

Sept. 29, 1959

E. R. GRAVES ET AL  
LOW VOLTAGE 14 MEV. NEUTRON SOURCE

2,906,903

Filed April 7, 1954

3 Sheets-Sheet 1

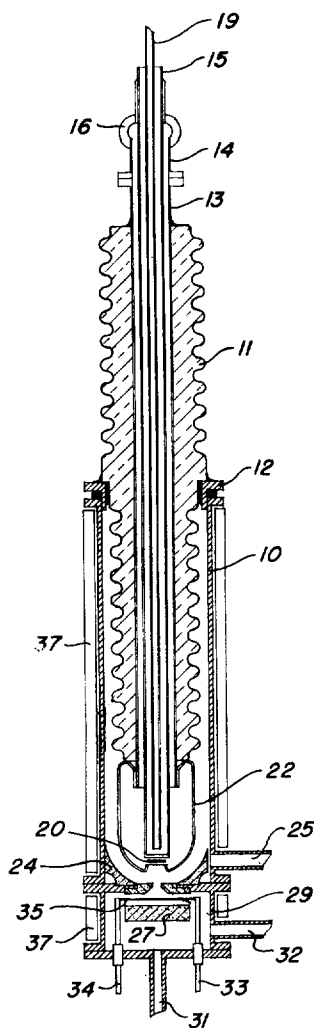


Fig. 1

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3 Sheets-Sheet 2

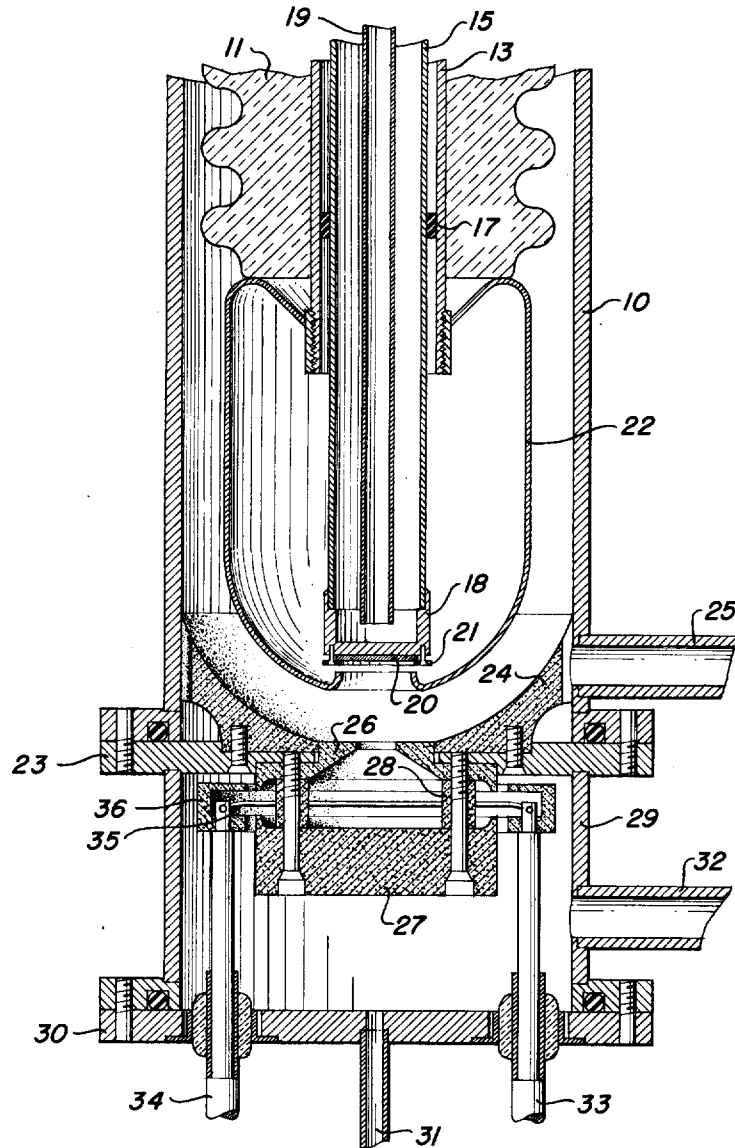


Fig. 2

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3 Sheets-Sheet 3

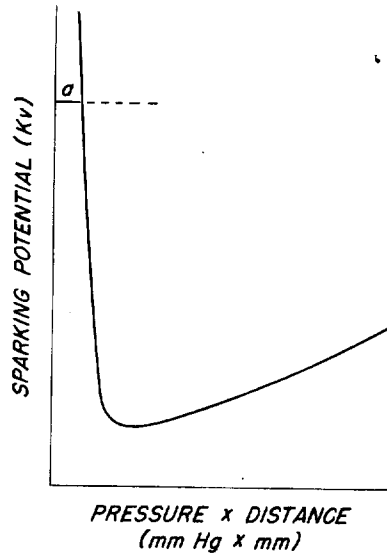


Fig. 3

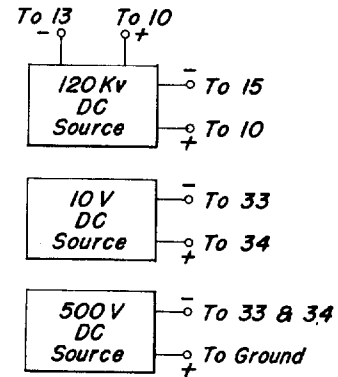


Fig. 4

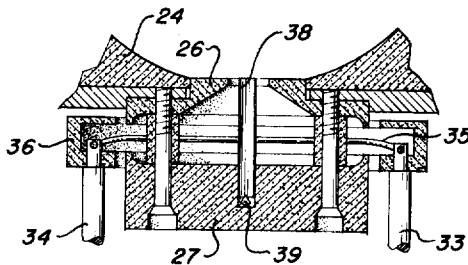


Fig. 5

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2,906,903

LOW VOLTAGE 14 MEV. NEUTRON SOURCE

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Application April 7, 1954, Serial No. 421,714

9 Claims. (Cl. 313-61)

The present invention relates to particle accelerators, and more particularly to devices in which positive ions are accelerated and produce neutrons upon impact with a high potential target.

It is well recognized in the construction of neutron producing ion accelerators that the production of high neutron yields necessitates high ion beam currents, requiring high ion densities, and, therefore, relatively high gas pressures for their production. However, in using gas pressures which are higher than conventional ion accelerator pressures, the problem of sustaining high accelerating potentials without troublesome discharges, i.e., gaseous breakdown, becomes increasingly important. Therefore, neutron producing ion accelerators of the prior art usually incorporate conventional long accelerating tubes and gaps using low gas pressures with resulting beam currents of about 100 microamperes and neutron yields of  $10^5$  per second. Furthermore, in the neutron producing devices of the prior art, the ionizing chamber and accelerating chamber are in many cases operated at different gas pressures. In these devices the ionizing chamber, which is maintained at a higher gas pressure than the accelerating chamber, is separated from the ion accelerating chamber by some device, such as a very small aperture, which will maintain some pressure difference but will still allow ion passage. These separate chambers are required because of the use of conventional long ion accelerating tubes. The accelerating tubes are long in order to focus the beam of ions, and low pressures are used in order to prevent voltage breakdown as well as to reduce ion beam scattering. Such devices are difficult to use in a portable fashion, because

