Nov. 22, 1966 KARL-GEORG GÜNTHER 3,287,589

ELECTRON-COLLISON ION SOURCE, PARTICULARLY FOR ELECTRIC MASS SPECTROMETERS

Filed March 7, 1961

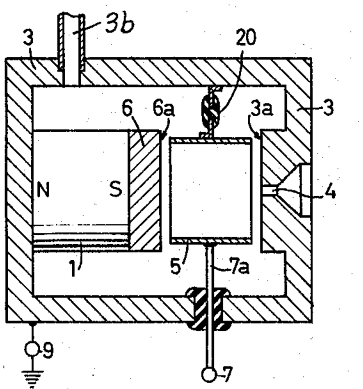

Fig. 1

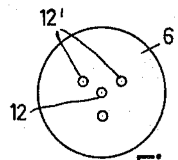

Fig. 4

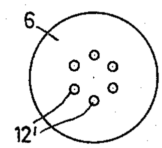

Fig. 5

Fig. 6

Fig. 7

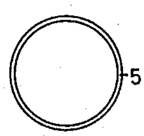

Fig. 8

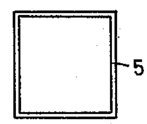

Fig. 9

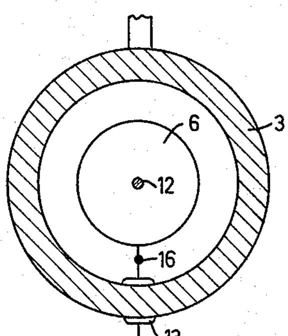

Fig. 3

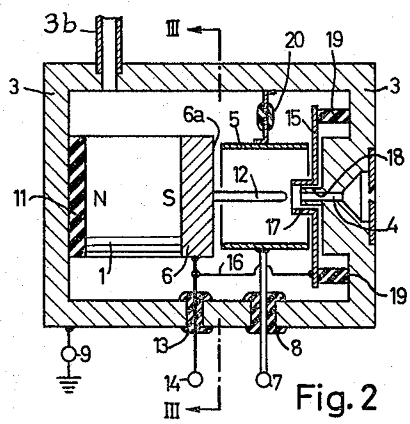

Fig. 2

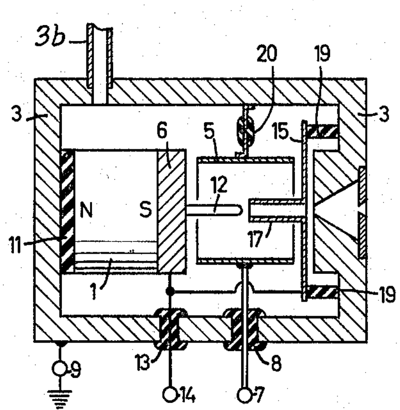

Fig. 10

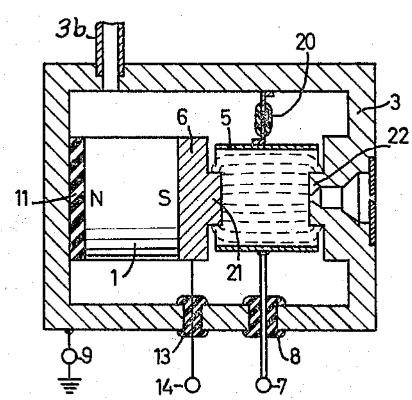

Fig. 11

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3,287,589

ELECTRON-COLLISION ION SOURCE, PARTICULARLY FOR ELECTRIC MASS SPECTROMETERS

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12 Claims. (Cl. 313—161)

My invention relates to an electron-collision ion source of the cold-cathode type generally suitable for purposes requiring a high-intensity directional beam of ions and particularly applicable in mass spectrometers or isotope separators of the type known from German Patent 944,900 and U.S. Patent 2,939,952.

