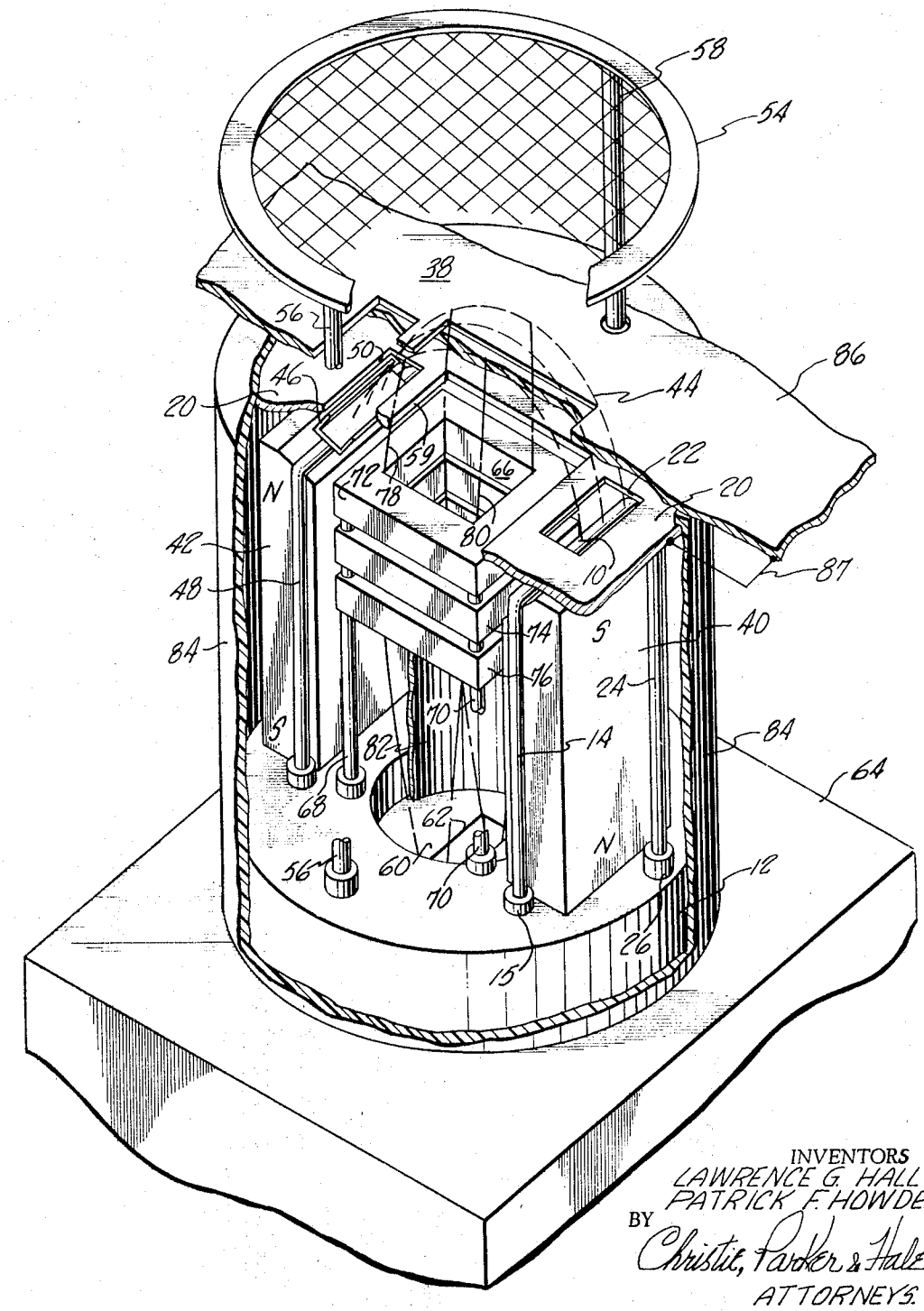
Jan. 10, 1967 L. G. HALL ETAL 3,297,894

APPARATUS FOR IONIZING PARTICLES IN A MASS SPECTROMETER

Filed June 26, 1961 3 Sheets-Sheet 1

FIG. 1



INVENTORS
LAWRENCE G. HALL
PATRICK F. HOWDEN
BY
Christie, Parker & Hale
ATTORNEYS.

