

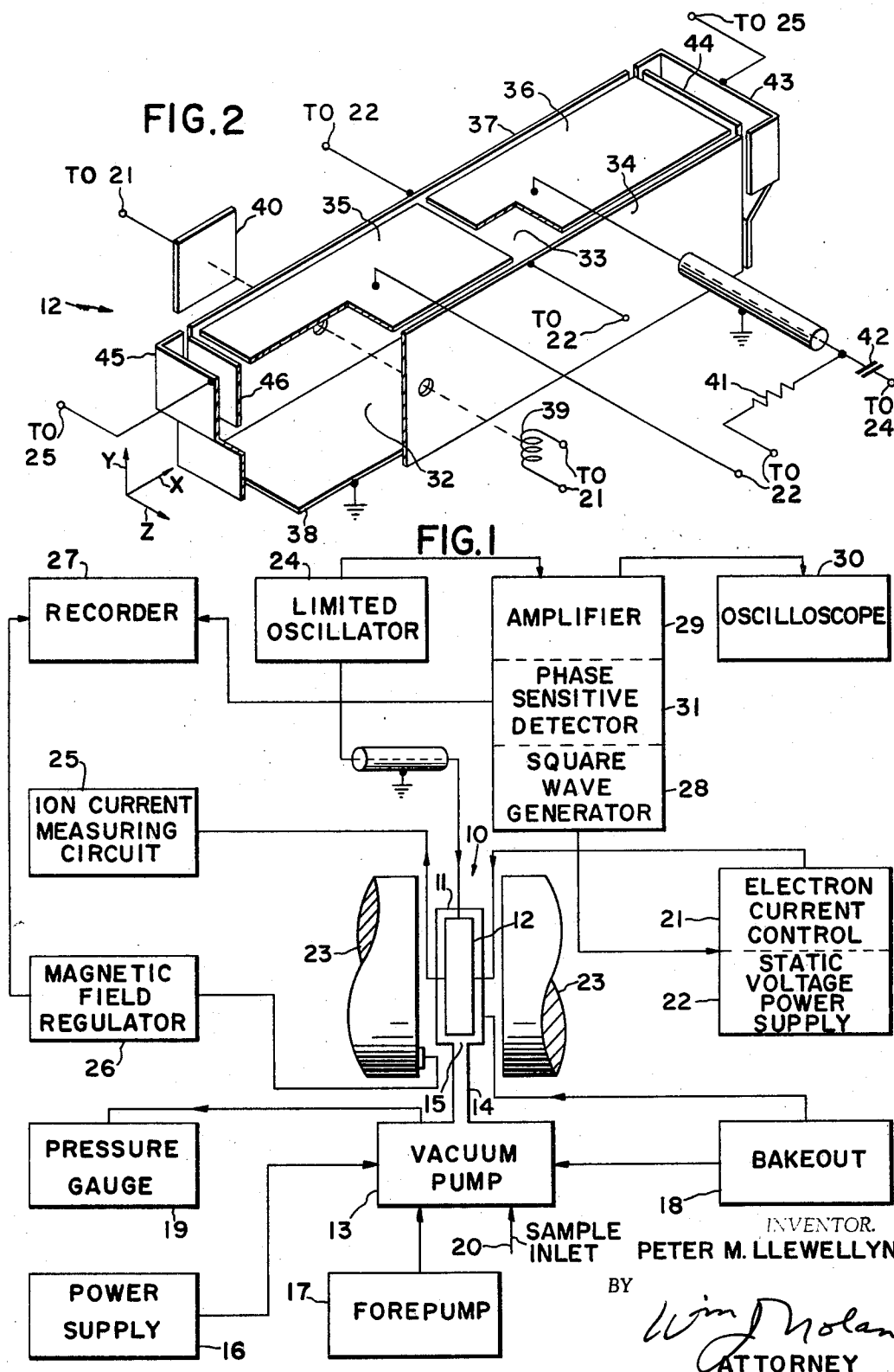
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ION CYCLOTRON RESONANCE MASS SPECTROMETER HAVING MEANS FOR DETECTING THE ENERGY ABSORBED BY RESONANT IONS

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ABSTRACT OF THE DISCLOSURE

A spectrometer is described which employs ion cyclotron resonance and energy absorption in mass analysis. In an evacuated envelope ions are formed in the first of two regions which are subjected to static magnetic and electric fields disposed at right angles to each other and to the common axis of the two regions. The ions are caused by the interaction of the fields to move with cycloidal motion into the second region which is additionally subjected to an oscillating electric field in the same direction as the static field. The ions in resonance with the oscillating field absorb energy therefrom and separate from the non-resonant ions. The energy absorbed by the resonant ions is then detected as a measure of the resonant ions.

