

April 20, 1954

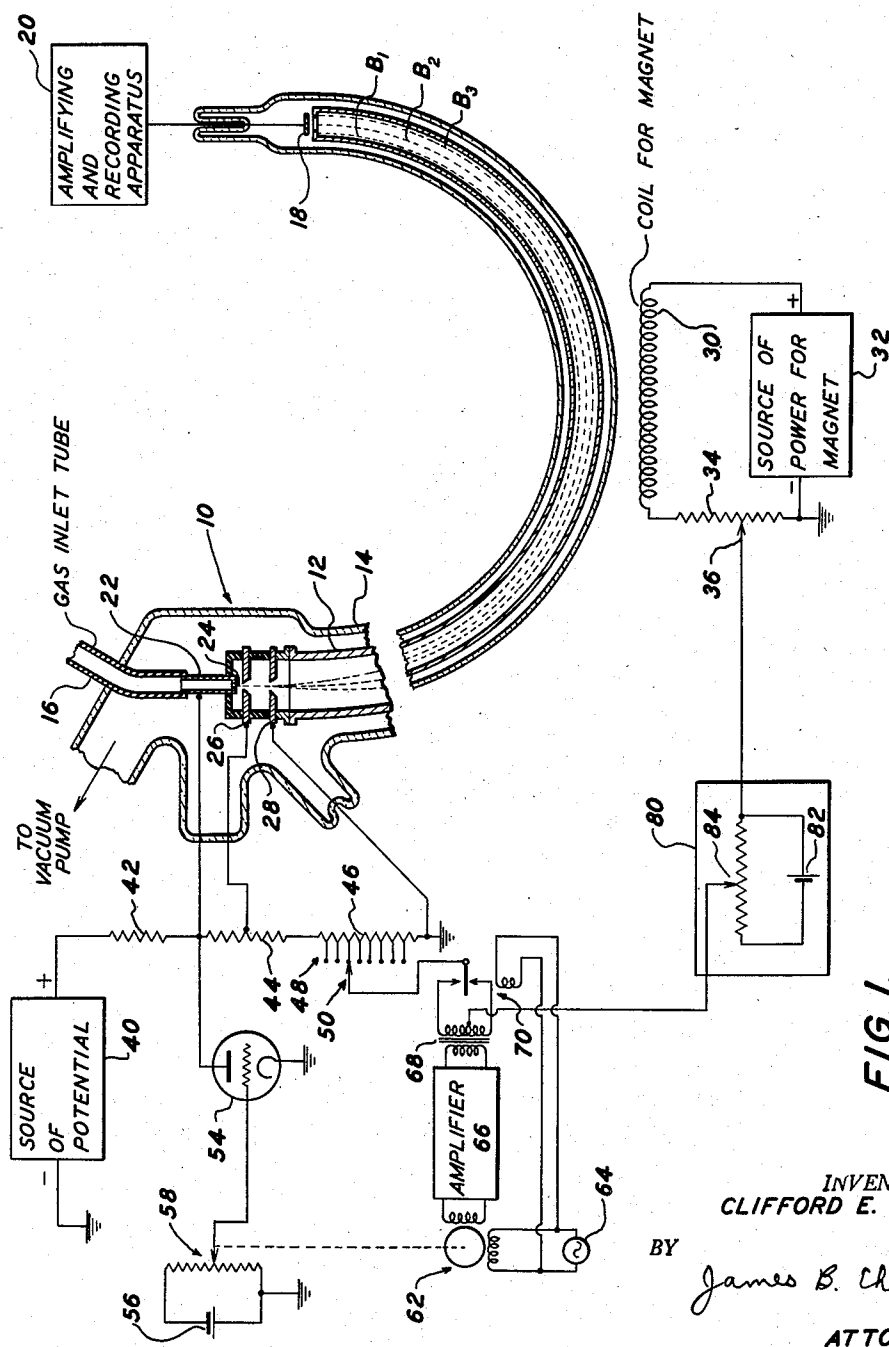
C. E. BERRY

2,676,264

AUTOMATIC CONTROL APPARATUS FOR MASS SPECTROMETERS

Filed Nov. 24, 1951

2 Sheets-Sheet 1



April 20, 1954

C. E. BERRY

2,676,264

AUTOMATIC CONTROL APPARATUS FOR MASS SPECTROMETERS

Filed Nov. 24, 1951

2 Sheets-Sheet 2

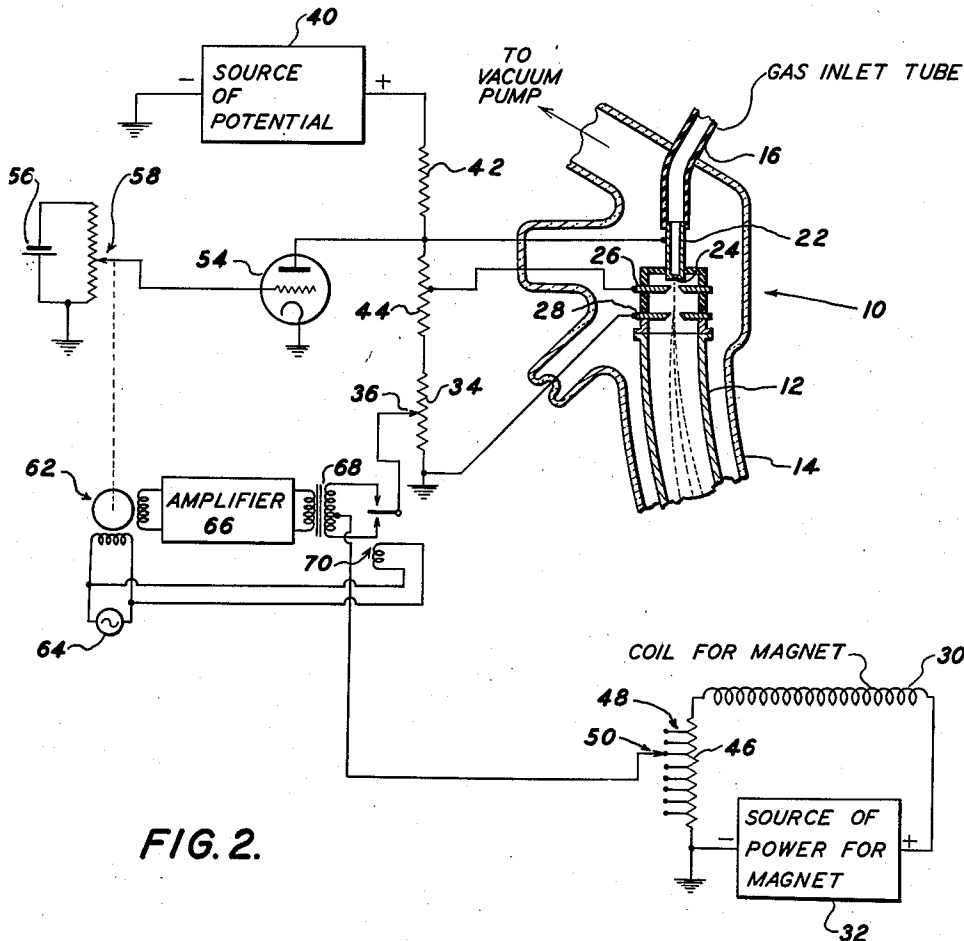


FIG. 2.

INVENTOR.
CLIFFORD E. BERRY

BY

James B. Christie

ATTORNEY

UNITED STATES PATENT OFFICE

2,676,264

AUTOMATIC CONTROL APPARATUS FOR
MASS SPECTROMETERSClifford E. Berry, Altadena, Calif., assignor to
Consolidated Engineering Corporation, Pasadena,
Calif., a corporation of California

Application November 24, 1951, Serial No. 258,004

9 Claims. (Cl. 250-41.9)

1

This invention relates to improved apparatus for automatically controlling the magnitude of the accelerating potentials for the ion source of a mass spectrometer.

A mass spectrometer is essentially an apparatus for producing ions and sorting them according to the ratio of their mass to their charge, i. e. according to their specific mass. In a typical mass spectrometer, a sample to be ionized, for example a gas mixture, is ionized in a chamber by electron bombardment, and the resulting ions are propelled by electrical potentials into an analyzer. The ions enter the analyzer as an unsorted beam, and in the analyzer they are sorted under the influence of an electro-magnetic field in accordance with their specific mass into a series of divergent, homogeneous ion beams. The sorted ions of the various ion beams are collected and discharged, the quantity of each kind of ions being measured by the amount of current that they discharge upon collection.

