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NEUTRON DISCHARGE TUBE

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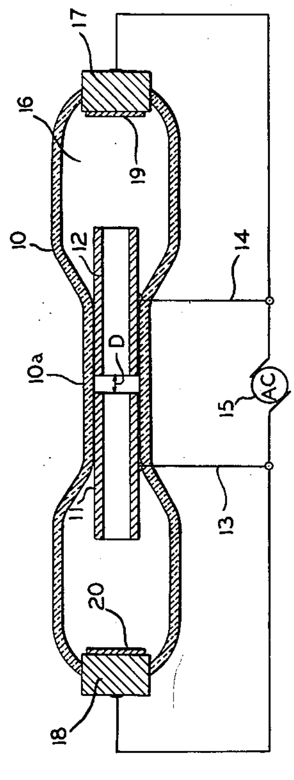

Fig. 1

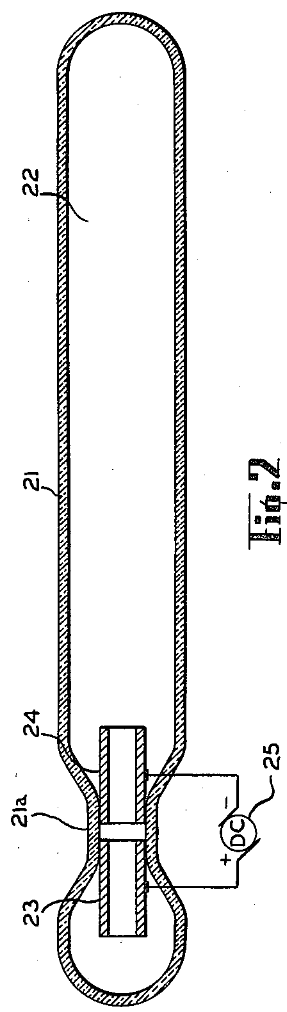

Fig. 2

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NEUTRON DISCHARGE TUBE

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The present invention is directed to an improved method and apparatus for providing a source of mono-energetic neutrons and is particularly directed to nuclear reactions between ions of deuterium and tritium.

In the past few years, considerable work has been done on exothermic nuclear reactions initiated by deuteron bombardment of the light elements. These reactions proceed on the basis that a reaction will occur if the deuterons and the light elements are given a sufficiently high relative velocity to overcome the electrostatic repulsion which exists between the two similarly charged nuclei. To achieve the relatively high potentials required to overcome this repulsion, generators of various descriptions have been employed. One of the most common is the Cockroft-Walton machine which employs a series of electrical capacitances which are progressively charged by the action of a vacuum tube switching circuit to potentials on the order of several hundred kilovolts. The deuterons are accelerated by these high potentials in an evacuated accelerating space and are directed toward a target containing the light element. However, machines of this type are extremely complex and expensive, and require continuous differential pumping of an evacuated accelerating column, precise control of a rather critical ion source and extractor mechanism, and frequently required cooling and special target structures.

Electrostatic machines of the Van de Graaff type have also been employed to initiate such reactions but the complexities incident to the operation of electrostatic machines of this type provides a distinct drawback to their extensive use.

With the foregoing in mind, an object of the present invention is to provide an improved method for generating neutrons from deuteron or triton bombardments.

Another object of the present invention is to provide mono-energetic neutrons in a controllable manner.

A further object of the invention is to provide a simplified apparatus for generating mono-energetic neutrons.

Another object of the invention is to provide a readily controllable apparatus for initiating and terminating deuteron or triton bombardment reactions.

Other and further objects and features of the present invention will be apparent to those skilled in the art from the following description and the attached sheet of drawings which illustrate a preferred embodiment of the invention.

The process of neutron generation employed in the present invention involves ionizing an atmosphere of deuterium into deuterons or tritium into tritons at a low absolute pressure, accelerating the deuterons through the atmosphere in which the deuterons were generated by means of an electrical potential sufficient to provide the ions with a sufficiently high energy level to undergo a neutron-liberating action with a suitable target, and then directing the accelerated deuterons or tritons at the target to cause such neutron liberation the target being located in the same atmosphere in which the ions were generated and accelerated.

The apparatus employed in the practice of the present invention may take various different forms, as evident from an inspection of the attached sheet of drawings in which:

Figure 1 is a cross-sectional view with parts in elevation illustrating somewhat schematically a neutron discharge tube embodying the principles of the present invention; and

Figure 2 is a cross-sectional view, with parts in elevation, of a modified form of neutron discharge tube.