This invention relates to mass spectrometry and in particular to mass spectrometry methods and apparatus employing the principles of ion cyclotron resonance.

It is known that one may produce high speed ions corresponding to a very high voltage from the cumulative action of a succession of accelerating impulses each requiring only a moderate voltage. In particular, the ions are caused to travel back and forth in curved paths in the nature of an expanding spiral between a pair of electrodes. The movement of the ions in such paths is effected by the action of a magnetic field such that their motion is repeatedly reversed with reference to the electric field between the electrodes and the voltages of such electrodes alternates or oscillates in synchronism or resonance with the reversal of the path of the motion of the particle. This phenomenon is commonly referred to as cyclotron resonance.

In mass spectrometry, a gas sample is bombarded by moving electrons to produce ions of various substances present in the sample, and the ions thus formed are separated into various components having different mass-to-charge ratios by subjecting the ions to the influence of electric or magnetic fields or both. The individual components are then usually directed upon an ion collector and discharged, and the intensity of the ion current is measured. Thus, the several components of the sample may be caused to fall successively upon the collector by varying the electric or magnetic field or both, or by moving the collector successively into the respective paths of the several components.

In one particular type of mass spectrometer employing cyclotron resonance as mentioned above, certain of the ions which are in resonance with the frequency of an oscillating field are caused to pursue an expanding spiral path while moving generally along the lines of force of a magnetic field, and will ultimately impinge on a collector electrode. Other ions, not in resonance with the frequency of the oscillating field, are sent in different paths and do not impinge on the collector. All or any portion of the total mass spectrum of a sample to be analyzed may be scanned by varying the frequency of the oscillating field or the strength of the magnetic field, or both so as to bring ions of differing mass-to-charge ratio into res-

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onance with the oscillating field. Such spectrometers, it will be seen, segregate among ions of differing mass-to-charge ratio on the basis of differences in the resonant frequency of the ions, which in turn is a function of the mass-to-charge ratio. These spectrometers are commonly referred to as cyclotron resonance or omegatron mass spectrometers.

There have been, however, certain limitations in the commercially available prior art omegatrons. In particular:

(1) Some ions, although not in resonance with the oscillating field, for example, those having high initial kinetic energy or those not formed by the primary electron beam, can reach the collector electrode thus reducing the utility of the instrument.

(2) Ionization normally occurs in the same region as mass analysis. This results in changes in resonant condition caused by the space charges of the electrons and/or ions.

(3) Only the partial pressure of the resonant ions of a given mass-to-charge ratio may be determined at a given time. One may not readily determine total pressure. This is due to the fact that no means are provided for monitoring total ion current at all times.

The present invention relates to a mass spectrometer which, while dependent on the basic phenomenon of cyclotron resonance, overcomes the above-mentioned difficulties of the prior art and contemplates many advantages including higher resolution and sensitivity than in any prior art instrument.

Briefly stated, in accordance with one teaching of the present invention there is disclosed a mass spectrometer comprising: an evacuable envelope to which a gas sample can be admitted; a plurality of spaced electrodes disposed within the envelope arranged about an axis and defining a first and second region spaced from each other along the axis; means for ionizing within the first region a gas sample admitted to the envelope; means for producing a magnetic field transverse to the axis; means for producing a static electrical field between electrodes defining the first region and the second region transverse to the lines of force of the magnetic field and the axis, whereby ions produced in the first region are continually moved along the axis from the first region through the second region irrespective of mass-to-charge ratio; means for producing an oscillating electrical field between electrodes defining the second region transverse to the lines of force of the magnetic field and the axis whereby certain of such ions in resonance with the oscillating electrical field absorb a net amount of energy therefrom; and means for sensing such resonant ions by measuring the energy so absorbed.