The present invention is directed toward attaining substantially higher neutron yields than the devices of the prior art, and at the same time reducing the overall dimensions of the neutron source. The present invention utilizes the principle of comparatively high gas pressures, high ion densities, and high ion beam currents, without the usually encountered problems of high voltage discharge, and pressure difference maintenance.

It is the object of the present invention to provide a small, compact, sturdy, portable, low voltage, neutron source capable of yielding at least  $10^8$  neutrons per second, for use in well logging operations and in laboratory experiments requiring periodic use in a variety of locations.

A further object of the present invention is to provide such a portable, high yield neutron source by ionizing deuterium gas and accelerating the resulting ions against a target containing a hydrogen isotope wherein the nucleus contains one or more neutrons.

A still further object of the present invention is to provide such a portable, high yield neutron source using ionized deuterium gas, which source has a short ion accelerating gap and is not susceptible to gaseous discharge of the high accelerating potential.

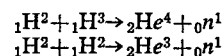
A still further object of the present invention is to

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provide such a portable, high yield neutron source using ionized deuterium gas and having a short accelerating gap, which source is contained within one chamber, said chamber being maintained at a uniform gas pressure throughout.

A still further object of the present invention is to provide such a portable, high yield neutron source using ionized deuterium gas, and having a short accelerating gap and a uniform gas pressure, which neutron source can be filled with deuterium gas and sealed off to eliminate burdensome gas inlet lines, deuterium gas supplies, and vacuum pumps.

A still further object of the present invention is to provide a portable, high yield neutron source using ionized deuterium gas, a short accelerating gap and uniform pressure, which neutron source may be sealed off and which produces neutrons according to one of the following reactions:



where the neutrons produced have energies of 14 mev. and 2.5 mev. respectively.

