

March 5, 1957

H. W. WASHBURN ET AL

2,784,318

MASS SPECTROMETRY

Filed June 13, 1945

4 Sheets-Sheet 1

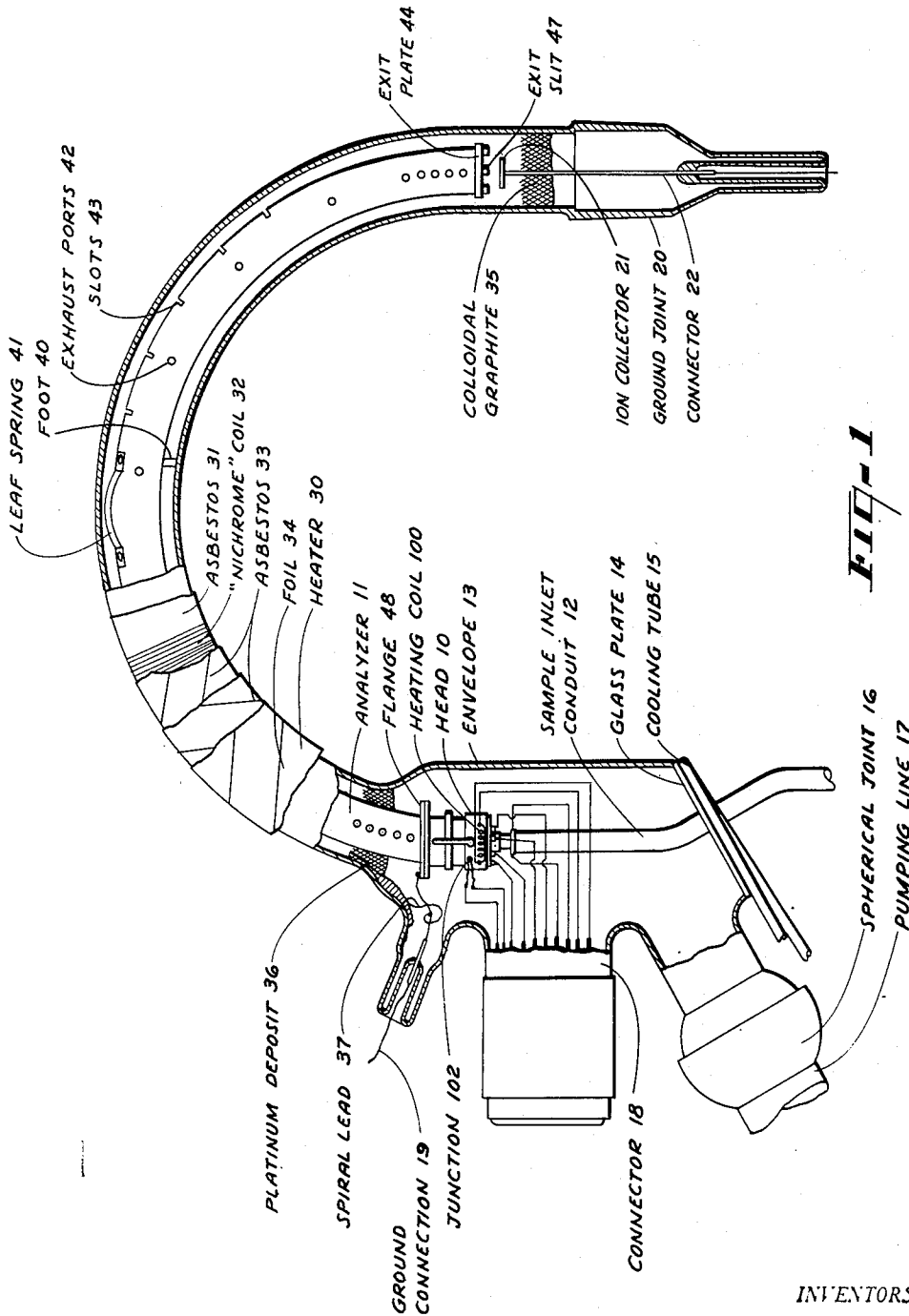


FIG. 1

INVENTORS
HAROLD W. WASHBURN
BY CLIFFORD E. BERRY
Christie and Angus
ATTORNEYS

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4 Sheets-Sheet 2

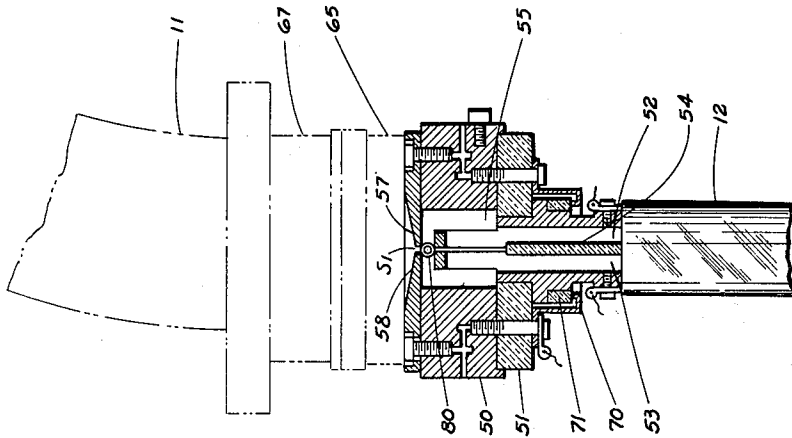


FIG. 2

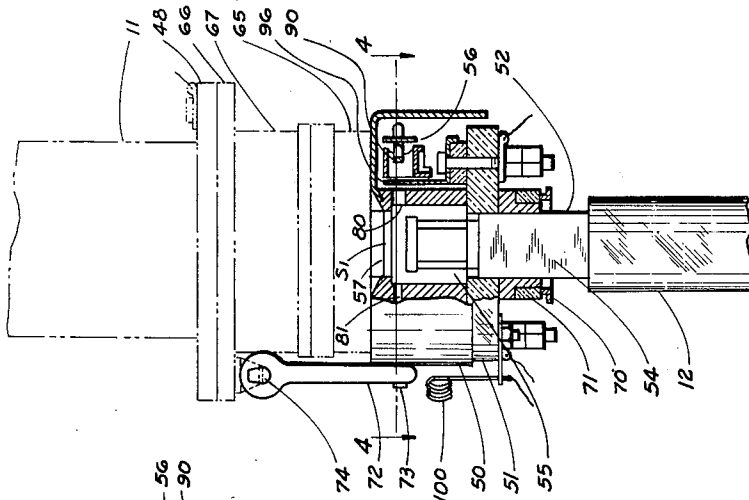


FIG. 3

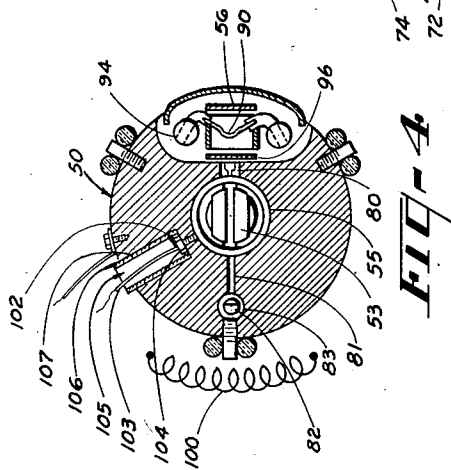


FIG. 4

INVENTORS
HAROLD W. WASHBURN
BY CLIFFORD E. BERRY

Christie and Angus
ATTORNEYS

2,784,318

4 Sheets-Sheet 3



INVENTORS
HAROLD W. WASHBURN
BY CLIFFORD E. BERRY
Christie and Angus
ATTORNEYS

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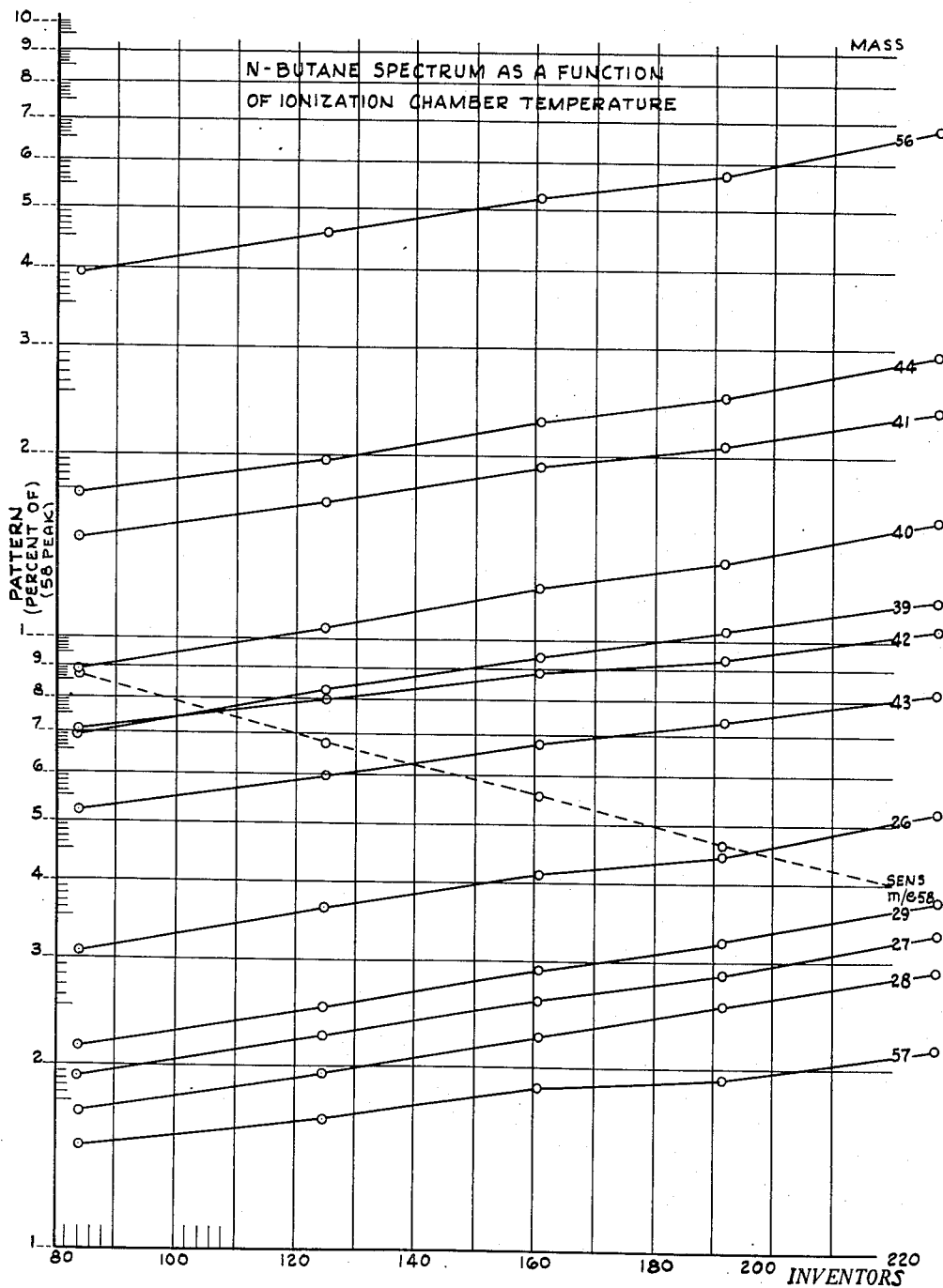


FIG. 7

HAROLD W. WASHBURN
BY CLIFFORD E. BERRY

Christie & Angus
ATTORNEYS

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2,784,318

MASS SPECTROMETRY

Harold W. Washburn and Clifford E. Berry, Pasadena, Calif., assignors, by mesne assignments, to Consolidated Electrodynamics Corporation, Pasadena, Calif., a corporation of California

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16 Claims. (Cl. 250—41.9)

This invention relates to mass spectrometry and is concerned particularly with the maintenance of uniform sensitivity in such an instrument.