One feature of the present invention is the provision of a method of mass spectrometry employing the principles of cyclotron resonance which involves forming the ions in a first region and continually causing them to move from a first region into and preferably through a second region spaced from the first region irrespective of their mass-to-charge ratio where they are subjected to the combined action of an oscillating electrical and magnetic fields, the motion of the ions preferably being transverse to the magnetic field.

Another feature of the present invention is the provision of a method of mass spectrometry employing the principles of cyclotron resonance in which ions formed in a first region are continually caused to move from the first region into and preferably through a second region by subjecting the ions to the action of a magnetic field while simultaneously subjecting them to the action of a static electrical field applied transverse to the lines of the force of the magnetic field in the first region and preferably in the second region as well.

Still another feature of the present invention involves in the method of the above type, modulating the static electrical field in the first region while simultaneously subjecting the ions to the action of the magnetic field.

A further feature of the present invention is the provision in a mass spectrometer employing ion cyclotron resonance of an ionizing region, an analyzing region spaced from the ionizing region and means for continually moving ions from the ionizing region into and preferably through the analyzing region.

A still further feature of the present invention is the provision in a mass spectrometer of the above type of a static electrical field applied transversely to a magnetic field in the first region and preferably the second region as well, for continually causing the ions to move from the ionizing region into and through the analyzing region.

Another feature of the present invention is the provision in a mass spectrometer of the above type of means for monitoring total ion current.

These and other objects and features of the present invention and a further understanding may be had by referring to the following description and claims, taken in conjunction with the following drawing in which:

FIG. 1 is a block diagram intended to show the functional interrelationship of the various components of the present invention; and

FIG. 2 is a diagrammatic perspective view partially broken away showing the novel ionizing and analyzing structure of the present invention.

Referring now to FIG. 1 there is disclosed a block diagram showing the functional interrelationship of the various components of the mass spectrometer apparatus. It will be observed that the mass spectrometer 10 has an evacuable envelope 11 containing an elongated structure 12 in which ionization and subsequent analysis occur. Evacuation to a very low pressure, typically 10^{-8} – 10^{-9} torr prior to sample introduction, is by means of a vacuum pump 13 connected through a tube 14 terminating at a point of inlet 15 to the envelope 11. A typical vacuum pump employed is a sputter-ion pump of the type disclosed in U.S. Patent No. 2,993,638 issued July 25, 1961 and assigned to the same assignee as the present invention.

Energization of the pump is by means of a power supply 16. As sputter-ion pumps do not operate efficiently at pressures above 10^{-1} – 10^{-2} torr, it is normal practice, prior to energization of the sputter-ion pump, to employ a fore-pump 17, for example, a refrigerated sorption pump of the type disclosed in U.S. Patent No. 3,116,764 issued Jan. 7, 1964 and assigned to the same assignee as the present invention, to reduce the pressure within the sputter-ion pump and apparatus to which it is connected to a level at which the sputter-ion pump will operate efficiently. Also, it is common practice, prior to and during, sometimes, energization of the sputter-ion pump, to employ a means 18 for baking out the sputter-ion pump and apparatus to which it is connected so as to greatly reduce the quantity of the gases on internal wall surfaces and thereby reduce the length of time necessary to reduce the pressure to a very low level. After bakeout and forepumping, the sputter-ion pump is energized.

The pressure is thereby reduced further, being measured by some means, for example, an ionization gauge 19 connected to the vacuum pump. Also, it is well known that the ion current of a sputter-ion pump is proportional to pressure so that measurement of the current drawn by the pump provides an indication of pressure. Once pump-down to 10^{-8} – 10^{-9} torr is obtained a gaseous sample to be analyzed may conveniently be introduced to the apparatus through an inlet 20 to the vacuum pump until a pressure in the 10^{-7} torr range is achieved.

Ions are produced within the structure 12 within a first region by the impact of electrons on molecules of the gas sample under study. As will be explained in more detail below, an electron stream passes through the ioniz-

ing region and is ultimately collected on an electron collector. The electron current is monitored by suitable control means 21 to provide stable electron emission—hence, ion current.

If a small electric field is applied in a $-y$ direction by means of a static voltage power supply 22, ions, irrespective of mass-to-charge ratio, will continually be caused to move in a $+x$ direction at a constant average velocity to an analyzing region where they are trapped by the combined action of an electrostatic field provided by the static voltage power supply and a magnetic field provided in the $-z$ direction by the magnetic poles 23.

