# United States Patent [19]

**Liebl et al.**

[11] **3,842,269**

[45] **Oct. 15, 1974**


[54] **MASS SPECTROMETER OF HIGH DETECTION EFFICIENCY**


[75] Inventors: **Helmuth Liebl**, Eching; **Klaus Rasskopf**, Munich, both of Germany

[73] Assignee: **Max-Planck-Gesellschaft zur Forderung der Wissenschaften e.V.**, Gottingen, Germany



[22] Filed: **Dec. 26, 1973**

[21] Appl. No.: **427,490**

**Related U.S. Application Data**

[63] Continuation of Ser. No. 292,332, Sept. 26, 1972, abandoned.

[30] **Foreign Application Priority Data**

Oct. 5, 1971 Germany ..... 2149716

[52] **U.S. Cl.** ..... **250/298,** 250/281, 250/427

[51] **Int. Cl.** ..... **H01j 39/34**

[58] **Field of Search** ..... 250/282, 281, 290, 298, 250/297, 300, 423, 424, 427



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,286,187 | 11/1966 | Gaber | 250/427 |
| 3,421,035 | 1/1969 | Brubaker | 250/41.95 B |
| 3,445,650 | 5/1969 | Liebl | 250/49.5 B |
| 3,705,998 | 12/1972 | Jennings et al. | 250/427 |
| 3,761,707 | 9/1973 | Liebl | 250/298 |



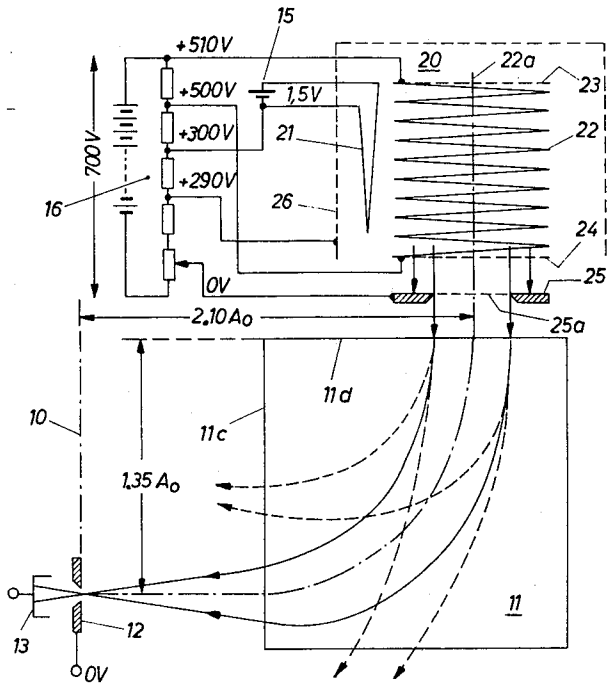
*Primary Examiner*—James W. Lawrence
*Assistant Examiner*—B. C. Anderson
*Attorney, Agent, or Firm*—Flynn & Frishauf



[57] **ABSTRACT**

The ion source of a mass spectrometer is designed to draw ions from a relatively large volume through a diaphragm with a relatively large opening into a magnetic field in a wedge shaped space between diverging plane pole faces, entering such space parallel to the line of intersection of the pole face planes near the wide end of said space. The ions are focused after 90° deflection into an exit slit or diaphragm on the line of intersection of the pole faces. Certain parameters for the position of the exit slit are given.


