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3,288,993

PLASMA PARTICLE SEPARATOR AND ANALYZER HAVING A GRID
STRUCTURE CONSISTING OF LINEAR TUBULAR PORTIONS

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Fig. 1.

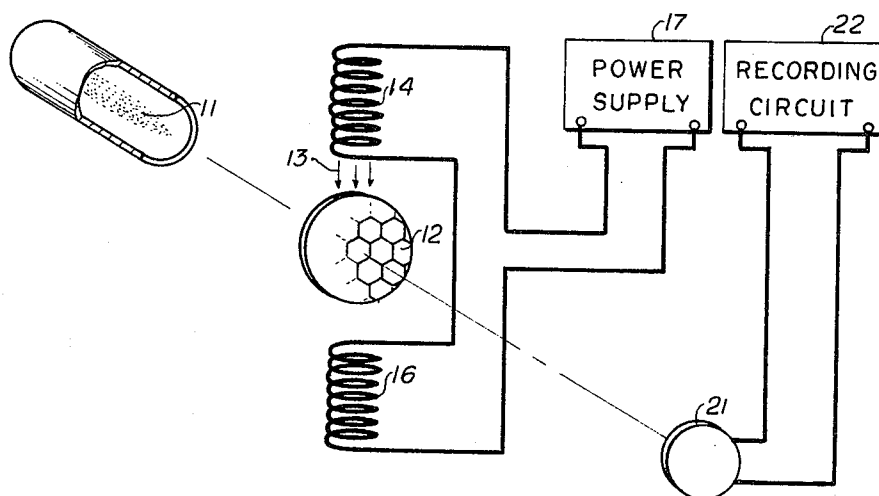


Fig. 2.

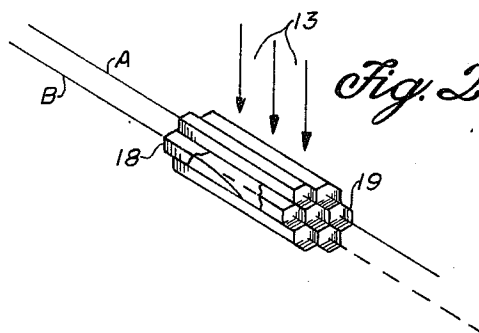
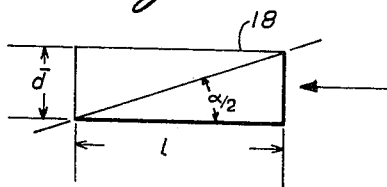


Fig. 3.



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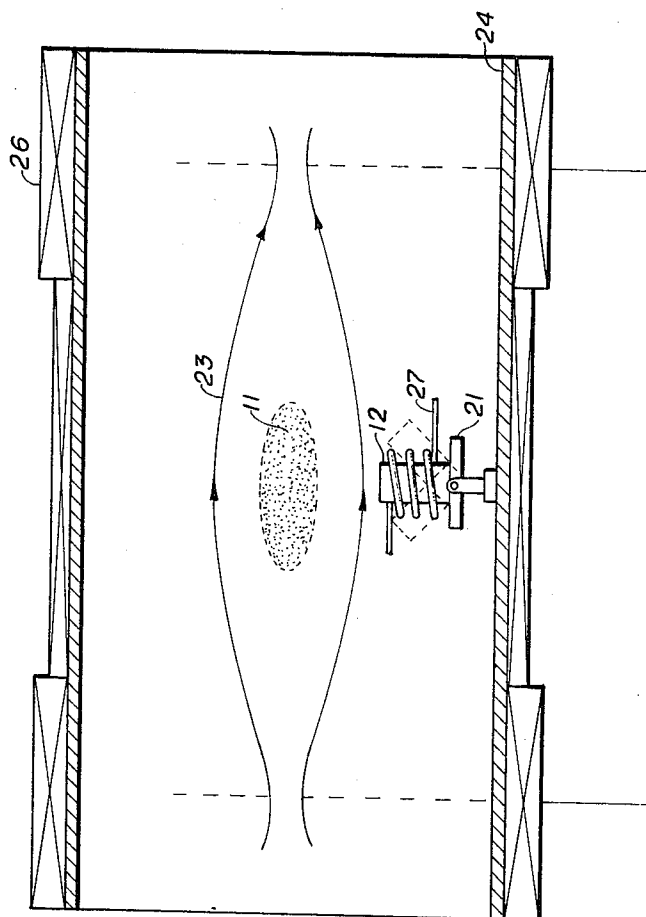
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Fig. 4.



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PLASMA PARTICLE SEPARATOR AND ANALYZER HAVING A GRID STRUCTURE CONSISTING OF LINEAR TUBULAR PORTIONS

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America as represented by the United States Atomic
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6 Claims. (Cl. 250-41.9)

The invention herein described was made in the course of, or under, Contract W-7405-ENG-48 with the United States Atomic Energy Commission.

