Nov. 17, 1964 J. E. M. O'MEARA 3,157,784

ION SOURCE FOR A MASS SPECTROMETER

Filed Dec. 7, 1961

FIG. 1

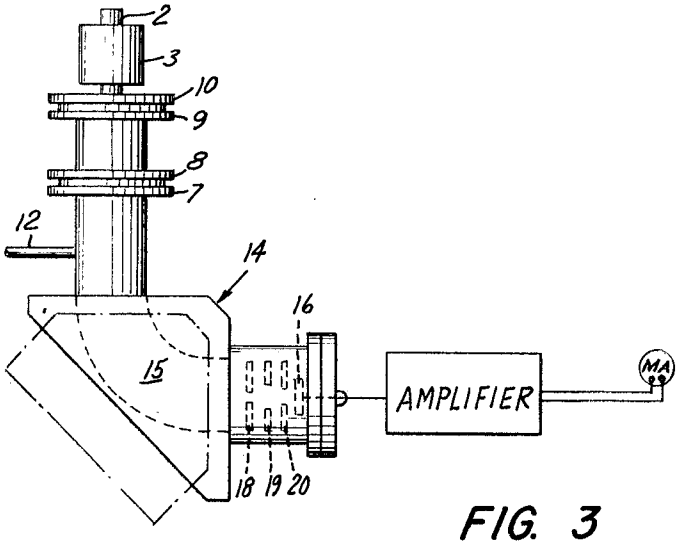


FIG. 2

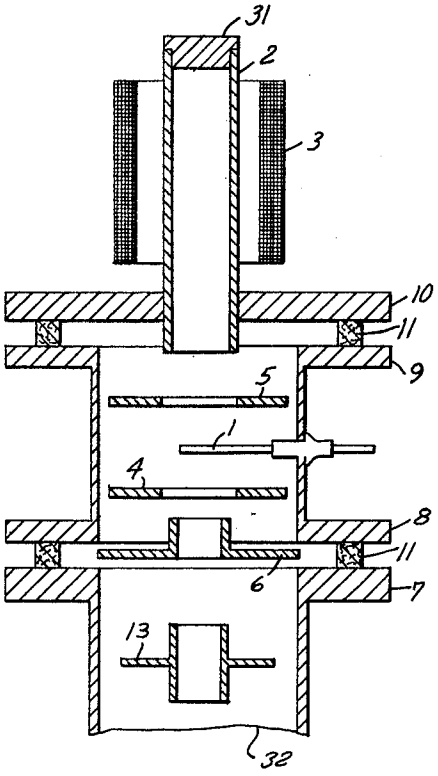
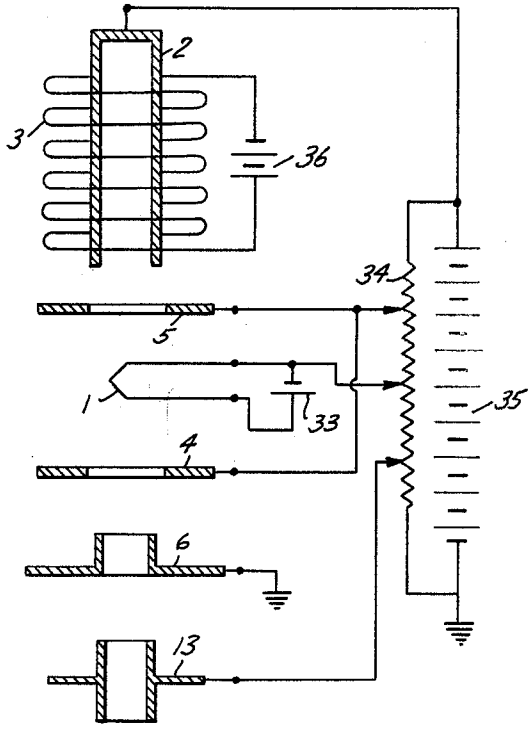


FIG. 3



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ION SOURCE FOR A MASS SPECTROMETER

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This invention relates to gas and vapor ionization devices, especilly those used as positive ion sources in mass spectrometers.

Other things being equal, the sensitivity of a mass spectrometer is proportional to the positive ion current generated by the source. In electron bombardment type sources, the positive ion current is essentially proportional to the electron (or ionizing) current and the average distance traveled by an electron in the ionization zone. The positive ion current is also proportional to the gas and vapor pressure and the ionization probability for the particular gases and vapors present. The last factor is a physical constant, while maximum pressure is limited by such things as gas scattering, filament burnout, and the size of the sample admitted to the system.

It is the principal objective of this invention to make more effective use of the ionization current by means of a new source geometry.