Jan. 10, 1967 L. G. HALL ETAL 3,297,894

APPARATUS FOR IONIZING PARTICLES IN A MASS SPECTROMETER

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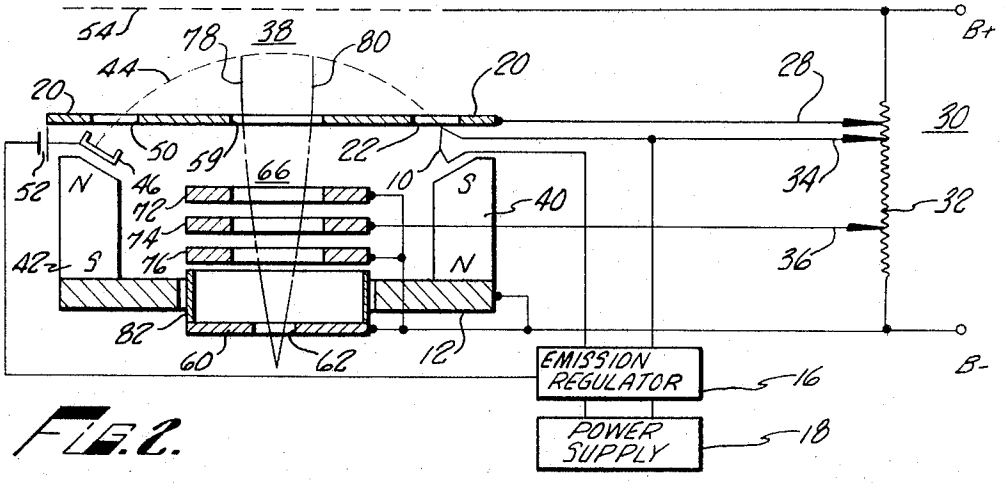
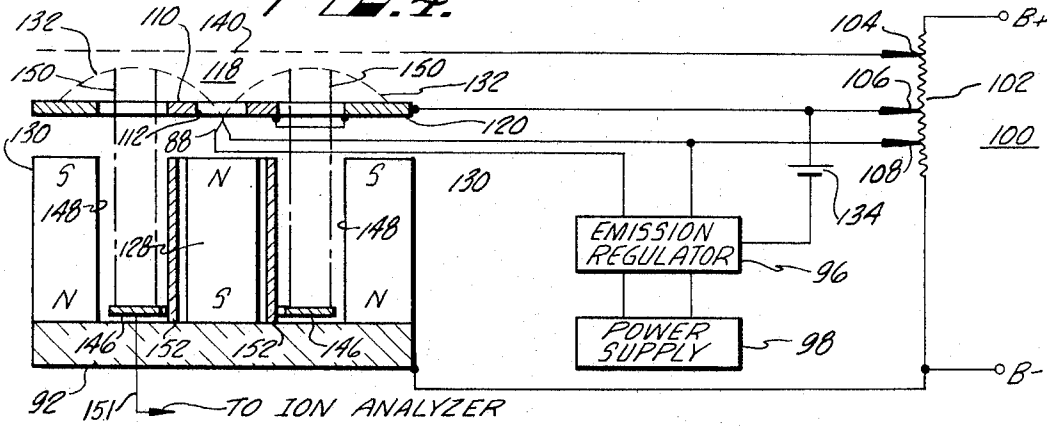


FIG. 2.

FIG. 4.



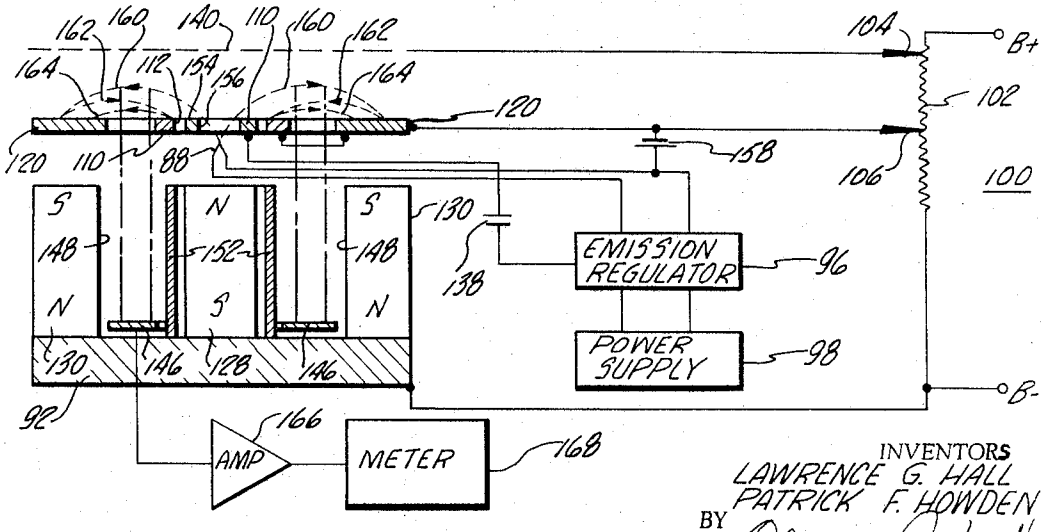


FIG. 5.

INVENTORS
LAWRENCE G. HALL
PATRICK F. HOWDEN
BY Christie, Parker & Hale
ATTORNEYS.