Other objects relating to the organization, arrangement and cooperation between the constituting elements will be apparent from the description and drawings. In the drawings, hereby made a part of the specification:

Figure 1 is a cross sectional view of the device showing the general relation and location of various parts,

Figure 2 is an enlarged sectional view of the ionization and accelerating chambers, showing in detail the interior components of the device,

Figure 3 is a graph showing, in general, the relationship between the sparking voltage and the product of pressure and distance,

Figure 4 shows schematically the electrical components and their connections to the apparatus, and

Figure 5 is an enlarged cross sectional view of a portion of the ionization chamber showing a modification.

Referring now to the drawings, Figure 1 shows the assembly and general arrangement of the elements constituting the neutron source, which consists of a cylindrical electrically grounded case 10 having flanged ends. This case is preferably fabricated of stainless steel, thereby simplifying the problem of outgassing hereinafter discussed in more detail.

A high frequency type electrical insulator 11, preferably made of a vitreous material, is sealed in a vacuum tight fashion to flange member 12. The insulator has a cylindrical longitudinal aperture through which the target support mechanism is inserted. The flange member 12 is sealed by means of an O ring or other similar sealing device to the upper flanged portion of the case 10. The flange member 12 is located approximately at the middle of the longitudinal length of insulator 11, so that each end of the insulator is about equidistant from the point of contact with the grounded case 10. A conducting tube 13 is located within the central aperture of the insulator 11, and extends from both ends of the insulator 11. The upper extending portion of tube 13 is sealed to the insulator 11 around the periphery of the tube, and has an outwardly extending flange at its extreme upper end. A sealing tube 14, having a flange at the lower end, is sealed by means of an O ring or other similar device to the upper flange of tube 13. The lower extending portion of the tube 13 is threaded.

Concentric with, spaced from, and extending from both upper and lower ends of tube 13, is target support tube 15. The upper extending portion of support tube 15 is sealed by means of an electrical insulating and vacuum tight seal 16 to the upper portion of sealing tube 14. The support tube 15 is kept concentric with and spaced

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from the tube 13 by means of the seal 16 and an insulating spacer 17 (see Figure 2), the latter being located at the lower extremity of tube 13. Thus, tube 13 and tube 15 are insulated from each other and, therefore, are capable of transmitting electrical potentials of different magnitude.

Referring now to Figure 2, a target backing element 18 is fixed to the lower extending extremity of target support tube 15, and comprises a cup shaped member with the periphery of the cup forming walls electrically connected and vacuum sealed, by means of solder or similar means, to the support tube 15. Thus, the interior of tube 15 is completely sealed off from the area adjacent its lower extremity, but is open to the area adjacent its upper extending portion. Extending into the open upper portion is a cooling tube or duct 19 which extends through the entire length of target support tube 15, and which terminates a short distance from the target backing element 18. The cooling duct 19 is maintained at the same potential as the target 20, but is electrically insulated from a high pressure air source (not shown). The air passing through duct 19 functions to cool the target backing element 18.

The target 20 consists of a tungsten backing having one surface of zirconium in which a hydrogen isotope containing one or more neutrons i.e., deuterium or tritium, preferably the latter, has been absorbed. The target backing element 18 and the back of the tungsten target, i.e., the surface opposite the tritium-containing surface, are each ground flat, and then lapped together to provide a maximum heat transfer surface between the target and the target backing element 18. It is essential that the target be maintained below the temperature at which tritium is released from the zirconium, otherwise the target life will be greatly reduced. In practice it is desirable to use a given tritium target for an indefinite length of time with negligible loss of yield from the D-T reaction in the target. If the target becomes too hot, tritium gas will be released and lost. This difficulty is avoided by operating the target below some critical temperature, hence the necessity for providing the cooling air duct 19. The highest temperature for safe operation of this device is of the order of 300° C.

The target 20 is firmly held against the target backing element 18 by means of a washer 21. This washer is fixed to target backing element 18 by means of bolts, or other well-known means, and its central opening is concentric with the periphery of the target.

Since the target 20, while under bombardment by accelerated deuterium ions, emits secondary electrons, a secondary electron suppressor 22 is provided. The suppressor 22, in the form of an open ended envelope is attached to the threaded lower extremity of tube 13. The upper periphery of the suppressor is formed so that upon assembly the envelope is firmly held against the bottom of the insulator 11, thereby reducing the distance from the grounded case 10 to the elements maintained at high voltage. The lower extremity of the suppressor envelope 22 has an inwardly extending opening, the opening being the same size as, and coincident with, the exposed area of the target 20. The envelope 22 has a hemispherical lower end surface which is concentric with the hemispherical anode hereinafter described.

