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MASS SPECTROMETER:

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Fig. 1.

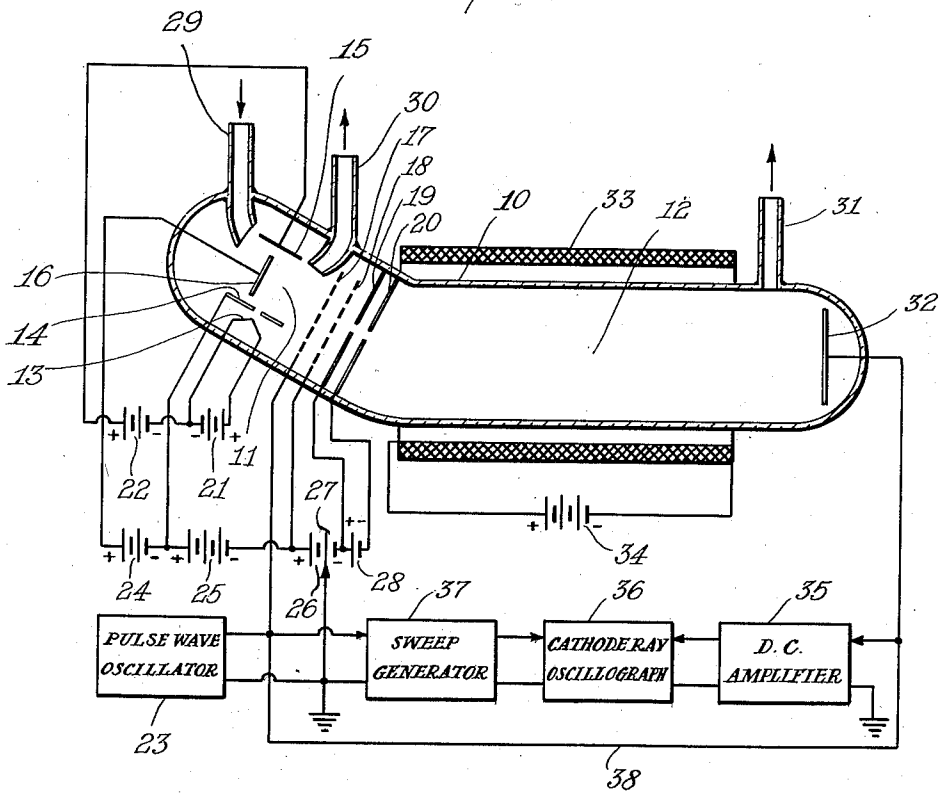
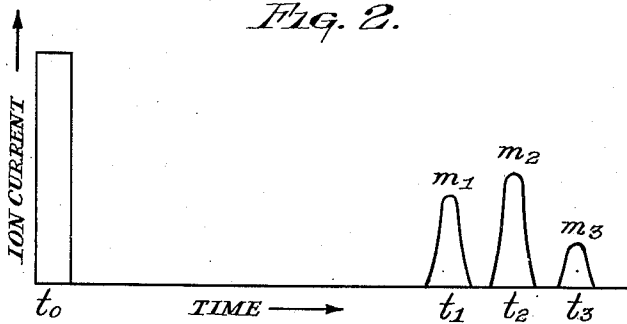


FIG. 2.



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MASS SPECTROMETER

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The invention relates to mass spectrometers of the type in which a composition of matter is analyzed by means of a mass-velocity electron discharge device.

Mass spectrometers utilizing an electron discharge tube for mass spectroscopy have been proposed. However, the prior spectrometers have not been widely used because of several important disadvantages among which is the great cost. More particularly, the heretofore proposed spectrometers require a strong magnetic field which must also be uniform over a large area, thereby necessitating an expensive and extremely bulky magnet which is difficult to construct. Furthermore, the envelope of the discharge tube embodied in the prior spectrometers is complicated in shape and difficult to manufacture. An important disadvantage of the prior spectrometers is their lack of compactness and portability.

It is an object of the invention to provide an electron discharge device for mass spectrometers which is inexpensive, simple to manufacture, compact and portable.

It is a further object of the invention to provide a novel and improved mass spectrometer which permits continuous and accurate spectroscopic analysis.

These and other objects of the invention will appear as the specification progresses.