Jan. 10, 1967 L. G. HALL ETAL 3,297,894

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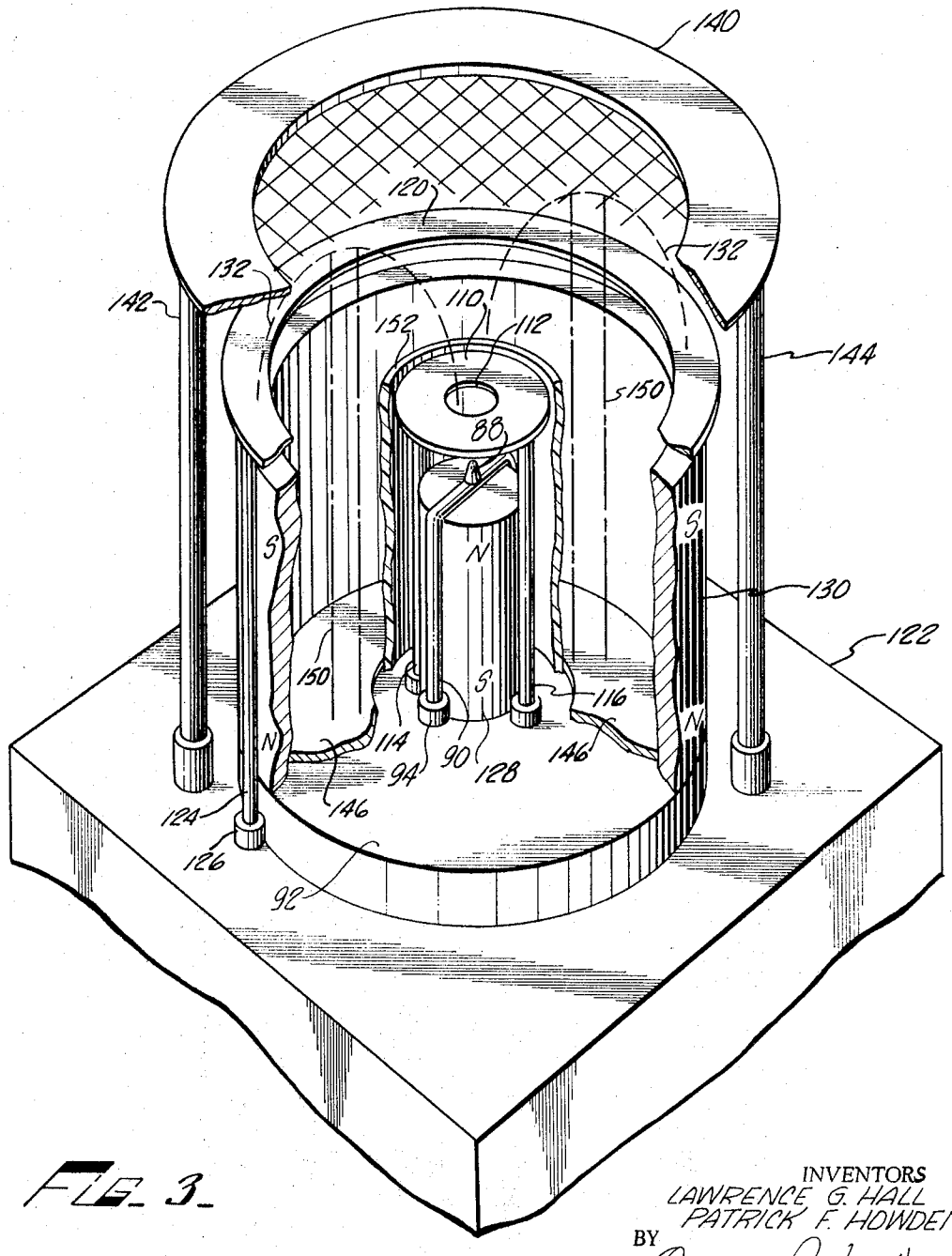


FIG. 3.

INVENTORS
LAWRENCE G. HALL
PATRICK F. HOWDEN
BY
Christie, Parker & Hale
ATTORNEYS.

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3,297,894

APPARATUS FOR IONIZING PARTICLES IN A MASS SPECTROMETER

Lawrence G. Hall, West Covina, and Patrick F. Howden, Los Angeles, Calif., assignors to SDS Data Systems, a corporation of California

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7 Claims. (Cl. 313—63)

This invention relates to apparatus for ionizing neutral particles and more particularly to an ion producing arrangement which is adaptable to use for ionizing particles in space.

Since it is difficult to directly analyze neutral particles it is common in the field of particle analysis to first convert the particles into ions which may be more readily analyzed. Generally this is accomplished by capturing the particles in a vessel and subjecting them to an electron beam which passes in a straight line between a pair of spaced electrodes within the vessel. The electrons of the electron beam in passing between the electrodes collide with particles to form ions. The ions are then drawn from the vessel by an electric field for analysis in an ion analyzer such as a mass spectrometer.

The above described apparatus is generally employed in the laboratory and is useful in the analysis of most particles. However, there are particles, such as free radicals, which are difficult to analyze in the presence of confining structure which may affect their nature or create undesirable chemical reactions. Also, in practice, it has become desirable to provide apparatus for ionizing particles which does not interact with the particles being ionized. This is particularly true in the field of space mass spectrometry wherein it is desired to analyze particles appearing in free space around a moving satellite. Since the satellite is rotating and traveling at high velocity as it orbits the earth, particles appearing in free space stream past and onto the surface of the satellite. To ionize the space particles utilizing the prior art type of ionizing apparatus it would be necessary to project a pair of spaced electrodes beyond the surface of the satellite to create a straight line beam of electrons for ionizing particles between the electrodes. Due to the velocity and rotation of the satellite, the electrodes would disrupt the flow of space particles thereby presenting a disturbed sample of particles for ionization. Also, the particles upon being ionized might collide with the electrodes and be neutralized, thereby presenting an erroneous sample of ions for analysis to the ion analyzer apparatus enclosed within the satellite.

In view of the above, the present invention provides means for ionizing particles without appreciable physical interference either with the particles or the ions formed from the particles.

To accomplish this, the present invention in a basic form includes apparatus isolated from the desired ionizing region of neutral particles. A beam of electrons removed from the ionizing region is projected to follow a curved path from the isolating structure into the ionizing region and caused to return to the isolating structure. The electrons in passing into and out of the ionizing region collide with particles to form ions. The ions are then drawn to receiving means located within the isolating structure for analysis.

More particularly, to project a beam of electrons in a curved path through the ionizing region, the present invention includes means for producing a curved magnetic field through the ionizing region and means for introducing electrons into the magnetic field—the electrons being constrained to follow the curved magnetic field to ionize the particles in the ionizing region.

To provide means for drawing the ions to the receiving means located within the isolating structure, means are included for developing an electric field transverse to the magnetic field—the ions being drawn by the force of the electric field to the receiving means.

To improve the concentration of ions received by the receiving means, a lens arrangement is provided within the isolating structure. Preferably the outer structure of the lens is maintained at such a potential that an electric field is created adjacent to the lens which is greater than the electric field in the ionizing region. This creates a leakage field into the ionizing region to produce a focusing action upon the ions. Thus an ion formed upon a collision between an electron and a particle is drawn from the ionizing region by the transverse electric field and focused by the lens arrangement to the receiving means which is positioned at the focal point of the lens.