Such mass spectrometers are applicable for anaylzing gaseous substance, separating isotopes, measuring partial pressures, locating leaks in vacuum plants, performing trace analyses, measuring vapor pressures, and related purposes. The mass spectrometers were originally equipped with an ion source of the hot-cathode type. Such an ion source renders the mass spectrometer considerably susceptible to trouble and limits its use to pressures below 10^{-4} mm. Hg. It has been found that measurement in the entire range of high vacuum (10^{-6} to 10^{-3} mm. Hg) and also to within the range of fine vacuum (10^{-3} to 10° mm. Hg) can be performed when using ion sources of the independent-discharge type that do not require an incandescent cathode.

For mass spectrometer purposes, such ion sources must satisfy various requirements:

(*a*) The ion current is to be constant during prolonged periods of time and to be free of fluctuations.

(*b*) The ion source should not cause a reduction in resolving power of the spectrometer portion into which the ion beam is directed.

(*c*) A definite and reproducible relation is to exist between partial pressure and ion current.

If these requirements are to be met by a rugged ion source with a cold cathode, considerable difficulties are encountered with ion sources of the type heretofore available, because the high operating voltages of some 1000 v. may cause a strong energy inhomogeneity of the ions being formed as well as undesired fluctuations in discharge. For use in mass spectrometers it is further desirable to have an ion source applicable within a large pressure range of about 10^{-6} to 10^{-2} mm. Hg, this being infeasible with ion sources of the known types.

It is an object of my invention to devise an electron-collision ion source with an electron emission excited by the discharge itself, which jointly satisfies the above-mentioned requirements (*a*) to (*c*) while avoiding the difficulties here encountered.

Another object of the invention is to provide an ion source which also affords the advantage of being applicable at relatively high pressures of the gaseous mixtures to be investigated, for example up to 10^{-2} mm. Hg.

A further object of the invention, subsidiary to those already mentioned, is to provide an ion source which is highly resistant to ingress of gas and which therefore has a long useful life because, in contrast to ion sources with a hot cathode, any breakthrough of gas does not appreciably impair the emission of the cathode and cannot destroy the cathode.

According to my invention the ion source is provided with magnet means and electrodes so designed and arranged that the fields produced thereby effect a spatial and temporal fixation of the discharge plasma in the vicinity of the extraction channel through which the ions pass into the space where they are to serve the intended purpose.

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According to a more specific feature of the invention, I provide the ion source with a tubular anode and two cathode surfaces axially opposite the respective ends of the anode in accordance with Penning's oscillating-electron principle, with the magnetic field lines extending in the direction of the extracted ion beam; and I provide such an ion source with one of more rod-shaped cathode members whose diameter is small with respect to the cylindrical anode, preferably smaller than 10% of the anode inner diameter, the axis of the rod member being parallel to the axis of the anode cylinder. According to another feature of my invention, the rod-shaped cathode member or members terminate at a point closely spaced from the inner end of the extraction channel, the preferable spacing being approximately equal to the diameter of the rod-shaped cathode.

It is preferable to give the tubular anode and the cathodic rod members a circular cross section. However, other cross-sectional shapes may be used. For example, the cathode rod may have a rectangular, square, elliptic or triangular cross section. Similarly, the cylinder anode may have a square or elliptic cross section, for example. In such cases, the foregoing statements relating to the diameter apply analogously to the average diameter of these electrodes.

In lieu of a single cathode rod, a plurality of such rods, preferably all of the same length, may be provided in narrow distribution around the extraction opening. If several rod cathodes of the same length are provided, the spacing of the cathode rods from the extraction channel is determined by the plane defined by the free ends of the rods. If the rod cathodes are not equal in length, the longest cathode or cathodes determine the just-mentioned spacing.

According to another feature of the invention, the discharge-adjacent end of the extraction channel is extended into the discharge space within the tubular anode. The portion of the extraction channel then protruding into the discharge space constitutes a portion or extension of the rod cathode.

According to another feature of my invention, the pole shoes of the magnet required for the discharge are so shaped that a concentration and fixing of the ions onto the range of the ion outlet opening takes place. For this purpose, the terminal faces of the pole shoes are provided with bosses in the vicinity of the axis.