According to the invention, these objectives are achieved by a novel mass spectrometer in which positive ions of a gas to be analyzed are subjected to an accelerating and a magnetic field, whereby the constituent ions are separated into spaced groups the relative positions of which are determined by the respective mass-velocity constants of the ions. The so-spaced groups of positive ions are made to impinge on a collector electrode, and the spacing respective of the groups and the quantity of ions in each group are indicated by means of a suitable visual indicating or recording instrument.

The invention will be described in greater detail with reference to the accompanying drawing forming a part of the specification and in which:

Fig. 1 is a schematic diagram of a mass spectrometer in accordance with the invention.

Fig. 2 is an idealized oscillogram obtained by means of the apparatus shown in Fig. 1.

Referring to Fig. 1, the device shown comprises an envelope 10, which may be of almost any configuration but which, preferably, is of tubular form, bent near one end to form an ion gun portion 11 and an ion trajectory portion 12.

The ion gun portion 11 comprises a filament

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13, a beam forming apertured electrode 14, and an anode 15, which elements produce a narrow beam of electrons traversing the tube normally to the axis of said gun portion of the envelope.

An impeller electrode 16 is mounted in a plane parallel to the electron beam and normal to the axis of the envelope. On the opposite side of the electron beam and in succession along said axis there are provided grid electrodes 17 and 18 and accelerating electrodes 19 and 20. Accelerating electrodes 19 and 20 have centrally located apertures by means of which, in conjunction with the impeller 16, a narrow beam of ions is injected into the ion trajectory portion 12 at an angle to the axis of said trajectory portion.

The filament 13 is heated by means of a battery 21 and the anode 15 is positively charged by means of battery 22. Grid 17 is coupled to a pulse wave generator 23 as later to be more fully explained and biased by means of the potential appearing across battery 26. The electrodes 14, 16, 18, 19 and 20 are given suitable operating potentials as shown by the batteries 24, 25, 26, 27 and 28. The gas to be analyzed is circulated through the gun portion 11, through an inlet passage 29 and an exhaust passage 30. An additional exhaust port 31 is preferably placed at the end of trajectory portion 12 to evacuate this portion.

At the end of the trajectory portion 12 remote from the gun portion 11, there is provided a collector electrode 32. The portion 12 is enclosed in a solenoid 33 energized by battery 34 to provide an axial magnetic field through the said portion.

The collector 32 is coupled to the input of a D. C. amplifier 35, the output of which is coupled to the vertical deflection plates of a cathode ray oscillograph 36. The horizontal deflection plates of oscillograph 36 are coupled to a sweep generator 37, which generator is coupled to the output of oscillator 23.

The operation of the device of the invention is as follows:

A sample of the matter to be analyzed is introduced in the form of a gas into the gun portion 11 through the inlet 29 and ionized by the electron beam from the cathode 13. The resulting positive ions are propelled by the positively charged impeller 16 toward the ion gate formed by the grids 17 and 18. By means of a varying voltage, preferably a pulse voltage, on the order of one microsecond, derived from the pulse wave oscillator 23, the positive ions are propelled into the portion 12 in the form of intermittent blocks of ions. Since the ions have equal kinetic energy and different velocities depending on their respec-

tive masses, different ions of each block will separate into a plurality of spaced groups, the relative spacing of which at any given point in the trajectory of the ion beam are determined by the velocities of the ions. The longitudinal magnetic field produced by coil 33 is given such a value that the ions which enter at an angle to the axis of the magnetic field assume a multi-turn helical path and impinge on the collector 32. The helical path thus provided is many times longer than the distance between the electrodes 20 and 32, and thereby assumes a trajectory sufficiently long to produce well defined space groups.

Since the magnetic field exerts its influence only at right angles to the axis of the field which is coincident with the axis of the portion 12, it is evident that minor variations of field strength will not affect the transit time of the ions along the axis of the portion 12.

In accordance with one form of the invention, the desired mass-velocity separation of the ions into individual spaced groups is realized by means of a tube 10 in which the portion 12 is 30 cm. long, the incident ion beam makes an angle of 20° with the axis of the magnetic field and the field has a strength of the order of 1000 gauss.