The mass spectrometer may be adjusted to selectively measure the quantity of ions of different specific mass by varying either the magnetic field or the accelerating potentials which are employed to propel the ions into the analyzer, but the latter method is preferred.

The accelerating potentials employed to propel the ions from the ion source into the analyzer are applied between a plurality of electrodes located in the ion source and adjacent to the analyzer.

The adjustment of the magnitude of the accelerating potentials may be made manually. However, when a mass spectrometer is employed to measure the quantity of numerous types of ions having different masses, it is preferable to provide means for automatically adjusting the magnitude of the accelerating potentials with respect to the flux density of the magnetic field so as to sort the ions of each specific mass to be measured.

The accelerating potentials required for measuring a predetermined series of different ions may be produced by providing a separate voltage divider for each type of ion to be measured, and the ion source may be switched from one voltage divider to another in order to measure the series of ions. However, when numerous types of ions, say 40, are to be selected, the power drain on the power supply becomes exorbitant when separate voltage dividers are employed. Also, variations in the resistance of the voltage dividers is a problem in such an arrangement because of the high currents required in some of the voltage dividers

2

in order to obtain the required accelerating potentials.

In accordance with a preferred embodiment of the present invention, a servo system is employed to cause a fractional part of the accelerating voltage to be maintained equal to a reference voltage which is derived either from the voltage or the current that is applied to the coil of the electromagnet which produces the magnetic field for the analyzer tube. The fractional part of the accelerating voltage which is employed determines the magnitude of the accelerating voltage and hence the mass of the ions which are measured by the mass spectrometer.

With this arrangement, the accelerating voltage is changed by changing the fractional part thereof which is compared with the reference voltage in the servo system, and a large number of different accelerating voltages may be produced without overloading the power supply which produces the reference voltages. Drifts due to varying the temperatures of the resistors are reduced by deriving the fractional parts of the accelerating voltage at low voltage and current levels.

In an alternative embodiment of the invention, the fractional part of the accelerating voltage which is applied to the servo system is fixed, and the accelerating voltage is changed by changing the magnitude of the reference voltage.

In both embodiments of the invention the accelerating voltage varies in accordance with the current or the voltage employed to produce the magnetic field, and hence the accelerating voltage is automatically adjusted so as to correct partially for changes in the magnetic flux density.

If desired, additional means may be employed to provide more complete correction of the magnitude of the accelerating voltage when the magnetic flux density changes.

The invention is explained with reference to the drawings, in which

Fig. 1 is a schematic diagram of a preferred embodiment of the invention; and

Fig. 2 is a schematic diagram of a modification of the apparatus shown in Fig. 1.

In Fig. 1, the apparatus for automatically adjusting the magnitude of the accelerating potentials is shown in conjunction with the essential components of one type of mass spectrometer. It will be apparent that the apparatus of the present invention is not limited to use in mass spectrometers of the type illustrated but that it may be employed in practically any type of mass spectrometer in which accelerating potentials

are employed to propel the ions into an analyzer.

An ion source 10 communicates with a conductive analyzer tube 12 which is enclosed within an envelope 14, through the wall of which a gas inlet tube 16 projects. A high degree of vacuum is maintained within the envelope by means of a vacuum pump (not shown) connected to the envelope.

The outlet end of the analyzer tube 12 is provided with a slot through which sorted ions are projected. An electrode 18 serves to collect the ions, and they are discharged through an amplifying and recording apparatus 20 which provides an indication of the quantity of the ions being measured.

The gas inlet tube 16 is composed of insulating material, and it communicates with an inlet electrode 22 in the form of a metallic tube which is partially closed at one end by a closure plate having a transverse slot 24 to accommodate an electron beam. The electron beam (not shown) may be produced and projected through the slot 24 in any suitable manner.

The molecules of a gas sample which are admitted into the ionization chamber through the inlet 16 are bombarded by the electron beam passing through the slot 24 and thus converted into ions. These ions are propelled as an unsorted beam into the analyzer tube 12 by electrical potentials established between the electrodes in the ion source 10, which potentials are produced by the electrical system which is attached to the electrodes.