The particular tube illustrated in Figure 1 is designed for energization by a source of alternating current, and includes an outer envelope **10** which supports a pair of spaced electrodes **11** and **12** therein. As seen in Figure 1, the electrodes **11** and **12** may each take the form of hollow cylinders composed of a metal such as stainless steel or the like. The electrodes **11** and **12** are spaced apart by a distance D which varies depending upon the gas pressure, the high voltage available, the electrode configuration, and the surface finish of the electrodes. The envelope **10** is necked down as indicated at **10*a*** to limit the discharge between the electrodes **11** and **12** to as short a path as possible.

The electrodes **11** and **12** are energized by means of leads **13** and **14** respectively from a source of high potential alternating current indicated schematically as an A.C. generator **15**.

The envelope **10** is filled with a gas **16** which preferably consists of a mixture of deuterium and tritium or it may consist simply of deuterium or, any ionizable gaseous isotope having at least one excess neutron per molecule.

In a gaseous discharge tube, if the breakdown potential is plotted against the product of the gas pressure and the distance between the electrodes, a curve results which exhibits a minimum breakdown potential at an intermediate pressure distance product. This is known as the Paschen's law curve for gaseous breakdown. The operation of the tube of the present invention is also governed by this law, and the pressure of the gas and the distance between the electrodes, distance D, is so regulated as to provide an operational range well below the point of minimum breakdown potential. The potential difference is then sufficient both to generate the ions and to accelerate them the required amount. While this pressure distance product will vary depending upon the gas or gaseous mixture present, I have successfully employed a distance of 0.7 centimeter between a pair of hollow cylindrical electrodes measuring two centimeters in diameter at a gas pressure of 0.1 millimeter of mercury (100 microns). Under these conditions, the potential between the electrodes was maintained at 55 kilovolts. The figures given are to be taken as typical and not as limitations. Generally, I may employ gas pressures within the tube ranging from about 1 micron to about 200 microns of mercury, absolute, depending upon the nature of the reactions sought to be accomplished.

In the particular apparatus illustrated in Figure 1, the deuterons are arranged to strike a solid target which may consist of a pair of metal blocks **17** and **18** both at opposite ends of the tube **10**, each of the blocks **17** and **18** having on its inner face a zirconium or similar plate **19** and **20**, on which is absorbed substantial quantities of tritium, resulting in a so-called zirconium hydride target. The blocks **17** and **18** are electrically connected to the electrodes **11** and **12**, as shown in Figure 1.

The tube shown in Figure 1 is designed for A.C. operation, i.e., at every half cycle of the generator output, the relative polarities of the electrodes **11** and **12** are reversed so that the ions are alternately directed at the target **19** and then at the target **20**.

The operation of the tube shown in Figure 1 is substantially as follows. The tube **10** is filled with sufficient deuterium gas to provide a gas pressure of about 0.01 millimeter of mercury absolute. An A.C. potential, preferably from fifty to one hundred kilovolts is provided between the electrodes **11** and **12** by the operation of the A.C. generator **15**. This potential is sufficient, from the Paschen's law curve, to break down the space between the electrodes **11** and **12** and cause ionization of the deuterium into deuterons and tritium into tritons. Under these conditions, the sustaining potential after breakdown is high compared to ordinary gap spacings, so that the electric field between the electrodes **11** and **12** remains intense. As the ions are produced, they are accelerated toward the cathode (which for purposes of illustration, will be taken as the electrode **12** at a particular instant of time). In passing through the accelerating space between the electrodes, most of the ions undergo collisions which reduce markedly the average energy of the ions reaching the cathode. This, however, does not mean that the ions are completely eliminated as reactants in the nuclear reaction. Actually, the deuterons or tritons possess what is known as a "persistence of velocity" so that an ion travelling half way down the tube might undergo a single kinetic theory collision causing it to lose let us say 100 volts, but leaving it practically unchanged in both energy and direction. Such noncatastrophic collisions result in what is known as the Kallman-Rosen effect. These collisions frequently result in charge exchange but seldom, if ever, in large changes of velocity. After a charge exchange collision, there remains a fast moving atom and a very slow moving ion. The atom will proceed down the tube and in all probability will undergo another Kallman-Rosen collision which will permit the electrostatic field to accelerate it further. The overall effect is that the ion arrives at the cathode with a velocity corresponding to the fraction of the time it was present as an ion in the gap. Thus, the effective accelerating voltage will be lower than the discharge sustaining voltage in such cases but still not zero. These partially accelerated ions therefore contribute to a nuclear yield in addition to that obtained from those ions which traverse the entire gap without a collision.