The current produced by the ions impinging on the collector electrode 32 is indicated by means of the oscillograph 36 through the intermediary of an amplifier 35. By synchronizing the oscillograph with the action occurring in the tube 10 a pattern is formed showing the quantities and distributions of the ions constituting the substance being analyzed. A point for establishing the absolute position of the pattern is attained by coupling the oscillator 23 to the amplifier 35, for example through the connection 38. Such a pattern is shown in Fig. 2, wherein the highly positive one microsecond pulse serving as a reference point is shown at t_0 , and pulses m_1 , m_2 , and m_3 corresponding to different ions constituting the substance being analyzed are shown at t_1 , t_2 and t_3 corresponding to the respective transit times and hence the velocities, of the ions. The areas of the pulses m_1 , m_2 and m_3 are a measure of the quantity of the ions in each group. Since the ions are repeatedly pulsed through the electrode 20 a stationary pattern of their distribution at the collector 32 is obtained on the oscillograph 36 and the time distribution and the quantity of the ions may be readily measured on the face of the oscillograph. As an alternate procedure, if one of the constituents has been determined by other means, as is often the case, the remainder of the constituents can be identified by measuring the difference in arrival times of the masses as indicated on the face of the oscillograph.

It is to be understood that the invention is not limited to the specific embodiment herein described, but that various modifications may be made without departing from the spirit and scope of the invention.

I claim:

1. A method of analyzing a composition of matter in gaseous form comprising the steps of ionizing the gas, forming a block of ions of the gas, trajecting said block of ions along a given course, separating said block of ions during the transit thereof through said course into a plurality of ion groups having a time spacing proportional to the masses of the individual ions of the gas, collecting said spaced groups of ions in succession and measuring the spacing of said spaced groups of ions.

2. Apparatus for analyzing a composition of matter in gaseous form comprising means to ionize the gas, means to form a block of the ions of the gas, electrical means to traject said block of ions along a given course, magnetic means to impart an equal force to the ions of all masses whereby the velocity of the ions shall depend upon their individual masses to separate said block of ions during the transit thereof through said course into a plurality of ion groups having a time spacing proportional to the masses of the individual ions of the gas, means to collect said spaced groups of ions in succession and means to measure the spacing of said spaced groups.

3. Apparatus for analyzing composition of matter in gaseous form comprising means to ionize the gas, means to form a block of ions of the gas, means to traject said block of ions in a given direction, means to produce a magnetic field having lines of force at an acute angle to said given direction to thereby impart a helical path to said ions, means to impart an equal electrostatic force to the ions of all masses to separate the block of ions into a plurality of groups having time spacing relative to each other proportional to the masses of the individual ions of the gas, means to collect said spaced groups of ions in succession, and means to measure the spacing of said spaced groups.

4. Apparatus for analyzing a composition of matter in gaseous form comprising means to ionize the gas, means to form a block of the ions of said gas comprising an accelerating electrode for the ions and a source of variable amplitude potential coupled to said electrode, means to traject said block of ions in a given direction, means to produce a magnetic field having lines of force at an acute angle to said direction to thereby impart a helical path to said blocks of ions, means to impart an equal electrostatic force to the ions of all masses to separate the block of ions into a plurality of ion groups having time spacing relative to each other proportional to the masses of the individual ions of the gas, means to collect said spaced group of ions in succession, and means to measure the spacing of said spaced group.

5. Apparatus for analyzing a composition of matter in gaseous form comprising electron beam bombarding means for ionizing the gas comprising a cathode, an apertured electrode and an anode, means to accelerate the ions in a given direction comprising an impeller electrode arranged adjacent to one side of said electrode beam and an accelerating electrode arranged on another side of said beam, means to form a block of the ions of the gas comprising a grid electrode interposed between said impeller electrode and said accelerating electrode and a source of variable amplitude potential coupled to said grid electrode, means to produce a magnetic field having lines of force at an acute angle to said given direction to thereby impart a helical path to said block of ions, said grid electrode imparting an equal electrostatic force to the ions of all masses to separate the block of ions into a plurality of ion groups having a time spacing relative to each other inversely proportional to the masses of the individual ions of the gas, an electrode arranged at the ends of said helical path for collecting said spaced ions in succession, and means comprising a cathode ray oscillograph having means incorporated therein to provide

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a time reference with which to measure the relative spacing of said ion groups.