A mass spectrometer is essentially an apparatus for forming ions from molecules and thereafter sorting them according to their mass-to-charge ratios, i. e. their specific masses. In the apparatus, molecules of a mixture (for example a mixture of gaseous petroleum hydrocarbons) are bombarded with ionizing particles such as electrons and thus converted into ions. The latter are propelled as a beam into an analyzer by means of an electrical potential impressed between spaced electrodes. In the analyzer the beam of unsorted ions is subjected to the influence of a magnetic or electric field and thus separated into a plurality of diverging beams of ions of a different specific mass, with the ions of each beam being of the same specific mass. By shifting the diverging beams relative to an ion collector, they are caused to impinge successively on the collector and are there discharged, the current obtained from each beam being an index of the amounts of the ions in that beam.

A known type of mass spectrometer comprises an ionization chamber maintained under a high vacuum, an electron source such as a heated filament which may be mounted in the chamber or in an adjacent space that communicates therewith, means such as electrodes for impressing a potential on the electrons and shooting them as a beam along a path in the chamber so as to strike the molecules and ionize them, a plurality of electrodes adapted to impress a potential on the ions thus formed and propel them as a beam into the analyzer, and an ion collector.

One of the principal difficulties encountered with the mass spectrometer resides in the fact that its calibration or sensitivity is likely to change during use with the result that unless the instrument is calibrated frequently by running known samples therein, the mass spectrum obtained from a given mixture may be very difficult to interpret.

As a result of our investigation, we have discovered that both the pattern of the spectrum obtained and the sensitivity of the spectrometer tend to vary with the temperature of the ionization chamber, and that a difference in temperature between surfaces on the interior of the ionization chamber tends to produce erratic results. Accordingly, in mass spectrometry involving the ionization of molecules in a chamber and the sorting of the resulting ions in a magnetic field, our invention contemplates the improvement which comprises heating the interior of the chamber during the ionization by conduction through the wall thereof. In this fashion, the source of heating is prevented from affecting the character of the sample by thermal cracking and the like, but at the same time, the conditions of operation in the ionization chamber are markedly stabilized. In our preferred practice of the invention, the temperature of the interior of the ionization chamber is maintained substantially constant (say with a variation of no more than a few tenths of a

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degree centigrade) during the ionization by supplying regulated amounts of heat to the interior of the ionization chamber by conduction through a wall thereof.

