

June 16, 1953

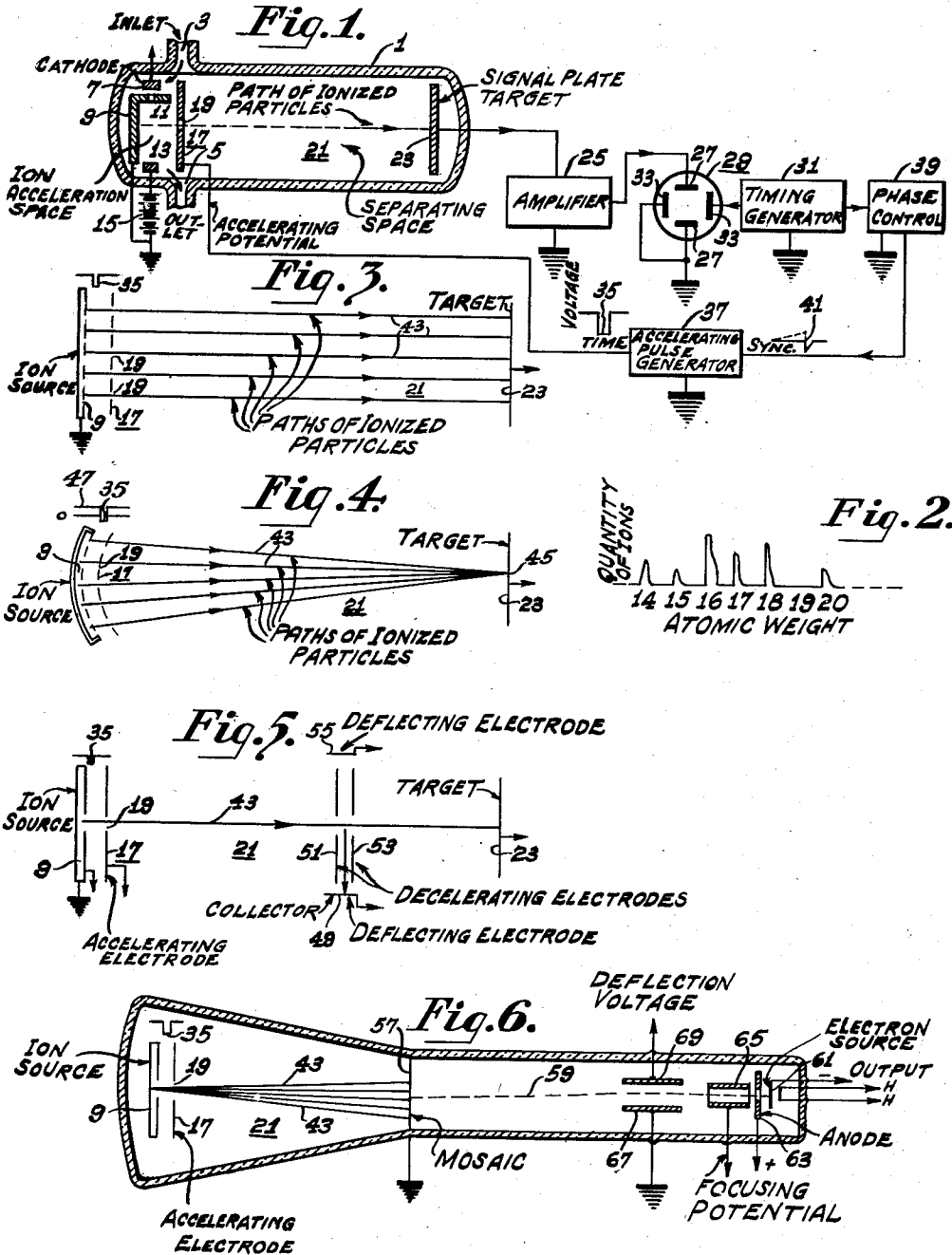
A. C. SCHROEDER

2,642,535

MASS SPECTROMETER

Filed Oct. 18, 1946

4 Sheets-Sheet 1



INVENTOR
 Alfred C. Schroeder
 BY
 C. D. Huska
 ATTORNEY

June 16, 1953