The envelope being connected to the tube 13 which is insulated from the target support tube 15 by means of seal 16 and insulator 17, can be maintained at a slightly greater negative potential with respect to the target. Thus, secondary electrons emitted from the target will be repelled by this negative potential and thereby induced to return to the lower negative potential area of the target 20. The suppressor 22 is preferably fabricated from stainless steel or similar material which has the characteristic of reduced field emission.

The ion source and focusing assembly consists of an anode support plate 23 which is attached and sealed to

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the lower flanges of case 10. The plate 23 has a central aperture through which the anode assembly extends. The anode assembly consists of a graphite cylindrical anode 24 having a hemispherical cavity at one end, and a centrally located circular aperture concentric with the axis of the hemispherical cavity extending the remaining length of this anode. The anode 24 has peripheral longitudinal grooves so that gas may be passed along its periphery. A pump lead 25 is connected through the case 10 adjacent the lower flange thereof, thereby connecting the pump lead to the peripheral grooves of anode 24. Thus, gas located in the area adjacent the envelope 22 and target 20 may be removed by means of a vacuum pump attached to pump lead 25. The envelope 22 and the interior surface of case 10 combined with the hemispherical cavity in anode 24, and the upper surface of anode 26, form a U shaped volume having a virtually constant thickness. Thus, the distance from the high electrical potential on envelope 22 and the exposed surface of target 20 is virtually constant in all perpendicular directions toward grounded elements 10, 24 and 26.

The anode 24 is fixed to support plate 23 so that the central aperture of anode 24 and the aperture of support plate 23 provide a continuous passage through both elements. Supported on the opposite side of plate 23 and extending through the continuous central aperture of elements 23 and 24 is a graphite focusing anode 26. Anode 26 consists of a circular plate with a centrally located aperture and an outwardly extending circular flange. The central aperture of anode 26 consists of an upwardly extending conical aperture which is coaxially truncated by a circular aperture extending the remaining distance through the circular plate of the anode 26. The circular aperture which faces the target is smaller than the diameter of the target so that stray ion current to the envelope 22 is minimized. The periphery of the outwardly extending flange has a downwardly extending radially tapering edge which terminates in an annular lower surface. Spaced from and concentric with the outer periphery of the flanges of anode 26 is a circular graphite anode 27. The upper peripheral edge of anode 27 has an upwardly extending radially tapering edge similar to anode 26, and also terminates in an annular surface. Thus, the tapering edges of anodes 26 and 27 define a cylindrical area having rounded edges.

Graphite supporting and spacing tubes 28 separate anode 26 and anode 27. Bolts inserted through holes provided in anode 27, in the supporting tubes 28, and in the flange portion of anode 26 terminate in threaded holes provided around the periphery of the central aperture of supporting plate 23, and support the anode assembly in a concentric arrangement.

The anode structure including cylindrical anode 24, focusing anode 26, circular anode 27, supporting tubes 28, and also the electrode shield 36 are preferably constructed of graphite. Graphite is chosen because of its high melting point, and low X-ray production under electron bombardment.

Integral with supporting plate 23 and coaxial with its central aperture is downwardly extending tubular case 29 having outwardly extending flanges on its lower end. Sealed to the lower flanges of case 29 is plate 30, thus describing a chamber having an opening formed by the central aperture of anode 26. This chamber, hereinafter referred to as the ionization chamber, has a deuterium gas inlet pipe 31 connecting the chamber to any suitable source of deuterium gas (not shown). A pump lead 32 is used to connect the ionization chamber to a vacuum pump (not shown). Extending through plate 30, electrically insulated therefrom, and vacuum sealed thereto, are two electrically conducting electrode supports 33 and 34. These supports extend into the ionization chamber and support a circular planar electrode 35. The electrode or filament 35 is connected to the supports 33 and 34 at two diametrically opposed points, and is located

on a plane intermediate the anodes 26 and 27, thus transversely bisecting the cylindrical volume defined by the radially tapering edges of these two anodes.