A certain percentage of the generated ions, even though quite small, pass through the cathode **12** and eventually strike the targets **19** and **20** to undergo a D, T reaction with the available tritium on the target **19**. The result is a liberation of a neutron at a controllable energy level for each such reaction.

Alternatively, the same type of reaction will occur if the envelope **10** is filled with gaseous tritium and the solid targets **19** and **20** contain absorbed deuterium.

Instead of employing solid targets of the type shown in Figure 1, the gaseous atmosphere itself may serve as a medium for the nuclear reaction. An apparatus suitable for carrying out this type of reaction has been illustrated in Figure 2 of the drawings. As seen in this figure, elongated tube **21** has an extended gas space **22** filled with a mixture of deuterium and tritium, or either gas alone, to a pressure of from about 1 to about 200 microns of mercury absolute. A pair of electrodes, comprising an anode **23** and a cathode **24** are located in the tube **21** in closely spaced relationship at which, considering the gas pressure in the tube, a high breakdown voltage will be required resulting in the presence of a high potential accelerating field. Both the electrodes **23** and **24** may consist of metallic hollow cylinders, as illustrated. The anode **23** and the cathode **24** are energized with an accelerating potential from a D.C. source such as a generator **25**. The tube **21** is also necked down as indicated at **21***a* to limit the discharge path available between the electrodes.

The break down potential employed will, of course, vary with the gas pressure and the nature of the mixture. For electrode spacing of 5 millimeters and employing a gaseous mixture of 50% tritium and 50% deuterium at a pressure of $\frac{1}{10}$ millimeter of mercury, the break down potential will be on the order of about 70,000 volts. The sustaining potential for such a system will be about one-half of the break down voltage or 35 kilovolts. At a pressure of $\frac{1}{10}$ millimeter of mercury, the mean free path for charge exchange may be taken as 1 millimeter. This figure is also of the order of magnitude of the kinetic theory mean free path since the two mean free paths are about equal.

In calculating the amount of neutrons produced under these conditions, several assumptions have to be made. First, it will be assumed that the number of ions present and available for acceleration in the vicinity of the anode is determined by the condition of zero net space charge in this region of the discharge and not by current equilibrium. In other words, the effective current carried through the tube by positive ions will be assumed to be inversely proportional to the square root of the ratio of the mass of an ion to that of an electron. This assumption implies that for every milliampere of current passed through the discharge, about 1% or 10 microamperes will be provided by deuterons.

Next, the tritium current will be ignored so that only the D, T reaction will be considered. Likewise, the reaction which might occur between 2 deuterons, namely, the D, D reaction will also be negligible compared to the D, T reaction.

In computing the number of high energy ions arriving in the vicinity of the cathode per milliampere of current through the discharge tube, the distribution and additional ions arriving due to the Kallman-Rosen effect will also be ignored.

With an electrode spacing of 5 millimeters and a mean free path of 1 millimeter, the probability of an ion traversing the accelerator gap with no collisions is e^{-5} or 7×10^{-3}. There would therefore be 7×10^{-5} milliamperes of fast deuterons per milliampere of total current in the discharge tube. These deuterons arrive at the cathode end of the gap with an energy of 35 kev. At this point, they are allowed to pass through the hollow core of the cathode and enter a field free space containing only a mixture of deuterium and tritium.

The yield of neutrons which might be expected under the conditions given can be calculated from existing data. It has been estimated, for example, that about 4.9×10^5 neutrons can be expected per microcoulomb of incident deuterons with certain types of targets. Hence, with the figures given previously, there will be approximately 3.5×10^4 neutrons per second per milliampere from the discharge tube.

The neutrons resulting from the D, T reaction under these circumstances will be essentially mono-energetic at an energy of 14 kev. The yield for the D, D reaction would be about $\frac{1}{1000}$ of the yield for the D, T reaction, and the reaction between deuterons and nitrogen 14 atoms would be about ¼ that of the D, D reaction. Nevertheless, in spite of these small yields, the reactions of this type furnish neutrons of sufficient intensity for instrument calibration and other purposes. The D, D reaction yields monoenergetic neutrons at about 2.5 mev. while the deuteron-nitrogen reaction yields neutrons at about 4.5 mev.