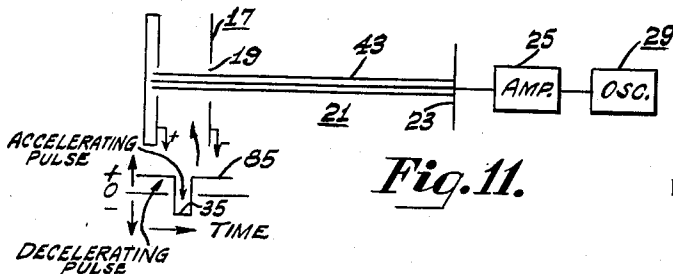
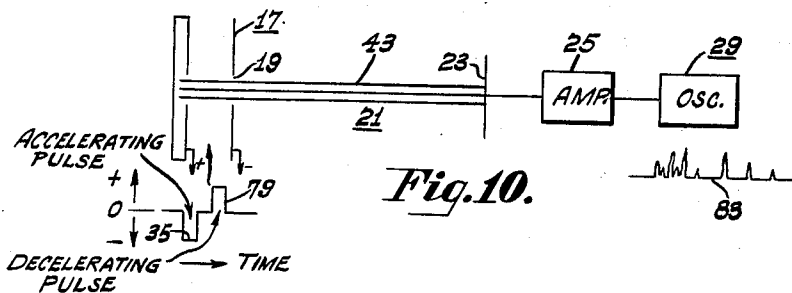
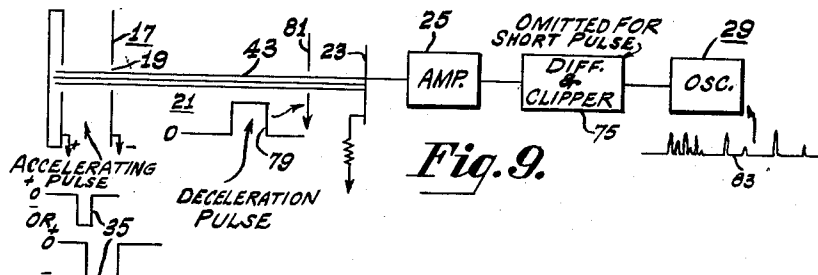
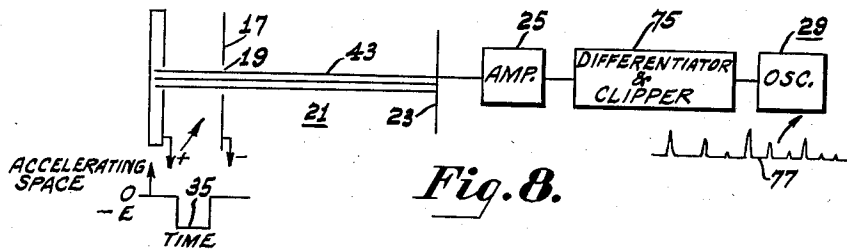
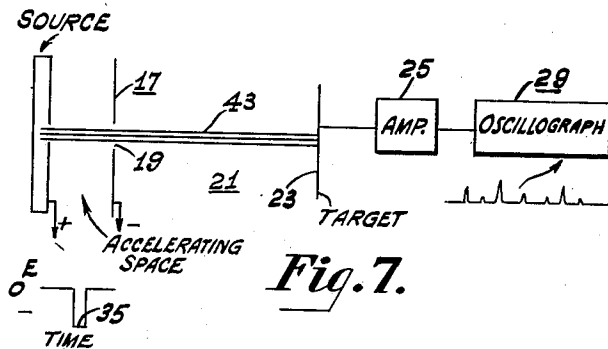
A. C. SCHROEDER