The above as well as other features of the present invention may be more fully understood by a reference to the following detailed description when considered with the drawings, in which:

FIGURE 1 is a perspective representation of an embodiment of the ion producing apparatus of the present invention;

FIGURE 2 is a schematic representation of the apparatus illustrated in FIGURE 1;

FIGURE 3 is a perspective representation of another embodiment of the ion producing apparatus of the present invention;

FIGURE 4 is a schematic representation of the apparatus illustrated in FIGURE 3; and

FIGURE 5 is a schematic representation of apparatus for ionizing particles particularly useful in a pressure gauge.

As briefly described above, the present invention includes means remote from an ionizing region including neutral particles, for developing a beam of electrons which is projected into the ionizing region and back to a point remote from the ionizing region and means for drawing ions formed by collisions between the electrons and the particles to a point remote from the ionizing region for analysis. To accomplish this, the embodiment of the present invention represented in FIGURES 1 and 2 includes an electron emission means in the form of a filament **10**. The filament **10** is mounted upon a base **12** of magnetic material by a pair of rods, one of which is represented at **14**. Preferably the rod **14** is composed of a conductive material and is insulated from the base **12** by an insulating mounting represented at **15**. To cause the filament **10** to emit electrons the filament **10** is coupled by its supporting rods through an emission regulator **16** to a power supply **18**. Current from the power supply **18** flowing through the filament **10** causes the filament to heat up and emit electrons.

To accelerate the emitted electrons, as well as to control the projection of the electrons from the surface of the filament **10**, an accelerator plate **20** is provided adjacent to the filament **10**. The accelerator plate **20** includes an opening **22** through which the electrons emitted by the filament **10** may pass and is supported above the filament **10** by a pair of conductive rods, one of which is represented at **24**. The rod is insulated from the base **12** by an insulating mounting represented at **26**.

The accelerator plate **20** is maintained at a positive potential relative to the filament **10**. This is accomplished by connecting the accelerator plate **20** to a movable contact arm **28** of a voltage divider arrangement **30**. In practice, this connection may be made through the rod **24**.

The voltage divider arrangement **30** basically includes a resistance element **32**, the terminals of which are connected to a source of positive and negative potential, represented generally at B+ and B—, respectively. Positionable along the resistance element **30** are a plurality of

movable contact arms 28, 34, and 36—the contact arm 34 being coupled to the filament 10.

Due to the potential difference between the accelerator plate 20 and the filament 10, electrons are drawn from the vicinity of the filament 10 and through the opening 22.

Under proper conditions, an electron accelerated along a magnetic field will follow or spiral along a line of flux and will tend to follow the line of flux regardless of the curvature of the flux path. Accordingly, to cause the electrons emitted by the filament 10 to traverse a curved path through the ionizing region 38, the present invention includes means for generating a strong curved magnetic field through the ionizing region 38. In the embodiment represented in FIGURES 1 and 2, this is accomplished by providing bar magnets 40 and 42 which are spaced from each other and mounted on the base of magnetic material 12. The magnet 40 is positioned adjacent to the filament 10 with its south pole face facing the accelerator plate 20. The magnet 42 has its north pole face facing the accelerator plate 20. Accordingly, curved lines of magnetic flux are set up between the magnets 40 and 42. The curved path of the lines of magnetic flux as well as their density in the ionizing region may be controlled to some extent by a shaping of the pole faces adjacent to the accelerator plate. For example, by making the pole faces of the magnets 40 and 42 substantially parallel to the accelerator plate 20 lines of flux may be created which approximate semicircular arcs in passing through the ionizing region 38 between the magnets 40 and 42. Thus by positioning the filament 10 over a flux line which traverses a curved path between the magnets 40 and 42 electrons emitted by the filament 10 follow, approximately, a semicircularly curved spiraling path through the ionizing region 38 toward the magnet 42. However, as illustrated in FIGURES 1 and 2, it has been found that in practice that in practice that it is preferable to inwardly shape the pole faces of the magnets 40 and 42 at an angle relative to the accelerator plate 20, such as forty-five degrees (45°). This materially increases the density of the curved lines of magnetic flux in the ionizing region 38. Thus with the pole faces of the magnets shaped to make substantially a forty-five degree angle with the plane of the accelerator plate 20, electrons emitted by the filament 10 over the shaped portion of the magnet 40 more readily follow a curved spiraling path such as represented at 44 through the ionizing region 38 toward the magnet 42.

To collect the electrons emitted by the filament after passing through the ionizing region 38, an electron collector means 46 is provided. The electron collector means 46 preferably takes the form of a basket for catching the electrons. The collector means 46 is supported on the base 12 above the north pole face of the bar magnet 42 by a pair of conductive rods, one of which is represented at 48. Preferably to aid in the collection of electrons emitted by the filament 10 the collector 46 is positioned over the shaped portion of the north pole face of the magnet 42 and tilted along the direction of the curved lines of magnetic flux between the magnets 40 and 42. The collector 46 is isolated from the ionizing region 38 by the accelerator plate 20 which is provided with a slot 50 above the collector 46 to allow electrons to pass to the collector 46. As represented by the battery 52, the collector 46 is maintained at a positive potential relative to the filament 10 and the accelerator plate 20 to aid in the collection of electrons. Accordingly, electrons traversing the curved path 44 through the ionizing region 38 are forced toward the accelerator plate 20 through the opening 50 to the electron collector 46.

As described above, electrons emitted by the filament 10 are initially accelerated and directed predominantly along the direction of the curved magnetic field, following which they are constrained to traverse a curved path substantially defined by the magnetic field to the electron collector means 46 through the ionizing region 38. This condition is readily achieved for a given physical configuration by so designing or adjusting the relative values of the magnetic field strength, electric field strength, and electron accelerating potential. In passing through the ionizing region 38, electrons collide with particles which, due to the collision, lose an electron and become positively charged ions. The rate at which ions are formed in the ionizing region 38 may be determined by several factors, including the density of neutral particles in the ionizing region and the number of electrons emitted by the filament 10.