The above-mentioned and other objects and features of my invention, said features being set forth with particularity in the claims annexed hereto, will be apparent from, and will be described in, the following with reference to the embodiments of electron-collision ion sources according to the invention illustrated by way of example in the accompanying drawings, in which:

FIG. 1 is an axially sectional view of an ion source generally of the Penning type but so modified as to form a basis for the invention proper, this illustration being presented for explaining the function of elements also contained in the sources according to the invention shown in the other illustrations.

FIG. 2 is an axial sectional view of an ion source according to the invention.

FIG. 3 shows schematically a cross section of the ion source along the line III—III in FIG. 2.

FIGS. 4 and 5 illustrate schematically two different, modified arrangements of rod cathodes.

FIGS. 6 and 7 exemplify two cross-sectional shapes of rod cathodes.

FIG. 8 is a cross section of the anode in the ion source according to FIG. 2.

FIG. 9 shows a modified anode of square cross section.

FIG. 10 is an axial, sectional view of another ion source according to the invention; and

FIG. 11 is a similar view of still another embodiment of such a source.

The ion source shown in FIG. 1, embodying Penning's principle but modified to represent a basis for the present invention proper, is provided with a cylindrical permanent magnet **1** whose poles are denoted by N and S. The magnet **1** is joined with a cylindrical hollow yoke structure **3** of magnetically soft (high-permeability) material in order to form a return path for the magnetic flux from the pole S to the pole N of the magnet. The front wall of the yoke structure **3**, facing the space where the generated beam of ions is to be utilized, is provided with a central extraction channel **4** through which the ions pass out of the source. The device is provided with a cylindrical anode **5** which surrounds the magnetic field space between the pole faces **3***a* and **6***a* of the magnetic circuit. The mangetic field structure also serves as the cathode of the ion source. That is, the pole faces **3***a* and **6***a*, located close to the anode **5** on axially opposite sides thereof, constitute the two parts of the cathode for the plasma discharge occurring within the device. The anode **5** is connected by a rod **7***a* with an external terminal **7** and is insulated from the yoke structure **3** by a bushing **8** and by an insulator **20**. The yoke **3** and the parts conductively connected therewith are preferably grounded at a terminal **9**. During operation the operating voltage is connected between the terminals **7** and **9** with the positive pole of the source attached to terminal **7**. It will be understood that when the ion source is in operative condition it is located in a discharge vessel which contains a gaseous substance at low pressure, this substance passing also into the interior of the ion source through an opening at **3***b*.

When the ion source is in operation, a voltage of approximately 1000 to 5000 v. is connected between the terminals **7** and **9**, with the positive pole at **7**. Due to the effect of the resulting electric field between the anode cylinder **5** and the two cathode faces **3***a* and **6***a*, the electrons present in the discharge gap are accelerated toward the anode cylinder **5**. Simultaneously, however, a magnetic field is effective in the axial direction of the cylinder anode between the two cathode faces. This axial magnetic field prevents the electrons from reaching an appreciable radial drift velocity. The electrons are rather excited to perform oscillations and in this manner travel over long distances so that even at low pressures (particularly below 10^{-3} mm. Hg) a sufficient probability of collision between electrons and gas molecules will exist, as required for initiating and maintaining a plasma discharge. The ions thus formed by electron collision are accelerated by the electric field in the direction toward the cathode faces **3***a* and **6***a*. Thus a portion of the generated ions is caused to pass through the extraction opening **4**.

It will be understood that in the low-pressure space in which the ion source is located, a collector anode is usually located on the axis of the extraction opening **4** but remote therefrom, so that the voltage between the ion source and the collector anode aids in extracting ions through the channel **4**. In this respect reference may be had for example to the above-mentioned U.S. Patent 2,939,952 dealing with the use of ion sources in an isotope separator.