If an oscillating field is produced across a second region by means of a limited oscillator 24, resonant ions, that is, ions whose mass-to-charge ratio generally satisfy the equation

$$\frac{e}{m} = \frac{\omega}{B}$$

wherein:

e =the charge of the ion,

m =the mass of the ion,

ω =the frequency of the oscillating field,

B =the transverse magnetic field strength,

will absorb energy from the oscillating field and are caused to pursue an expanding spiral path whose origin moves at a constant velocity in the $+x$ direction. The net amount of energy absorbed can be detected in a suitable circuit and without resonant ion collection. Non-resonant ions will move in a cycloidal motion of small amplitude along the x -axis until ultimately they pass through the second region and are collected. The number of non-resonant ions so collected may be monitored in a suitable measuring circuit 25 permitting in the absence of resonance total ion current to be monitored.

Ions of differing charge-to-mass ratio may be brought into resonance with the oscillating field by varying the frequency of the oscillating field or the strength of the magnetic field, or both. As illustrated in the diagram, means 26 are provided for regulating the magnetic field intensity providing, for fixed frequency ω , a linear readout of mass-to-charge versus field strength and when used with an x - y recorder 27 a linear mass-to-charge versus position readout. The magnetic field regulator 26 which can be used to reverse the direction of the field as well may be of the type disclosed in copending application Ser. No. 252,939 filed Jan. 21, 1963, now Patent No. 3,267,368 and assigned to the same assignee as the present invention.

As stated above, the oscillating voltage required is derived from the limited oscillator 24 and where resonant absorption takes place in the analyzing region a change in the oscillating level occurs. In order to detect these small changes a modulation method is employed. Modulation of the magnetic field, the frequency, the electron current and the electron voltages have all been successfully used. As illustrated in the diagram, modulation of the electrode voltages is accomplished by the provision of a square wave or other pulse type generator 28 applied to the static voltage power supply 22, thence to the analyzing region. At resonance, the signal will be an amplitude modulated radio frequency from the limited oscillator 24. This signal is detected and amplified at 29 and can either be monitored on an oscilloscope 30 or fed to a phase sensitive detector 31. This compares the signal against the square wave and gives an output to the recorder 27 proportional to the absorption in phase with the modulation originally fed to the static voltage power supply 22.

Referring now to FIG. 2 it will be observed that the structure 12 is composed of a plurality of spaced electrodes disposed within envelope 11 shown diagrammatically in FIG. 1, arranged about an axis and defining a first 32 and second 33 region spaced from each other

along the x-axis. The structure 12 is illustrated as being four-sided, of rectangular cross section and includes a first plate 34 forming a first side, a second 35 and third 36 plate forming a second side, a fourth plate 37 forming a third side and a fifth plate 38 forming a fourth side. In a typical embodiment all the plates are of non-magnetic metal such as molybdenum or rhodium plated beryllium copper. Plates 34, 37 and 38 are 5.062" long, plates 34 and 37 are 1.450" wide, plate 38 is 0.950" wide, and the plates 35, 36 are 2.50" long and 0.950" wide. The plates are held in fixed spaced relation within envelope 11 by means of insulating support bars (not shown). From the description thus far it will be seen that there is provided along the x-axis a first region 32 defined by plate 35 and a portion of plates 34, 37, and 38 and a second region 33 defined by plate 36 and portions of plates 34, 37, and 38.

An electron gun including a filament 39 usually made of rhenium and typically maintained at -50 volts is mounted within envelope 11 and discharges a stream of electrons typically 2 microamps in a -z direction parallel to the magnetic lines of flux, which stream passes through an aperture typically 0.040" in plate 34 typically maintained at 0-+1 volt, region 32, an aperture typically 0.060" in plate 37 typically maintained at 0-+1 volt onto a plate 40 for collection of electrons. Plate 40 is typically maintained at +10-20 volts to recapture secondary electrons emitted upon primary electron impact. The combined gas conductance of the spaces between and apertures in the electrode plates of which structure 12 is composed is sufficiently high that gas molecules admitted to envelope 11 can freely diffuse into the interior of structure 12. As the electron stream passes through region 32 it ionizes a portion of the gas molecules which have found their way into region 32. It is to be understood that gas molecules can be admitted and ionization accomplished in region 32 in many manners other than as illustrated.

