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2,664,515

MAGNETIC ELECTRON MULTIPLIER

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2 Sheets-Sheet 1

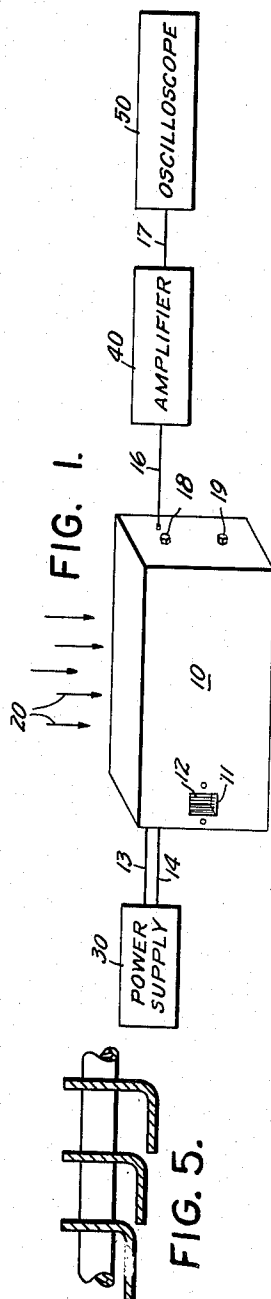
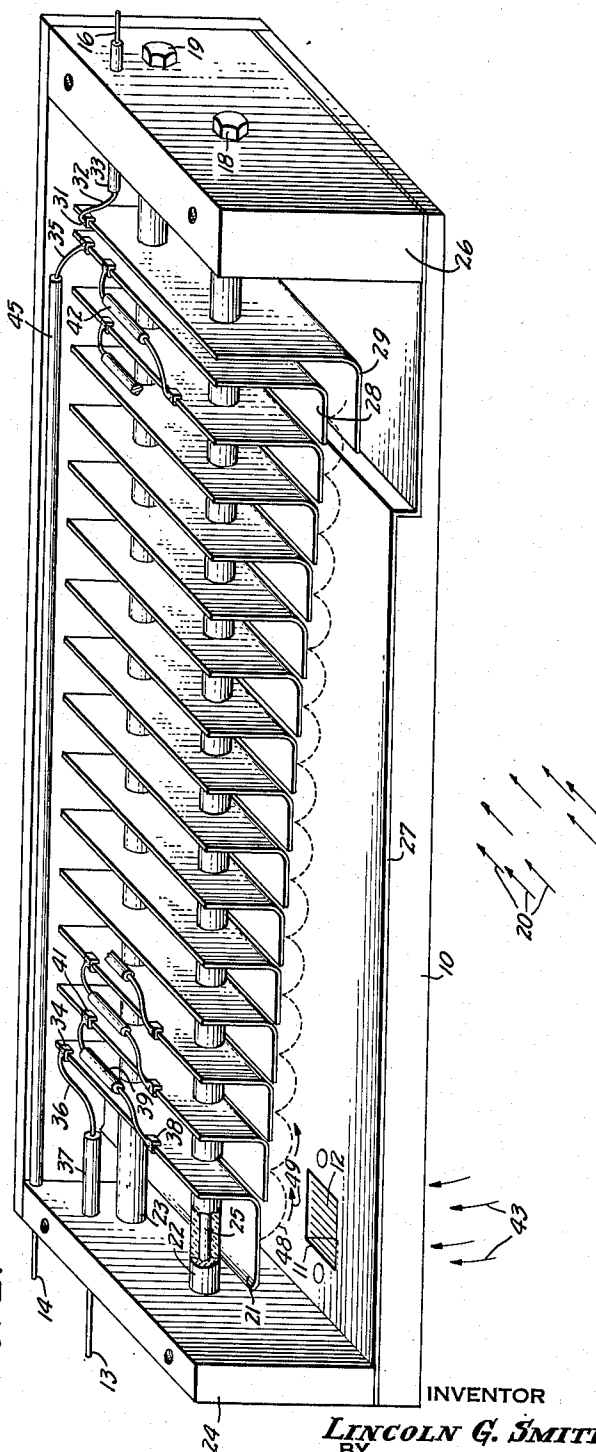


FIG. 2.