Dealing now with the invention proper, it will be noted that the ion source according to the invention as shown in FIG. 2 comprises all components described above with reference to FIG. 1 and thus, basically, secures the same performance. However, the source shown in FIG. 2 is further provided with a rod cathode **12** for the purpose of fixing the plasma near the inlet opening of the extraction channel. The components denoted by **1**, **3**, **4**, **5**, **6**, **6***a*, **7**, **8**, **9** and **20** correspond to those denoted by the same reference numerals in FIG. 1. In distinction from FIG. 1, however, the cylindrical terminal magnet **1** is joined with the yoke **3** by an intermediate insulating plate **11** and hence is electrically insulated from the yoke. The soft-iron pole shoe **6** of the magnet **1** carries the rod cathode **12**. This cathode is oriented axially with respect to the cylindrical anode **5** and hence also with respect to the extraction opening **4**. The diameter of the rod cathode **12** is small relative to the cylinder anode **5**, being preferably smaller than 10% of the anode inner diameter. The rod cathode **12** terminates closely ahead of the ion extraction channel **4**, the distance from the discharge-adjacent opening of the channel being preferably substantially equal to the diameter of the rod **12**.

The second cathode proper is formed by a sheet member **15** which is mounted on the yoke structure by means of insulating supports **19**. The cathode sheet **15** has in its center a tubular extension **17** protruding inwardly toward the cathode rod **12**. The cathode sheet **15** is electrically connected by a lead **16** with the pole shoe **6** and cathode rod **12**, and also with a cathode terminal **14**. The terminal **14** is insulated from the yoke structure **3** by a bushing **13**. The portion of the yoke structure immediately surrounding the extraction channel **4** forms a tubular neck **18** which protrudes into the discharge space towards the rod cathode **12** in concentric relation to the tubular extension **17** of sheet **15**. The extraction voltage is impressed between the cathode faces **6***a* and **15** on the one hand and the yoke structure **3** on the other hand. That is, the operating voltage, up to about 100 v., is connected between the terminals **14** and **9** with the positive pole at **14**, and the discharge supporting voltage, such as 1000 to 5000 v., is connected between terminals **14** and **7** with the positive pole at **7** (as shown in FIGS. 10 and 11). For example, with terminal **9** at zero voltage, the terminal **14** may be kept at +100 v. and the terminal **7** at +1000 v.

In lieu of using a single axially located cathode rod **12**, a plurality of such rods may be mounted on the pole shoe **6** of the magnet. Thus, FIG. 4 shows a central cathode rod **12** as described above, with three additional cathode rods **12'** uniformly spaced about the central rod **12** in a triangular arrangement. FIG. 5 shows a group of six cathode rods **12'** uniformly spaced about the axis of the discharge gap, no central cathode rod being provided.

While the cross section of the cathode rods is preferably circular, it may also be given a square shape as shown in FIG. 6, an elliptical shape as shown in FIG. 7, or any other desired shape. Analogously, the anode tube or cylinder, while preferably having a circular cross section as shown in FIG. 8, may be given some other cross-sectional shape, for example the square shape shown in FIG. 9.

The ion source according to FIG. 10 differs from the one described above with reference to FIG. 2 in that the cathode rod **12** extends only up to about the middle of the discharge space in the interior of the tubular anode, whereas the inwardly directed tubular extension **17** of the cathode sheet **15** is greatly extended and has a considerably reduced inner and outer diameter as compared with FIG. 2. In such a device the concentrating action of the rod cathode **12** is considerably augmented.

In the embodiment shown in FIG. 11, the pole shoes of the magnet system are provided with bosses located opposite each other on the axis of the discharge gap. The pole shoe **6** of the magnet **1**, this pole shoe serving as part of the cathode, is provided with a central boss protuberance **21** facing the extraction opening. The central boss protuberance **21** is preferably of ferromagnetic materials. The axially opposite side of the yoke structure **3** is likewise provided with a boss **2** facing the boss **21**. The two bosses protrude into the discharge space surrounded by the anode **5**. As a result of such a design, the magnetic field lines do not extend parallel but are curved in keg shape, as is schematically indicated in FIG. 11 by broken lines. In all other respects the ion source of FIG. 11

is designed and operative in accordance with those described above.