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4 Sheets-Sheet 2



INVENTOR
Alfred C. Schroeder
BY
C. D. Huska
ATTORNEY

June 16, 1953

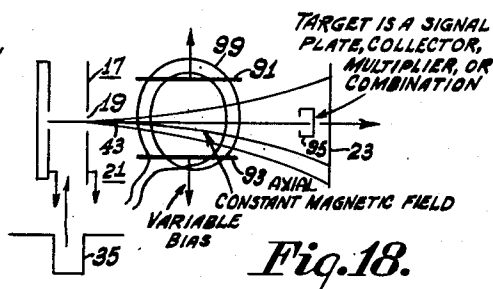
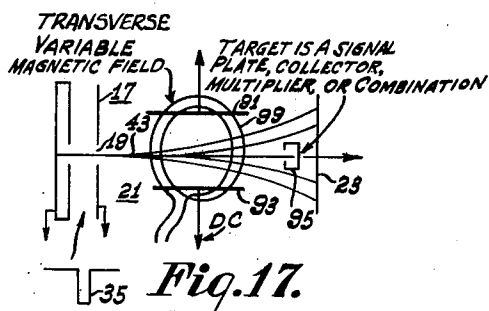
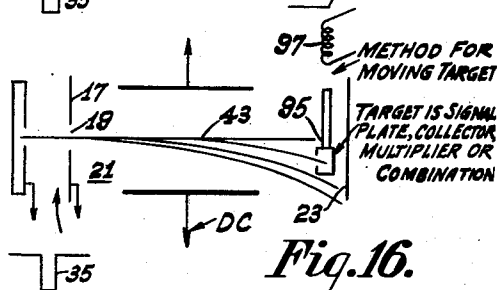
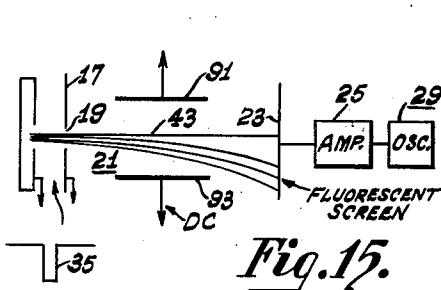
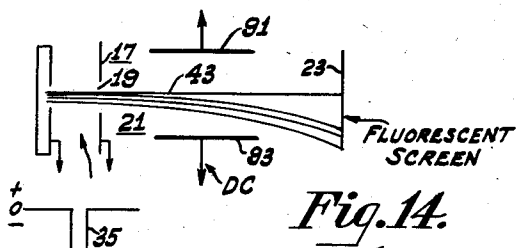
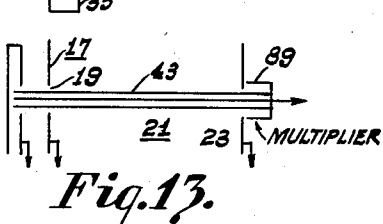
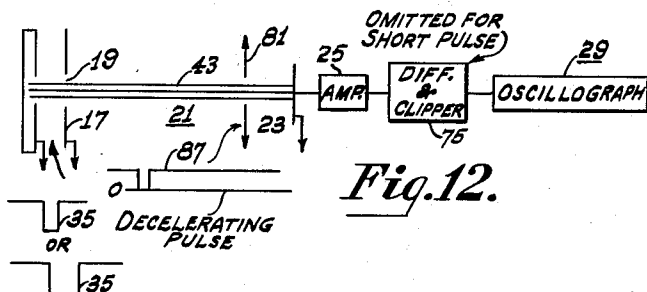
A. C. SCHROEDER

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MASS SPECTROMETER

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4 Sheets-Sheet 3



INVENTOR
 Alfred C. Schroeder
 BY *CO Huska*
 ATTORNEY

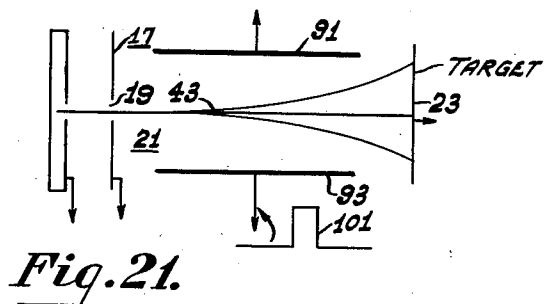
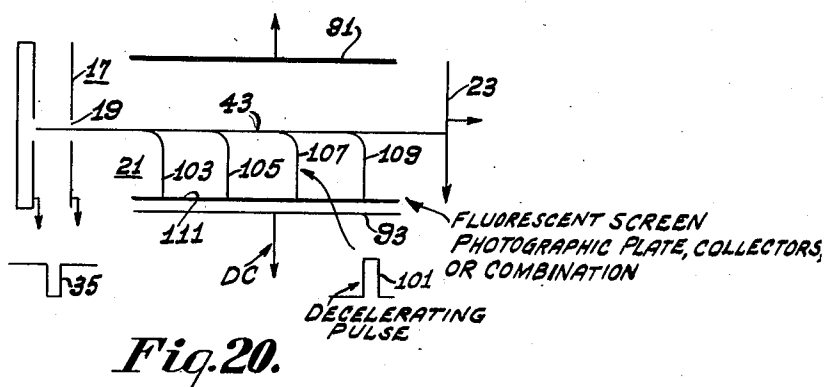
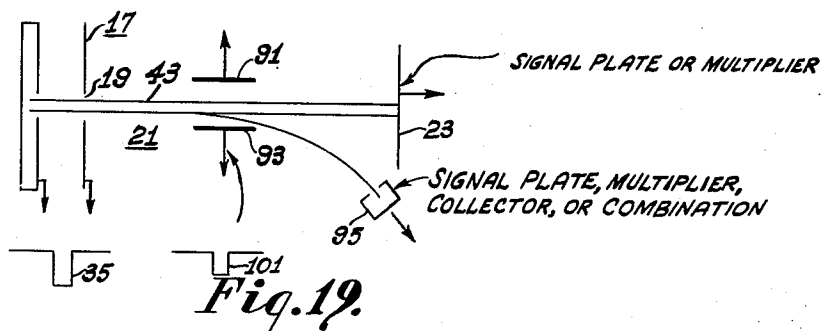
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A. C. SCHROEDER
MASS SPECTROMETER

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4 Sheets-Sheet 4



INVENTOR
Alfred C. Schroeder
BY *W. Huska*
ATTORNEY

UNITED STATES PATENT OFFICE

2,642,535

MASS SPECTROMETER

Alfred C. Schroeder, Feasterville, Pa., assignor to
Radio Corporation of America, a corporation of
Delaware

Application October 18, 1946, Serial No. 704,116

5 Claims. (Cl. 250—41.9)

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This invention relates generally to improved methods of and means for analyzing charged particle radiations and more particularly to improved mass spectrometers and the like for analyzing the relative abundance and masses of ions or other charged particles.