**6 Claims, 2 Drawing Figures**



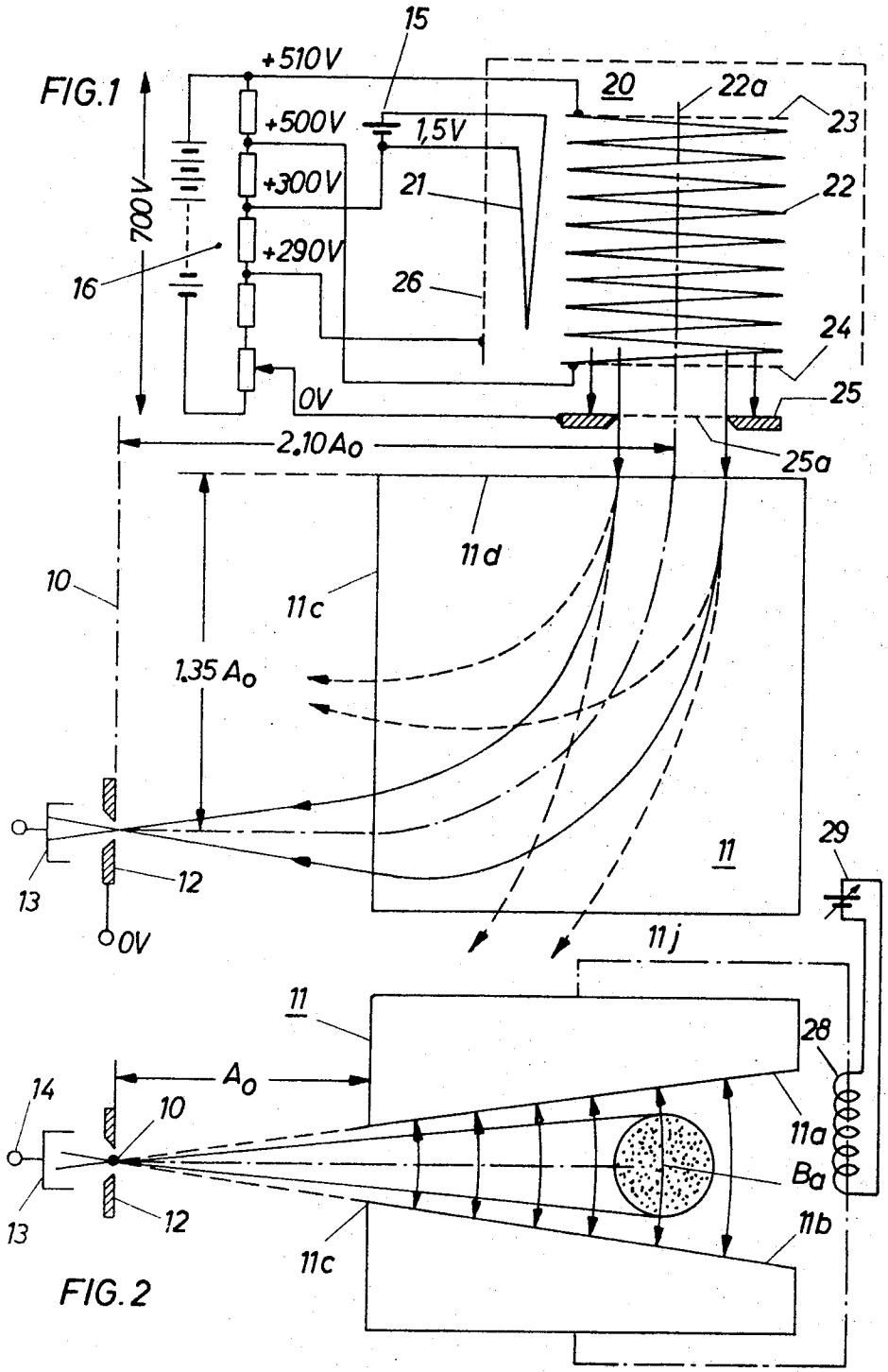


FIG.1
+510V
15
+500V
1,5V
+300V
21
+290V
26
700V
16
0V
20
22a
23
22
24
25
2.10Ao
25a
11d
10
11c
1.35Ao
11
29
12
13
0V
11j
11
28
Ao
14
10
11a
Ba
12
13
11c
11b
FIG.2

# MASS SPECTROMETER OF HIGH DETECTION EFFICIENCY

This is a continuation, of application Ser. No. 292,332, filed Sept. 26, 1972 now abandoned.