In ion sources according to the invention as embodied in the illustrated devices, the high anode voltage and the resulting axial component of the electric field strength is shielded from the ion exit opening by the surrounding tubular anode and also by the small spacing between the cathode faces and the respective edges of the tubular anode. In this manner, an excessively high axial ion velocity is prevented. For this purpose, the ratio of inner diameter to axial length of the anode is preferably within the limits of 1 to 2.5, and the axial spacing between the respective ends of the anode and the two cathode faces is preferably less than 5% of the anode inner diameter.

Due to the provision of a rod cathode and its small spacing from the ion exit opening, a defined potential surface is established in the vicinity of this opening, thus also securing a well-defined discharge plasma at the same locality. The relatively thin rod cathode in the interior of the anode cylinder creates a particularly intensive field strength at the rod cathode. As a result, a high radial electric field strength in the vicinity of the axis is produced. This secures high impact energies of the ionizing electrons and a uniform ionization of all gas components. Care is also taken in this manner to have a negligibly slight axial ion energy in the vicinity of the ion extraction opening. Therefore, the ion exit velocity is almost exclusively determined by the extraction voltage applied between cathode sheet and mass (yoke), and is kept substantially independent of the burning (discharge or plate) voltage of the ion source.

It will be understood by those skilled in the art, upon a study of this disclosure, that ion sources according to the invention can be modified in various respects, for example by combining various features described above with reference to separate illustrations, and that ion sources according to the invention are suitable for uses other than in mass spectrometers of the type described above, without departing from the essential features of my invention and within the scope of the claims annexed hereto.

I claim:

1. An electron-collision ion source of the cold-cathode type for use in gas under vacuum pressure in a mass spectrometer, comprising cathode structure having an extraction channel through which ions may pass into the space where they are to be utilized, anode means coaxially related to said extraction channel, said cathode structure comprising electric-field concentrating means having its maximum field density near said extraction channel at the anode side thereof, said extraction channel and said concentrating means having respective portions on opposite sides of said anode means along the axis of said extraction channel, and magnet means having a magnetic pole end near said extraction channel, whereby said electric and magnetic fields spatially and temporally fix the discharge plasma near said extraction channel.

2. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a generally ring-shaped anode extending around the cathode axis between said two cathode parts and being insulated therefrom, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillatingly travelling electrons, one of said cathode parts having a ferromagnetic cathode structure protruding in the interior space of said anode toward said other cathode part and having a width smaller than the inner width of said anode to intensify the magnetic and electric field near the entrance of said extraction channel.

3. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a generally ring-shaped anode extending around the cathode axis between said two cathode parts and being insulated therefrom, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillatingly travelling electrons, and said magnetic circuit comprising a rod-shaped member extending from one of said cathode parts toward the vicinity of the other in the interior space of said anode and having a width smaller than the inner width of said anode.

4. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a tubular cylindrical anode extending between said two cathode parts in coaxial relation to said channel, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillating electrons, and a rod-shaped cathode member extending from the other cathode part toward said one part and having a diameter less than 10% of the inner diameter of said anode.

5. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a tubular cylindrical anode extending between said two cathode parts in coaxial relation to said channel, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with electrons, and a rod-shaped cathode member extending on said axis from the other cathode part toward said one part and having its free end spaced from said channel a distance approximately equal to the rod diameter.

6. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a hollow magnetizable yoke structure having an interior magnetic pole face, a magnet mounted in said yoke structure and having one of its poles joined therewith, a pole shoe mounted on the other magnet pole and being axially spaced from said pole face, a cathode of which said pole shoe forms part, said cathode having another part at said yoke structure, a generally tubular anode coaxially surrounding the magnetic axis of said yoke structure and being axially spaced from each of said two cathode parts, said other cathode part and said yoke structure having an ion extraction channel traversing said pole face on said axis, and ferromagnetic protuberance means extending from said pole shoe toward said extraction channel in the interior space of said anode.

7. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a tubular cylindrical anode extending between said two cathode parts in coaxial relation to said channel, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillating electrons, and a rod-shaped cathode member extending from the other cathode part toward said one part and having a diameter less than 10% of the inner diameter of said anode, said rod-shaped cathode member terminating a short distance from said extraction channel and being spaced therefrom a distance approximately equal to the diameter of said rod-shaped cathode member.

8. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a generally ring-shaped anode extending around the cathode axis between said two cathode parts and being insulated therefrom, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillatingly travelling electrons, one of said cathode parts having a ferromagnetic cathode structure protruding in the interior space of said anode toward said other cathode part and having a width smaller than the inner width of said anode to intensify the magnetic and electric field near the entrance of said extraction channel, said cathode structure comprising a plurality of rods uniformly distributed about said cathode axis.

9. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a generally ring-shaped anode extending around the cathode axis between said two cathode parts and being insulated therefrom, said anode having a cylindrical shape and having a ratio of inner diameter to axial length between about 1 and about 2.5, said anode having its two circular ends spaced from the respective cathode parts a distance less than 5% of said inner diameter, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillatingly travelling electrons, one of said cathode parts having a ferromagnetic cathode structure protruding in the interior space of said anode toward said other cathode part and having a width smaller than the inner width of said anode to intensify the magnetic and electric field near the entrance of said extraction channel.

10. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a generally ring-shaped anode extending around the cathode axis between said two cathode parts and being insulated therefrom, a magnetic circuit comprising a magnet and having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillatingly travelling electrons, one of said cathode parts having a ferromagnetic cathode structure protruding in the interior space of said anode toward said other cathode part and having a width smaller than the inner width of said anode to intensify the magnetic and electric field near the entrance of said extraction channel, said cathode structure comprising a rod member joined with said one cathode part in coaxial relation to said extraction channel and a tubular member coaxially aligned with said extraction channel and protruding from said other cathode part toward said rod member, said rod member and said tubular member having their respective ends axially spaced from each other in the interior of said anode.

11. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a generally ring-shaped anode extending around the cathode axis between said two cathode parts and being insulated therefrom, a magnetic circuit comprising a ferromagnetic yoke surrounding said anode and a permanent magnet having one pole joined with said yoke and another pole having a pole shoe which forms one of said cathode parts, said yoke having a pole portion axially spaced from said pole shoe and traversed by said extraction channel, said magnetic circuit having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillatingly travelling electrons, said one of said cathode parts having a ferromagnetic cathode structure protruding in the interior space of said anode toward said other cathode part and having a width smaller than the inner width of said anode to intensify the magnetic and electric field near the entrance of said extraction channel, said cathode structure comprising a plurality of rods uniformly distributed about said cathode axis.

12. A cold-cathode ion source for use in gas under vacuum pressure in a mass spectrometer, comprising a cathode having two parts axially spaced from each other and having an ion extraction channel extending axially through one of said parts, a generally ring-shaped anode extending around the cathode axis between said two cathode parts and being insulated therefrom, a magnetic circuit comprising a ferromagnetic yoke surrounding said anode and a permanent magnet electrically insulated from said yoke having one pole joined with said yoke and another pole having a pole shoe which forms one of said cathode parts, said yoke having a pole portion axially spaced from said pole shoe and traversed by said extraction channel, said magnetic circuit having a flux path through said two cathode parts to provide a magnetic field therebetween whereby, when voltage is impressed across cathode and anode, ionization of the gas occurs due to collision with oscillatingly travelling electrons, said one of said cathode parts having a ferromagnetic cathode structure protruding in the interior space of said anode toward said other cathode part and having a width smaller than the inner width of said anode to intensify the magnetic and electric field near the entrance of said extraction channel, said other cathode part including a member mounted on the pole portion of said yoke and being electrically insulated therefrom.

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