A static voltage, typically of 0-+1 volt is applied between plate 36 and grounded plate 38 producing a static electrical field in the -y direction in region 32 which is transverse to the x-axis and the magnetic lines of force in the -z direction established between the poles 23. Similarly, a static voltage typically of 0-+1 volt is applied between plate 36 and plate 38 through a series connected resistor 41, typically 10⁷ ohms producing within region 33 a static electrical field in the -y direction which is transverse to the x-axis and to the magnetic lines of force in the -z direction established between the poles 23. The combined action of the magnetic and static fields causes ions formed in region 32 irrespective of their mass-to-charge ratio to move in a cycloidal motion of small amplitude with respect to the dimensions of structure 12 about the x-axis, at constant velocity typically 100-500 cm./sec. in the +x direction from region 32 into region 33. By reversing the static electrical fields and the magnetic field, negative ions may be made to behave in a similar manner.

An R.F. voltage, typically 100 millivolts is applied between plate 36 and ground through a capacitor 42, typically 50 picofarads producing an oscillating electrical field within region 33 which is transverse to the magnetic lines of force and the x-axis. As ions move through region 33 those ions in resonance with the oscillating field will gain energy therefrom and pursue a cycloidal trajectory in the nature of an expanding spiral whose origin, due to the action of the static field, continually moves linearly in the +x direction. The net amount of energy absorbed by the resonant ions is detected and amplified as explained above. The capacitor 42 connects to a tuned circuit of high impedance forming with the capacitance of the structure 12 and the tuned circuit, the frequency determining components of the limited oscillator 24.

Most of the resonant ions are ultimately discharged on the plates 34, 36, 37 and 38. In the presence of the

oscillating field a large proportion of the non-resonant ions, due to the combined action of the magnetic and static fields moves through region 33 and is ultimately discharged on a collector electrode 43. The collector electrode 43 and an extension 44 of the plate 36 form an aperture through which non-resonant ions pass prior to discharge on collector electrode 43. The plate 44 is typically electrically connected to plate 36. The ions discharged on the collector electrode may be monitored in circuit 25 providing an index to total ion current, hence total pressure.

Where somewhat greater accuracy is required, the direction of the magnetic field can be reversed 180° and ions formed within region 32 are directed in a -x direction and are discharged on a similar collector electrode 45 bounding the non-oscillating first region 32 after passing through an aperture between electrode 45 and plate 46 similar to plate 44. Additionally, a collector electrode may be made to extend into region 32. Alternatively, the ionizing region end of structure 12 can be left open to make possible experiments using light.

Since many changes can be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In mass spectrometry involving in an evacuable space the formation of ions and the detection of ions so formed of a given mass-to-charge ratio by subjecting the ions so formed to the action of a magnetic field while simultaneously subjecting them to the action of an oscillating electrical field applied transversely to the lines of force of the magnetic field whereby such ions of a given mass-to-charge ratio in resonance with the oscillating electrical field absorb a net amount of energy therefrom, the improvement comprising forming said ions in a first region of two distinct and separate regions disposed along a common axis, subjecting the ions in said first region to the action of a magnetic field directed transverse to said axis while simultaneously subjecting the ions to the action of a static electrical field transverse to the lines of force of the magnetic field and transverse to said axis thereby continually causing the ions to move in a cycloidal path into the second region spaced from said first region irrespective of their mass-to-charge ratio where they are subjected to the combined action of the oscillating electrical and magnetic fields.

2. The improvement according to claim 1 including modulating the static electrical field while simultaneously subjecting the ions to the action of the magnetic field.