The present invention relates to a mass spectrometer of high detection efficiency and more particularly to a mass spectrometer of the type having an ion source in which a gas to be analyzed is ionized by electron bombardment, an apparatus for producing a substantially static magnetic field through which the ions produced in the ion source and projected therefrom by an electric field through a first diaphragm are deflected on the basis of their effective mass so that ions of different effective mass are focused along a focus line at different places and there enter an ion detection devie in which the ions to be detected enter through a diaphragm suitably positioned in the focus line.

In known types of mass spectrometers of high detection efficiency, particularly those used for analysis of residual gas or for detection of leaks in vacuum systems, the effective magnetic field provides the analysis by mass by projecting the intake slit ion-optically on the exit slit. The mass resolution thus depends primarily on the ratio of the deflection radius to the sum of the slit widths. Since in the case of residual gas analysis apparatus and the like a compact form of construction is desired, the deflection radius and likewise the intake slit width cannot be made so large as would be desired with reference only to the mass resolution. And since, moreover, the ion jet may have a spreading angle of only a few degrees, the known mass spectrometers of this type can detect ions only from a small ionization volume in the ion source. For a given ionization density the obtainable detection efficiency is, however, proportional to the volume from which the ions can be detected. The detection efficiency of the known residual gas analyzers therefore leaves much to be desired.

The object of the present invention is accordingly to provide a mass spectrometer of high detection efficiency in which ions can be drawn from a large ionization volume in spite of a compact form of construction.

## SUBJECT MATTER OF THE PRESENT INVENTION:

Briefly, the ion source in which the gas to be analyzed is ionized by electron bombardment includes an open metallic helix, such as a wire helix, a source of electrons external to the helix biased electro-negatively with respect to the helix and two open grids perpendicular to the axis of the helix respectively adjacent the two ends of the helix, one at the positive pole of the power supply and the other one slightly more negative. An acceleration voltage is provided between the less positive of these two grids and an adjacent diaphragm which also has an open grid across its opening and which serves as the intake diaphragm of the mass spectrometer proper. This diaphragm has an opening that is relatively large compared so that of the output diaphragm. The equipment for applying the magnetic field includes two pole pieces having mutually inclined pole faces lying in planes that intersect in a line parallel to the axis of the helix of the ion source. The pole pieces also have two mutually perpendicular sides lying in the same mutually perpendicular planes. One of these



planes intersects the throat of the diverging pole faces and is parallel to the line of intersection of the pole face planes and at a distance $A_0$ therefrom. The other of these two mutually perpendicular planes is perpendicular to the axis of the helix of the ion source and hence also of the incoming ion jet. The distance between that axis and the line of intersection of the pole face planes is substantially 2.10 $A_0$. Finally, the exit diaphragm is bisected by the aforesaid line of intersection of the pole face planes and is offset from the plane extending the side of the pole faces which is adjacent to the intake diaphragm and perpendicular to its axis by a distance equal to 1.35 $A_0$.

By these arrangements the result is obtained that ions can be drawn from a large ionization volume in the ion source and the intake diaphragm or slit through which the ions proceed from the ion source into the magnetic field can be made very large in comparison to residual gas analyzers heretofore known, so that according to the invention a mass spectrometer can be provided which has a detection efficiency of about one order of magnitude better than the conventional residual gas analyzers.