The prior art has used, most commonly, ion sources of the Nier Type. This is described in U.S. Patent 2,490,278, issued December 6, 1949, to Alfred O. C. Nier, and entitled "Mass Spectrometer Tube Ion Source Assembly." In this type of source, emission from a hot filament is collimated by a slit. The electron current passing through an ionization chamber produces positive ions by collision with gas moleucles present in the chamber. A small electric field is present in the source, causing the positive ions to move toward the negative wall of the chamber. An exit slit permits a portion of the ions to emerge and undergo further acceleration in the direction of the spectrometer analyzer. This source has sufficient positive ion yield to be used in many applications, but it does make relatively inefficient use of the electron beam; i.e., only a small fraction of the total electron emission enters the ionization chamber, and, further, only ions formed immediately opposite the exit slit are able to leave the ion chamber and be subsequently analyzed.

As is known to those versed in the art, attempts to increase the positive ion ejection by increasing the voltage on the repeller electrode are not effective due to distortions resulting in the electron beam and the generation of an ion beam which is not mono-energetic. Beams which are not mono-energetic cause dispersion in the beam with a subsequent loss in resolution and/or sensitivity.

A second type of ion source has been developed by Stein et al. This is described in U.S. Patent 2,563,626, issued August 7, 1951, to Stein, Binns, Rise, and Bashkin, and entitled "Ion Source." This source is of a co-axial configuration; i.e., the filament is surrounded by the anode, with an axial magnetic field. This source uses fine grid structures which intercept a portion of the electron beam as well as the positive ion beam. Such fine grids limit the electron current because of heat considerations and give rise to undesirable secondary electron emission or secondary positive ions. In addition, the location of the filament is such that positive ions that are attracted to it are withdrawn from the analyzer region and hence lost.

The primary object of this invention is to improve ion sources of the electron beam bombardment type. Another object is to increase the sensitivity of mass spectrometers through the utilization of a positive ion source which has a greater positive ion yield for a given gas pressure.

A more specific object is to provide an ion source in which the gas molecules may be bombarded by electrons in a space which is free of electrostatic field. A further object is to provide an ion source which employs focusing and accelerating electrodes having clear passages therethrough, that is, passages which are unobstructed by screen or mesh. Another object is to provide an ion source of increased efficiency in that most of the electron current discharged from the cathode is made available for the bombardment of gas molecules. A further object is to provide a relatively long electron path through a region of substantial length in which the gas molecules are present for greater opportunity for ioniziation.

Differently expressed, an object of this invention is to provide a source having electrodes, geometry and construction such that a large electron current can be utilized over a relatively long length in a region which is electrostatically field free, thereby producing a relatively strong mono-energetic positive beam.

To accomplish the foregoing general objects and other more specific objects which will hereinafter appear, my invention resides in the ion source elements and their relation one to another as are hereinafter more particularly described in the following specification. The specification is accompanied by drawings in which:

FIG. 1 is a partially sectioned schematic elevation showing a mass spectrometer in which the present ion source is utilized;

FIG. 2 is a schematic section, drawn to larger scale, through an ion source embodying features of my invention; and

FIG. 3 is a diagrammatic view showing the relative polarization of the different parts of the ion source.

Referring to the drawing, and more particularly to FIG. 2, the ion source is closed at one end, in this case the end **31**, and is open at the opposite end **32** for the discharge of an ion stream. The device comprises an electron emitting cathode **1**, and a drift tube **2** disposed on the side of the cathode remote from the discharge end **32** of the source. The drift tube is also an anode for the emitted electrons. A cylindrical magnet **3** surrounds the drift tube **2**, to keep the electron stream in an axial path. In addition there are appropriate focusing and accelerating electrodes.

In the specific case here shown there is a focusing electrode **5** which is disposed between the cathode **1** and the drift tube **2**. On the opposite side of the cathode, that is, going toward the discharge end **32**, there are, in succession, a focusing electrode **4**, an ion accelerating electrode **6**, and another focusing electrode **13**.

Referring now to FIG. 3 of the drawing, the power supply is for simplicity indicated as though using dry cells, but it will be understood that the more usual forms of power supply may be employed. The part **33** represents a supply to heat the cathode **1**. A voltage divider **34** connected across a high voltage or "B" supply **35** may be used to obtain various desired voltages, and it will be seen that the drift tube **2** is polarized positively relative to the cathode **1**. The focusing electrodes **4** and **5** are polarized at an intermediate potential. Thus, the focusing electrode **5** may serve either for the electron stream flowing in reverse direction from cathode **1** toward and through the drift tube **2**, or for the ion stream flowing in forward direction from the drift tube **2** through the electrodes toward the discharge end of the ion source.

In the particular form here shown the accelerating electrode **6** is at ground potential, which is the most negative potential employed. The focusing electrode **13** is at a potential somewhat higher than ground, although it is highly negative relative to the electrodes **4** and **5**.