In the operation of the tube, I prefer to use voltages on the order of 50,000 to 100,000 volts. At potentials in excess of about 100,000 volts, difficulties may occur from the Fowler-Nordheim field emission effect which occurs when the potential difference is sufficient to draw electrons from the metal of the electrodes.

From the foregoing it will be apparent that the method and apparatus of the present invention provides a convenient means for generating monoenergetic neutrons at a controllable intensity. One of the advantages of the system described is the fact that it can be pulsed, i.e., it can be turned on and off at will by simply turning the electrical potential on and off. Pulsed neutron sources are extremely valuable in certain applications of nuclear physics.

Another advantage stems from the fact that the accelerating space, the ion generating space, and the target are in the same gaseous atmosphere, so that no pressure differential exists between them. This eliminates the many problems incident to maintaining an extremely high vacuum column as part of the apparatus.

It will be evident that various modifications can be made to the described embodiments without departing from the scope of the present invention.

I claim as my invention:

1. An apparatus for generating neutrons which comprises an envelope, a pair of spaced electrodes in said envelope defining an accelerating space therebetween, said accelerating space including a freely flowable ionizable atmosphere of an isotope having at least one excess neutron per molecule, the pressure in said envelope being in the range from about one micron to about 200 microns of mercury absolute, means for applying a potential difference between said electrodes, and means providing a gaseous atmosphere in open communication with said accelerating space, said gaseous atmosphere being capable of reacting with the ionized isotope to liberate a neutron by said reaction, said gaseous atmosphere having a dimension substantially longer than the dimension of said accelerating space in the direction of acceleration of the ionized isotope.

2. An apparatus for generating neutrons which comprises an envelope, a pair of spaced electrodes in said envelope defining an accelerating space therebetween, said accelerating space including a freely flowable atmosphere comprising deuterium at a pressure in the range from about 1 micron to about 200 microns mercury absolute, means for applying a potential difference between said electrodes, and means providing a gaseous atmosphere capable of reacting with deuterons formed and accelerated in said accelerating space to liberate neutrons by said reaction, said gaseous atmosphere having a dimension substantially longer than the dimension of said accelerating space in the direction of acceleration of the ionized isotope.

3. An apparatus for generating neutrons which comprises an envelope, a pair of spaced electrodes in said envelope defining an accelerating space including a freely flowable atmosphere comprising a mixture of tritium and deuterium at a pressure in a range from about 1 micron to about 200 microns of mercury absolute, and means for applying a potential difference between said electrodes, said envelope extending a sufficient distance beyond said electrodes to provide an atmosphere of tritium and deuterium capable of reacting with deuterons formed and accelerated in said accelerating space to liberate neutrons by said reaction.

4. An apparatus for generating neutrons which comprises an envelope, a pair of spaced electrodes in said envelope defining an accelerating space therebetween, said accelerating space including a freely flowable atmosphere comprising deuterium at a pressure in the range from about 1 micron to about 200 microns of mercury absolute, means for applying a potential difference between said electrodes, and an atmosphere including gaseous tritium at the same pressure as said accelerating space and capable of reacting with deuterons formed and accelerated in said space to liberate neutrons by said reaction, said atmosphere extending a distance which is many times the dimension of said accelerating space in the direction of deuteron travel.

5. An apparatus for generating neutrons which comprises an envelope, a pair of spaced hollow cylindrical electrodes defining an accelerating space therebetween, said accelerating space including a freely flowable atmosphere comprising deuterium at a pressure in the range from about 1 micron to about 200 microns of mercury absolute, means for applying a potential difference between said electrodes, and means providing a gaseous isotope atmosphere capable of reacting with deutrons formed and accelerated in said accelerating space to liberate neutrons by said reaction, said atmosphere extending a distance which is many times the dimension of said accelerating space in the direction of deuteron travel.

6. An apparatus for generating neutrons which comprises an envelope, a pair of spaced electrodes in said envelope defining an accelerating space including an atmosphere comprising a mixture of deuterium and tritium at a total pressure in the range from about 1 micron to about 200 microns of mercury absolute, said envelope extending a sufficient distance beyond said electrodes to provide an atmosphere of deuterium and tritium capable of reacting with deuterons formed and accelerated in said accelerating space to liberate neutrons by said reaction, and means for applying a potential difference between said electrodes.

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