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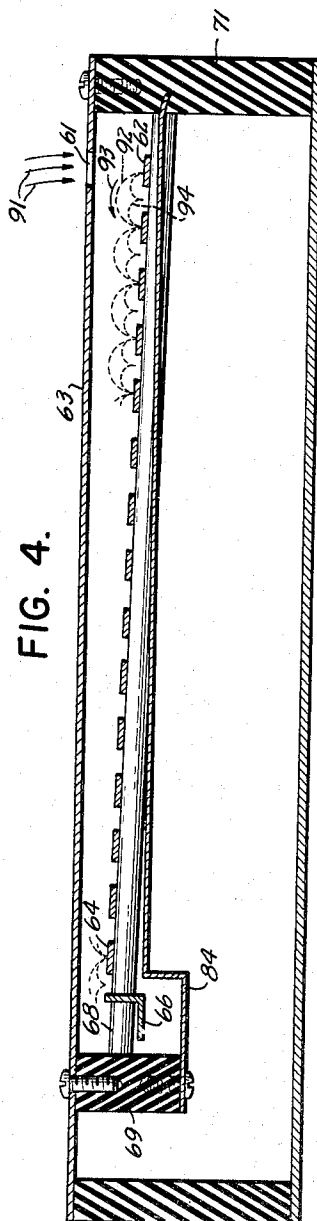
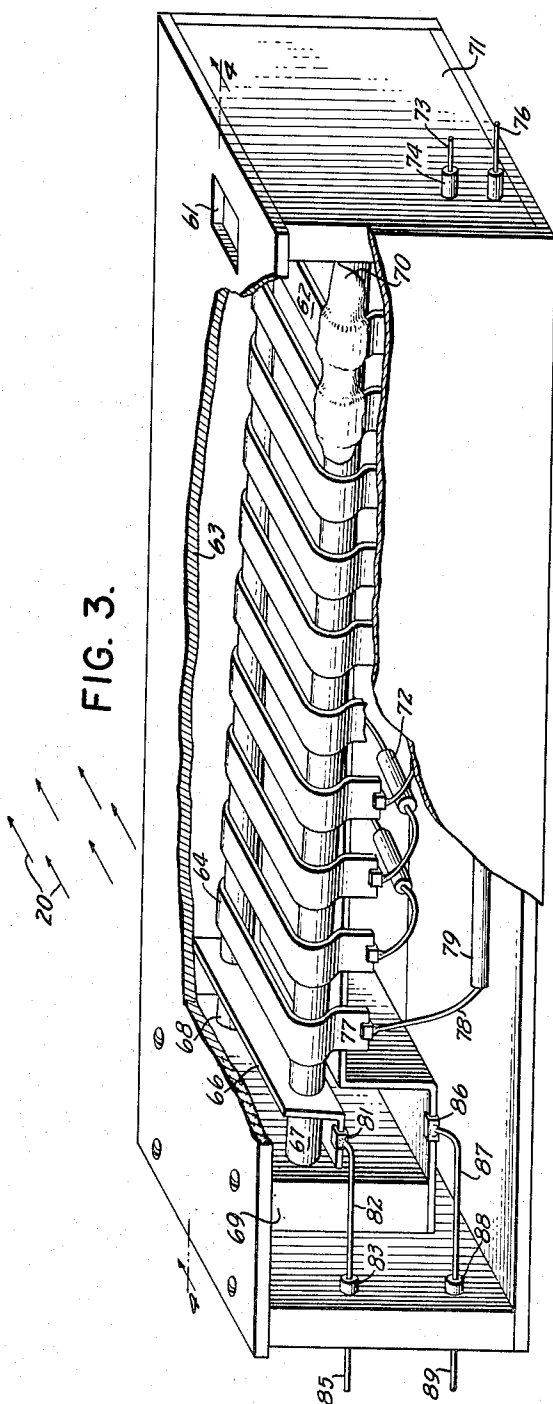
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MAGNETIC ELECTRON MULTIPLIER

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6 Claims. (Cl. 313-105)

1

The present invention relates to an electron multiplier capable of operating in a magnetic field. In mass spectrometers and other similar analytical devices wherein a beam of ions is projected into a magnetic analyzer which resolves the beam into its characteristic mass components, there is a need for apparatus capable of detecting ion pulses of extremely small magnitudes. For example, certain types of mass spectrometers such as the time-of-flight mass spectrometer disclosed in application S. N. 83,258 (S. A. Goudsmit) require associated apparatus capable of detecting with accuracy short ion pulses of very weak intensity. Moreover, in this type of instrument it is also desired to have the time between the formation of a pulse in the ion source of the spectrometer and its arrival at the detector represent an integral number of periods of rotation of an ion in a homogeneous magnetic field. It is accordingly necessary to have the sensitive surface of the detector located in the magnetic field. Conventional electron multipliers, such as are used in electron multiplier phototubes, will have their operation seriously impaired if they are located in the magnetic field of the spectrometer. By contrast, the apparatus of the present invention makes use of the magnetic field to focus secondary electrons from each emissive electrode on to the next.