The electromagnet **3** is energized from any suitable source of direct current, here shown as a battery **36**.

A permanent magnet may be used, requiring no power supply.

With reference to FIG. 2 it should be understood that the electron stream from cathode **1** flows in reverse direction through the drift tube toward the closed end **31** of the ion source. The cylindrical magnet **3** helps keep the electron beam in an axial path. This is a relatively long electron path, and runs through a space which is free of electrostatic field, thus providing an optimum condition for bombardment of gas molecules with consequent formation of ions. The positive ions flow in forward direction, that is, in a direction opposite to the direction of the electron stream, and through the focusing and accelerating electrodes toward the discharge end **32** of the source. It will further be noted that the accelerating and focusing electrodes have open or clear passages which are devoid of screen or mesh obstruction.

In referring to the closed end **31**, it is not meant that the drift tube **2** need itself be closed. The drift tube may be open at both ends if located within another enclosing sealed envelope. In some cases it may be desired to admit the gas sample through the end of the drift tube. It is the ion source as a whole which is considered to have a closed end **31** and an open end **32**, rather than the drift tube.

FIGURE 1 illustrates one application of my invention, as used in a single stage direction focusing mass spectrometer generally designated **14**. A sample of gas may be admitted at an inlet **12**. Positive ions ejected by the source located at **7–10** are separated by mass/charge ratio in a suitable magnetic field located at the curved portion **15** of the spectrometer tube. By selecting the proper voltage and/or magnetic field, a given or specified desired mass/charge number may be focused on a beam detector or collector **16**. Apertures in appropriate associated electrodes **17, 18, 19,** and **20** serve to permit only the desired ion beam from reaching the beam collector **16**. Since any beam collector is limited as to the smallest current it can read, the higher the positive ion current for a given pressure the more sensitive the overall spectrometer becomes, which is an important advantage of the present invention.

The operation of the device is as follows: In reference to FIGURE 2, the filament **1** is heated to emitting temperature. A positive potential is applied to the drift tube **2** causing the electrons emitted by the filament **1** to be attracted toward it. A cylindrical magnet **3** (magnetized axially) and the focus electrode **5** restrain the electrons in a path such that a large portion travels the entire length of the drift tube. Since the entire drift tube is at the same potential, positive ions are formed in an electrostatically field-free space. The thermal velocity of a particular ion causes it to travel in a helical path axially along the drift tube. Those positive ions travelling toward the filament are accelerated by the negative potential of the filament, and by the even more negative potential of the extraction or accelerating electrode **6**, and flow to the analyzer region of the spectrometer. Electrodes **4, 5,** and **13** serve to focus the positive ion beam.

Flanges **7, 8, 9, 10** and gaskets **11** provide vacuum seals for the device. Feed through electrodes, of which **12** is typical, provide means of supplying proper voltages to the various electrodes.

It is believed that the construction and operation of my improved ion source, as well as the advantages thereof, will be understood from the foregoing detailed description. The new source has a relatively high ionization current. The amount of positive ion generation is proportional to the electron current. For instance, the Nier type source has a typical ionization current of only a few microamperes, compared to this new source, one presently used model of which has an ionization current of a few milliamperes.

The amount of positive ion generation is proportional to electron path length. The new source has a relatively long path length for the ionization current, in an electrostatic field-free space. Formation of ions in a field-free space is necessary for a "mono-energetic" beam. Actually, truly mono-energetic beams are impossible, but the present source is excellent in this regard. The arrangement of the electrodes and their potentials are such that the electron trajectory and the positive ion trajectory are compatible. In other ion sources the filament location is such that positive ions attracted toward it are not moving in the direction of the spectrometer analyzer.

It will be understood that while I have shown and described the improved ion source in a preferred form, changes may be made without departing from the scope of the invention, as sought to be defined in the following claims.

I claim:

1. An ion source, said source being closed at one end and open at the opposite end for discharge of an ion stream, said source comprising a gas connection for supply of a gas to be ionized, an electron-emitting cathode, a long drift tube disposed on the side of the cathode remote from the discharge end of the source, a magnet surrounding the drift tube, a focusing electrode between the cathode and the drift tube, the opposite side of the cathode leading to the open end of the source having focusing and accelerating electrodes, means to polarize the drift tube positively relative to the cathode, and means to appropriately polarize the focusing and accelerating electrodes, said cathode being the sole source of electrons, the arrangement being such that an electron stream flows in reverse direction through the drift tube toward the closed end of the source, and resulting ions flow in a forward direction opposite to the direction of the electron stream and through the focusing and accelerating electrodes toward the discharge end of the source.