It is customary to produce the electrons which convert the molecules of the sample into ions by means of a heated filament. This heated filament may be disposed outside the ionization chamber, in which case an electron beam is directed into the ionization chamber through an aperture, or the filament may be located directly within the ionization chamber itself. In either case, we have discovered that the interior surfaces of the ionization chamber, i. e. the walls of the chamber itself and the surfaces of electrodes and insulators therein tend to become heated at different rates and also to different temperatures by the filament. Moreover, the temperature of the chamber is affected by changes in ambient temperature. The net result is that analyses performed with the instrument tend to be somewhat erratic. This difficulty however, can be cured substantially completely by employing an auxiliary heating element, for example a resistance coil located outside but adjacent the ionization chamber. The heating element should be so disposed and so energized that the heat which it supplies compensates for the variation in the temperature of the chamber as a whole and for the various surfaces within the chamber due to variations in the supply of heat from the filament which serves as an electron source. These and other features of my invention will be understood more thoroughly in the light of the following detailed description taken in conjunction with the accompanying drawings, of which:

Fig. 1 is a sketch of a mass spectrometer assembly including an ionization chamber assembly or head, an auxiliary heating means disposed adjacent the head in accordance with the invention, an analyzer and a collector all disposed within an envelope;

Figs. 2 and 3 are longitudinal sectional views of the head of Fig. 1, taken through the axis of the assembly and, respectively, perpendicular and parallel to a magnetic field impressed on the ionization chamber and analyzer tube by a magnet (not shown);

Fig. 4 is a section through the head of Figs. 2 and 3 taken along the line 4—4 of Fig. 3 of the apparatus;

Fig. 6 is a schematic wiring diagram showing the auxiliary heating coil adjacent the ionization chamber and a preferred form of temperature control for the ionization chamber; and

Fig. 7 is a graph showing the effect of ionization chamber temperature upon the spectrum of normal butane.

In the type of mass spectrometer herein described, the envelope and the elements which it encloses normally are mounted in a horizontal plane between the poles of an electromagnet (not shown).

Referring to Fig. 1, it will be seen that the instrument is provided with a head 10 which includes an ionization chamber connected at one end to a semi-circular analyzer tube 11 and at the other end to a glass conduit 12 through which the gas sample to be analyzed may be admitted. The head and analyzer tube are enclosed within a glass envelope 13. The head end of the envelope is enlarged and has a flat section 14 through which the gas introduction conduit passes. Conveniently, this flat section is a glass plate secured to the envelope with wax which is kept from melting during the operation of the spectrometer by a cooling fluid circulated through a copper tube 15 in contact with the glass plate near the wax joint.

The enlarged section of the envelope has three side branches. One of these is terminated in a spherical joint 16 adapted for connection to a pumping line 17. A second side branch is terminated by an electrical connector 18 having plug terminals for supplying various currents and voltages to elements in the ionization chamber. A

lead 19 which may be used as a ground connection is sealed in the third branch. The second and third branches are spaced considerably apart to assure the insulation of the ground lead from the plug terminals. These latter are operated at voltages which may be either positive or negative with respect to ground, but in either event may differ greatly from ground potential.

The collector or rear end of the envelope, i. e. the part remote from the enlarged section, has a tapered ground joint surface 20 on the outside. A metal disk 21 which acts as ion collector is mounted on a rod 22 coaxial with the ground joint and within the envelope. The rod extends through a glass seal at the end of the envelope and makes an electrical connection to the grid of an amplifying tube contained in an evacuated metal tube (not shown) which fits over the ground joint.

An envelope heater 30 is provided for heat treating, or baking out the envelope assembly. It covers the semi-circular portion of the envelope between the enlarged section and the ground joint, and comprises: a layer of asbestos 31; a coil of "Nichrome" wire 32 adapted to be heated by electric current; two layers of asbestos 33; and a layer of metal foil 34.

In order to provide against the accumulation of any electrical charges on the inside wall of the envelope, it is coated with a layer 35 of colloidal graphite which is maintained at ground potential through a platinum deposit 36 on the wall and a spiral lead 37 which is connected to the ground lead within the envelope.

The asbestos layers serve to insulate the coil from the foil and also to distribute the heat from the coil over the surface of the glass envelope. The foil aids in heating the assembly by reducing outward radiation of heat from the coil.