It is accordingly an object of the present invention to provide a new and improved method and apparatus for detecting moving charged particles.

Another object of the invention is to provide a new and improved ion detector which can be used in a magnetic field.

A third object of the invention is to provide a new and improved magnetic electron multiplier with a high gain and a short response time.

A further object of the present invention is to provide a new and improved magnetic electron multiplier that utilizes the focusing properties of a uniform electrostatic field perpendicular to a magnetic field.

Other objects and advantages will be in part obvious and in part pointed out hereinafter.

More particularly, a preferred embodiment of the apparatus of the present invention comprises the combination including a homogeneous magnetic field, an electrically conductive plate located in said magnetic field and parallel to the lines of flux of said magnetic field, a plurality of secondary electron emission dynodes located in said magnetic field and disposed in echelon parallel relation with respect to said conductive plate,

2

means for establishing a uniform electrostatic field between said plate and said dynodes, said electrostatic field being perpendicular to said magnetic field, means for causing the moving charged particles to be detected to impinge on the dynode, most remote from said plate whereby secondary electrons are produced which are attracted and amplified by the remaining dynodes in successive steps and means for collecting the amplified number of secondary electrons produced by the last dynode.

The many objects and advantages of the present invention may best be appreciated by reference to the accompanying drawings, the figures of which illustrate apparatus incorporating a preferred embodiment of the present invention and capable of carrying out the method of the invention.

Figure 1 is a schematic view showing the exterior of the magnetic electron multiplier in relation to the conventional instruments connected thereto.

Figure 2 is a perspective view of the apparatus rotated through 90 degrees from the position shown in Figure 1 and with two side plates removed to show the internal constructional details.

Figure 3 is a perspective view of a second embodiment of the apparatus of the present invention with a portion of the side plates broken away.

Figure 4 is a transverse sectional view taken along the line 4-4 of Figure 3.

Figure 5 is a transverse sectional view of three successive dynodes of Figure 2.

Referring to Figure 1 the magnetic electron multiplier 10 is shown positioned in a homogeneous magnetic field the direction of which is represented by arrows 20. The moving charged particles to be detected enter the multiplier 10 through window 11 containing grid wires 12. Operating potentials for multiplier 10 are provided by power supply 30 connected to the multiplier by conductors 13 and 14. The amplified output of the multiplier is connected on conductor 16 to a conventional amplifier 40. Amplifier 40 is used only if it is desired to further amplify the electron pulse received from multiplier 10. The output of amplifier 40 can be connected to an oscilloscope 50 by conductor 17 or to any other conventional indicating instrument. Also shown on one end wall of multiplier 10 are pressure screws 18 and 19 used for mounting purposes as will be described hereinafter.