Electrode supports 33 and 34 also support a graphite electrode shield 36, which consists of a circular channel forming member having the channel forming edges extending toward its center. The upper surface of the cylindrical area defined by these channel forming edges is coplanar with the annular lower surface of anode 26, while the lower surface of this cylindrical area is coplanar with the annular upper surface of anode 27. The inwardly extending extremity of the upper channel forming member is of greater radius than the peripheral surface of anode 26, and is thus electrically insulated therefrom. The lower channel forming member of shield 36 is similarly spaced from anode 27. The filament 35 is located concentric with, and transversely bisecting the cylindrical area defined by the shield 36. Thus, the filament is virtually enclosed by the anodes 26 and 27 and the shield 36. The shield 36 is operated at the same high negative potential as the filament, and is electrically connected and supported by electrode support 33. However, in order that the filament heating voltage will not be shorted through the shield 36, the shield is supported by, but is electrically insulated from, support post 34.

The purpose of this arrangement, i.e., the enclosing of the filament and the high negative voltage impressed upon filament shield 36 will be discussed hereinafter in the operation of the device.

The outer surfaces of cases 29 and 10 are surrounded by a water containing cooling jacket 37 to maintain the assembly at workable temperatures.

The compactness and portability of the present device results from the utilization of a short accelerating gap. This one factor results in the removal of the formerly encountered obstacles of gaseous discharge and pressure differentials within a device.

In eliminating pressure differentials it has been pointed out above that the length of the accelerating gap determines the pressure differential required in the prior art devices. The present invention makes use of accelerating gaps sufficiently short so that no pressure differential is required, and has the further effect of allowing higher gas pressures to be used throughout the device. Furthermore, although short accelerating gaps are used, their length with relation to the accelerating voltage and gas pressure is determined in such a manner that no gaseous discharge takes place. This result is attained by first considering the fundamental characteristics of a voltage discharge in a gas.

According to the general theory of sparking potentials in gases, and with particular reference to Paschen's law, it is well recognized that the electrical potential required to initiate a discharge through a gas from the high voltage electrode to a grounded electrode is a function of both the gas pressure and distance between the electrode and ground (see Loeb, *Fundamental Processes of Electrical Discharge in Gases* (Wiley and Sons, 1939) pages 408-414). Thus, for a particular gas, a curve may be obtained in which the high voltage, commonly referred to as sparking potential, is plotted as the ordinate, and in which the product of pressure and distance between the electrode and ground is plotted as the abscissa. Figure 3 shows a representative curve of this type.

The straight portion of the curve below the minimum which extends upwardly to the left follows to a good degree of approximation the equation,

$$V_s = A - B \log(pd)$$

where  $V_s$  is equal to the sparking potential in kv.,  $p$  is the pressure in mm. of Hg,  $d$  is the distance between electrodes, i.e., the distance between the high voltage elements, such as 20 and 22, and grounded elements such as 10, 24 and 26 in the present invention, and  $A$  and  $B$

are constants which are functions of the characteristics of the gas. The values of  $A$  and  $B$  are determined by routine experiments in accordance with ordinary procedures. See Quinn, *Physical Review*, 55, 482 (1939) for examples of these procedures. See also Loeb, *supra*, pages 476 to 484.

Therefore, after routinely determining the values of  $A$  and  $B$  for the particular gas and electrodes to be used, a curve is obtained from which there can be determined the various combinations of  $V_s$  and  $pd$  at which a gaseous discharge will occur. Once an accelerating voltage range has been selected, either the distance or the pressure may be varied in such a manner that their product is less than the value required to initiate a discharge. This product would be any value which would fall to the left of the curve defined by  $V_s = A - B \log(pd)$  at the accelerating voltage used. By selecting a voltage a horizontal line ( $a$ ) is defined as shown in Figure 3. The portion of this line lying to the left of the curve defines various products of pressure distance values at which no gaseous discharge will occur. Therefore, by selecting a gas pressure of 10 to 20 microns, for example, the distance from the high voltage to ground is easily determined. In the present device a distance of 1 cm. was found to be less than the value required to satisfy the pressure-distance product which would give a discharge at the selected voltage. Another factor to consider in the selection of the gap length is the mean free path of the accelerated ions. The gap length should be some small fraction of this mean free path, so that ion beam losses are very low. Thus, in the present device operating at a pressure of about two microns, 80 percent of the ions will have traveled five centimeters without making a collision. The gap length used is only one-fifth that distance. Once this distance is determined, all elements maintained at high potential, such as elements 20 and 22, are located within this predetermined distance from the grounded elements, such as case 10 and anodes 24 and 26. It is readily apparent, therefore, that the suppressor envelope 22 functions to reduce the distance between the high voltage target 20 and support tube 15, and the surrounding grounded elements, thereby increasing the maximum allowable pressure that can be used before a gaseous discharge takes place, as well as to suppress secondary electrons emitted from the ion bombarded target.

