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ION SOURCE

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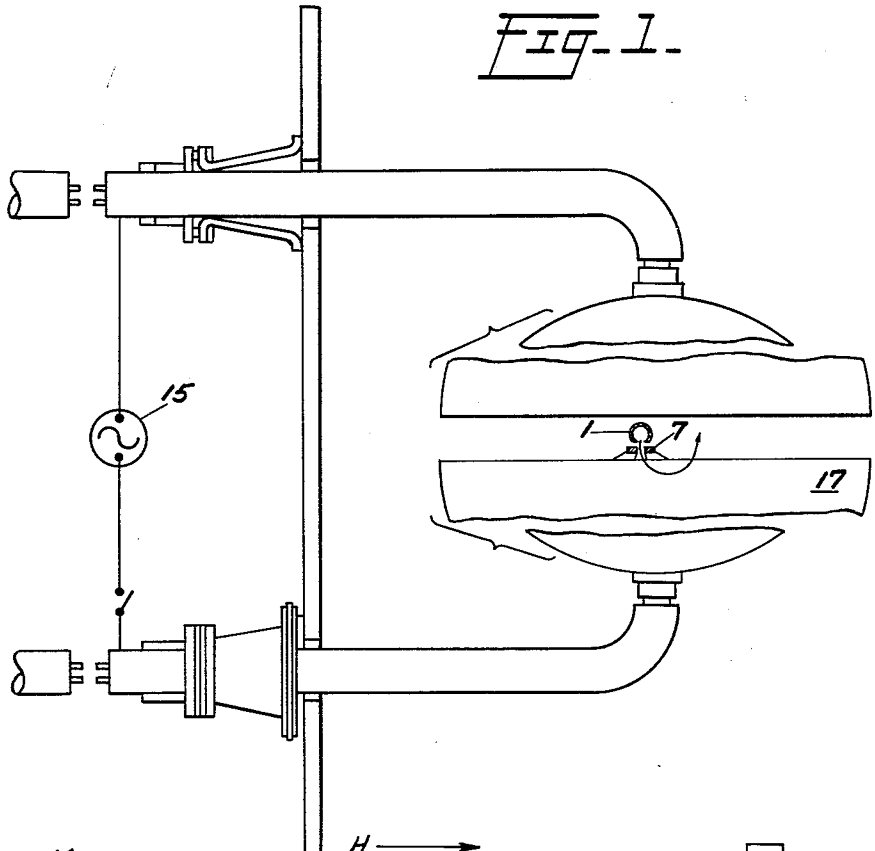

Fig. 1.

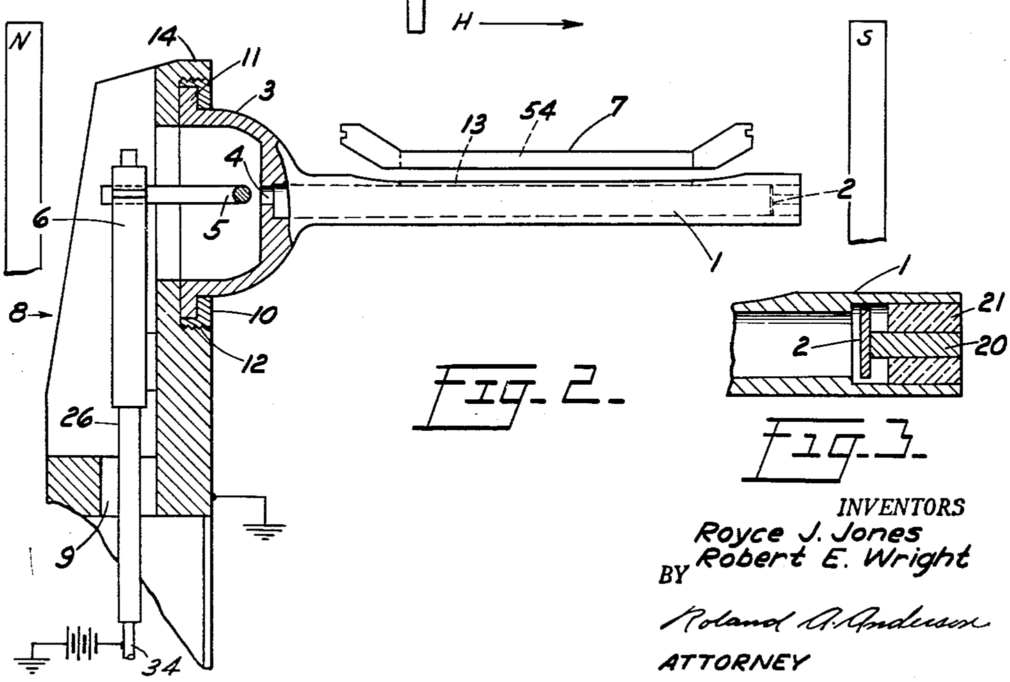

Fig. 2.