To control the number of electrons emitted by the filament 10, the present invention includes an emission regulator 16. By way of example, the emission regulator 16 may be of the type described at page 144 of Modern Mass Spectrometry, 1953 edition, published by The Institute of Physics (British publication). As represented in FIGURE 2, electrons received by the collector means 46 are transported to the emission regulator 16 and compared with a reference signal from the power supply 18 to control the current flowing to the filament 10 at a predetermined value. The current flowing to the filament 10 in turn determines the rate of electron emission by the filament 10 and hence the rate of ionization of the particles appearing in the ionizing region 38.

Electron emission regulation is particularly useful in the field of mass spectrometry wherein it is desired to provide a stable reference for the number of ions flowing into the mass spectrometer for analysis.

As briefly mentioned above, the present invention includes means for drawing ions from the curved magnetic field within the ionizing region 38 to a point remote from the ionizing region 38. To accomplish this, the present invention provides apparatus for developing an electric field transverse to the curved magnetic field. Accordingly, ions formed in the ionizing region 38 are acted upon by the transverse electric field and are drawn from the ionizing region.

To provide a desired electric field, the embodiment of the invention represented in FIGURES 1 and 2 includes a metallic repeller grid structure represented generally at 54 which is supported above the base 12 by a pair of insulated rods 56 and 58, respectively. Due to the screen arrangement of the repeller grid 54, it is substantially transparent to uncharged particles. The repeller grid 54 is maintained at a positive potential by a direct connection to the source of positive potential B+. In practice, this may be accomplished by an electrical connection through one of the rods 56 or 58 which may be conductive. Due to the positive potential of the repeller grid 54, an electric field is produced which extends from the repeller grid 54 toward the accelerator plate 20. Thus, positive ions formed in the ionizing region 38 are drawn from the magnetic field toward a central opening 59 in the accelerator plate 20. If it is desired to draw in negative ions, the electric fields should be reversed.

To provide means for receiving the ions which pass through the opening 59 that they may be transported to an ion collecting or analyzing arrangement, such as a mass spectrometer, the present invention includes ion receiving means positioned beneath the opening 59. The ion receiving means represented in FIGURES 1 and 2 preferably takes the form of a plate 60 having an opening 62 for receiving the ions. As represented in FIGURE 1, the plate 60 is positioned in a plane beneath the magnet base 12 and provides an opening into an ion analyzer, represented generally at 64. The receiving plate 60 as well as the base 12 are maintained at a negative potential by a direct connection to the source of negative potential, B—. Thus the ions drawn from the magnetic field by the electric field developed by the repeller grid 54 are attracted toward the receiving plate 60.

To improve the concentration of ions received at the receiving plate 60, a lens arrangement 66 is disposed between the ionizing region 38 and the receiving plate 60. The lens 66 is mounted above the base 12 between the

magnets **40** and **42** by four insulated rods two of which are represented at **68** and **70**. The lens **66** basically includes three focusing members **72**, **74** and **76**. The focusing members **72**, **74** and **76** are aligned along a central axis to focus ions in the ionizing region **38** at the receiving plate **60** which may be placed at the focal point of the lens. The members **72** and **76** are electrically connected to the source of negative potential B— and the member **74** to the movable arm **36**. Due to the electrical connection of the member **72** to B— a large electric field is developed between the outer lens member **72** and the accelerator plate **20**. In particular, this electric field is substantially greater than the electric field between the repeller grid **54** and the accelerator plate **20**. Accordingly, a leakage field is created into the ionizing region **38**. The leakage field has the effect of producing a focusing of ions in the ionizing region **38** to the lens **66**. Thus ions in the ionizing region **38** lying within the space defined by the broken lines **78** and **80** traverse a converging curved path into the lens **66**. The curved path aids the lens **66** in focusing the ions at the receiving plate **60**. The ions lying outside the lines **78** and **80** in being focused by the lens **66** contact the accelerator plate **20**, the focusing members of the lens **66** or the receiving plate **60** and are neutralized. Thus the portion of the ionizing region **38** lying within the lines **78** and **80** represents a preferred ionizing region from which ions are drawn to be analyzed by the ion analyzer **64**.

Thus, electrons emitted by the filament **10** traversing a curved path to the collector **46** collide with particles in the ionizing region **38** to form ions which, due to the electric field in the ionizing region, are drawn from the ionizing region to the lens **66** and focused at the opening **62** in the receiving plate **60** for analysis within the ion analyzer **64**. To prevent the flow of ions through the ion lens **66** to the receiving plate **60** from being affected by any electric fields caused by potentials on the supporting rods to the filament **10**, the accelerator plate **20**, collector **46** and/or the lens **66**, a shield represented at **82** is mounted on the receiving plate **60** surrounding the opening **62**.

Although, as described above, it was considered that the electrons in traversing a path between the filament **10** and the collector **46** traveled a path which substantially conformed to the curved magnetic field between the bar magnets **40** and **42**, due to the crossing of the magnetic and electric fields, the electrons travel a slightly perturbed path to the collector **46**. As an electron is drawn from the filament **10** and is accelerated along a magnetic line of flux between the magnets **40** and **42**, it is acted upon by the electric field which tends to draw the electron toward the repeller grid **54**. The electron is being drawn toward the repeller plate **54** crosses magnetic lines of flux which tends to cause the electron to move in a circular path normal to the magnetic field. As a result of the forces of the crossed fields the electron is caused to traverse a repetitive cycloidal path with reference to the curved lines of magnetic flux extending between the bar magnets **40** and **42**. The average motion of the electrons relative to a plane extending between the magnets **40** and **42** forms an angle from the filament **10** the tangent of which is proportional to a magnitude ratio of the electric and magnetic fields. Accordingly, in the embodiment of the present invention represented in FIGURES 1 and 2, electrons emitted by the filament **10** traverse a curved path in a plane which makes a small angle relative to the center plane extending between the bar magnets **40** and **42**. Thus the collector **46** must be displaced by a small amount from the plane of the magnets **40** and **42**, the amount of displacement of the collector means **46** depending upon the magnitude of the magnetic and electric fields as well as the distance between the bar magnets **40** and **42** and the initial velocity imparted to the electrons.