3. In mass spectrometry involving in an evacuable space the formation of ions and the detection of ions so formed of a given mass-to-charge ratio by subjecting the ions so formed to the action of a magnetic field while simultaneously subjecting them to the action of an oscillating electrical field applied transversely to the lines of force to the magnetic field whereby such ions of a given mass-to-charge ratio in resonance with the oscillating electrical field absorb a net amount of energy therefrom, the improvement comprising forming said ions in a first region, subjecting the ions in said first region to the action of a magnetic field while simultaneously subjecting them to the action of a static electrical field transverse to the lines of force of the magnetic field, thereby continually causing the ions to experience cycloidal movement in a direction normal to the applied electric and magnetic fields irrespective of mass-to-charge ratio and into a second region spaced from said first region where they are subjected to the combined action of the oscillating electrical and magnetic fields, and simultaneously subjecting them to the action of a static electrical field in said second region transverse to the lines of force of the magnetic field

and the direction of ion movement, thereby continually causing them to move through said second region.

4. The improvement according to claim 3 including modulating the static electrical field while simultaneously subjecting the ions to the action of the magnetic field.

5. In a mass spectrometry involving in an evacuable space the formation of ions and the detection of ions so formed of a given mass-to-charge ratio by subjecting the ions so formed to the action of a magnetic field while simultaneously subjecting them to the action of an oscillating electrical field applied transversely to the lines of force of the magnetic field whereby such ions of a given mass-to-charge ratio in resonance with the oscillating electrical field absorb a net amount of energy therefrom, the improvement comprising forming said ions in a first region, subjecting the ions in said first region to the action of a magnetic field while simultaneously subjecting them to the action of a static electrical field transverse to the lines of force of the magnetic field, thereby continually causing the ions to move into a second region spaced from said first region in a direction normal to said static electrical and magnetic fields where they are subjected to the combined action of the oscillating electrical and magnetic fields and simultaneously subjected to the action of another static electrical field in said second region transverse to said direction and to the lines of force of the magnetic field, thereby continually causing the ions to move through said second region.

6. The improvement according to claim 5 including modulating the static electrical field while simultaneously subjecting the ions to the action of the magnetic field.

7. A mass spectrometer comprising: an evacuable envelope providing a closed chamber to which a gas sample may be admitted, said chamber being provided with first and second regions spaced from each other along a common axis; means for ionizing within said first region a gas sample admitted to said envelope; means for continually moving ions from said first region to said second region; means for producing an oscillating electrical field across said second region normal to said axis and the direction of travel of said ions; means for producing a magnetic field across the second region transverse to the oscillating electrical field and to said axis whereby certain of such ions in resonance with said oscillating field absorb a net amount of energy therefrom; and means for sensing such resonant ions.

8. A mass spectrometer comprising: an evacuable envelope providing a closed chamber to which a gas sample may be admitted; said chamber being provided with first and second regions spaced from each other; means for ionizing within said first region a gas sample admitted to said envelope; means for continually moving ions at a substantially constant average velocity from said first region through said second region; means for producing an oscillating electrical field across said second region and normal to the net direction of ion movement; means for producing a magnetic field across the second region transverse to the oscillating electrical field whereby certain of such ions in resonance with said oscillating field absorb a net amount of energy therefrom without a concomitant change in average velocity through the region; and means for sensing such resonant ions.

9. A mass spectrometer comprising: an evacuable envelope providing a closed space to which a gas sample may be admitted; said chamber being provided with first and second regions spaced from each other; means for ionizing within said first region a gas sample admitted to said envelope; means for producing movement of said ions in a direction from said first region into said second region; means for producing an oscillating electrical field across said second region transverse to said direction of movement of said ions in said second region; means for producing a magnetic field across the second region transverse to the oscillating electrical field and said direction of movement of said moving ions whereby certain of such

ions in resonance with the oscillating electric field absorb a net amount of energy therefrom; and means for sensing the energy absorbed by the resonant ions from the oscillating electric field.

10. A mass spectrometer comprising: an evacuable elongated envelope providing a closed chamber to which a gas sample may be admitted; said chamber being provided with first and second regions spaced from each other in the direction of elongation; means for ionizing within said first region a gas sample admitted to said envelope; means for producing a magnetic field across said envelope; means for producing a static electrical field across said first region transverse to the lines of force of said magnetic field and transverse to the direction of elongation of said envelope, thereby continually causing said ions to move from said first region into said second region; means for producing an oscillating electrical field across said second region transverse to the lines of force of said magnetic field and the path followed by said moving ions whereby certain of such ions in resonance with said oscillating electrical field absorb a net amount of energy therefrom; and means for sensing such resonant ions.

11. The spectrometer according to claim 10 including means for modulating the static electrical field across said first region.