6. Apparatus for analyzing a composition of matter in gaseous form comprising means to ionize the gas, means to form a block of the ions of said gas comprising an accelerating electrode for the ions and a pulse wave oscillator coupled to said electrode, means to traject said block of ions in a given direction, means to produce a magnetic field having lines of force at an acute angle to said direction to thereby impart a helical path to said blocks of ions means to apply an equal electrostatic force to the ions of all masses to separate the block of ions into a plurality of ion groups having time spacing relative to each other proportional to the masses of the individual ions of the gas, means to collect said spaced group of ions in succession, and means to measure the spacing of said spaced groups.

7. Apparatus for analyzing a composition of matter in gaseous form comprising means to ionize the gas, means to form a block of the ions of said gas comprising an accelerating electrode for the ions and a pulse wave oscillator coupled to said electrode, means to traject said block of ions in a given direction, means to produce a magnetic field having lines of force at an acute angle to said direction to thereby impart a helical path to said blocks of ions means to apply an equal electrostatic force to ions of all masses to separate the block of ions into a plurality of ion groups having time spacing relative to each other proportional to the masses of the individual ions of the gas, means to collect said spaced group of ions in succession, means to measure the time spacing of said spaced groups, said means comprising a cathode ray oscillograph having a first cathode ray beam deflecting means and a second cathode ray beam deflecting means normally disposed to said first deflection means, said first deflection means being coupled to said collector means to indicate the ion current thereof and said second deflection means being coupled to the output of a sweep generator to provide a time base, and means to synchronize the output of said sweep generator with the output of said pulse wave oscillator.

8. Apparatus for analyzing a composition of matter in gaseous form comprising an electron discharge device comprising a tubular envelope having means to exhaust the interior of said envelope, inlet means for the gas, electron beam bombarding means for ionizing the gas comprising a cathode, an apertured electrode and an anode, means to accelerate the ions in a given direction comprising an impeller electrode arranged adjacent to one side of said electrode beam and an accelerating electrode arranged on another side of said beam, means to form a block of ions of gas comprising a grid electrode interposed between said impeller electrode and said electrode and a pulse wave oscillator coupled to said grid electrode, means comprising a solenoid surrounding a portion of said envelope to produce a magnetic field having lines of force at an acute angle to said given direction to thereby impart a helical path to said block of ions, said grid electrode separating the block of ions into a plurality of ion groups having a time spacing relative to each other inversely proportional to the masses of the individual ions of the gas, an electrode arranged at the ends of said helical path for collecting said spaced ions in succession, means comprising a direct current amplifier

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coupled to said collector means to amplify the ion current thereof, means comprising a cathode ray oscillograph having a first cathode ray beam deflecting means and a second cathode ray beam deflecting means normally disposed to said first deflection means, said first deflection means being coupled to the output of said amplifier to indicate the ion current of said collector means and being coupled to said pulse wave oscillator to provide a time reference with which to measure the spacing of said ion groups and said second deflection means being coupled to the output of a sweep generator to provide a time base, and means to synchronize the output of said sweep generator with the output of said pulse wave oscillator.

9. A method of analyzing a composition of matter in gaseous form comprising the steps of ionizing the gas, forming a block of ions of the gas, trajecting said block of ions along a given course, separating said block of ions during the transit thereof through said course into a plurality of ion groups having a time spacing proportional to the masses of the individual ions of the gas, collecting said spaced groups of ions in succession and measuring the spacing and magnitudes of said spaced groups of ions.

10. A mass spectrometer comprising an envelope, means for maintaining low pressure within said envelope, an inlet port for the admission of a gas sample to said envelope, means for ionizing said gas sample, means for generating an ion beam consisting of discrete pulses of ions, each of said discrete pulses of ions comprising ions representative of the composition of the said gas sample, voltage potential means for accelerating said ion beam whereby each of the ions of the said discrete pulses attains a velocity proportional to its specific mass, collecting means positioned in said ion beam for detecting the electrical charges of the ions, and indicating means associated with said collecting means and synchronized with the said means for generating an ion beam of discrete pulses of ions to indicate the electrical charges as a function of time.

11. In a mass spectrometer, means for ionizing a gas sample whereby heterogeneous ions are obtained representative of the composition of the said gas sample, means for generating a beam of ions consisting of discrete pulses of ions, each of said pulses being composed of heterogeneous ions representative of the composition of the said gas sample, means for accelerating said beam of ions whereby ions of the said discrete pulses attain velocities proportional to their specific mass, and indicating means positioned in said ion beam for indicating the electrical charges of the ions.