Among the objects of the invention are to provide an improved method of and means for measuring the relative quantities and masses of charged particle radiations. Another object is to provide an improved mass spectrometer for analyzing gaseous specimens. An additional object is to provide an improved mass spectrometer having a linear mass indicating scale. A further object is to provide an improved mass spectrometer or the like wherein ions derived from a source to be analyzed are accelerated by extremely short duration, square wave accelerating potentials, the accelerated ions are segregated according to their relative velocities so that they reach a target electrode at successive time intervals, and signals derived from the target electrode are applied to a cathode ray oscilloscope to provide indications of the relative abundance of particles of predetermined different mass.

Other objects of the invention are to provide an improved mass spectroscopy utilizing square wave accelerating and/or decelerating voltage pulses for segregating ions of different mass. An additional object is to provide an improved mass spectrometer utilizing accelerating and/or decelerating square wave voltage pulses for segregating ions of different mass, and ion deflecting means for selecting or rejecting ions within predetermined mass limits. A further object is to provide an improved mass spectrometer utilizing square wave, short duration, accelerating and/or decelerating pulses for segregating ions of different masses, and ion multiplying signal plate means responsive to the accelerated and/or decelerated ions for providing signals characteristic of the relative abundance and mass of the ions to be analyzed.

A still further object of the invention is to provide an improved mass spectrometer or the like wherein ions to be analyzed are accelerated by short duration square wave pulses and projected against an ion-sensitive mosaic; resultant potentials established upon the mosaic being scanned by a cathode-ray beam to provide an output signal characteristic of the relative abundance and atomic weight of the projected ions. Another object is to provide an improved mass spectrometer wherein ions to be analyzed are accelerated by short duration, square wave pulses, and the

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accelerated ions are collected and indicated as a function of their different travel times. A still further object is to provide an improved mass spectrometer providing constant indications of the relative abundance and atomic weight of ions derived from a source to be analyzed.

Briefly, the system required for providing the improved mass spectrometer comprises an envelope enclosing an ion source (or means for generating ions from gaseous samples introduced therein), an ion accelerating space, an ion separating space, and a target electrode or screen. In a special case the accelerating and separating spaces may be combined. The ions entering the accelerating space pass through an apertured partition to the separation space, and travel to an ion-sensitive target electrode or mosaic from which potentials may be derived characteristic of the relative abundance and velocities, or travel times, of the ions impinging thereon. Ionized particles from the source are accelerated by successive square-wave, short-duration pulses of accelerating potential, and pass into the separating space where the accelerated particles of different mass are separated by any of a number of methods which will be described hereinafter.

For example, in the simplest form of the invention, ions leaving the ion source are accelerated in the accelerating space by a pulse of such short duration that the ions to be observed have not yet reached the end of the accelerating space. (Ions which are lighter than those to be examined or separated may already have entered the separating space, and in some forms of the invention these particles are separately analyzed or excluded.) Because all of the particles to be analyzed have been accelerated for the same length of time, the lighter particles will travel faster than the heavier ones at the conclusion of the acceleration pulse interval. If no further forces act upon the particles, the lightest ones will traverse the separating space more quickly than the heavier ones, and the various particles will strike the target electrode or mosaic at time intervals determined by their relative mass.

The time of flight of a particle from source to target will be directly proportional to its mass (if initial velocities are neglected). If the target electrode is coupled to a suitable oscilloscope or other indicating apparatus, a series of pulses of different magnitudes, depending upon the quantity of ions which produce each particular signal indicator pulse, and spaced in time proportionately to the mass of the particles, will provide continuous indications of the relative abundance

and mass of the particles under observation. One of the coordinates of the oscilloscope may be calibrated in relative quantities of ions, and the other coordinate may be calibrated directly in atomic weight of the particles under observation. If a space occurs between adjacent pulses corresponding to a particular atomic weight, the absence of ions of this particular atomic weight in the specimen is indicated. The calibration range of the instrument may be varied by changing the magnitude or duration, or both, of the accelerated pulses, or by changing the characteristics of the timing signals applied to the oscilloscope. It should be understood that the timing signals must be synchronized with, and properly phased with respect to the accelerating pulses.