Fig. 3.

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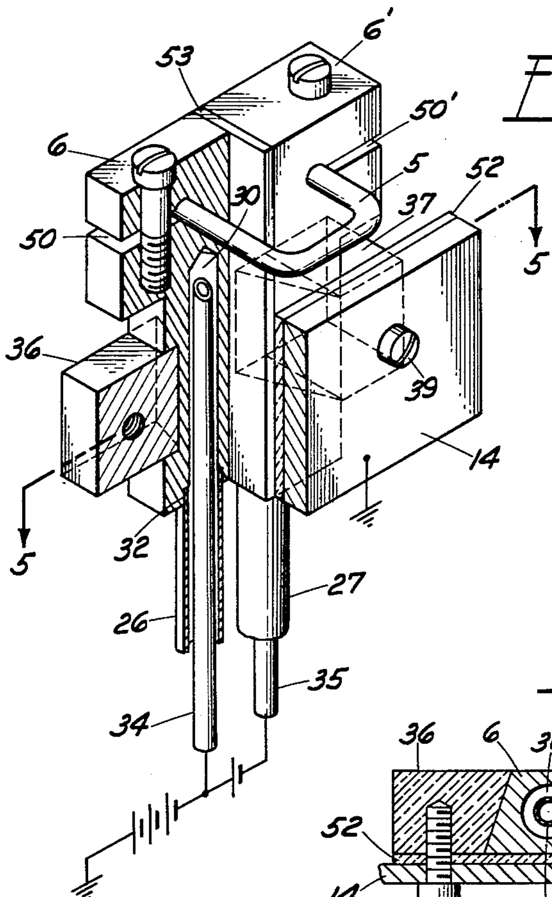


Fig. 4

Fig. 5

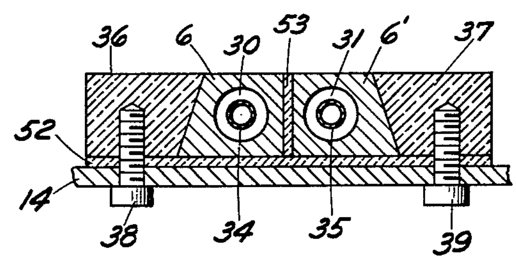
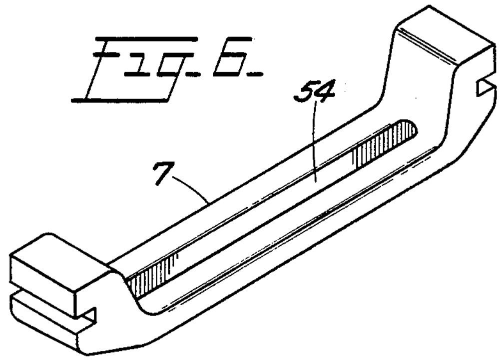


Fig. 6



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ION SOURCE

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3 Claims. (Cl. 313—63)

The present invention relates to gaseous electric discharge apparatus, and especially to an improved source of ions for a particle accelerator such as a cyclotron.

The cyclotron is an instrument for accelerating particles to high velocities by combined electric and magnetic fields, and is based upon the principle that the angular velocity of a particle moving in such fields is independent of the translational velocity. It comprises two metal D's, which are semicylindrical chambers shaped like the letter D, insulated from each other in a vacuum chamber disposed between the poles of a magnet so that the magnetic field is perpendicular to the faces of the D's. Charged particles leave a source near the center of the D's and are accelerated into one of the D's by the action of a high-frequency electric field impressed upon the D's by an oscillator. Inside the D's the particles will travel in a circular path at a constant velocity under the influence of the magnetic field. But when the particles reach the gap, they are accelerated thereacross by the electric field, the oscillator frequency and magnetic field strength being so adjusted that the particles require one-half the oscillator period to travel around one D. At each crossing of the gap, the particles are further accelerated, and travel in a larger orbit, until they are led away from the periphery of the D to a target.