12. A mass spectrometer comprising: an evacuable envelope providing a closed chamber to which a gas sample may be admitted; said chamber being provided with first and second regions spaced from each other; means for ionizing within said first region a gas sample admitted to said envelope; means for producing a magnetic field across said envelope; means for producing a static electrical field across said first region and said second region transverse to the lines of force of said magnetic field, thereby continually causing said ions to move from said first region through said second region in a direction transverse to said electric and magnetic fields; means for producing an oscillating electrical field across said second region transverse to the lines of force of said magnetic field and the direction of movement of said moving ions whereby certain of such ions in resonance with said oscillating electrical field absorb a net amount of energy therefrom; and means for sensing such resonant ions.

13. The spectrometer according to claim 12 including means for modulating the static electrical field across said first region.

14. A mass spectrometer comprising: an evacuable envelope to which a gas sample can be admitted; a four-sided elongated structure of generally rectangular cross-section disposed within said envelope having a plurality of electrode plates spaced from each other including, (1) a first plate forming a first side, (2) a second and a third plate disposed lengthwise and forming a second side, (3) a fourth plate forming a third side and, (4) a fifth plate forming a fourth side; said second plate and a portion of said first, fourth and fifth plates forming a first region; said third plate and the remaining portions of said first, fourth and fifth plates forming a second region; means for ionizing within said first region a gas sample admitted to said envelope; means for producing a magnetic field across said structure, the magnetic lines of force being substantially perpendicular to said first and fourth plates; means for producing a static electrical field between said second and fifth plates whereby ions produced continually move from said first region into said second region; means for producing an oscillating electrical field across said second region transverse to the lines of force of said magnetic field and to the direction of movement of said moving ions whereby certain of such ions in resonance with the oscillating electrical field absorb a net amount of energy therefrom; and, means for sensing such resonant ions.

15. A mass spectrometer comprising: an evacuable envelope to which a gas sample can be admitted; a four-sided elongated structure of generally rectangular cross-

section disposed within said envelope having a plurality of electrode plates spaced from each other including, (1) a first plate forming a first side, (2) a second and a third plate disposed lengthwise and forming a second side, (3) a fourth plate forming a third side and, (4) a fifth plate forming a fourth side; said second plate and a portion of said first, fourth and fifth plates forming a first region; said third plate and the remaining portions of said first, fourth and fifth plates forming a second region; means for ionizing within said first region a gas sample admitted to said envelope; means for producing a magnetic field across said structure, the magnetic lines of force being substantially perpendicular to said first and fourth plates; means for producing a static electrical field between said second and fifth plates and between said third and fifth plates whereby ions produced continually move from said first region through said second region; means for producing an oscillating electrical field across said second region transverse to the lines of force of said magnetic field and to the direction of movement of said moving ions whereby certain of such ions in resonance with the oscillating electrical field absorb a net amount of energy therefrom; and, means for sensing such resonant ions.

16. A mass spectrometer comprising: an evacuable envelope to which a gas sample can be admitted; a plurality of spaced electrodes disposed within said envelope arranged about an axis and defining a first and second region spaced from each other along said axis; means for ionizing within said first region a gas sample admitted to said envelope; means for producing a magnetic field transverse to said axis; means for producing static electrical fields between the electrodes defining said first region and between the electrodes defining said second region said fields being transverse to the lines of force of said magnetic field and the axis, whereby ions produced

in said first region are continually moved along the axis from said first region through said second region irrespective of their mass-to-charge ratio; means for producing an oscillating electrical field between electrodes defining said second region transverse to the lines of force of said magnetic field and the axis whereby certain of such ions in resonance with said oscillating electrical field absorb a net amount of energy therefrom; and means for sensing such resonant ions by measuring the energy absorbed thereby.

17. The spectrometer according to claim 16 including means for modulating at least one of said fields affecting the resonant conditions of the ions.

18. The spectrometer according to claim 16 including means for modulating the magnetic field within said first region.

19. The spectrometer according to claim 16 including a collector electrode spaced from and bounding the end of said second region for collecting ions which pass completely through said second region.

20. The spectrometer according to claim 16 including means for reversing the direction of said magnetic field and a collector electrode spaced from and bounding the end of said first region for collecting ions formed within said first region.

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