If instead of utilizing extremely short accelerating pulses, they are of longer duration, so that the particles of interest leave the accelerating space before the conclusion of the accelerating pulse, the time required for a particle to traverse the space to the target will be proportional to the square root of the mass of the particles. This type of operation crowds together the indications of the heavier particles, if examined in the same manner as described heretofore, and if the accelerating pulses are relatively long, some or all of the indicated pulses may overlap adjacent ones. By differentiating and/or rectifying the signals derived from the signal plate and applied to the oscilloscope, the indicated pulses may be separated from each other, but the atomic weight scale still will be proportional to the square root of the relative masses of the particles.

If greater separation is desired between particular pulse indications on the oscilloscope, a decelerating pulse of proper duration and amplitude to slow down some or all of the particles (but not stop them) can be applied to the particles as they traverse the separating space, or in any event immediately before the lightest particle to be examined reaches the target. A decelerating pulse also may be applied to the particles in the accelerating space just before the lightest particle to be examined leaves the accelerating space. This type of operation produces a separation of the pulses arriving at the target equivalent to a very much shorter accelerating pulse. However, the effect applies only to particles heavier than a desired minimum value, which can be as small as 1.

A further manner of providing greater segregation of the times of arrival of particles of different mass at the target electrode is to apply a decelerating bias in the accelerating space during the time that the accelerating pulse is not applied thereto. The decelerating bias slows down the heavy particles more than the lighter ones since the lighter ones pass into the unbiased separating space sooner than the heavier ones because they are closer to the separating space when the accelerating pulse is concluded. All particles heavier than some predetermined mass, determined by the size and duration of the accelerating pulse, the amount of decelerating bias, and the length of the accelerating space, are decelerated to zero velocity, or less, and returned to the source.

When employed a decelerating field to maintain substantially all of the ionized particles in the region of the source except during the intervals of the accelerating pulses, it is possible to employ higher gas pressures in the ion source, providing the gas is substantially completely ion-

ized. This operation also permits the use of an ion source of larger area wherein the ion forming electrodes may be shaped so that the ionized particles are focused to a point, preferably at a target. Such a focused ion beam permits greater signal output than an unfocused one. If desired, the signals derived from the signal plate may actuate an ion multiplier (of similar characteristics to an electron multiplier), or the signal plate potentials may be amplified prior to application to the oscilloscope or other indicator.

If, in a mass spectrometer operated with a short duration accelerating pulse, a steady deflecting field is applied to part or all of the separating space, the particles of different mass may be caused to strike different parts of the target. This feature has been employed in prior art devices to segregate ions of different atomic weight which have been accelerated by sawtooth accelerating potentials. In an improvement upon such known devices, and in accordance with the invention, the target may comprise a fluorescent electrode or screen so that particles of different mass may be seen directly upon different portions of the fluorescent target, the deflection thereof being characteristic of the relative masses of the various particle groups. Also if desired, the target electrode may be fluorescent, and at the same time a signal plate, in which case the quantity of ions would be determined by the measured magnitudes of the indicated pulses, and the mass by the relative position of the indicated pulses on the fluorescent screen. If desired, the signal plate or fluorescent target screen might be sufficiently small so that only particles of one predetermined mass could be observed at any one time, the deflection voltages applied to the separating space being adjusted to analyze separately groups of particles of each desired mass. Furthermore, magnetic or electrostatic fields may be applied to the separating space to vary the relative segregation of the particles of different mass.

Various other methods and means for providing other combinations and arrangements of accelerating pulses, decelerating pulses and/or deflecting systems, as well as various types of fluorescent screen or signal plate targets will be described hereinafter in greater detail by reference to the accompanying drawings wherein Figure 1 is a schematic diagram of a preferred embodiment of the system, Figure 2 is a graphic example of a typical cathode ray oscillographic indication provided by the circuit of Fig. 1, Figure 3 is a schematic ion ray diagram of the system of Fig. 1, Figure 4 is a focused ray diagram for such a system, Figure 5 is a ray diagram indicating acceleration, deceleration and deflection of the ion beam in a modification of said system, Figure 6 is a cross-sectional, partially schematic view of a second embodiment of the invention utilizing an ion mosaic and cathode ray scanning system, Figure 7 is a schematic diagram of a system utilizing an extremely short duration accelerating pulse in the accelerating space, Figure 8 is a schematic diagram of the system showing a relatively long accelerating pulse in the accelerating space, Figure 9 is a schematic diagram of the system showing a relatively short accelerating pulse in the accelerating space and a relatively long decelerating pulse in the separating space, Figure 10 is a schematic diagram of the system showing successive accelerating and decelerating pulses applied to the accelerating space, Figure 11 is a schematic diagram of the system showing a decelerating bias applied