Ions for acceleration can be produced by a stream of electrons between the D's from a hot filament to an anode, and also by an electric discharge passing through a gas in a closed chamber. In the discharge type ion source, a capillary passage aligned with the entrance to the D's is normally provided, and the gas is ionized during its passage therethrough. However, neither of the above source types has proven entirely satisfactory for producing intense proton beams, because of beam divergence, low ion currents, and the low ratio of overall protons to other positive ions in the beam. Since the number of the desired type of particles striking the target of a particle accelerator can be no greater than the number of that type of ion produced in and ejected from the source, it is apparent that the overall efficiency of a source in converting gas molecules to the desired ions will determine to a great degree the efficiency of the accelerator.

It is, therefore, the primary object of our invention to provide an ion source characterized by its unusually high overall efficiency of ion production.

Another object of our invention is to provide a means for producing a relatively intense current of protons.

A further object is to provide an improved cyclotron source of the hot cathode arc type.

The above objects are attained in the present invention by providing an intense arc inside an elongated and enclosed chamber, through which arc all molecules of the gas to be ionized must pass before reaching the arc chamber. The gas is admitted behind the filament, and flows around the filament, and through the arc into the chamber. Electrodes are provided outside a long, narrow slit in the chamber to draw ions out of the chamber and to focus and define the beam before it enters the cyclotron D.

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A preferred form of apparatus with which the above objects may be accomplished is illustrated in detail in the appended drawings, in which:

Fig. 1 illustrates schematically our improved source in place between the D's of a cyclotron,

Fig. 2 is a sectional view illustrating the construction of a preferred embodiment of our improved ion source adapted for use in a cyclotron.

Fig. 3 is an enlarged sectional view illustrating the anode assembly of our improved ion source.

Fig. 4 is an isometric view, partly in section, illustrating the assembly of the filament and cooling tubes, and means for holding said assembly in position,

Fig. 5 is a sectional view taken along line **5—5** of Fig. 4,

Fig. 6 is an isometric view illustrating the accelerating and focusing electrode **7** shown in Fig. 2.

Referring now to Figs. 2 and 3, the source includes an elongated tubular envelope **1** forming the arc chamber. The anode assembly includes a disc **2**, mounted on stem **20**, around which an insulating sleeve **21** fits snugly. The sleeve is press fitted inside the envelope **1**, so that the entire assembly forms a substantially gas-tight joint, closing one end of the envelope **1**. A bulbous, bell-shaped housing **3** carrying flange **11** thereon extends from the opposite end of the envelope **1** and defines a filament chamber. As may be seen from Figs. 4 and 5, one leg of an electron emissive filament **5** is clamped in a slot **50** in a filament supporting member **6**, while the opposite leg is clamped in a similar slot **50′** in the support **6′**. The filament extends into the filament chamber in direct alignment with both the anode **2** and a slot or aperture **4**. A U-shaped tantalum filament .170 inch in diameter is preferred, but it is apparent that other thermionic filaments, such as wolfram, of greater or lesser diameter, and shaped in various configurations could also be employed. The relatively large cross-section of the filament prevents the magnetic forces from warping it and thus eliminates the need for radio-frequency heating.

The collimating slot **4**, for optimum results, should be located so as to be tangent to an imaginary line along the inner edges of the arc chamber aperture slit **13** as shown in Fig. 2. The collimating slot is desirably .142 inch in diameter and $\frac{3}{32}$ inch in depth. These dimensions, which are critical for maximum source efficiency, are very close to optimum since the use of a larger and shallower hole decreases the proton output efficiency, while a smaller, deeper hole does not allow sufficient positive ions to reach the filament **5** to maintain a stable arc.

A substantially gas-tight metal box **8** forms a chamber into which the charge gas, such as hydrogen, may be introduced through entry port **9**. Annular ring **10**, threaded around its periphery and recessed to receive flange **11**, engages a corresponding threaded cylindrical recess **12** in the wall **14** of the box **8** to hold the chambers firmly in place.

Supports **6** and **6′**, having blind holes **30**, **31** and counterbores **32**, **33** are rigidly fastened to wall **14** of box **8** by means of tapered insulator wedges **36**, **37** and screws **38** and **39**. Tubes **26**, **27** are brazed into counterbores **32**, **33**. Within the tubes **26**, **27** and coaxial therewith extend copper tubes **34**, **35**, of a substantially smaller diameter, which terminate at a point near the filament clamps. Cooling water may enter through tubes **34**, **35** and be expelled through holes **30**, **31** and tubes **26**, **27**. Electrical leads from a source of filament power may be connected to the inner tubes **34**, **35**, which should be made of copper or other good electrical conductor.