Referring now to Figure 2 it can be seen that

the multiplier 10 is in a homogeneous magnetic field which is in a direction represented by arrows 20. At the left hand portion of Figure 2 is window 11 in which are mounted the grid wires 12. Directly opposite window 11 is an L-shaped secondary electron emissive dynode 21 which is mounted on two insulated rods and spaced from end wall 24 of multiplier 10 by two electrically insulated spacers 22 and 23. Spacer 22 is shown broken away so that one of the insulated mounting rods 25 may be visible. The insulated mounting rods run the entire length of the multiplier and are terminated in pressure screws 18 and 19 mounted in the end wall 26 of the multiplier. Pressure screws 18 and 19 are used to force the rods securely into recesses in the opposite end wall 24. Also mounted on the rods are a plurality of L-shaped secondary electron emissive dynodes which are separated by insulated spacers of a construction similar to spacers 22 and 23. The dynodes are electrodes made of or coated with a material capable of high secondary emission. When moving charged particles impinge on the electrode a number of electrons are emitted. When a high secondary emissive material is used more electrons are emitted by the electrode than arrive thereon resulting in electron amplification. Mounted along one side of multiplier 10 is an electrically conductive plate 27. Each of the dynodes has one surface parallel to the plate 27. The distance between each of these surfaces and plate 27 decreases in successive steps progressing from left to right in the multiplier so that the first dynode 21 is most remote from plate 27 and the last dynode 28 is closest to the plane of the plate 27. Accordingly, these dynode surfaces are disposed in echelon parallel relationship with respect to plate 27. That is, each of the dynode surfaces is successively closer to plate 27 and the surfaces are parallel to one another. Mounted next to the last dynode 28 is a collector plate 29 of the same general shape as the secondary electron emissive dynodes. At the right hand portion of the multiplier, plate 27 is depressed so that the parallel surface of collector 29 lies in the plane of the plate 27. Attached to collector plate 29 by means of a clip 31 is a conductor 32 which is connected to output conductor 16 by means of a conventional connector 33 mounted in the end wall 26 of multiplier 10. Attached to the first dynode 21 by means of a clip 34 is a conductor 36 that is connected to power supply conductor 13 through a conventional connector 37 mounted in the end wall 24 of multiplier 10. Also connected to dynode 21 by means of a clip 38 is one end of the resistor 39. The other end of resistor 39 is connected to the dynode immediately adjacent dynode 21 by means of clip 41. In the same manner, resistors are connected between adjacent dynodes mounted in multiplier 10 up to and including resistor 42 connected to the last dynode 28. Dynode 28 is connected to the remaining power supply lead 14 by means of conductor 35 and connector 45.

In operation the multiplier 10 is placed in the magnetic field so that plate 27 is disposed parallel to the flux lines of the magnetic field represented by arrows 20. The ions to be detected, which travel in a plane perpendicular to the lines of flux of the magnetic field, arrive from the direction indicated by arrows 43. A negative operating potential is applied on lead 13 to the first dynode 21 by means of connector 37, conductor 36 and clip 34. This negative poten-

tial is reduced in successive steps by the resistors connected between adjacent dynodes so that dynode 21 is at the most negative potential and dynode 28 is at the least negative potential. The electrically conductive plate 27 is connected to ground potential. This connection is not shown but may be easily carried out by a suitable connection to the mounting screws holding the multiplier assembly together. Collector plate 29 is connected to ground through an external resistance, for example, the input resistor of amplifier 46. The connection of the operating potentials as described hereinabove results in a uniform electric field between plate 27 and the surfaces of the dynodes parallel to plate 27 because the potential of each dynode is proportional to its distance from plate 27. That is, as each dynode is spaced closer to plate 27 its potential is made proportionately less negative due to the voltage dropping resistors. Therefore, when the ions to be detected arrive at window 11 they are immediately attracted to dynode 21 which is maintained at the most negative potential in multiplier 10. Due to the secondary electron emissive properties of dynode 21 the impingement of the ions thereon gives rise to secondary electrons. These electrons would normally be attracted to plate 27 which is maintained at the most positive potential in multiplier 10. However, due to the action of the magnetic field the path of the electrons, represented by dotted line 48, curves in the direction shown by the arrow 49 so that the electrons impinge on dynode adjacent dynode 21. The orbit represented by dotted line 48 is trochoidal with a cusp at each dynode. It is well known that the orbit of electrons in a crossed magnetic and electrostatic field is a trochoidal orbit. Therefore by properly adjusting the spacing and potentials of adjacent dynodes the secondary electrons are made to follow the path represented by dotted line 48 causing the cusps of the orbit to occur at each adjacent dynode. More secondary electrons are emitted from the next dynode than impinge thereon due to its higher potential and its emissive properties. These emitted electrons continue to be amplified in the same manner throughout the remaining dynodes with successive amplification taking place due to the fact that each succeeding dynode is more positive than the one previous to it. This amplification continues until the amplified secondary electrons reach the last dynode 28. They are thereupon attracted to the collector plate 29 giving rise to an output pulse on conductor 32 which is transmitted to output conductor 16.