The analyzer tube is centered within the glass envelope with the aid of feet 40 extending outwardly from the walls of the analyzer tube and flexible curved leaf springs 41 secured to the outside of the analyzer tube. These centering springs are secured at one end rigidly to the analyzer tube and are held in axial alignment with the tube by means of screw heads at the other end which overlap slotted parts of the spring.

Small exhaust ports 42 are drilled into the analyzer tube at numerous points throughout its length at the front and back thereof.

Slots 43 are cut into the outside circumferential edge of the analyzer tube. Metal baffles (not shown) may be inserted into these slots to aid in the elimination of "ghosts" (which may arise because of the reflection of ion beams at the inner wall of the analyzer tube).

At the outlet end of the analyzer tube there is secured an aperture plate 44 having an exit slit 47 through which ions are projected from the analyzer tube onto the collector.

At the inlet end of the analyzer tube, there is a flange 48 to which the head 10 is secured by pivoted clamps.

The head including the ionization chamber is shown in considerable detail in Figs. 2, 3 and 4. It comprises a block 50 in the form of a thick-walled metal cylinder (preferably "Nichrome"), a quartz disk 51 secured to the inlet end of the block, a pair of metal pusher segments 52, 53 separated by a quartz insulator 54 and extending into the block bore 55 through the quartz disk, an electron gun 56 (Fig. 3) mounted on the quartz disk, a pair of jaws 57, 58 positioned at the outlet side of the block to define a first slit S_1 , a second pair of jaws (not shown) separated from the first pair of jaws by a Pyrex insulating ring 65 and defining a second slit (not shown), and a head-mounting flange 66 spaced from and electrically connected to the second pair of jaws by means of a copper spacer 67.

The pusher segments are secured to the block by means of a pusher clamp 70 (which covers a Pyrex pusher locking ring 71 surrounding the two pusher segments) secured to the block through the quartz disk. The block

and first pair of jaws, the Pyrex insulating ring, the second pair of jaws, the copper spacer, and the head mounting flange are held together by quartz links 72 each of which has an eye at one end (which is positioned over a link-stud screw 73 which extends outwardly from the side of the block wall) and at the other end a second eye perpendicular to the first eye. The second eye is secured to the head-mounting flange by means of spring link clips 74.

On one side of the block, there is a cut-away section in which the elements of the electron gun are mounted. Electrons from this source are projected through a slotted insert 80 in the wall of the block into the ionization chamber and thence through a coaxial bore 81 in the other side of the block onto an electron catcher 82 which is supported by the quartz disk and extends into a bore 83 drilled part way into the block perpendicular to the bore 81.

The block, the pusher segments, the central part of the quartz disk and the first pair of slit jaws form a substantially enclosed space that serves as an ionization chamber.

The entire assembly is so arranged that the adjacent but spaced edges of the pusher segments, the axis of the electron beam, the axes of slits between jaws, and the axis of the exit slit of the analyzer tube are all parallel to each other and to lines of force of the magnetic field in which the entire envelope assembly is to be placed.

The front faces of the pusher segments, i. e. the faces nearest the slit S_1 and parallel to the jaws 57, 58 are highly polished, as are the adjacent faces of the jaws 57, 58 and the parallel faces of the jaws which define the second slit. Conveniently, the two pusher segments and the jaws are made of alloys such as "Nichrome" containing substantial quantities of chromium. The polishing is conducted by hand with 0000 emery polishing paper or similar fine abrasive or the like until the surface acquires a mirror finish.

A filament 90 acts as an electron source in the gun. Electrons originating at the filament are projected through an apertured electron accelerating electrode 96 and through the gun barrel 80 into the ionization chamber.

Considered from an electrical standpoint, the block and first jaws represent a first ion accelerating electrode, and the jaws forming the second slit comprise a second ion accelerating electrode. The two pusher segments are pusher electrodes.

The voltages of the filament, the electron accelerating electrode, the block and the pusher electrodes may be controlled independently. In normal operation, when interested in the analysis of positive ions, these electrodes are all at high positive potentials with respect to the second ion accelerating electrode, which is at ground.

In the operation of the foregoing apparatus, a gas mixture, say a mixture of hydrocarbons is analyzed by introducing it at low pressure into the ionization chamber through the sample inlet conduit 12. Thus the gas enters the ionization chamber in the head 10 through a passageway between the two pusher segments 52, 53.