Sheet 52 of mica or other suitable insulator is disposed between the wall 14 and the supports 6, 6', and sheet 53 of like material is disposed between the supports 6, 6' to prevent shorting of the filament supply, through wall 14 to the housing 3 or through the conductive supports, respectively. The insulator wedges 36, 37 may be Melamine, Teflon, or other suitable electrical insulator possessing good structural strength, and are provided to insulate the filament structure from wall 14 and screws 38, 39, which assume the potential of housing 3, and therefore differ in potential from the filament by the electron accelerating voltage used to strike and maintain the arc. The sleeve 21 is preferably quartz to insulate envelope 1 from item 20.

The envelope 1 has an ion exit slit or aperture 2½ inches long disposed along its surface. Adjacent the slit, the wall is cut away to a thickness of .018 inch.

An electrode 7, shown in Fig. 6, is rigidly mounted on the lower D 17 and disposed in confronting relation with the slit 13. The slit 54, 3/32 inch wide, is thereby maintained substantially ⅓ inch from the lip of the exit slit 13.

The electrode 7, the tubular envelope 1, housing 3 and ring 10 may preferably be carbon, but other conductive materials which will withstand high temperatures, such as stainless steel, might also be employed. Carbon, however, will be less affected by the arc and ion beam.

Operation of our invention may best be understood from the following description, when read in conjunction with the appended figures.

The above listed dimensions are those of a preferred embodiment of our invention, and are those which lead to optimum results with the apparatus illustrated. They should not be considered as critical in the absolute sense; for larger or smaller ion sources they should be proportionately changed.

The filament 5 is heated to incandescence by any suitable low-voltage high current power source, which may, for example, furnish 350 amperes at 2.5 volts. A selected gas, such as hydrogen, from a storage bottle, is introduced through port 9, enters the back of the filament chamber, flows around the filament 5, and proceeds through defining slot 4 into the chamber 1. An arc is created within the chamber when the electrons are accelerated through aperture 4 into the chamber 1 by the potential between the filament and grounded envelope by the copious quantity of electrons emitted by the filament, and the partial neutralization of the space charge around the filament by the positive ions resulting from electron collisions with the gas molecules as the electrons oscillate through the arc. This arc is collimated by a large magnetic field directed in the same direction as the long dimension of envelope 1; that is, into the paper in Fig. 1. This field may be, for example, 6,000–8,000 oersteds, and may be provided by the large electromagnets of the cyclotron, shown schematically in Fig. 2.

Ions are removed from the arc chamber through slit 13 and accelerated toward lower D 17 by an electrostatic field set up by accelerating and focusing electrode 7, which is maintained at the lower D potential with respect to envelope 1 by a suitable power source or oscillator 15. After entering the lower D, the particles are accelerated by the cyclotron in the conventional manner.

In considering the usefulness of an ion source, the rate at which the source produces ions is a prime consideration. It is apparent that if a higher pressure could be maintained in the neighborhood of the filament, more molecules would be subject to ionization, and a greater number of ions would result. Counterbalancing that effect, however, is the greatly increased scattering of the ion beam resulting from the higher pressure outside the arc, so that the useful beam intensity is limited to an undesirably small magnitude. We have overcome the seeming impasse due to the above conflicting pressure effects by providing an elongated tubular arc chamber, closed at one end by an anode and communicating at the opposite end with the filament chamber, and communicating with the evacuated space between the cyclotron D's only by a long, narrow slit. By means of our arrangement, we may maintain a relatively high gas pressure in the arc, and so get maximum ion production; yet we also may keep a relatively low gas pressure outside our arc chamber so that we avoid excessive scattering of our ion beam.

The quality of ion beam which leaves the exit slit in the arc chamber may be further improved by the provision of two accelerating electrodes outside the slit. The electric field they establish in effect draws positive ions out of the arc chamber and accelerates them toward one D. An essential function of the electrodes is to define and focus the beam, greatly increasing the percentage of ions produced which may be effectively used to bombard a target, and minimizing beam scattering at the ion exit slit due to the pressure outside the chamber. In open arcs, the arc plasma will tend to bow away from the electric accelerating field, causing the beam to diverge from the source. But in our improved source, the electric field established by the accelerating electrodes reaches past the thin lips of the ion exit slot to maintain the plasma more nearly parallel to the slot, effectively reducing such divergence.