This invention relates in general to separation of atomic particles and, more particularly, to apparatus and a method for separating particles having different momentum-to-charge ratios.

Heretofore, the separation and analysis of plasma particles having different momentum-to-charge ratios proved a vexatious problem due to the random distribution of the particles within the plasma. For example, a technique employed in the art utilizes magnetic action on the particles originating from a plasma to isolate the various particle constituents thereof. However, as a result of the random distribution of the particles in the plasma, difficulties are experienced in their separation and detection. Firstly, particles of the same momentum-to-charge ratio would not necessarily converge at a single point. And secondly, particles of different momentum-to-charge ratio which originate at different locations in the plasma can converge at the same point. Hence, it can be seen that the resolution of this technique is poor at best.

The present invention provides apparatus and a method which overcome many of the limitations and disadvantages of prior art particle separating techniques.

More particularly, the present invention utilizes a grid structure, substantially composed of a multiplicity of tubes secured together in parallel. The grid structure is disposed in a magnetic field of predetermined strength having a field component perpendicular to the principal axis of the grid structure. The tubular grid structure is disposed to receive the particles of a plasma. Each tube of the grid structure provides a separate channel through which a portion of the particles are passed and acted upon by the magnetic field. The magnetic action causes those particles of predetermined momentum-to-charge ratios to be deflected to impinge on and be collected by the tubular wall while those of other selected momentum-to-charge ratios are allowed to pass therethrough. By utilizing tubes of a very small inside mean diameter in the construction of the grid, the particles to be intercepted by the walls of the tube need only be deflected a small degree from their original direction of motion (and hence the magnetic field strength may be low) to fully separate those particles of different predetermined momentum-to-charge ratios.

The equation governing the deflection of particles in a magnetic field is given by

$$R = \frac{mv}{eB} \quad (1)$$

where

m = the mass of the particle,

v = the velocity of the particle,

e = the electrostatic charge of the particle,

B = the magnetic field component perpendicular to the path traveled by the particle,

R = the radius of curvature of the path followed by a charged particle in the magnetic field B .

As can be seen from the equation, the apparatus and method of the present invention can be utilized to yield in-

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formation in regards to the mass, energy and charge characteristics of particles.

The apparatus and method of the present invention is particularly useful in analyzing the momentum-charge characteristics of the particles in a plasma. For example, since uncharged particles (neutral particles) are not affected by a magnetic field, the method of the present invention may be utilized to separate charged from uncharged particles from a plasma to determine, for example, the location of charge exchange phenomena with a high degree of resolution by observing the escaping energetic neutral particles. Furthermore, the method of the present invention may be utilized to determine the energy profile of charged particles of a given mass-to-charge ratio, the density distribution of charged particles in a plasma, the net kinetic temperature of a plasma, the energy loss resulting from charged particles escaping from the plasma, and the mass profile of a plasma comprised of particles including contaminants.

A most unique feature of the present invention is that the aforementioned measurements are made without detrimentally interfering with the magnetic plasma confining fields. This is accomplished by disposing the tubular grid structure either without the magnetic confining field or only at the extreme periphery thereof.

Accordingly, it is a primary object of the present invention to provide apparatus and a method for separating atomic particle having a selected momentum-to-charge ratio from those having a different momentum-to-charge ratio.

More particularly, it is an object of this invention to provide apparatus utilizing a tubular grid structure in combination with a magnetic field for separating particles having different momentum-to-charge ratios.

It is another object of this invention to provide apparatus for separating and analyzing particles of a plasma in order to obtain information in regards to their mass, energy and charge characteristics.

It is a further object of this invention to provide a method for analyzing the characteristics of particles of the plasma without detrimentally interfering with the magnetic plasma confining fields.

Additional objects and advantages of the present invention will become apparent from the following description considered together with the accompanying drawings in which:

FIGURE 1 is a schematic diagram of preferred apparatus for conducting the method of the invention.

FIGURE 2 is a cut-away of a section of a tubular grid structure illustrating the method of the present invention.

FIGURE 3 is a cross section of a tube of the tubular grid section.

FIGURE 4 is a drawing illustrating a preferred method of determining the neutral particle profile of a magnetically confined plasma.

Considering now the apparatus and method of the present invention with reference to the accompanying drawings, it is contemplated that there will first be provided in the initial steps of the method a source of charged and uncharged particles, e.g., plasma 11.