In the ionization chamber, the molecules of gas are bombarded by an electron beam originating at the filament of the electron gun and passing through the gun barrel 80. An electrical potential is impressed between the pusher electrode (i. e. the interior ends of the two pusher segments) and the jaws 57, 58 which define the slit S_1 . This potential pushes the ions through the slit S_1 as a heterogeneous ion beam. This beam is further accelerated by a potential impressed between the jaws defining the slit S_1 and the jaws defining the other slit. The two slits act as a collimator and the heterogeneous ion beam or ribbon is projected through the slits into the analyzer tube. In the analyzer tube the ions are acted upon by a magnetic field which separates them according to their specific masses into a plurality of curved

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homogeneous ion beams which diverge from each other and are focused at different points within the analyzer, for example on the exit plate. By varying the magnetic field the radii of the curving ion beams may be changed so that the beams are swept successively across the exit slit 47 of the instrument. In this fashion the several beams may be brought to focus successively on the ion collector and there discharged. The currents thus formed constitute the mass spectrum of the gas mixture and, if amplified and recorded, produce a mass spectrogram.

In a preferred form of my apparatus, means are provided for impressing a substantial potential, say at least about 1.8 volts, between the pusher electrodes and the first accelerating electrode containing the slit S_1 . At the same time the apparatus should be so arranged that the pusher potential is as high as possible without causing appreciable defocusing. It should not be less than $\frac{1}{2}\%$ of that impressed between the first and second accelerating electrodes. Optimum operation requires that the voltage between accelerating electrodes be 100 to 200 times the voltage between S_1 and the pusher electrodes.

In the operation of the above described apparatus, the temperature of the filament of the electron gun may vary considerably. As the filament ages, it may be necessary to change the filament current in order to obtain the same emissivity of electrons and in such case, the amount of heat given off by the electron gun varies and the effect thereof on the temperature of various surfaces within the ionization chamber will also vary. Thus the surfaces of the pusher electrodes may be considerably hotter or cooler than the interior surfaces of the block or of the jaws, since the pusher electrodes are separated from the block by a ring of insulating material with low heat-conductive properties. Moreover, since the filament is located eccentrically of the block, various portions of the interior block surface may also be at different temperatures. As indicated hereinbefore, we have discovered that it is desirable from the standpoint of uniformity of pattern and sensitivity that all interior surfaces in the electron chamber be at constant and preferably the same temperatures. In accordance with our invention, this result is obtained by means of a heating coil 100 (see Figs. 1, 3 and 4) located adjacent the block which encloses the ionization chamber opposite the cut-out portion in which the electron gun is mounted. The amount of energy supplied to this heating coil is regulated automatically in response to changes in the temperature of a thermo-couple 101 (see Fig. 6), one junction of which 102, is disposed in the block of the ionization chamber adjacent its interior surface (see Figs. 2 and 6). As shown in Fig. 6, the junction 102 of the thermo-couple is formed by a "Constantan" wire 103 welded to a "Nichrome" screw 104, threaded in to the interior of the block at the end of a horizontal bore hole 105. Since the block itself is of "Nichrome," the junction connection is completed by a "Nichrome" wire 106 fastened to the outside of the block. To prevent the "Constantan" wire 103 from coming in contact with "Nichrome," except at the desired junction, an insulator tube 107 lines the bore 105.

Fig. 6 illustrates a preferred null method for maintaining constant the temperature of the interior of the ionization chamber. The junction 102 of the "Constantan"- "Nichrome" thermo-couple 101 is matched by a second "Nichrome"- "Constantan" junction 103. This second junction is disposed in a closed null heating chamber 110 located outside the mass spectrometer assembly. The temperature of the null heating chamber is maintained constant by means of a contact-making thermometer 111 which makes and breaks a circuit through a power source 112 and a relay 113 which operates a switch 114 in closed circuit with a heating coil 115 (disposed within the null heating chamber) and a second power source 116. When the temperature in the null heating chamber drops below a predetermined point,

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the contact in the thermometer is opened. This causes switch 114 to close so that the heating coil 115 is energized by the power source 116 whereupon the null heating chamber is heated to the predetermined temperature.

The two junctions of the thermo-couple 101 are in effect opposed to each other through a galvanometer 117. When the temperatures in the null heating chamber and the ionization chamber are equal, nothing happens. However, any difference in temperature between the two junctions causes current to flow in the thermo-couple, with subsequent movement on the part of the galvanometer which is provided with a mirror 118. This mirror receives a beam of light from a source 119 and reflects it toward a photoelectric cell 120. A mask 121 is interposed in the path of the light ray from the mirror to the photoelectric cell so that the light ray only touches the photoelectric cell over a certain arc. The photoelectric cell is energized by means of a power source 122 in circuit with the photoelectric cell and a resistance 123. The input side of a triode amplifier 124 is connected across the photoelectric cell, through a bias battery 130. Current generated in the photoelectric cell when the light strikes it is amplified by the triode amplifier, which is energized by another power source 125 with the result that a relay 126 actuates a switch 127 that is connected to the heating coil 100 through a source of heating current 128. The major control of heating current for the coil 100 is accomplished by means of a variable resistance 129 which shunts the switch 127. Consequently, some current is supplied constantly to the heating coil and the automatic regulating mechanism just described varies the amount of current over a rather narrow range in order to compensate for minor changes in temperature within the ionization chamber.