Since the electric field created between the high negative potential envelope 22 and the case 10 and anode 24 will be essentially perpendicular to all surfaces of the grounded elements surrounding the envelope 22, there is no problem of creating a spurious gaseous discharge between, for example, the upper surface of anode 26 and the extreme upper portion of the envelope 22. As noted above, the upper portion of the envelope 22 is held firmly against the bottom of insulator 11. The purpose of this contact is to reduce the perpendicular distance from the case 10 to the high voltage elements 13 and 15, so that this distance will be less than the distance required to initiate a high voltage breakdown, as defined in the above equation.

#### Electrical circuit

The target 20 is connected through target backing element 18 and target support tube 15 to the negative side of any standard 120 kv. direct current power source (see Figure 4). The positive side of this power source is grounded to the case 10, which grounds the anode 24, focusing anode 26, and circular anode 27. The target 20 being at a high negative potential will attract all positively charged particles and repel all negatively charged particles. The suppressor 22 is also connected to the negative terminal of the 120 kv. power source, through tube 13. The connections to target 20 and suppressor 22 are arranged in any standard manner so

that the voltage of one may be varied independently of the other.

Anode 27 may also be connected directly to the grounded positive terminal of the 120 kv. power source, in order to minimize transient electrical effects between circular anode 27, focusing anode 26 and cylindrical anode 24.

The electrode 35 and its electrically connected shield electrode 36 are maintained by means of a 500 v. direct current source at a negative potential of 500 volts. An electrode heating voltage of 10 volts D.C. is impressed between the supports 33 and 34. This voltage is not shorted through the shield electrode 36, since this electrode is electrically insulated at its connection to support 34 by means of an insulator (not shown). Thus, while being maintained at the negative 500 volt potential, the shield 36 does not form a parallel conducting path for the heating voltage of electrode 35.

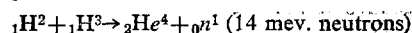
#### Operation

In operation the device is first outgassed by baking and pumping out gas emitted from the elements surrounding the internal chambers. The device is then flushed with deuterium gas, so that upon subsequent operation at elevated temperatures no gas impurities will be contained within the device or emitted from the various internal elements. Deuterium gas is admitted through gas inlet 31 until a gas pressure of from 10 to 20 microns is attained. The inlet 31 is then sealed. This permits the use of the device without the necessity of burdensome gas inlet leads, gas supplies, vacuum pumps and vacuum pump leads, and consequently makes the device easily transportable.

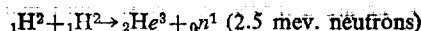
If desired, however, the neutron source may be operated with a small pressure difference between the accelerating chamber and the ionization chamber. This is accomplished by connecting the pumping leads 25 and 32 to independent vacuum pumps which evacuate the respective chambers at different rates. See The Review of Scientific Instruments, vol. 24, No. 6, pages 426-427, June 1953, for a discussion of this type of operation.

With filament heating voltage of 10 v., the negative electrode potential of 500 v. D.C., and the target 20 and suppressor 22 high voltage of negative 80 kv. D.C., impressed on the respective elements of the device, electrons are emitted from the filament 35. These electrons are forced away from the filament, since it is maintained at a negative 500 volts D.C., and toward the grounded anodes 26 and 27. The shield electrode 36 being at the same negative voltage as the filament also functions to constrict the emitted electrons to the area at the center of the circular filament 35. This arrangement permits the use of a short positive ion accelerating gap, yet allows the ionizing electrons to have a fairly long path to increase the probability of collision and resulting ionization. Ionization of the surrounding deuterium gas occurs in the area enclosed by shield 36, circular anode 27, and focusing anode 26. Thus, the major portion of the ionization takes place adjacent the aperture in focusing anode 26. The formed ions, being positive particles, are influenced by the presence of the negative potential on the target 20, and are attracted in that direction. The accelerating voltage functions as a focusing voltage, and the penetration of the electrical field of this voltage functions to pull the ions toward and through the central aperture in the focusing anode in the form of a beam, which is accelerated against the target 20.

The positive ions are accelerated by the high negative voltage of the target 20 and bombard the target. The bombarding of the hydrogen isotope which is absorbed in the target material results in the liberation of neutrons according to one of the reactions;



or



The first of these reactions involving the bombardment of a tritium containing target is the preferred embodiment, since the energy and number of the released neutrons is considerably higher than that obtained by the second reaction.