The improvement of the performance of the embodiment hereinabove described is primarily due to the uniform electrostatic field maintained between the active surfaces of the dynodes and the electrically conductive plate 27. The constructional feature which accomplishes this result is the progressively smaller distance between each dynode and plate 27. Also the slight overlapping of each emissive surface prevents any abrupt break in the uniformity of the electric field. In this manner the required potential difference of several hundred volts between adjacent dynodes is established without resort to a non-uniform electric field. This useful feature also requires only one-half the number of insulated plates normally used in magnetic electron multipliers due to the fact that only one accelerating electrode, namely conductive plate 27, is used. Another advantage in the embodi-

5

ment shown in Figure 2 is that there is no component of the electrostatic field which tends to draw ions from the region near the output stage toward the input stage thereby causing a breakdown or noise due to ion feedback.

Referring to Figure 3 a second embodiment employing the features of the present invention is shown. The magnetic field in which this multiplier is located is in a direction represented by arrows 20. The ions to be detected enter the multiplier through window 61. Located opposite window 61 is the secondary electron emissive surface of dynode 62. The dynodes of the multiplier shown in this figure are co-planar and mounted at an acute angle with respect to the electrically conductive plate 63, with the first dynode 62 being farthest from plate 63 and the last dynode 64 being closest to plate 63. The dynodes all have their longitudinal edges parallel to plate 63. Following the last dynode 64 is collector plate 66. The dynodes and the collector plate 66 are all mounted on two insulated rods 67 and 68 each of which have one end secured in the insulated end plate 69 and the other end secured in end plate 71. The dynodes are secured to the rods 67 and 68 by a suitable adhesive material, 70, which is shown only on the first two dynodes in order to make clear the construction of the dynodes. The ends of the dynodes are bent around rods 67 and 68 to permit convenient electrical connection thereto and resistors such as resistor 72 are connected between adjacent dynodes in the manner shown. In order to supply operating potential to the first dynode 62, power supply conductor 73 is connected to the interior of the multiplier through a conventional connector 74. Connection is made from the last dynode 64 to the return power supply conductor 76 by means of clip 77, conductor 78 and connector 79. The amplified output of the multiplier is taken from collector plate 66 by means of clip 81, conductor 82, connector 83 and external conductor 85. Collector plate 66 is connected to ground in a similar manner to collector plate 29 of Figure 2. Mounted on the insulated end plate 69 is a second electrically conductive plate 84 which is parallel to plate 63 in the operating area of the multiplier. Plate 84 is supported at its other end in a curved slot in insulated end plate 71. Electrical connection to plate 84 is made by means of clip 86, conductor 87 and connector 88 leading to the external conductor 89. The operation of this embodiment will be described hereinbelow with respect to Figure 4.

Referring to Figure 4 the lines of flux of the magnetic field are now directed perpendicular to the plane of Figure 4. The ions to be detected arrive in a direction indicated by arrows 91. Dynode 62 is connected to a source of negative potential with the return lead of the source connected to dynode 64. Since resistors are connected between adjacent dynodes each dynode is successively less negative with respect to the one before, progressing from said first dynode 62 to the last dynode 64. Plate 84 is connected to a source of potential more negative than dynode 62. Plate 63 is connected to ground potential. The negative potential of each dynode and of plate 84 is proportional to its distance from plate 63. Therefore when the ions arrive at the window 61 they are attracted to dynode 62, the most negative dynode. Secondary electrons arise upon the impingement of the ions. These electrons are attracted towards grounded plate 63 but are

6

deflected towards the next dynode by the magnetic field so that they follow the path represented by dotted line 92 and arrow 93. Since there are spaces between adjacent dynodes the uniformity of the electrostatic field between the dynodes and the plate 63 would be disturbed were it not for the inclusion of plate 84 which provides a uniform electrostatic field between plates 63 and 84 throughout the operating region. Therefore with a homogeneous magnetic field and a perpendicular uniform electrostatic field the secondary electrons follow trochoidal orbits with cusps at each succeeding dynode as represented by the dotted line 92 of Figure 4. The secondary electrons are successively attracted to each succeeding dynode, with more electrons being emitted from the dynodes than impinge thereon, until the last dynode 64 is reached. Here the amplified number of electrons are attracted to the collector plate 66 giving rise to an output pulse on the conductor connected thereto. If necessary this pulse can be further amplified by conventional amplifying equipment located outside the magnetic field and visually indicated on an oscilloscope.

