and means for causing particles originating in said negative ion source to travel through said electron stripping device, whereby said negative ions are accelerated from said high negative voltage terminal to said high positive voltage terminal, and whereby electrons are stripped from said negative ions within said high positive voltage terminal so as to form positive ions which are then accelerated away from said high positive voltage terminal.

4. Apparatus for the acceleration of charged particles comprising a grounded source of low velocity positive ions and a charge neutralizing device associated therewith, a high negative voltage terminal having within it an electron adding device, a high positive voltage terminal having an electron stripping device within it, a grounded target and means for causing particles originating in said positive ion source successively to travel through said charge neutralizing device, said electron adding device, and said electron stripping device, and onto said target whereby said particles originating in said positive ion source are neutralized to permit them to reach the high negative voltage terminal at low velocity, whereby electrons are added to said neutrals within said high negative voltage terminal so as to form negative ions which are then accelerated from said high negative voltage terminal to said high positive voltage terminal, and whereby electrons are stripped from said negative ions within said high positive voltage terminal, so as to form positive ions which are then accelerated away from said high positive voltage terminal and onto said target.

5. Apparatus for the acceleration of charged particles comprising a source of positive ions, a charge neutralizing device, a high (with respect to said charge neutralizing device) positive voltage terminal having an electron stripping device within it, and means for directing positive ions from said positive ion source successively through said charge neutralizing device and said electron stripping device, whereby the positive ions are neutralized to permit them to reach the high positive voltage terminal, and whereby electrons are stripped from said neutrals within said high positive voltage terminal so as to form positive ions which are then accelerated away from said high positive voltage terminal.

6. A method of producing high velocity charged particles, which method comprises producing positive ions, neutralizing some of said positive ions to form neutrals, directing said neutrals across a potential difference which is large relative to the potential difference used to give said positive ions their velocity into a region of high positive potential, removing electrons from said neutrals so as to form positive ions, and directing said positive ions away from said region of high positive potential.

7. Apparatus for the acceleration of charged particles comprising a negative voltage terminal having within it a source of negative ions, a positive voltage terminal having a charge stripping device within it, each of said terminals being supported within a grounded tank and maintained at a voltage with respect to ground which is high relative to the potential difference used to give said negative ions their velocity at the formation thereof, means for directing negative ions from said negative ion source through said charge stripping device, whereby electrons are stripped from said negative ions within said high positive voltage terminal so as to form positive ions, and means including beam deflecting fields for directing said positive ions away from said high positive voltage terminal and into said high negative voltage terminal.

8. Apparatus for the acceleration of charged particles comprising a first negative voltage terminal having within it a source of negative ions, a positive voltage terminal having a charge stripping device within it, a second negative voltage terminal, each of said terminals being supported within a grounded tank and maintained at a voltage with respect to ground which is high relative to the potential difference used to give said negative ions their velocity at the formation thereof, means for directing negative ions from said negative ion source through said charge stripping device, whereby electrons are stripped from said negative ions within said high positive voltage terminal so as to form positive ions, and means for directing said positive ions away from said high positive

voltage terminal and into said second high negative voltage terminal.

9. Apparatus for the acceleration of charged particles comprising a negative voltage terminal having within it a source of negative ions, a positive voltage terminal, each of said terminals being supported within a grounded tank and maintained at a voltage with respect to ground which is high relative to the potential difference used to give said negative ions their velocity at the formation thereof, means for causing particles originating in said negative ion source to travel through said high positive voltage terminal, whereby said negative ions are accelerated from said high negative voltage terminal to said high positive voltage terminal, and stripping means adapted to remove a sufficient number of electrons from some of said particles so that they have a plurality of net positive electronic charges while being accelerated away from said high positive voltage terminal.

10. Apparatus for the acceleration of charged particles comprising a source of positive ions, a charge neutralizing device, a high (with respect to said charge neutralizing device) positive voltage terminal, means for directing particles from said positive ion source successively through said charge neutralizing device and said high positive voltage terminal, whereby the positive ions are neutralized to permit them to reach the high positive voltage terminal, and stripping means adapted to remove a sufficient number of electrons from some of said particles so that they have a plurality of net positive electronic charges while being accelerated away from said high positive voltage terminal.

11. Apparatus for the acceleration of charged particles comprising a high positive voltage terminal, means for injecting particles into said high positive voltage terminal, a stripping device within said high positive voltage terminal adapted to remove a sufficient number of electrons from some of said particles so that they are left with at least a single electronic net positive charge, and a second stripping device posterior to said first stripping device whereby additional electrons are removed.

12. Apparatus for the acceleration of charged particles comprising at least one high voltage terminal supported within a grounded tank and centrally between the extremities of a column comprising a multiplicity of alternating insulating annuli and apertured equi-potential planes, the apertures within said annuli and within said planes being aligned and evacuated, said annuli and planes being the sole support of the column which includes an endless insulated charge-carrying belt passing through the column and operating between grounded pulleys at each end thereof.

13. Apparatus for the acceleration of charged particles comprising at least one high voltage terminal supported within a grounded tank and centrally between the extremities of a column comprising a multiplicity of alternating insulating annuli and apertured equi-potential planes, the apertures within said annuli and within said planes being aligned and evacuated, said annuli and planes being the sole support of the column which includes an endless insulated charge-carrying belt passing through the column and operating between two grounded pulleys at each end thereof so that belt spacing is less than the pulley diameter.

14. Apparatus for the acceleration of charged particles comprising at least one high voltage terminal supported within a grounded tank and centrally between the extremities of a column comprising a multiplicity of alternating insulating annuli and apertured equi-potential planes, the apertures within said annuli and within said planes being aligned and evacuated, said annuli and planes being the sole support of the column which includes an endless insulated charge-carrying belt passing through the column and operating between grounded pulleys at each end thereof and means for injecting non-positively-charged particles into said evacuated region at one extremity of said column.

15. A method of producing high velocity positive ions by means of voltage producing apparatus capable of generating not more than V volts with respect to ground, which method comprises generating a voltage of approximately $-V$ with respect to ground at a first terminal, generating a voltage of approximately $+V$ with respect to ground at a second terminal, producing negative ions in the vicinity of said first terminal using a voltage which is low relative to V, directing said negative ions towards said second terminal, removing, in the vicinity of said second terminal, electrons from at least some of said negative ions so as to form positive ions and directing said positive ions away from said second terminal.

16. A method of producing high velocity positive ions by means of voltage producing apparatus capable of generating not more than V volts with respect to ground, which method comprises generating a voltage of approximately $-V$ with respect to ground at at least one negative terminal, generating a voltage of approximately $+V$ with respect to ground at a positive terminal, producing negative ions in the vicinity of an aforementioned negative terminal using a voltage which is low relative to V, directing said negative ions towards said positive terminal, removing, in the vicinity of said positive terminal, electrons from at least some of said negative ions so as to form positive ions and directing said positive ions away from positive terminal towards an aforementioned negative terminal.

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2,847,607	8/1958	Pierce	250—27
2,883,606	4/1959	Gale et al.	310—5
2,890,348	6/1959	Ohkawa	250—27
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