The acceleration voltage, the magnetic field, or both may be made variable. The electron source is located outside the helix and is preferably a hairpin type thermionic cathode, biased substantially negative relative to the helix and the grids at its ends, but considerably less negative than the diaphragm adjacent one end of the helix which serves as an accelerating electrode. An electrostatic screen may enclose the electron source as well as the helix, including the back end of the helix, and this screen is preferably at about the potential of the electron source or slightly more negative. An illustrative embodiment of the invention is described below in further detail with reference to the accompanying drawing in which:

FIG. **1** is a greatly simplified plan view of a mass spectrometer according to the invention, and

FIG. **2** is a side view of a portion of the mass spectrometer shown in FIG. **1.**

The embodiment shown in FIGS. **1** and **2** for illustration of the invention includes a mass analyzer **11** which works with a magnetic field that is produced between two plane pole faces that are inclined with respect to each other so as to form a wedge shaped magnetic gap. The lines of force of the field, as shown in FIG. **2** by arrows, are circular arcs having as center the line of intersection **10** of the two planes containing the pole faces **11***a* and **11***b* respectively. The field strength between the pole pieces is inversely proportional to the distance from the intersection line **10.** Charged particles describe cycloidal paths in such a field. It is known (H. Lieb**1**, J. Appl. Phys., vol. 38 (1967) pages 5,277, 5283) that when a parallel jet of charged particles enters perpendicularly to the magnetic field at an offset distance $A = \mathbf{2.10}\ A_0$ from the intersection line **10,** with the momentum *p*, it will be focused after a 90° deflection at a point on the intersection line if the field strength is so adjusted that at the distance $A = \mathbf{2.10}\ A_0$ from the intersection line it has the value

$$B_A = \mathbf{1,35}\ p/Ae \qquad (1)$$

In the above expression:
p = particle momentum
e = particle charge

$A_o$ = distance of the intersection line **10** from the pole piece wall surface **11***c*, which is parallel to the intersection line **10.**

The focusing effect follows a second approximation: the distance of the focus from the entrance edge of the pole pieces is substantially **1.35** $A_o$.

At the location of the focus an output diaphragm **12** in provided, for example in the form of a slit, behind which an ion detector, for example an ion capture device **13,** is located for detecting the ions penetrating through the gap of the diaphragm **12** and for producing a corresponding electrical output signal at an output terminal **14** for processing in the usual way.

The ion source designated **20** as a whole in the drawing comprises a cylindrical wire helix **22** and an electron source **21** outside the helix and extending parallel to the helix axis (in the simplest case in the form of a hairpin filament connected to a suitable source of heating surrent **15**). At the two ends of the helix are parallel open wire grids or similar reticular structures **23** and **24,** perpendicular to the axis **22***a* of the helix **22** and preferably connected with the adjacent ends of the helix. An electrostatic screen **26,** which may be of wire screening in cup shape, surrounds the elements just named, the electron source **21** as well as the helix **22** and the grids **23** and **24.**

Spaced somewhat away from the grid **24** is a first diaphragm **25,** the opening of which is bridged by another open wire grid **25***a* parallel to the grid **24.** The diaphragm **25** serves as an accelerating electrode for the ion source and as the intake diaphragm or slit for the magnetic field portion of the mass spectrometer.

The opening of the intake diaphragm **25** is relatively large, its area being of the order of magnitude of the crosssectional area of the helix **22.** Preferably the area of the opening is at least 50 percent on the area of the cross-section of the helix **22.**

The electrodes of the ion source are connected during operation of the mass spectrometer with a voltage source **16,** which is shown only diagrammatically in the drawing. It includes for example a voltage divider adapted to supply the voltages specified in FIG. **1.**

The mass spectrometer above described operates as follows:

The electrons emitted by electron source **21** are accelerated by the positive bias voltage of helix **22** relative to electron source **21** and oscillate a few times through the helix until they finally land on it. In consequence the gas molecules inside the helix are ionized by electron bombardment. The oscillation of the electrons just mentioned increases the effective path of the electrons, as is known in the particular context of the Bayard-Alpert ionization manometers. In contrast to the operation of the ionization manometers just mentioned, however, in the ion source of the present invention a small voltage (preferably less than 5 percent and usually even smaller than 2 percent of the acceleration voltage U between grid **24** and diaphragm **25**) is applied between the parallel open grids **23** and **24** at the ends of the spiral **22,** so that a weak homogeneous electrostatic field is present on the inside of the helix. This field is so directed that the ions produced by electron bombardment are propelled towards grid **24.** Between the latter and the diaphragm **25** the actual acceleration voltage U (preferably a variable voltage in the neighborhood of, for example, 500 volts) is applied to produce an electrostatic acceleration field between the grids **24** and **25***a*, which are arranged in parallel planes. The ion projected through the diaphragm **25** produce a parallel stream or jet that enters the magnetic field between the pole faces **11***a* and **11***b* at their edge **11***d*.