As described above, the electric field tends to attract the electrons emitted by the filament **10** toward the repeller grid **54**. Thus the magnitude of the electric field developed in the ionizing region relative to the magnitude of the magnetic field must be controlled to prevent undesired escapage of electrons from the magnetic field. For example, it has been found that when the electrons emitted by the filament **10** are subjected to an accelerating potential of tens to hundreds of volts, that an electric field (E) of about 250 volts per centimeter between the repeller grid **54** and the accelerator plate **20** and a magnetic field (B) of about 200 gauss in the ionizing region **38** provides a suitable electron ionizing beam configuration.

As represented in FIGURE 1, in a practical embodiment of the present invention, the apparatus for producing the curved magnetic field as well as the emission of electrons to follow a curved path between the filament **10** and the collector **46** is isolated from the ionizing region **38** by a casing **84**. The casing **84** includes slots which communicate with the openings in the accelerating plate **20**. Accordingly, the electrons are free to pass from the filament **10** to the collector **46** and ions are free to pass through the lens **64** to the opening **62** in the receiving means **60**.

The isolation of the apparatus of the present invention from the ionizing region **38** avoids considerable undesired disturbance of the particles within the ionizing region **38** as well as of the ions formed by collision between the particles and the electrons emitted by the apparatus of the presnet invention. As previously mentioned, this is of prime importance in the field of space mass spectrometry. Thus the apparatus of the present invention may be mounted within the satellite, a surface of which with suitable openings therein is depicted by way of illustration at **86**. As represented at **87** in FIGURE 1, in this arrangement the accelerator plate **20** and the surface **86** are electrically coupled to each other. This prevents undesired electric fields from existing between the accelerator plate **20** and the satellite which might effect paths traversed by the electrons and ions between the surface **86** and the accelerator plate **20**. Thus, with the present invention positioned within the satellite a means is provided for ionizing the space particles which stream past and into the satellite without appreciably interfering with the stream of particles or with the ions produced by operation of the present invention.

To further reduce any interference with the particle stream, it may be desired to eliminate entirely any structure remote from the surface of the satellite or extending beyond the casing **84**. Thus it may be desired to eliminate the repeller grid **54** and the supporting rods **56** and **58**. In this case, the potential of the accelerator plate **20** relative to lens element **72** would necessarily be increased to provide a leakage electrical field transverse to the magnetic field sufficient to draw ions from the ionizing region **38** through the lens **64** to the receiving plate **60**. Also, in general, the potential of the accelerator plate **20** relative to the filament **10** would be increased.

Referring to FIGURES 3, 4 and 5 there is shown an embodiment of the present invention which has the advantage of not necessitating a critical positioning of the electron collector means relative to the electron emission means due to the path traversed by electrons emitted by the electron emission means in crossing magnetic and electric fields. This embodiment is also particularly useful as ionizing apparatus for a pressure gauge arrangement.

As represented, to provide a source of electrons, a filament **88** is mounted by means of a pair of conductive rods, one of which is shown at **90**, on a base of magnetic material **92**. The rod **90** is insulated from the base **92** by an insulating mounting represented at **94**.

To cause the filament **88** to emit electrons the filament **88** is coupled by its supporting rods through an emission regulator **96** to a power supply **98**. Current from the power supply **98** flowing through the filament **88** causes the filament to heat up and emit electrons.

The filament **88** is also maintained at a positive potential from a voltage divider arrangement, indicated generally at **100** in FIGURE 4. The voltage divider arrangement **100** includes a resistance element **102**, the terminals of which are connected to a source of positive potential and a source of negative potential represented at B+ and B—, respectively. Disposed along the resistance element **102** are a plurality of movable contact arms **104**, **106**, and **108**, the filament **88** being connected to the movable arm **108**.

To accelerate the emission of electrons from the filament **88**, an accelerating plate **110** having an opening **112** for passing electrons is mounted by a pair of insulated rods **114** and **116** on one side of the filament **88**. As represented in FIGURE 4, the accelerating plate **110** is maintained at a positive potential relative to the filament **88** by a connection to the contact **106**. Accordingly, electrons emitted by the filament **88** are accelerated through the opening **112** into an ionizing region, represented generally at **118**.

In accordance with the present invention, the electrons emitted by the filament **88** are caused to traverse a curved path through the ionizing region **118** to an electron collector means which is positioned remote from the ionizing region **118**. In particular, in the embodiment of the present invention represented in FIGURES 3, 4 and 5, the collector means includes a ring-shaped collector plate **120** radially spaced from the filament **88** and the accelerating plate **110**. The collector plate **120** is mounted on supporting base **122** by a pair of rods, one of which is represented at **124**. As represented in FIGURES 4 and 5 the collector plate **120** is maintained at a positive potential relative to the filament **88** by a connection to the emission regulator **96** through a battery **134**. In practice this electrical connection may be through the rod **124** which is conductive and insulated from the supporting base **118** by an insulating mounting **126**.