The present device can also be operated with the target at ground potential and the chamber at a high positive voltage. The potential difference between the anode 26 and the target 20 would be the same as that in the preferred embodiment.

As a result of the higher gas pressures used in the present device, i.e., 10 to 20 microns, the ion densities in the ionization region are increased over those of prior art devices. As a result of this large ion density and the low ion losses over the short accelerating gap, the ion beam current to the target is approximately one milliamp. This is an increase over prior art devices by a factor of from ten to a hundred.

The larger beam current, however, reduces to some extent the target life, since the focused ion beam strikes the target at a spot with a diameter of less than 1 mm. The ion beam spot diameter may be increased by the following additional apparatus. A tube 38 (see Figure 5), preferably platinum, about 1/8 inch in diameter and having thin walls is inserted in a centrally located hole in the circular anode 27. The tube 38 extends upwardly through the aperture in focusing anode 26, and terminates at the upper face of anode 26. This tube functions as a guide for the positive ions being accelerated toward the target, and results in a spreading of the ion beam target spot to a value of about 6 mm. The spot using this apparatus has its greatest intensity near the center and along the circumference.

The presence of the tube 38 also has the effect of focusing secondary electrons escaping from target into a beam less than 1/16 inch in diameter. These electrons proceed down the axis of the tube 38 and strike the circular anode 27. In order to prevent secondary electron penetration of the anode 27, a diamond 39 or other similar hard substance is provided at the lower extremity of the tube 38. The electrons proceeding down the tube strike the diamond 39. The electrons striking the diamond, however, will drill a hole through the diamond after extensive use of this mechanism. Thus, this apparatus, while effectively increasing the ion impact spot diameter on the target, can with little modification be used as a means for drilling holes in diamonds or other similar hard substances.

The present invention produces neutrons at a rate of at least  $10^8$  neutrons per second. The exact value of the yield depends upon the precise combination of accelerating voltage, target current, and gas pressure. The following table shows the yield for different operating conditions, for the D, T reaction.

Acc. Volt., kv.	Target Current, ma.	Pressure, Microns	Neutrons per sec. ( $\times 10^8$ )
55	7.0	12	1.3
62	4.2	17	0.2
80	3.0	17	1.7
92	2.0	7	1.9
97	5.0	9	1.1
80	0.5	5	1.1
80	1.5	5	2.2

The accelerating voltage range of from 55 kv. to 97 kv. gives a range of target currents varying from .5 to 7.0 ma. for pressures ranging from 5 to 17 microns. The neutron yields for these ranges vary from  $.2 \times 10^8$  to  $2.2 \times 10^8$  neutrons per second. It should be noted that the relationship between neutron yield and any other variable is not consistent or predictable. This lack of a definite relationship apparently indicates that for certain combinations of variables an ion species is produced which is less favorable to neutron production. One explanation

of this is that the ratio of  $D^+$  ions to  $D_2^+$  ions, i.e., the ratio of atomic ions to molecular ions, varies for different operating conditions, resulting in unpredictable fluctuations in the target current. The molecular ions have the effect of reducing the neutron yield, since their mass is greater and, therefore, their acceleration is less. Molecular ions are formed by the combination of atomic ions upon impact with metal surfaces. Thus, the production of molecular ions can be considerably reduced by coating the inner metal surface of the device with a ceramic material. Although such a coating will to a certain degree reduce the ruggedness of the present device, the neutron yield should be effectively increased.

The yields of the present neutron source are, however at least  $10^8$  neutrons per second in all cases, representing an increase in yield by a factor of from 100 to 1000 over prior art devices.

What is claimed is:

1. In a neutron source the combination of an electrically grounded chamber, deuterium gas in said chamber, means located at one end of said chamber for forming ions in said gas, a target containing a hydrogen isotope having at least one neutron supported in opposed relation to said ion forming means, means for impressing a high negative potential on said target for attracting ions formed in said ion forming means, ion focusing means including an electrically grounded anode located between said ion forming means and said target for focusing into a beam ions attracted to said target, an envelope having open ends supported adjacent, electrically insulated from, and enclosing said target, said target being supported within said envelope and adjacent one of said open ends, means for impressing a high negative potential on said envelope for suppressing electrons emitted from said target, said target and said envelope located with respect to said electrically grounded chamber and anode so that the distance between the surfaces of said high voltage target and envelope and the adjacent surfaces of said electrically grounded anode and chamber is substantially constant.