Typical potentials for the electrodes of the ion source are, with respect to ground potential = 0 volts:

| | |
|---|---|
| Diaphragm 25 | 0 V |
| Grid 24 | +500 V |
| Grid 23 | +510 V |
| Electron source 21 | +300 V |
| Screen 26 | +290 V |

The theoretical mass resolution is

$$\Delta M/M = \Delta U/U + S/A_o + 1.4\,\theta \qquad (2)$$

In the above expression:

$\Delta U$ = energy spread of the ions

U = acceleration voltage

S = width of the slit shaped opening of the exit diaphragm **12** in the plane of deflection

$A_o$ = distance of the exit diaphragm **12** from the field edge **11***c*;

$\theta$ = angular spread of the parallel particle stream or jet at entrance into magnetic field.

The energy spread $\Delta U$ arises primarily from the small voltage applied between the ends of the helix and causes the ions to arise at somewhat different potential. The angle spread $\theta$ comes into play in the calculation of the mass resolution in the place of the entrance slit width which comes up in the corresponding formula for conventional equipment. The angular spread $\theta$ is composed primarily of alignment errors of the grids **24** and **25***d* and their deviation from parallel plane relation and also the penetration of fields through these grids.

In a practical example of construction of equipment according to the invention, a partial pressure detection efficiency of $10^{-2}$ A/Torr was obtained for a half value resolution of **30.** This detection sensitivity is about one order of magnitude better than that of most conventional residual gas analyzers.

The embodiment from which the above results was obtained had the following physical parameters:

$A_o$ = 4 cm

$B_A$ = variable, e.g.

730 Gauss for mass 2 ($H_2$+);

2,720 Gauss for mass 28 ($N_2$+);

3,410 Gauss for mass **44** ($CO_2$+).

angle between the pole faces **11***a* and **11***b* = 8°

diameter of helix **22** = 1.5 cm

distance between grids **23** and **24** = 1.5 cm

diameter of opening in diaphragm **25** = 1 cm

The adjustment of the mass spectrometer for a desired effective ion mass (ion mass/ion charge) can be accomplished by variation of the magnetic field strength and/or variation of the acceleration voltage applied between grids **24** and **25***a*. The acceleration voltage can readily be varied by an adjustable tap of a potentiometer in the voltage source **16.** For variation of the magnetic field $B_A$ a magnet coil **28** may be used which is connected to a source **29** of variable current and is associated with a magnetic yoke **11***j* which is only schematically represented in FIG. **2** as forming part of the magnetic circuit which includes the pole pieces **11** and the pole faces **11***a* and **11***b*.

Although the invention has been described with reference to a single specific embodiment, it is to be understood that modifications and variations may be made within the inventive concept without departing from the spirit of the invention. In particular, although the element **22** is described as a "helix," it is clear that other cylindrical open cages of wire, rods, etc., would function in an equivalent fashion, and the use herein of the work "helix" must be taken with that understanding.