To provide means for causing the electrons emitted by the filament **88** to traverse a curved path through the ionizing region **118** to the collector plate **120**, the present invention includes means for generating a curved magnetic field through the ionizing region **118**. In the embodiment of the present invention illustrated in FIGURES 3, 4, and 5 this is accomplished by a bar magnet **128** surrounded by a ring-shaped magnet **130**. The bar magnet **128** is mounted on the base of magnetic material **92** adjacent to the filament **88**, and has one of its pole faces (the north pole) positioned on one side of the plane of the collector plate **120** facing the filament **88**. The ring-shaped magnet **130** is mounted on the base **92** adjacent to the ring-shaped collector plate **120** and has one of its pole faces (the south pole) facing the collector plate **120** on the same side of the plane of the collector plate **120** as the bar magnet **128**. Accordingly, curved lines of magnetic flux are set up between the bar magnet **128** and the ring-shaped magnet **130** and completed through the base **92**. As described similarly in connection with FIGURES 1 and 2, electrons, emitted by the filament **88** and initially accelerated by accelerating plate **110** along the direction of the curved lines of magnetic flux extending between the magnets **128** and **130**, traverse a spiraling curved path to the collector plate **120** through the ionizing region **118**. In traversing the curved path, which is represented generally by the dotted line **132**, the electrons collide with particles to form ions. The rate at which ions are formed in the ionizing region **118** may be determined by several factors, including the density of neutral particles in the ionizing region and the number of electrons emitted by the filament **88**.

To control the number of electrons emitted by the filament **88**, the present invention includes an emission regulator **96** which may be of the type described in connection with FIGURE 2. Thus electrons received by the collector plate **120** are transported through a battery **134** to the emission regulator **96** and compared with a reference signal from the power supply **98** to control the current flowing to the filament **88** at a predetermined value. The current flowing to the filament **88** in turn determines the number of electrons emitted by the filament **88** and hence the rate of ionization of the particles appearing in the ionizing region **118**.

To provide means for drawing the ions from the ionizing region **118** that they may be analyzed, the present invention includes means for developing an electric field transverse to the curved magnetic field. This may be accomplished by a repeller grid **140** mounted by a pair of insulated rods **142** and **144** which is substantially parallel to and remote from the plane of the collector plate **120**. Due to the screen-like structure of the repeller grid **140**, it is substantially transparent to neutral particles passing into the ionizing region **118**. The repeller grid **140** is maintained at a positive potential relative to the accelerating plate **110** and the electron collector plate **120** by a direct connection to the movable contact arm **104**. In practice this may be accomplished by a connection through one of the rods **142** or **144** which may be conductive. Since the base **92** is maintained at a relative negative potential by a direct connection to the source of negative potential B—, electric fields are set up between the repeller grid **140** and the accelerating plate **110** and between the accelerating plate **110** and the base **92** which are transverse to the curved magnetic field. Thus ions formed by collisions of electrons with particles located in the ionizing region **118** are drawn from the magnetic field toward the base **92**.

To provide means for collecting the ions, a receiving plate **146** is disposed in the annular slot **148** between the bar magnet **128** and the ring-shaped magnet **130**. Thus, electrons emitted by the filament **88** and traversing a curved path through the ionizing region **118** to the collector plate **120** collide with particles and form ions which are drawn from the ionizing region by the electric field between the repeller grid **140** and the base **92** to the ion receiving plate **146** along a path indicated by the broken line **150**. The ions may then be passed to an ion analyzer for analysis as indicated by the flow line **151**.

To maintain the path of ion flow unaffected by an electric field which may be caused by potentials on the supporting rods of the filament **88** and the accelerating plate **110**, an insulating shield **152** is mounted on the base **92** around the magnet **128**.

As described in connection with FIGURES 1 and 2, due to the crossing electric and magnetic fields, electrons in traveling between the electron emission means and the electron collector means traverse a path which makes an angle with the plane of the bar magnets **40** and **42**. In the apparatus of FIGURES 1 and 2, this may require that the collector means be slightly displaced from the plane of the magnets **40** and **42**, depending on the chosen values of field strengths, accelerating potentials and physical dimensions. In the embodiment of the present invention represented in FIGURES 3, 4 and 5, it is not necessary to displace the electron collector means since the electron collector **120** is a circular plate and since the electrons are emitted from a point centrally located in the plane of the collector **120** to traverse a curved path to the circular collector plate.

As mentioned above, the apparatus illustrated in FIGURE 3 is particularly useful in providing ionizing apparatus for a pressure gauge which does not interfere with the particles, the pressure of which is to be determined. To provide such an arrangement, the apparatus of FIGURE 3 is modified in the manner represented in FIGURE 5. In particular, an accelerating electron collector plate **154** having an opening **156** is positioned within the opening **112** and maintained at a positive potential relative to the filament **88** by connection to a battery **138**. Preferably plate **154** has an annular thickness which is substantially less than that of the plate **110**. The ring-shaped collector plate and the accelerator plate **110** are main-

tained at a potential which is slightly negative relative to the filament **88** by a battery **158** and act as electron repeller plates. Thus electrons emitted by the filament **88** are accelerated by the plate **154** through the opening **156** into the ionizing region **118**. Due to the curved magnetic field, the electrons are constrained to travel a curved path represented by the dotted line **160** toward the ring-shaped plate **120**. However since the plate **120** is negative relative to the filament **88** a portion of the electrons are reflected from the plate **120**. These electrons are attracted toward the repeller grid **140** and constrained by the curved magnetic field to traverse a curved path substantially as represented by the dotted line **162** toward the filament **88**. In entering the area adjacent to the filament **88** the electrons encounter the relatively negative field of the plate **110**. Since the plate **110** has an annular thickness which is substantially greater than that of the plate **154**, only a small portion of the electrons are collected by the plate **154** while a major portion of electrons are again repelled back toward the plate **120** along a path substantially as represented by the dotted line **164**. This, in effect, creates a cloud of electrons between the filament **88** and the collector plate **120** which collide with particles in the ionizing region **118**. The collisions of the electrons with the particles produces ions, the number of ions being proportional to the density of the particles in the ionizing region and hence the pressure of the ionizing region. Accordingly, the number of ions collected by the ion collector plate **146** represents a measure of the pressure of the ionizing region **118**. To determine the pressure of the ionizing region, the ions collected by the ion collector plate **146** are passed to an ion amplifier **166** and hence to a meter **168** which may be calibrated to directly measure ion flow in terms of pressure.