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to the accelerating space except during the interval of a relatively short accelerating pulse, Figure 12 is a schematic diagram of the system showing a relatively short accelerating pulse applied to the accelerating space and a much longer duration decelerating pulse applied to the separating space, Figure 13 is a schematic diagram of the system showing an ion multiplier forming a portion of the ion target of the system of Fig. 1, Figure 14 is a schematic diagram of the system showing steady electrostatic deflection of ions projected toward a fluorescent screen target electrode, Figure 15 is a schematic diagram of a system similar to that of Fig. 14 wherein the fluorescent screen also is a signal plate coupled to a cathode ray oscilloscope, Figure 16 is a schematic diagram comprising a modification of the systems of Figs. 14 and 15 including a movable target collector electrode, Figures 17 and 18 are schematic diagrams showing further modifications of the systems of Figs. 14, 15 and 16 and including both electrostatic and electromagnetic deflection of the accelerated ions, Figures 19, 20 and 21 are schematic diagrams of the system including the deflection of the accelerated ions by means of short duration deflection pulses applied to the ions in the separating space. Similar reference characters are applied to similar elements throughout the drawings.

Referring to Figure 1 of the drawings, the system includes an evacuable envelope 1 having an input port 3 connected to a source of gas to be analyzed and an output port 5 connected to a vacuum pumping system. The ion generating source within the evacuable envelope includes a thermionic cathode 7, a cathode shield 9 having an aperture 11 therein, and an anode 13 maintained at positive potential with respect to the cathode shield 9 by an anode battery 15. Atoms of the gas to be analyzed pass through the path of the electron beam between the cathode and anode electrodes, are ionized and the ions are accelerated by the field produced by accelerating pulses applied to an adjacently disposed accelerating electrode 17. The ions accelerated by the field in the accelerating space between the accelerating electrode 17 and the cathode shield 9 are projected through a central aperture 19 in the accelerating electrode and traverse a separating space 21 to impinge upon a signal plate target 23. As explained heretofore, the short duration, square-wave accelerating pulses establishing the field in the ion accelerating space (between the accelerating electrode 17 and the cathode shield 9) accelerate each of the gaseous ions to a degree inversely proportional to the mass thereof, whereby the lighter ions reach the signal plate earlier than the heavier ones, and all ions of a particular mass reach the signal plate at substantially the same instant, thereby bunching the ions according to mass, and developing voltage pulses upon the target 23. The voltages developed upon the target 23 are amplified by an amplifier 25 and applied to the vertical deflection elements 27 of a cathode ray oscilloscope 29. Timing voltages for providing horizontal deflection of the cathode ray oscilloscope 29 are derived from a timing generator 31 and applied to the horizontal deflecting elements 33 of the oscilloscope.

The accelerating pulses, comprising short duration, square wave negative pulses 35, are produced by an accelerating pulse generator 37 which is synchronized with the timing generator 31 through an adjustable phase control 39. The

timing generator 31 may comprise, for example, a sawtooth, low frequency generator to provide a linear time scale for the oscilloscope, and the accelerating pulse generator 37 may comprise a conventional keyed multivibrator which is actuated by synchronizing pulses 41 derived from the adjustable phase control 39 and the timing generator 31. Either positive or negative polarity synchronizing pulses may be employed for initiating the accelerating pulses, depending upon the particular multivibrator circuit arrangement utilized for the accelerating pulse generator 37. Multivibrators for generating successive positive and negative pulses of the same or different duration in each complete cycle of operation are generally known in the art, and such devices may be keyed by synchronizing pulses to provide any desired type of accelerating and/or decelerating or deflecting pulses. If desired, the zero voltage level of the pulses may be varied by adding or subtracting D.-C. potentials to the pulses.

The indications provided upon the fluorescent screen of the cathode ray oscilloscope 29 may be as shown in Fig. 2 wherein the vertical axis is characteristic of the quantity or abundance of ions, and the horizontal axis is a linear function of ion mass or atomic weight. It is noted that in Figure 2 no indication is provided at the point corresponding to an atomic weight of 19. This indicates that no ions of this particular atomic weight are present in the gas under analysis, whereas the relative vertical deflections at other atomic weights indicate the relative abundance of ions having such atomic weights. The vertical indicating scale may be adjusted by varying the sensitivity of the amplifier or by adjusting the magnitude of the accelerating pulses applied to establish the accelerating field. The timing scale may be adjusted by varying the speed of the sawtooth timing signal. If desired, any portion of the timing sweep may be expanded in accordance with established oscillographic technique.

Figure 3 is a diagram indicating a plurality of ionized particle paths 43 from the ion source 9 after acceleration in the ion accelerating space between the ion source 9 and the accelerating electrode 17 in a modification of the device of Fig. 1. The accelerated ions pass through a plurality of apertures 19, traverse the separating space 21 and impinge upon the signal plate target 23.