We claim:

**1.** A mass spectrometer of high detection efficiency comprising:

an ion source (**20**) including a chamber in which a rarified gas to be analyzed is adapted to be ionized, a metallic open helix (**22**) surrounding a portion of said chamber, a source of electrons (**21**) outside said helix, open grids (**23, 24**) adjacent to and obstructing the two ends of said helix (**22**), a first diaphragm (**25**) spaced from one end of said helix (**22**) centered axially thereto, an open grid (**25***a*) across the opening of said first diaphragm, each of the aforesaid grids (**23, 24, 25***a*) perpendicular to the axis (**22***a*) of said helix (**22**), and means for applying electric potential (**16**) so as to make said grid (**23**) adjacent the end of said helix (**22**) farthest from said first diaphragm (**25**) most positive, said grid (**24**) adjacent the other end of said helix (**22**) slightly less positive, said helix (**22**) at a potential intermediate that of said end grids (**23, 24**), said electron source (**21**) considerably less positive, and said first diaphragm (**25**) and its grid (**25***a*), most negative, the voltage between said end grids (**23, 24**) of said helix being less than 5 percent of the acceleration voltage between the said open grid (**24**) at the end of said helix (**22**) nearer said first diaphragm (**25**) and the open grid (**25***a*) across said first diaphragm;

means for producing a substantially steady magnetic field (**11, 28, 29**) directed at right angles to the axis (**22***a*) of said helix (**22**) of said ion source (**20**) including two pole pieces (**11**) having diverging pole faces (**11**a, **11***b*) lying in planes intersecting in a line (**10**) parallel to the axis (**22***a*) of said helix (**22**) of said ion source (**20**) and each having also first and second mutually perpendicular sides (**11***c*, **11***d*) forming edges with said pole faces (**11***a*, **11***b*), said first sides (**11***d*) being perpendicular to the axis (**22***a*) of said helix (**22**) and said second sides (**11***c*), being parallel to the line of intersection (**10**) of said pole face planes and respectively intersecting said diverging pole faces (**11***a*, **11***b*) in lines defining their edge of nearest approach and hence also defining the throat of the space enclosed by said diverging faces, and

a second diaphragm (**12**) in the form of a slit bisected by said line of intersection (**10**) of said pole face planes, said second diaphragm (**12**) being at a distance $A_0$ from a boundary plane comprising said second sides (**11***c*) of said pole pieces which is parallel to said line of intersection (**10**) as aforesaid, being also offset by a distance of substantially **1.35** $A_0$ from a plane comprising said first sides (**11***d*) of said pole pieces, and being further offset by a distance of substantially **2.10** $A_0$ from said axis (**22***a*) of said helix (**22**).

**2.** A mass spectrometer as defined in claim **1** in which said second diaphragm (**12**) has an opening which is small compared to the opening of said first diaphragm (**25**) and in which the voltage between the open grids (**23, 24**) at the ends of said helix is not more than 2 percent of said acceleration voltage.

**3.** A mass spectrometer as defined in claim **1** in which said helix (**22**), said source of electrons (**21**) and said open grids (**23, 24**) at the ends of said helix are surrounded by an electrostatic screen (**26**) which also encloses the end of said helix (**22**) farthest from said first diaphragm (**25**) and in which said electrostatic screen (**26**) is connected to said means for applying electric potential (**16**) so that it is at a potential in the neighborhood of that of said source of electrons (**21**).

**4.** A mass spectrometer as defined in claim **3** in which said source of electrons (**21**) is a thermionic cathode of substantially hairpin shape and in which said electrostatic screen (**26**) is connected to said means for applying of potential (**16**) so as to maintain it at a voltage slightly more negative than the potential at which said source of electrons (**21**) is maintained.

**5.** A mass spectrometer as defined in claim **1** in which said open grids (**23, 24**) adjacent to the extremeties of said helix (**22**) are electrically connected to the respectively adjacent ends of said helix (**22**).

**6.** A mass spectrometer as defined in claim **1** in which there are provided means for varying either the acceleration voltage or the magnetic field strength, or both, said acceleration voltage being defined as a voltage between said first diaphragm (**25**) and its grid (**25***a*) and that one (**24**) of said open grids (**23, 24**) which is adjacent the end of said helix (**22**) nearer said first diaphragm (**25**).

* * * * *