It has been found that the null method employed to control the temperature of the interior of the ionization chamber is considerably more accurate and effective than efforts at direct control.

It will be observed that the heating coil 100 is so positioned with respect to the filament (which acts as an electron source and incidentally as a heater), that the temperature gradient set up between the various points on the interior surface of the ionization chamber is compensated. Thus the apparatus described not only maintains the temperature of the interior constant, but also in large part eliminates temperature gradient within the interior. Both of these factors are important from the standpoint of keeping the sensitivity and the calibration of the apparatus within close limits.

Referring now to Fig. 7, which is a plot of the spectrum of normal butane on a logarithmic scale against temperature on a linear scale, it will be observed that the variations of pattern coefficients and sensitivity are very nearly linear, i. e. a given temperature differential causes the same percent in a given pattern coefficient or sensitivity within the range investigated, extending up to 220° C. Sixteen other hydrocarbons were tested in the same way in a mass spectrometer equipped with a small auxiliary heater of the type described, and a "Constantan"- "Nichrome" thermo-couple also described hereinbefore. In general, all of the substances showed the linear characteristic illustrated in Fig. 7.

In the course of the investigations of the type described, the following observations were made:

1. In general, the heavier the molecule, the greater the dependence of both pattern and sensitivity upon temperature.

2. Iso-pentane and iso-butane show slightly greater slopes than the corresponding normal compounds.

3. Olefins and diolefins show considerably smaller slopes of pattern coefficients than do paraffins. The sensitivities of the spectrometer are affected about as much by temperature in the case of olefins and diolefins as in the case of paraffins.

We claim:

1. In mass spectrometry involving the ionization of molecules in a chamber by electron bombardment from an electron source in close proximity to the chamber with resulting unequal heating of interior surfaces of the chamber, the improvement which comprises compensating at least in part for such uneven temperature of the interior surfaces during the ionization by supplying heat to the otherwise cooler portions thereof by conduction from another source located outside the chamber.

2. In mass spectrometry involving the introduction of a stream of molecules into a chamber, the continuing ionization of the molecules therein, and the projection of a stream of the resulting ions from the chamber, the improvement which comprises maintaining the temperature of the interior of the chamber substantially constant during the ionization by supplying thereto regulated amounts of heat from a source out of contact with the molecules.

3. In a mass spectrometer, the combination which comprises an ionization chamber, means for admitting molecules to be ionized into the chamber, a heated source of electrons adjacent the chamber, a passage for admitting electrons thereinto for ionizing the molecules, a second source of heat located outside the chamber opposite the heated source of electrons and adapted to supply heat to the chamber by conduction through a wall thereof, a temperature measuring means located adjacent the interior of the chamber, and automatic means for varying the amount of heat supplied to the chamber from the second source in response to variations in the temperature measuring means.

4. In a mass spectrometer, the combination which comprises an ionization chamber, means for admitting molecules to be analyzed into the chamber, a heated source of electrons adjacent the chamber, a passageway for admitting electrons from the source into the chamber for ionizing the molecules, a source of heat located outside the chamber and adapted to supply heat thereto by conduction through a wall thereof, a second chamber remote from said ionization chamber, a thermocouple having one junction disposed adjacent the interior of said ionization chamber and one junction disposed in said second chamber, means for maintaining the interior of said second chamber at a constant predetermined temperature, and means operable responsive to current flow in said thermocouple to vary the heat supplied from said source to said ionization chamber.

5. Apparatus according to claim 4 wherein said means for maintaining the second chamber at a constant predetermined temperature comprises an electrically energized heater disposed in the chamber, a relay, a source of electrical energy connected to said heater through the relay, and a contact-making thermometer inserted in said chamber and connected to open and close said relay responsive to temperature variations in said chamber.

6. In a mass spectrometer, the combination which comprises an ionization chamber, means for admitting molecules to be analyzed into the chamber, a heated source of electrons adjacent the chamber, a passageway for admitting electrons from the source into the chamber for ionizing the molecules, an electrically energized source of heat located outside the chamber and adapted to supply heat thereto by conduction through a wall thereof, a source of electrical energy connected to said source of heat, a second chamber remote from said ionization chamber, a thermocouple having one junction disposed adjacent the interior of said ionization chamber and one junction disposed in said second chamber, means for maintaining the interior of said second chamber at a constant predetermined temperature, and means operable responsive to current flow in said thermocouple to vary the electrical energy supplied from said source of electrical energy to said source of heat.