A much more efficient type of system for a device similar to Fig. 1 but having a relatively large ion source area is shown in Figure 4 wherein the ion source 9 and accelerating electrode 17 are curved to focus the accelerated ions at a common point 45 on the signal plate target 23. The focused ion beam arrangement of Fig. 4, in combination with a positive bias 47 applied to the accelerating space during the time intervals between the occurrence of negative accelerating pulses 35, permits higher gas pressures to be employed (providing substantially all of the gas is completely ionized), thereby increasing the sensitivity of the system and providing greater signal output from the target electrode 23.

In a tube operated by short duration accelerating pulses 35, a steady deflecting field can be applied to part or all of the separating space, or to both the accelerating and separating spaces. The particles of different mass may be caused to strike different parts of the target electrode 23, or ionized particles of predetermined mass may be deflected to a collector electrode 49 as shown in Figure 5. If a short duration decelerat-

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ing pulse is applied to a pair of decelerating electrodes 51, 53 disposed in the path of the ionized beam 43, preferably in the separating space 21, and the decelerating pulse is applied at the proper time, it will decelerate only those particles of a desired atomic weight whereby a deflecting field provided by deflecting electrodes 55 will deflect particles of said predetermined atomic weight to the collector electrode 49 without substantially deflecting or affecting the velocity of particles of other atomic weights.

Figure 6 shows a second embodiment of the invention wherein the ionized particles traversing the separating space 21 after acceleration by the accelerating electrode 17 are caused to travel divergent paths by means of an electromagnetic field applied thereto from an external source, not shown. The ions traversing the divergent paths 43 impinge upon an ion-sensitive mosaic 57 to develop thereon potentials corresponding to the velocities and quantities of such ions. The mosaic 57 is scanned by an electron beam 59 produced by an electron gun, electron focusing elements and electron beam deflection elements.

The apparatus comprising the electron beam generating and deflection means may comprise a thermionic cathode 61, an anode 63, biased positively with respect to the cathode, an electron lens electrode 65, and a pair of electron beam deflecting elements 67, 69. Deflection voltages applied to the deflection electrodes 67, 69 cause the electron beam 59 to traverse the mosaic 57, (in the same manner as in television iconoscope pickup tubes), thus changing the cathode potential with respect to the mosaic potential and providing, from the cathode, output voltages characteristic of the relative abundance and travel times of the ions impinging on the mosaic.

The output voltage derived from the cathode 61 may be applied to the vertical deflecting elements of a cathode ray oscilloscope in the same manner as described heretofore by reference to the circuit of Fig. 1. The accelerating pulses applied to the accelerating electrode 17 and the deflection voltages applied to the deflection electrodes 67, 69 may be synchronized with the timing generator of the indicating oscilloscope in the same manner as described in the circuit of Fig. 1.

Each of the embodiments of the invention described heretofore may be operated according to the following methods of pulsing, accelerating, decelerating and deflecting the ion beam. In Figure 7, a short duration, negative pulse is applied to the accelerating electrode 17 which establishes a short duration field in the accelerating space. The accelerated ion beam passing through the aperture 19 in the accelerating electrode 17 traverses the separating space 21 and impinges upon a signal plate target 23. Since the accelerating pulse is completed before the lightest ions leave the accelerating space, all of the ions are accelerated as a direct function of their respective atomic weights. Ions of each atomic weight are bunched together in passing through the separating space and impinge upon the target 23 at successive time intervals. The voltage pulses established upon the target electrode 23 are amplified by the amplifier 25 and are applied to the vertical deflecting elements of the oscillograph 29. If a linear timing voltage, such as a voltage of sawtooth waveform, is applied to the horizontal deflecting elements of the oscilloscope, the vertical "pips" will have

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magnitudes corresponding to the relative abundance of the ions of the several atomic weights, and the horizontal spacing of the "pips" will be linearly characteristic of the respective atomic weights.

Figure 8 illustrates a system of the general type described heretofore wherein a relatively long duration accelerating pulse 35 is applied to the accelerating space. The accelerating pulse is of sufficient duration so that the ionized particles of interest have left the accelerating space before the completion of the accelerating pulse. With this arrangement the travel times of the ions of the several atomic weights of interest will be proportional to the square root of the mass of the particles, and the heavier particles may provide indications on the cathode ray oscilloscope which overlap on the higher atomic weight end of the oscilloscope horizontal scale.

If a differentiating and clipper circuit 75 is serially interposed between the amplifier 25 and the vertical deflecting elements of the oscilloscope 29, sharp separated vertical "pips" may be obtained throughout the length of the oscilloscope timing scale. By differentiating the amplified pulses derived from the target 23, short duration pulses of opposite polarity will be obtained from each pulse established upon the target electrode. Only a predetermined positive or negative portion of the differentiated pulse pairs is selected and applied to the oscilloscope vertical deflecting elements, and the remainder of the differentiated pulses are rejected. Such differentiating and clipper circuits are well known in the electrical wave shaping arts.