The embodiment illustrated in Figures 3 and 4 may generally be used in more intense magnetic fields than the embodiment of Figure 2. This results from the fact that the distance between successive cusps of the trochoidal orbit is proportional to the value of the electrostatic field and inversely proportional to the square of the value of the magnetic field. This may be represented by the equation, $\partial aE/H^2$ where b is the distance between cusps, E is the value of the electrostatic field and H is the value of the magnetic field. It is apparent that the minimum distance between cusps is the width of a dynode. Therefore, if it is desired to double the intensity of the magnetic field for a given width of dynode, it would be necessary to quadruple the value of the electrostatic field in order to maintain the distance, b , constant. As the intensity of the magnetic field is increased to higher levels, the electric field would have to be increased to such a value that an electrical discharge would occur between the dynodes. The construction of the embodiment of Figures 3 and 4 overcomes this when the spaces between dynodes are made equal to the width of a dynode. In this event, the secondary electrons can be made to undergo two trochoidal cycles between successive dynodes as illustrated by the dotted line 94 of Figure 4. In this manner, the distance, b , between cusps can be kept the same in higher magnetic fields without the danger of a discharge occurring between the dynodes. It is evident that the distance between successive dynodes can be made equal to any integral number of dynode widths and the same result obtained by causing the secondary electrons to go through an equal integral number of trochoidal cycles between dynodes.

The following materials and dimensions were found satisfactory in the construction of the embodiment of Figure 2: 15 dynode plates whose active surfaces are parallel and slightly overlapped are used; the dynodes are 1" high, made of commercial beryllium copper 0.007" thick, supported on two $\frac{1}{8}$ " O. D. insulated tubes made of a suitable material, as for example the material commercially known as steatite and spaced by sections of $\frac{1}{4}$ " O. D. insulated tubing such as steatite; the grid window is made $\frac{3}{8}$ " wide by $\frac{1}{2}$ " high; the distance between corresponding points on adjacent active dynode surfaces is

0.375" in a parallel direction and 0.022" in a perpendicular direction; dynode 21 is spaced 0.594" and dynode 23, 0.236" from plate 27; each of the resistances connected between adjacent dynodes are $\frac{1}{2}$ watt, 1 megohm carbon resistors.

In use with the time-of-flight mass spectrometer an apparatus constructed as hereinabove indicated has the following characteristics: the multiplier is usable at a maximum sensitivity in magnetic fields from about 250 to 460 oersteds corresponding to over-all negative voltages from 2600 to 3500 volts. At less than maximum sensitivity the multiplier has been used up to 535 oersteds.

The multiplier shown in Figures 3 and 4 has been found to operate satisfactorily when made in the following materials and dimensions: 15 dynodes are used and are made of beryllium copper, $\frac{1}{8}$ of an inch wide; tubes 67 and 69 are made of insulated tubing such as steatite, $\frac{1}{8}$ " O. D., and $1\frac{1}{2}$ " apart; end plates 63 and 71 are made of a suitable insulating material, as for example the material commercially known as lavite; plate 64 is kept at a distance of $\frac{1}{8}$ " from plate 63; the voltage dividing resistors are one megohm each; window 61 is $\frac{1}{8}$ " wide and $\frac{5}{8}$ " high. Dynode 22 is $\frac{1}{4}$ " from plate 63 and dynode 64 is $\frac{1}{8}$ " from plate 63. Therefore, the distance between corresponding points on adjacent dynodes is 0.250 in a parallel direction and 0.009 inch in a perpendicular direction.

In the design of Figures 3 and 4, over-all voltages of about 3500 volts (i. e. between plate 24 and plate 25) can be used corresponding to magnetic fields up to 1100 oersteds. With the magnetic field equal to 1100 oersteds and the over-all voltage equal to 3500 volts the voltage per stage is 242 volts and the electrostatic field equals 10,720 volts/cm.

Since the embodiments of the apparatus of the present invention are primarily intended for use inside of mass spectrometers no provision has been made for evacuation of the operating volume of the multiplier. In normal operation the multiplier is mounted in the proper position in the mass spectrometer and the entire spectrometer is evacuated thereby causing evacuation of the operating volume of the multiplier. However, if the multiplier is to be used externally, provisions for enclosing the apparatus within an evacuated envelope may easily be made by conventional methods.

Since many embodiments of the apparatus of the present invention might be made and since many other changes may be made in the preferred embodiments described above it is to be understood that the foregoing description is to be interpreted as illustrative only and not in a limiting sense except as required by the appended claims.