12. In a method of mass spectrometry, the improvements which comprise the step of forming a beam of discrete ion pulses, each of said ion pulses consisting of heterogeneous ions representative of the total ion composition, the step of imparting a velocity to each ion of each of the said discrete pulses which velocity is a function of the specific mass of the ion, and the step of maintaining each of said ions at the said velocity for a period of time whereby ions in each pulse are segregated according to their specific mass.

13. The method of mass spectroscopy comprising intermittently and recurrently accelerating ions to be analyzed according to their respective atomic weights, collecting said accelerated ions at successive time intervals determined by their

atomic weights, and indicating the relative quantities of said collected ions and the successive ion travel time intervals for determining the relative proportions and atomic weights of the ions of said gas.

14. The method of mass spectroscopy comprising ionizing a gas to be analyzed, intermittently and recurrently pulse accelerating said ions as a function of their respective atomic weights, separating said accelerated ions according to their velocities, collecting said separated ions at successive time intervals determined by their atomic weights, and indicating the relative quantities of said collected ions and the successive ion travel time intervals for determining the relative proportions and atomic weights of the ions of said gas.

15. A mass spectrometer including, in combination, a source of ions of a material to be analyzed, means for intermittently and recurrently accelerating said ions as a function of their respective atomic weights, means for collecting at least some of said accelerated ions at successive time intervals determined by their relative velocities, means for indicating the relative travel times of said collected ions to indicate the atomic weights of said collected ions, and means for indicating the relative numbers of said collected ions at said successive time intervals.

16. A mass spectrometer including, in combination, a source of ions of a material to be analyzed, means for intermittently and recurrently accelerating said ions as a function of their respective atomic weights, means for collecting at least some of said accelerated ions at successive time intervals determined by their relative accelerations, said intermittent acceleration intervals being short with respect to the sum of said successive time intervals, means for indicating the relative travel times of said collected ions to indicate the atomic weights of said collected ions, and means for indicating the relative numbers of said collected ions at said successive time intervals.

17. A mass spectrometer including, in combination, an envelope containing a source of ions of a material to be analyzed, an electrode spaced from said source forming therebetween an ion accelerating space, a source of short duration intermittently recurring voltage pulses, means for applying said pulses to said electrode for intermittently and recurrently accelerating said ions as a function of their respective atomic weights, ionic target means spaced from said accelerating space for collecting at least some of said accelerated ions at successive time intervals determined by their relative accelerations, means responsive to ions collected by said target means for indicating the relative travel times of said col-

lected ions to indicate the atomic weights of said collected ions, and means for indicating the relative numbers of said collected ions at said successive time intervals.

18. A mass spectrometer including, in combination, an envelope containing a source of ions of a material to be analyzed, an electrode spaced from said source forming therebetween an ion accelerating space, a source of short duration intermittently recurring voltage pulses, means for applying said pulses to said electrode for intermittently and recurrently accelerating said ions as a function of their respective atomic weights, ionic target means spaced from said accelerating space for collecting at least some of said accelerated ions at successive time intervals determined by their relative velocities, means responsive to ions collected by said target means for generating voltages characteristic of the quantities of said collected ions, an oscilloscope having at least two independent deflecting elements, a timing signal generator connected to one of said elements, means for applying said generated voltages to the other of said elements for indicating the relative travel times of said collected ions to indicate the atomic weights of said collected ions, and calibration means for indicating the relative numbers of said collected ions at said successive time intervals.

19. The method of ion mass spectroscopy comprising differently accelerating in sharply defined intermittent bursts the ions to be analyzed and indicating the relative abundance and travel times of said accelerated ions.

20. In mass spectrometry involving the formation of ions and the separation thereof, the improvement which comprises causing ions to travel in the direction of a target and to impinge thereon as spatially separated pulses and measuring only those pulses of a given mass-to-charge ratio.

21. In mass spectrometry involving the formation of ions and the separation thereof, the improvement which comprises causing the ions to travel in the direction of a target as spatially separated pulses responsive to a high frequency pulsating current impressed on accelerating electrodes located in the field of ionization and measuring only those pulses of a given mass-to-charge ratio.

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