The gas feed system of our invention provides that the gas enter behind the filament, flow around it into a critically-positioned collimating slot, then enter the arc chamber. By introducing the gas at the filament, an arc may be struck across the chamber with only a relatively small gas flow rate, such as 1–10 c. c. per minute. If the gas were fed directly into the arc chamber, for example, not enough positive ions would reach the filament to maintain the arc, even though it would strike, at desired gas flow rates. In addition, mounting of the source unit between the D's is simplified when the gas enters at the filament. The collimating slot referred to above serves to define the arc, and, in addition, provides the sole exit port for electrons from the filament and for gas molecules to be ionized. It thus insures that every molecule must pass through the arc before reaching the arc chamber, and greatly increases the probability that a given molecule will be ionized.

While a preferred embodiment of our improved ion source has been described in connection with a cyclotron, it will be apparent to one skilled in the art that various combination of the novel features herein illustrated may be adapted for use in other particle accelerators and the like. Therefore, our invention is not to be construed as limited to the embodiment herein described, but only by the scope of the appended claims.

We claim:

1. In a cyclotron, a pair of confronting accelerating D electrodes, means for establishing a magnetic field normal to the confronting faces of said electrodes, an ion source comprising a longitudinally apertured elongated hollow cylinder defining an arc chamber disposed parallel to the direction of the magnetic field and equidistant from the accelerating electrodes of said cyclotron, the longitudinal aperture of said chamber providing an exit slit for ions formed therein, a bell-shaped extension of one end of said cylinder defining a filament chamber, anode and filament electrodes for producing an electric arc through said chambers, said filament being disposed within said filament chamber and said anode being disposed at the distal end of said arc chamber and electrically insulated therefrom, means defining an aperture between said filament chamber and said arc chamber, means for establishing an arc discharge in said cylinder from said filament, said aperture being aligned with and in spaced relation to said filament for collimating the arc through the arc chamber, a gas chamber communicating with said filament chamber and having a port for receiving gas from a source, and an electrode member disposed parallel to said arc chamber and in spaced relation to the ion

exit slit of said chamber and defining a second slit for passage of ions emitted through said ion exit slit.

2. An ion source of the character described comprising a tubular envelope forming an arc chamber; a first housing of substantially greater diameter than said envelope connected to one end thereof and forming a filament chamber, one wall of said housing being provided with a first passageway of smaller diameter than said envelope and communicating with both of said chambers; a second housing forming a gas chamber and adapted to receive one end of said first housing in substantially gas-tight relation; a support member; and a filament mounted on said support member within said second housing and extending into said first housing in longitudinal alignment with said passageway; said support member comprising first and second blocks of electrical insulating material provided with at least one inclined side and mounted on said second housing with said sides in spaced apart, confronting relation; third and fourth blocks of electrically conductive material provided with correspondingly inclined sides disposed between and abutting against said confronting inclined sides, with blind passageways therein for receiving a coolant, and with mounting slots for said filament, and being adapted to conduct electric current to and from said filament; and respective sheets of electrical insulating material disposed between adjacent sides of said conductive blocks and between said blocks and said second housing.

3. An ion source of the character described comprising a tubular envelope forming an arc chamber; a first housing of substantially greater diameter than said envelope connected to one end thereof and forming a filament chamber, one wall of said housing being provided with a first passageway of smaller diameter than said envelope and communicating with both of said chambers; a second housing forming a gas chamber and adapted to receive one end of said first housing in substantially gas-tight relation; a support member; and a filament mounted on said support member within said second housing and extending into said first housing in longitudinal alignment with said passageway; said support member comprising first and second wedges of electrical insulating material secured to said second housing in confronting relation; third and fourth wedges of electrically conductive material, correspondingly tapered to conform to the slopes of said first and second wedges, abutting thereagainst and provided with apertures for receiving opposite extremities of said filament and with blind passages for receiving a coolant; respective sheets of electrical insulating material disposed between said third and fourth wedges and between said wedges and said second housing; and means for delivering both electrical power and coolant to said third and fourth wedges comprising first and second electrically conductive coaxial tubes, the outer tubes thereof being connected to corresponding conductive wedges at the entrances to said passages and the inner tubes thereof extending into corresponding passages for delivery of coolant.

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