2. In a neutron source the combination of a chamber; deuterium gas in said chamber; means located at one end of said chamber for forming ions in said gas; high voltage target means supported in opposed relation to said ion forming means for attracting ions formed in said ion forming means; focusing means including an anode located between said ion forming means and said high voltage target means for focusing into a beam ions attracted to said target means; high voltage open ended envelope means located adjacent said target means for suppressing secondary electrons emitted from said target means, said target means and said envelope means being located with respect to said anode and said chamber at a distance less than the distance defined by the equation:

$$V_s = A - B \log(pd)$$

where

$V_s$  = target voltage

A and B are constants

$p$  = deuterium gas pressure in chamber

$d$  = distance.

3. The neutron source of claim 2, wherein said first named means includes a circular planar electron emitting filament, a filament shield located adjacent the periphery of said filament, and negative high voltage means connected to said shield for restricting said electrons to the area defined by said filament.

4. The neutron source of claim 2, wherein said focusing means includes a centrally apertured anode located with respect to said target so that the field created by said target high voltage means penetrates into said ion forming means through said anode aperture.

5. In a neutron source the combination of an electrically grounded chamber, deuterium gas in said chamber; said chamber containing ion forming means, ion focusing means including an electrically grounded anode,

and a target in opposed relation to said ion forming means; high voltage means connected to said target for accelerating said ions toward said target; said anode being located between said ion forming means and said target; open ended envelope means connected to said high voltage means and insulated from said target for suppressing secondary electrons emitted from said target, said envelope means and said target being located with respect to said chamber and said anode at a distance less than the distance defined by the equation: target voltage =  $A - B \log(\text{deuterium gas pressure} \times \text{distance})$ , where A and B are constants.

6. In a neutron source the combination of an electrically grounded chamber; a deuterium gas pressure in said chamber; means located at one end of said chamber for forming ions in said gas; a target supported at and electrically insulated from the other end of said chamber; said target having one surface containing a hydrogen isotope having at least one neutron in opposed relation to said ion forming means; high voltage means electrically connected to said target for accelerating said ions away from said ion forming means and against said target; means including an anode for focusing into a beam said ions accelerated away from said ion forming means, said anode being located between and concentric about a line connecting said ion forming means and said target, said anode being electrically grounded; open ended envelope means electrically connected to said high voltage means and surrounding, and electrically insulated from, said target for suppressing electrons emitted from said target, said envelope means being located with said open ends concentric about said line; said envelope means and said target being located with respect to said electrically grounded chamber and focusing means at a distance less than the distance defined by the equation: target voltage =  $A - B \log(\text{deuterium gas pressure} \times \text{distance})$ , where A and B are constants.

7. In a neutron source the combination of an electrically grounded chamber, deuterium gas in said chamber; a circular planar electron emitting cathode supported proximate the end of said chamber; means surrounding said cathode for confining electrons emitted from said cathode within the area defined by said circular cathode; a target supported in said chamber in opposed relation to said cathode; an electrically grounded anode having a central aperture, said anode supported intermediate said filament and said target; high voltage means; means connecting said high voltage to said target for accelerating ions, formed by the bombardment of said gas by said electrons, through said anode aperture and against said target; open ended envelope means supported adjacent said target and connected to said high voltage means for suppressing secondary electrons emitted from said target; said target and said envelope means being located with respect to said electrically grounded chamber and anode a distance less than the distance required to initiate a gaseous discharge of said high voltage on said target and said envelope means to said ground, where said last named distance is defined in the equation: target voltage =  $A - B \log(\text{deuterium gas pressure} \times \text{distance})$ , where A and B are constants.

8. In a neutron source the combination of an electrically grounded chamber; deuterium gas in said chamber; a circular electron emitting filament supported proximate the end of said chamber; means for focusing electrons emitted from said filament, a first electrically grounded apertured anode; a second electrically grounded anode; a target supported in said chamber in opposed relation to said filament; said first anode supported between said filament and first named means and said target; said second anode supported adjacent said filament and on the opposite side of said filament from said target; said target containing a hydrogen isotope having at least one neutron; means for impressing a high negative potential on said target for accelerating ions, formed by



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the bombardment of said gas by said electrons, against said target; open ended envelope means supported adjacent said target for suppressing secondary electrons emitted from said target; said target and said envelope means being located with respect to said chamber and said first anode at a distance less than the distance defined by the equation:

Target voltage= $A-B \log (pd)$  where A and B are constants  
 $p$ =deuterium gas pressure in said chamber  
 $d$ =distance.

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9. The apparatus of claim 8 having means including a thin walled small diameter tube for increasing the area of impact upon said target of said ions accelerated against said target.

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