A pair of electrodes 26 and 28 serve as accelerating and collimating electrodes for the ion source. The electrodes 26 and 28 have slots which are aligned with the slot 24 in the tube 22 so that the ions are propelled from the outlet 24 of the tube 22 into the analyzer tube 12 under the influence of the electrical potentials which are established between the tube 22 and the electrode 26, and between the electrodes 26 and 28.

The ions enter the analyzer tube 12 as a homogeneous, unsorted beam. In the analyzer tube 12, the unsorted beam is separated into a plurality of diverging homogeneous ion beams B₁, B₂, B₃ by means of a transverse magnetic field produced in the analyzer tube by an electromagnet.

The coil for the electromagnet is shown at 30. A source of power 32 is connected through a resistor 34 to the coil 30. An adjustable tap 36 is provided on the resistor for producing a reference voltage between the tap and ground having a magnitude which is proportional to the current which flows through the coil 30. Thus, the magnitude of the reference voltage varies with variations in the power supplied to the coil 30 and hence with variations in the density of the magnetic field which is applied to the analyzer tube 12.

The reference voltage produced at the tap 36 is compared in a servo system with a second reference voltage which is a fractional part of the accelerating voltage, and the servo system serves to control the accelerating voltage so that the magnitude of the fractional part thereof is maintained equal to the magnitude of the reference voltage produced at the tap 36.

A source of potential 40 having resistors 42, 44 and 46 connected in series across its output provides the accelerating voltages for the electrodes of the ion source 10. The tube 22 is connected to the junction between the resistors 42 and 44, the accelerating electrode 26 is connected to a tap on the resistor 44, and the accelerating electrode

28 is connected to the grounded terminal of the source of potential 40.

The accelerating voltage which is applied to the ion source 10 is developed across the resistors 44 and 46, and a plurality of taps 48 on the resistor 46 provide voltages between the taps and ground which are fractional parts of the accelerating voltage. The voltages produced at the taps 48 are selectively applied to the servo system by means of a switch 50.

The magnitude of the accelerating voltage which is produced across the resistors 44 and 46 is controlled by varying the voltage drop across the resistor 42. A triode vacuum tube 54 having its plate connected to the junction between the resistors 42 and 44 and having its cathode connected to ground serves to control the voltage drop across the resistor 42 by means of the current which the tube 54 draws through the resistor 42.

The magnitude of the current which the tube 54 draws is controlled by the voltage which is applied to the grid of the tube, which voltage is produced by a battery 56 and a potentiometer 58. The position of the adjustable tap on the potentiometer 58 is controlled by a servomotor 62. Thus, the tube 54 serves as a variable impedance connected in series with the resistor 42, and the magnitude of the impedance is controlled by the servomotor 62.

The motor 62 is a reversible, two-phase type having one of its windings connected to a source of alternating current power 64 and having its other winding connected to the output of an amplifier 66.

The secondary winding of a transformer 68 is connected to the input circuit of the amplifier. The primary winding of the transformer is connected to a chopper 70 which is energized by the source of alternating current power 64.

The selector arm of the switch 50 is connected to the armature of the chopper 70, and the adjustable tap 36 is connected to a center tap on the primary winding of the transformer 68.

A correction circuit 80 may be inserted in the lead between the tap 36 and the transformer 68 if desired. The circuit 80 is not essential and the operation of the apparatus will be discussed first as if the circuit 80 were omitted.

The direction of the flow of current in the primary winding of the transformer 68 is determined by the relative magnitudes of the reference voltage produced at the tap 36 and the fractional part of the accelerating voltage which is produced at the selector arm of the switch 50. Thus, the phase of the signal produced by the amplifier 66 with respect to the alternating voltage produced by the source 64 is determined by the relative magnitudes of the reference voltage and the fractional part of the accelerating voltage which are compared in the chopper.

The servo system serves to compare the relative magnitudes of the reference voltage and the fractional part of the accelerating voltage and to control the magnitude of the current which flows through the tube 54 so that the reference voltage and the fractional part of the accelerating voltage are maintained substantially equal. Hence, the magnitude of the accelerating voltage is determined by the setting of the switch 50 and it varies with variations in the reference voltage.

Since the magnitude of the accelerating voltage is proportional to the magnitude of the reference voltage, the magnitude of the accelerating

voltage is maintained constant even though the voltage produced by the source 40 drifts or fluctuates.