Such plasma 11 may be formed for example by the method and apparatus disclosed in the application of Richard F. Post, assigned to the U.S. Atomic Energy Commission, entitled Pyrotron Thermonuclear Reactor and Process, S.N. 443,447, filed on July 14, 1954, issued as Patent No. 3,170,841 on February 23, 1965. A tubular grid structure 12 of low shadow ratio and composed of a non-ferrous conducting material, e.g., copper, is positioned to receive particles originating from plasma 11. A magnetic field 13 is established by energizing coils 14 and 16 with a current supplied by a conventional power

supply 17. The magnetic field 15 must be so established that a component of it is perpendicular to the principal axis of the grid structure 12.

With particular reference to FIGURE 2 lines A and B each represent a path followed by a particle from plasma 11; the momentum-to-charge ratio of the particle following path A differing from that of the particle following path B. The strength of magnetic field 13 is selectively adjusted to cause, for example, the particle following path A to curve and impinge upon the wall of tube 18 and be collected thereon; while that particle following path B is transmitted through the tube 19.

A particle detector means 21 is disposed to receive those particles transmitted through grid structure 12. Suitable recording means 22 is electrically connected to detector 21 to receive an electrical signal therefrom indicative of, e.g., the number of or the mean energy of, the particles impinging thereon.

The high resolution obtained from the method of the present invention is attributed to the small diameter and relative long length of the individual tubes of grid structure 12. This can be seen more readily by referring to FIGURE 3. A single tube, e.g., tube 18, of length l and means inside diameter $\bar{d}$ will prevent the transmission of substantially all particles entering tube 18 without the solid angle α where the angle is derived from the equation

$$\alpha = 2 \tan^{-1} \frac{\bar{d}}{l} \quad (2)$$

Hence, for a tube of mean diameter 0.03 inch and length 1.0 inch the transmission angle, α , would be $3^\circ 26'$.

Of the various methods for the production of grid structures, as utilized herein, a preferred process is the manufacture by explosive swaging as disclosed in the application of Donald E. Davenport, assigned to the U.S. Atomic Energy Commission entitled, Polycellular Tubular Grid Structures and Method of Manufacture, S.N. 260,929, filed on February 25, 1963, issued as Patent No. 3,222,144 on December 7, 1965. This technique which results in a grid structure, having the excellent properties of resistance to deformation, involves inserting copper coated aluminum wires into a copper pipe, explosively swaging the combination, and removing the aluminum by an acid bath leaving a copper grid structure. A typical structure may be constructed by the insertion of approximately 870 copper coated aluminum wires inside a 1.084 inch I.D. copper pipe. The aluminum wires are of 0.03 inch diameter with an additional 0.001-0.005 inch of electroplated copper coating. The assembly is swaged and machined to any convenient length. The aluminum may then be removed in the acid bath leaving the copper grid structure, as an integral unit.

Considering now a particular application of the method of the present invention, attention is directed to FIGURE 4 where the apparatus for performing the method is arranged to locate, with a high degree of resolution, the regions where energy losses attributed to charge exchange phenomena within a plasma occur. (For a treatment of the phenomena refer to Controlled Thermonuclear Reactions by Samuel Glasstone and Ralph H. Lovberg, D. Van Nostrand Company, Inc., New York (1960), sec. 12.4, p. 451.) Although it is to be noted that a plasma may be confined by various types of magnetic field configurations, the following description will be made considering a plasma confined by a magnetic mirror field of the class disclosed in the aforementioned application of R. F. Post.

Plasma 11 is confined by a magnetic mirror field 23 in an evacuated chamber 24. The magnetic field 23 is established by energizing a coil 26 disposed about chamber 24. As a result of the charge exchange phenomena, neutral particles are formed which are not affected by the magnetic field 23. These neutral particles travel in randomly directed straight line paths across the field lines and

eventually escape to the walls of the chamber 24 and there lose their energy.

Tubular grid structure 12 is pivotally mounted at the periphery of magnetic field 23 so that a component of magnetic field 23 is at all times perpendicular to its principal axis. As a result of the random nature of the origin of the neutral particles, a number of such particles representative of the total will at all times be traveling toward grid structure 12 and in a direction to pass therethrough. As a result of the magnetic confining field, all charged particles will be prevented from passing through the grid structure 12. This field imparts a curvature to the charged particles, and therefore any entering the grid structure impinge upon and are collected on its walls. A detector 21 sensitive to the energy of impinging particles, e.g., a thermistor, is disposed to receive those neutral particles transmitted through grid structure 12. Recording means 22, e.g., a bridge type instrument sensitive to impedance changes, is electrically connected to detector 21 to receive an electrical signal therefrom representative of the average energy of the flux of impinging particles.

It is seen that by pivoting grid structure 12, the entire plasma 11 can be scanned to accurately determine its charge exchange profile.