I claim:

1. A magnetic electron multiplier for the detection of moving charged particles in a homogeneous magnetic field which comprises an electrically conductive plate located in said magnetic field and parallel to the lines of flux of said field, a plurality of secondary electron emissive dynodes located in said field and disposed in echelon parallel relation with respect to said plate, means for establishing a uniform electrostatic field between said dynodes and said conductive plate, said electrostatic field being perpendicular to said magnetic field, means for causing said moving charged particles to impinge on the dynode most remote from said conductive plate whereby sec-

ondary electrons are produced which are attracted and amplified by the remaining dynodes in successive steps and means for collecting the electrons produced by the last dynode.

2. A magnetic electron multiplier for the detection of moving charged particles in a homogeneous magnetic field which comprises an electrically conductive plate located in said field and parallel to the lines of flux of said magnetic field, a plurality of secondary electron emissive dynodes located in said field parallel to said plate and disposed in echelon parallel relation with respect to said plate, means for producing a direct current potential difference between each of said dynodes and said conductive plate, the value of said potential difference being proportional to the distance between said dynodes and said conductive plate thereby establishing a uniform electrostatic field therebetween, said electrostatic field being perpendicular to said magnetic field, means for causing said moving charged particles to impinge on the dynode most remote from said conductive plate whereby secondary electrons are produced which are attracted and amplified by the remaining dynode in successive steps and means for collecting the electrons produced by the last dynode.

3. A magnetic electron multiplier for the detection of positively charged particles in a homogeneous magnetic field which comprises an electrically conductive plate located in said magnetic field and parallel to the lines of flux of said field, a plurality of secondary electron emissive dynodes located in said field, parallel to said plate and disposed in echelon relation with respect to said plate, means for electrically grounding said conductive plate, means for applying a direct current negative potential between each of said dynodes and said conductive plate, the value of said applied negative potential decreasing an amount proportional to the distance between each of said dynodes and said conductive plate thereby establishing a uniform electrostatic field between said dynodes and said plate, said electrostatic field being perpendicular to said magnetic field, means for causing said positively charged particles to impinge on the most negative dynode whereby secondary electrons are produced which are attracted and amplified by the remaining dynodes in successive steps and means for collecting the number of electrons produced by the most positive dynode.

4. A magnetic electron multiplier for the detection of moving charged particles in a homogeneous magnetic field which comprises an electrically conductive plate located in said magnetic field and parallel to the lines of flux of said field, a plurality of co-planar secondary electron emissive dynodes located in said field and disposed at an acute angle with respect to said plate, the longitudinal edges of said dynodes being parallel to said plate, means for producing a direct current potential difference between each of said dynodes and said conductive plate, the value of said potential difference being proportional to the distance between said dynodes and said plate, a second electrically conductive plate located in said magnetic field parallel to the first said plate and positioned to include said dynodes between said plates, means for producing a direct current potential difference between said plates thereby establishing a uniform electrostatic field between the dynode and said conductive plates, means for causing said moving charged particles to impinge on the dynode most remote from the

9

first said conductive plate whereby secondary electrons are produced which are attracted and amplified by the remaining dynodes in successive steps and means for collecting the number of electrons produced by the last dynode.

5. A magnetic electron multiplier for the detection of moving charged particles in a homogeneous magnetic field which comprises an accelerating electrode located in said magnetic field and parallel to the lines of flux of said field, a plurality of L-shaped beryllium copper dynodes, each of said dynodes having one surface located in said magnetic field, said surfaces being disposed in echelon parallel relation with respect to said accelerating electrode, means for establishing a uniform electrostatic field between said dynode surfaces and said electrode, said electrostatic field being perpendicular to said magnetic field, said accelerating electrode containing an aperture opposite the dynode most remote from said electrode whereby said moving charged particles enter said electrostatic field through said aperture and impinge on said dynode surface most remote from said electrode

10

thereby producing secondary electrons which are attracted and amplified by the remaining dynodes in successive steps and means for collecting the electrons produced by the last dynode.

6. The apparatus of claim 5 wherein the means for establishing a uniform electrostatic field comprises means for producing a direct current potential difference between each of said dynodes and said accelerating electrode, the value of said potential difference being proportional to the distance between said dynodes and said accelerating electrode.

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