7. In a mass spectrometer, the combination which comprises an ionization chamber, means for admitting molecules to be analyzed into the chamber, a heated source of electrons adjacent the chamber, a passageway for admitting electrons from the source into the chamber for ionizing the molecules, a heating coil located outside the chamber and adapted to supply heat thereto by conduction through a wall thereof, a source of electrical energy connected to said heating coil, a second chamber remote from said ionization chamber, a thermocouple having a first junction disposed adjacent the interior of said ionization chamber and a second junction disposed in said second chamber, a galvanometer connected in series between said first and second thermocouple junctions, means for maintaining the interior of said second chamber at a constant predetermined temperature, and means operable responsive to deflections of said galvanometer to vary the electrical energy supplied from said source to said heating coil.

8. In a mass spectrometer, the combination which comprises an ionization chamber, means for admitting molecules to be analyzed into the chamber, a heated source of electrons adjacent the chamber, a passageway for admitting electrons from the source into the chamber for ionizing the molecules, a heating coil located outside the chamber and adapted to supply heat thereto by conduction through a wall thereof, a source of electrical energy and an adjustable tap variable resistor connected in series circuit with said heating coil so that a tapped off portion of the source energy is supplied to said heating coil, a second chamber remote from said ionization chamber, a thermocouple having a first junction disposed adjacent the interior of said ionization chamber and a second junction disposed in said second chamber, a galvanometer connected in series between said first and second thermocouple junctions, means for maintaining the interior of said second chamber at a constant predetermined temperature, and means operable responsive to deflections of said galvanometer to connect said source of electrical energy directly across said heating coil.

9. Apparatus according to claim 8 wherein the means operable responsive to deflections of said galvanometer to connect said source of electrical energy directly across said heating coil comprises a light source, a photocell sensitive to light reflected by said galvanometer from the source to the photocell, an amplifier connected to amplify the output of the photocell, and a switch operable responsive to the amplifier output to short said series circuit across said variable resistor.

10. Apparatus for automatically controlling the temperature within a first chamber which comprises a source of heat located outside the chamber and adapted to supply heat thereto by conduction through a wall thereof, a second chamber remote from the object, a thermocouple having one junction disposed in the first chamber and one junction disposed in the second chamber, means for maintaining the interior of the second chamber at a constant predetermined temperature, and means operable responsive to current flow in the thermocouple to vary the heat supplied from the source.

11. Apparatus according to claim 10 wherein said means for maintaining the second chamber at a constant predetermined temperature comprises an electrically energized heater disposed in the chamber, a relay, a source of electrical energy connected to said heater through the relay, and a contact-making thermometer inserted in said chamber and connected to open and close said relay responsive to temperature variations in said chamber.

12. Apparatus for automatically controlling the temperature within a first chamber which comprises a heating coil located outside the chamber and adapted to supply heat thereto by conduction through a wall of the chamber, a source of electrical energy connected to the heating coil, a second chamber remote from the first chamber, a thermocouple having a first junction dis-

posed adjacent the interior of the first chamber and a second junction disposed in the second chamber, a galvanometer connected in series between the first and second thermocouple junctions, means for maintaining the interior of the second chamber at a constant predetermined temperature, and means operable responsive to deflections of the galvanometer to control the electrical energy supplied from the source to the heating coil.

13. Apparatus for automatically controlling the temperature within a first chamber which comprises a heating coil located outside the chamber and adapted to supply heat thereto by conduction through a wall of the chamber, a source of electrical energy and an adjustable tap variable resistor connected in series circuit with the heating coil so that a tapped off portion of the source energy is supplied to the heating coil, a second chamber remote from the first chamber, a thermocouple having a first junction disposed adjacent the interior of the first chamber and a second junction disposed in the second chamber, a galvanometer connected in series between the first and second thermocouple junctions, means for maintaining the interior of the second chamber at a constant predetermined temperature, and means operable responsive to deflections of the galvanometer to connect the source of electrical energy directly across the heating coil.

14. Apparatus according to claim 13 wherein the means operable responsive to deflections of the galvanometer to connect the source of electrical energy directly across the heating coil comprises a light source, a photocell sensitive to light reflected by the galvanometer, an amplifier connected to amplify the output of the

photocell, and a switch operable responsive to the amplifier output to short the series circuit across the variable resistor.

15. In a mass spectrometer, the combination which comprises an ionization chamber, means for admitting gas molecules into the chamber, a heated source of electrons proximate to the chamber and communicating therewith for bombarding and ionizing molecules in the chamber with a beam of electrons projected into the chamber from the source, and an auxiliary source of heat located outside the chamber for supplying heat to the coolest portions of the interior surface of the chamber by conduction through the chamber walls.

16. In a mass spectrometer, the combination comprising a chamber, means for admitting gas molecules into the chamber, means for projecting a stream of the resulting ions from the chamber, and means including a regulated source of heat located out of contact with the molecules for maintaining the temperature of the interior of the chamber substantially constant during the ionization.

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