2. An ion source, said source being closed at one end and open at the opposite end for discharge of an ion stream, said source comprising a gas connection for supply of a gas to be ionized, an electron-emitting cathode, a long drift tube disposed on the side of the cathode remote from the discharge end of the source, a magnet surrounding the drift tube, a focusing electrode between the cathode and the drift tube, the opposite side of the cathode leading to the open end of the source having focusing and accelerating electrodes, means to polarize the drift tube positively relative to the cathode, and means to appropriately polarize the focusing and accelerating electrodes, said cathode being the sole source of electrons, the arrangement being such that an electron stream flows in reverse direction through the drift tube toward the closed end of the source, and resulting ions flow in a forward direction opposite to the direction of the electron stream and through the focusing and accelerating electrodes toward the discharge end of the source, the aforesaid cathode and focusing and accelerating electrodes all having large open passages devoid of screen or mesh obstruction.

3. An ion source, said source being closed at one end and open at the opposite end for discharge of an ion stream, said source comprising a gas connection for supply of a gas to be ionized, an electron-emitting cathode, a long drift tube disposed on the side of the cathode remote from the discharge end of the source, a magnet surrounding the drift tube, a focusing electrode between the cathode and the drift tube, the opposite side of the cathode leading to the discharge end of the source having in succession a focusing electrode, an accelerating electrode and another focusing electrode, means to heat the cathode, means to polarize the drift tube positively relative to the cathode, and means to appropriately polarize the focusing and accelerating electrodes, said cathode being the sole source of electrons, the arrangement being such that an electron stream flows in reverse direction through the drift tube toward the closed end of the source, and resulting ions flow in a forward direction opposite to the direction of the electron stream

and through the focusing and accelerating electrodes toward the discharge end of the source.

4. An ion source, said source being closed at one end and open at the opposite end for discharge of an ion stream, said source comprising a gas connection for supply of a gas to be ionized, an electron-emitting cathode, a long drift tube disposed on the side of the cathode remote from the discharge end of the source, a magnet surrounding the drift tube, a focusing electrode between the cathode and the drift tube, the opposite side of the cathode leading to the discharge end of the source having in succession a focusing electrode, an accelerating electrode and another focusing electrode, means to heat the cathode, means to polarize the drift tube positively relative to the cathode, and means to appropriately polarize the focusing and accelerating electrodes, said cathode being the sole source of electrons, the arrangement being such that an electron stream flows in reverse direction through the drift tube toward the closed end of the source, and resulting ions flow in a forward direction opposite to the direction of the electron stream and through the focusing and accelerating electrodes toward the discharge end of the source, the aforesaid cathode and focusing and accelerating electrodes all having large open passages devoid of screen or mesh obstruction.

5. An ion source for use in a mass spectrometer, said source being closed at one end and open at the opposite end for discharge of an ion stream into the spectrometer tube, said source comprising a gas connection for supply of a gas to be ionized, an electron-emitting cathode, a long drift tube disposed on the side of the cathode remote from the discharge end of the source, a magnet surrounding the drift tube, a first focusing electrode between the cathode and the drift tube, the opposite side of the cathode leading to the discharge end of the source having in succession a second focusing electrode and an accelerating electrode and a third focusing electrode, means to heat the cathode, means to polarize the drift tube positively relative to the cathode, and means to polarize the first and second focusing electrodes at a positive potential less than that of the drift tube, and to polarize the third focusing electrode more negatively than the cathode, and the accelerating electrode more negatively than the third focusing electrode, said cathode being the sole source of electrons, the arrangement being such that an electron stream flows in reverse direction through the drift tube toward the closed end of the source, and resulting ions flow in a forward direction opposite to the direction of the electron stream and through the focusing and accelerating electrodes toward the discharge end of the source.

6. An ion source for use in a mass spectrometer, said source being closed at one end and open at the opposite end for discharge of an ion stream into the spectrometer, said source comprising a gas connection for supply of a gas to be ionized, an electron-emitting cathode, a long drift tube disposed on the side of the cathode remote from the discharge end of the source, a magnet surrounding the drift tube, a first focusing electrode between the cathode and the drift tube, the opposite side of the cathode leading to the discharge end of the source having in succession a second focusing electrode and an accelerating electrode and a third focusing electrode, means to heat the cathode, means to polarize the drift tube positively relative to the cathode, and means to polarize the first and second focusing electrodes at a positive potential less than that of the drift tube, and to polarize the third focusing electrode more negatively than the cathode, and the accelerating electrode more negatively than the third focusing electrode, said cathode being the sole source of electrons, the arrangement being such that an electron stream flows in reverse direction through the drift tube toward the closed end of the source, and resulting ions flow in a forward direction opposite to the direction of the electron stream and through the focusing and accelerating electrodes toward the discharge end of the source, the aforesaid cathode and focusing and accelerating electrodes all having large open passages devoid of screen or mesh obstruction.

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RALPH G. NILSON, *Primary Examiner.*