In cases where the present invention is utilized to determine the charged particle profile of a plasma, the grid structure 12 may be positioned to receive those particles escaping through the magnetic mirror field regions, e.g., as illustrated in FIGURE 1. The neutral particles emerging from the mirror field region could be prevented from being transmitted through grid structure 12 by, for example: (1) angularly displacing the grid structure with respect to the principal longitudinal axis of the magnetic confined field, or (2) by utilizing a curved tubular grid structure wherein each tube has the same radius of curvature. The charged particles of the selected momentum-to-charge ratio would be directed to pass through grid structure 12 by appropriately selecting the strength of magnetic field 13 to cause those chosen particles to have a radius of curvature as defined by Equation 1 which would allow their transmission through grid structure 12.

In some cases where particles of extreme densities or velocities are analyzed, gas molecules will be produced in the tubes of the grid structure 12 when the particles collide with the walls of the tubes. These gas molecules interfere with the transmission of the particles of interest through grid structure 12 and hence are undesirable. By surrounding grid structure 12 with suitable tubing 27 and passing a coolant therethrough, e.g., liquid helium, grid structure 12 would be cooled and gas molecules normally set free by the aforementioned particle-wall collisions are trapped on the walls of the tubes of grid structure 12. Such cooling would preferably take place in a highly evacuated region in order that a minimum residual background gas is accumulated in the grid structure 12.

While the present invention has been hereinbefore described in terms of apparatus and a method for performing an analysis of the various particle characteristics, it is to be noted that this was for illustrative purposes only and it is not intended to limit the invention except by the terms of the following claims.

What is claimed is:

1. In apparatus for separating and analyzing atomic particles of a mixture including charged particles having different momentum to charge ratios and traveling along linear paths, the combination comprising:

(a) a grid structure comprising linear tubular portions defining a plurality of channels each providing a lineal free path of a generally uniform radial diameter, $\bar{d}$, along its length, l , said free lineal paths being disposed in parallel relationship, said grid structure being adapted for positioning to align said lineal paths with said linear particle paths to direct the particles in said mixture to be analyzed into one end of said

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channels, said average diameter, $\bar{d}$, and length, l , of said free lineal path determined by the expression,

$$\alpha = 2 \tan^{-1} \frac{\bar{d}}{l}$$

wherein α is the angle of acceptance of said free lineal paths for particles of the mixture traveling along said linear paths;

- (b) means for establishing a magnetic field in said grid structure, said magnetic field having a selected intensity component, B , perpendicular to said lineal path, to confine particles of said mixture having a desired momentum to charge ratio to travel a path therein to emerge from the second end of said channels, said path defined by the equation

$$R = \frac{mv}{eB}$$

where m equals the mass of the particles, v the velocity of the particles, e equals the electrostatic charge of the particles, and R equals the radius of curvature of the path followed by the particles of desired momentum to charge ratio; and

- (c) particle detector means disposed to intercept atomic particles emerging from the second end of said channels.

2. Apparatus as defined in claim 1, wherein said particle detector means comprises a particle energy detector element disposed to intercept said emerging particles and adapted to provide an electrical signal representative of the energy of said particles and means adapted to receive and display said signal to indicate the energy of said particles.

3. Apparatus as defined in claim 1, wherein said particle detector means comprises a particle number detector element disposed to intercept said emerging particles and adapted to provide an electrical signal representative of the number of said particles and means adapted to receive and display said signal to indicate the number of said particles.

4. Apparatus for separating and analyzing atomic particles of a mixture emerging along linear paths from a plasma confined in a magnetic field in an evacuated system, comprising:

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- (a) a grid structure defining a plurality of channels each providing a lineal free path of a generally uniform radial diameter, $\bar{d}$, and length, l , therealong, and having an angle of acceptance, α , with respect to said particle linear paths, said average diameter, $\bar{d}$, and length, l , being determined by the expression

$$\alpha = 2 \tan^{-1} \frac{\bar{d}}{l}$$

said free lineal paths being disposed in parallel relationship;

- (b) means for positioning said grid structure in said evacuated system with a component of said magnetic field perpendicular to said lineal free path and with said lineal free path in acceptance alignment with a region of said plasma for directing energetic particles emerging therefrom into one end of said channels for separation of neutral and selected momentum-to-charge ratio particles therein and direction of desired separated particles along said lineal path to emerge from the end of said channels; and

- (c) particle detector means including a detector element disposed to intercept particles emerging from said channels.

5. Apparatus as defined in claim 4, wherein coolant means are provided in heat transfer relation to said grid structure for cooling said grid to cryogenic temperatures.

6. Apparatus as defined in claim 4, wherein said channels are curved to provide lineal free paths having a longitudinal curvature such that the lineal free path emerging from the second end of said channels diverges with respect to the lineal path at the first end by an angle greater than said angle of acceptance, α .

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