The ratio of the square of the density of the magnetic field to the magnitude of the accelerating voltage should be a constant for each setting of the switch 50. Since the magnitude of the accelerating voltage varies with variations in the magnitude of the reference voltage, and since the magnitude of the reference voltage is proportional to the density of the magnetic field produced by the coil 30 of the electromagnet, variations in the density of the magnetic field are partially corrected by a corresponding change in the ion accelerating voltage.

If the resistor 34 is non-linear so that its resistance is proportional to the current which flows through it, a complete correction is obtained, because the magnitude of the accelerating voltage is then maintained proportional to the square of the magnet current and hence is maintained proportional to the square of the density of the magnetic field.

The correction circuit 80 is an alternative arrangement for correcting for variations in the density of the magnetic field. A source of potential 82 is connected across a potentiometer 84, and the voltage developed across the potentiometer is applied in series to the circuit between the tap 36 and the center-tap on the primary winding of the transformer 68. Preferably, the magnitude of the voltage of the source 82 should be regulated so that it will not drift and introduce errors.

The voltage introduced to the circuit by the potentiometer 84 is adjusted to be equal to one-half the reference voltage developed by the resistor 34. Then a 1% change in the current through the resistor 34 causes a corresponding 2% change in the accelerating voltage produced across the resistors 44 and 46. To a first approximation, this is the same as keeping the ratio of the square of the density of the magnetic field to the accelerating voltage constant.

The locations of the taps 48 on the resistor 46 are determined by the magnitudes of the accelerating voltages which are required for the series of ions to be measured, and the magnitudes of the accelerating voltages are determined by specific masses of the ions to be measured.

The apparatus disclosed herein is particularly suitable for measuring the quantity of a large series of different types of ions (such as 40 types, for example) because a large number of taps 48 may be employed on the resistor 46 without causing excessive current drain on the source 40.

In operation, the gas to be analyzed is admitted through the inlet tube 16, and the switch 50 is set so as to contact one of the taps 48. Then the tap 36 is adjusted on the resistor 34 so that the recording apparatus 20 indicates a maximum for the type of ions which corresponds to that setting of the switch 50. Then the movable arm of the switch 50 may be connected to any of the taps 48, and the recording apparatus will indicate the quantity of the ions which correspond to the various settings of the switch 50.

With the taps 48 on the resistor 46 arranged to cause the appropriate accelerating voltages to be applied to the ion source 10, the quantities of a predetermined series of different ions may be recorded in the recording apparatus 20 merely by causing the movable arm of the switch 50 to contact the taps 48 in sequence.

If desired, the switch 50 may be a stepping

type which is actuated electrically, in which case the switch will cause the apparatus to select the series of ions in sequence and the quantity of each type of ion will be recorded during a predetermined interval of time.

It will be apparent that the reference voltage, which in Fig. 1 is produced by the magnet current which flows through the resistor 34, may be produced by a potentiometer connected across the source 32 of power for the magnet. With such an arrangement, the reference voltage varies with the magnet voltage and hence with the magnet current as before.

In the embodiment of the invention shown in Fig. 2, the locations of the resistors 34 and 46 are interchanged. This embodiment of the apparatus functions in essentially the same manner as the embodiment shown in Fig. 1.

I claim:

1. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions and also having an electromagnet for producing a magnetic field which acts upon the accelerated ions, the combination comprising adjustable means for providing an accelerating voltage for said electrodes, means for producing a first reference voltage having a predetermined magnitude, means for producing a second reference voltage having a magnitude which is a predetermined fraction of the accelerating voltage, and a servo system responsive to the first and second reference voltages for controlling said adjustable means and causing the relative magnitudes of the first and second reference voltages to be maintained in a predetermined relationship.

2. The apparatus of claim 1 in which one of the means for producing a reference voltage is provided with a switch for selectively causing the magnitude of the reference voltage to be one of a plurality of predetermined values.

3. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions and also having an electromagnet for producing a magnetic field which acts upon the accelerated ions, the combination comprising adjustable means for providing an accelerating voltage for said electrodes, means for producing a first reference voltage having a magnitude which varies with variations in the density of said magnetic field, means for producing a second reference voltage having a magnitude which is a predetermined fraction of the accelerating voltage, and a servo system responsive to the first and second reference voltages for controlling said adjustable means and causing the magnitude of the second reference voltage to be maintained in a fixed relationship with respect to the magnitude of the first reference voltage.

4. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions and also having means for producing a magnetic field which acts upon the accelerated ions, the combination comprising means for producing a first reference voltage having a magnitude which varies with variations in the flux density of said magnetic field, a source of potential coupled to the accelerating electrodes for providing an accelerating voltage, means for selectively producing a second reference voltage having a magnitude which is a predetermined fraction of the magnitude of the accelerating voltage, adjustable means coupled to the source of potential for varying the magnitude of the accelerating voltage, and a servo system responsive

to said first and second reference voltages for controlling said adjustable means and causing the magnitude of the second reference voltage to be maintained substantially equal to the magnitude of the first reference voltage.

5. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions and also having means for producing a magnetic field which acts upon the accelerated ions, the combination comprising means for producing a first reference voltage having a magnitude which varies with variations in the flux density of said magnetic field, a source of potential coupled to the accelerating electrodes for providing an accelerating voltage, means for producing a second reference voltage having a magnitude which is a predetermined fraction of the magnitude of the accelerating voltage, adjustable means coupled to the accelerating electrodes for varying the magnitude of the accelerating voltage, and a servo system responsive to said first and second reference voltages for controlling said adjustable means and causing the magnitude of the second reference voltage to have a predetermined relationship with respect to the magnitude of the first reference voltage.

6. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions and also having means for producing a magnetic field which acts upon the accelerated ions, the combination comprising means for producing a first reference voltage having a magnitude which varies in accordance with variations in the flux density of said magnetic field, a source of potential, a voltage divider coupled across the output of the source of potential and connected to the accelerating electrodes for providing an accelerating voltage, means for selectively producing second reference voltages having magnitudes which are predetermined fractions of the magnitude of the accelerating voltage produced by the voltage divider, adjustable means coupled to the voltage divider for varying the magnitude of the accelerating voltage, and a servo system responsive to said first and second reference voltages for controlling said adjustable means and causing the magnitudes of the two reference voltages to have a predetermined relationship.

7. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions and also having means for producing a magnetic field which acts upon the accelerated ions, the combination comprising control means for producing a first reference voltage having a magnitude which varies with the flux density of said magnetic field, a source of potential, first and second resistances connected in series across the output of the source of potential, means connecting the accelerating electrodes to the first resistance for providing an accelerating voltage

between the electrodes having a magnitude proportional to the voltage drop across the resistance, an adjustable impedance connected across the first resistance for varying the magnitude of the accelerating voltage, adjustable means coupled to the first resistance for selectively producing second reference voltages having magnitudes which are predetermined fractions of the magnitude of the accelerating voltage, and a servo system connected to said control means and to said adjustable means for controlling the impedance of the adjustable impedance and causing the magnitudes of the first and second voltages to have a fixed relationship.

8. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions, the combination comprising adjustable means for providing an accelerating voltage for said electrodes, means for producing a first reference voltage having a predetermined magnitude, means for producing a second reference voltage having a magnitude which is a predetermined fraction of the accelerating voltage, and means operable responsive to the algebraic sum of the first and second reference voltages for controlling the adjustable means and causing relative magnitudes of the first and second reference voltages to be maintained in a predetermined relationship.

9. In a mass spectrometer having an ion source including at least two electrodes for accelerating the ions and an electromagnet for producing a magnetic field which acts upon the accelerated ions, the combination comprising adjustable means for providing an accelerating voltage for the electrodes, means for producing a first reference voltage having a magnitude which varies with variations in the density of the magnetic field, means for producing a second reference voltage having a magnitude which is a predetermined fraction of the accelerating voltage, and means operable responsive to the algebraic sum of the first and second reference voltages for controlling the adjustable means and causing the magnitude of the second reference voltage to be maintained in a fixed relationship with respect to the magnitude of the first reference voltage.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
2,370,631	Berry	Mar. 6, 1945

OTHER REFERENCES

"A Mass Spectrometer for Isotope and Gas Analysis" by Alfred Nier, published in The Review of Scientific Instruments, vol. 18, No. 6, June 1947, pages 398-411.