Although the structure shown in FIGURE 3 when modified in accordance with FIGURE 5 has been described as being useful in ionizing particles for a pressure gauge, it is to be understood that the apparatus is also applicable to a mass spectrometer. In particular, in such a combination, a lens arrangement, similar to that described in connection with FIGURES 1 and 2, may be disposed within the annular opening **148** between the bar magnet **128** and the ring-shaped magnet **130** to focus ions on an opening in the mass spectrometer.

The apparatus described in connection with FIGURES 3 and 4 may also be useful in space mass spectrometry in that an electron beam may be directed from within isolating structure to an ionizing region and return to the isolating structure to ionize particles without interfering with the ionizing region or the ions formed by collisions of the electrons with the particles.

In a configuration wherein the apparatus of FIGURES 3 and 4 is utilized to provide means for ionizing particles in space, it may be desired to eliminate repeller grid **140**. In such a case, the accelerating plate **110** and collector plate **120** may be maintained at larger positive potentials relative to the electron emission means, the magnets and shielding structure thereby providing a leakage electric field which is transverse to the curved magnetic field for drawing ions from the magnetic field to the ion receiving means.

What is claimed is:

1. Apparatus for ionizing particles in an ionizing region comprising: an electron emission means remote from the ionizing region; electron collector means spaced from the electron emission means and remote from the ionizing region; means for developing a magnetic field having lines of flux extending along a curve intersecting the electron emission means and the electron collector means through the ionizing region; means for accelerating electrons from the electron emission means in the direction of said flux lines where they intersect the emission means, whereby electrons emitted by the electron emission means travel a curved path to the electron collector means thereby converting particles in the ionizing region into ions; and means for developing an electric field across the magnetic field to draw ions from the ionizing region.

2. The apparatus of claim **1** including means for focusing the ions drawn from the ionizing region at an ion receiving means.

3. Apparatus for ionizing particles in an ionizing region comprising: an electron emission means remote from the ionizing region; electron collector means spaced from the electron emission means and remote from the ionizing region; means for developing a magnetic field having lines of flux intersecting the electron emission means and the electron collector means along a curved path through the ionizing region; means for accelerating electrons emitted by the electron emission means in the direction of said flux lines where they intersect the electron emission means to follow the curved magnetic field through the ionizing region to the electron collector means thereby converting particles in the ionizing region into ions; means for developing an electric field across the magnetic field to draw the ions from the ionizing region to an ion receiving means; and means coupled to the electron emission means for controlling the rate at which electrons are emitted from the electron emission means to control the rate of ionization.

4. Apparatus for ionizing particles in an ionizing region comprising: an electron emission means remote from the ionizing region; electron collector means spaced from the electron emission means remote from the ionizing region; an electron accelerating plate positioned in a plane between the ionizing region and the electron emission means and having slots therein to provide means whereby electrons emitted by the electron emission means may pass into the ionizing region and return to an electron collector means spaced from the electron emission means and positioned to a side of the accelerator plate remote from the ionizing region; magnet means having a first one of its pole faces positioned adjacent to the electron emission means remote from the accelerator plate and tapered away from the plane of the accelerator plate toward the collector means; and a second one of its pole faces positioned adjacent to the collector means remote from the accelerator plate and tapered away from the plane of the accelerator plate toward the first magnet to produce a curved magnetic field between the first and second pole faces through the ionizing region whereby electrons emitted by the electron emission means follow a curved path to the electron collector means to ionize particles in the ionizing region.

5. The apparatus defined in claim **4** wherein the pole faces of the first and second magnets are tapered away from the accelerator plate to make an angle of substantially 45 degrees with the accelerator plate.

6. Apparatus for ionizing particles in an ionizing region comprising: an electron emission means remote from the ionizing region; an electron collector means spaced from the electron emission means and positioned remote from the ionizing region; an electron accelerator means positioned adjacent the electron emission means in a plane between the ionizing region and the electron emission means; a first magnet having one of its pole faces positioned adjacent to electron emission means remote from the electron accelerator means and tapered away from a plane extending between the electron emission means and the electron collector means; a second magnet having one of its pole faces positioned adjacent the electron collector means remote from the electron accelerator means and tapered away from the plane between the electron collector means and the electron emission means toward the first magnet to produce a curved magnetic field between the first and second magnets through the ionizing region whereby electrons emitted by the electron emission means follow a substantially curved path through the ionizing region to the electron collector means to ionize particles in the ionizing region; means for developing an

electric field across the curved magnetic field to draw ions from the ionizing region; and means for receiving ions drawn from the ionizing region positioned remote from the ionizing region.

7. Apparatus for ionizing particles in an ionizing region comprising: an electron emission means remote from the ionizing region; an electron accelerating plate positioned in a plane between the ionizing region and the electron emission means and having slots therein to provide means whereby electrons emitted by the electron emission means may pass into the ionizing region and return to an electron collector means spaced from the electron emission means and positioned to a side of the accelerator plate remote from the ionizing region; a magnet means having a first one of its pole faces positioned adjacent to the electron emission means remote from the accelerator plate and a

second one of its pole faces positioned adjacent to the collector means remote from the accelerator plate to produce a curved magnetic field between the first and second pole faces through the ionizing region whereby electrons emitted by the electron emission means follow a curved path to the electron collector means to ionize particles in the ionizing region.

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R. F. POLISSACK, J. D. KALLAM, *Assistant Examiners.*