The indications provided upon the oscilloscope screen will be as shown in graph 77 wherein the "pips" at the right-hand side of the timing scale, and corresponding to particles of relatively high atomic weight, are more closely spaced than at the left-hand side of the scale where the "pips" correspond to particles of relatively lower atomic weight.

If greater separation is desired between the voltage pulses established at the target 23, a positive decelerating pulse 79 may be applied to a decelerating electrode 81, or to the target 23, to slow down the previously accelerated ions at a time just before the lightest particle to be observed reaches the target electrode. If a relatively short accelerating pulse 35 is applied to the accelerating space, the differentiator and clipper 75 may be omitted, whereas if a relatively longer accelerating pulse is employed, the differentiator and clipper should be included in the circuit, as in the system of Figure 8. The indication provided upon the oscilloscope screen is illustrated in graph 83 wherein the lighter atomic weight indications are crowded rather closely together, and indications of ions exceeding some predetermined atomic weight are more widely spaced due to the action of the decelerating field applied to the separating space 21.

Alternatively, both a short duration accelerating pulse 35 and a short duration decelerating pulse 79, of opposite polarity and immediately following the accelerating pulse, may be applied to the accelerating electrode 17 in a manner whereby the decelerating pulse 79 is completed before the lightest particle to be examined leaves the accelerating space. This type of operation provides a separation of the indicated pulses equivalent to that obtainable by using a very much shorter accelerating pulse in the accelerating space for particles which are heavier than

some predetermined minimum value, which value may be as low as one.

Figure 11 illustrates the manner in which a negative polarity accelerating pulse 35 is applied to the accelerating electrode 17, and a positive bias 85 is applied to the accelerating electrode during the intervals between successive negative polarity accelerating pulses. The resultant decelerating field applied to the accelerating space tends to keep the ionized particles in the vicinity of the source except during the accelerating pulse intervals. Such operation permits higher gas pressures to be employed (providing the gas is substantially completely ionized), and permits the use of a much larger area ion source as in the systems of Figs. 3 and 4. A relatively large ion source permits greater signal output to be obtained from the target electrode 23, thereby requiring less amplification. The decelerating bias applied to the accelerating space also tends to increase the separation of the indicated pulses on the oscilloscope, since the heavier ion particles are slowed down more than the lighter ones. All ion particles heavier than a predetermined mass, determined by the size and duration of the accelerating pulse, the amount of the decelerating bias, and the length of the accelerating space, are decelerated to zero velocity, or less, and returned to the ion source.

Another method of operating the system utilizes either a short duration or relatively long duration accelerating pulse 35 in the accelerating space, and a positive decelerating bias applied to a decelerating electrode 81 or to the target 83 in the separating space 21. The decelerating bias should comprise relatively long pulses 87 occurring between the short duration recurrent accelerating pulses applied to the accelerating space. If a short duration accelerating pulse 35 is employed, the differentiator and clipper 75 may be omitted.

The sensitivity of the systems described may be increased, and a more compact unit may be employed, if the target 23, or a portion thereof, includes an ion multiplier 89. An ion multiplier may be constructed similarly to an electron multiplier but the materials employed for secondary ion emission, or for secondary electron emission in response to ion bombardment, are such that the ion beam 43 traversing the separation space 21 initiates operation of the multiplier. It should be understood that the impinging primary particles on the multiplier are not electrons, but ions having the charge of an electron.

Figure 14 shows a system wherein a short duration negative polarity, accelerating pulse 35 is applied to the accelerating electrode 17, and a steady deflecting field is applied to part or all of the separating space, or to the whole tube. Due to the different velocities of the ions of different mass, the steady deflecting field will cause the ions to impinge upon different parts of the target 23. If the target is a fluorescent screen, so that the points of impingement thereon of the ions of different mass may be directly observed, the deflection of the several points of ion impingement on the target will be proportional to the ion mass, and the intensity of illumination at each point will be proportional to the abundance of ions of each particular mass. The intensity of the several point indications on the fluorescent screen may be measured by photoelectric or other means.

If, in a system as described heretofore by ref-

erence to Figure 14, the fluorescent screen also is an ion-responsive signal plate, the abundance of the ions of each observed atomic weight may be indicated by the relative vertical deflection of a plurality of "pips," as described heretofore by reference to the system of Fig. 7. At the same time the relative deflection of the ions impinging upon the fluorescent screen target will indicate the respective atomic weights. The systems of Figs. 14 and 15 merely require that a steady unidirectional deflecting voltage be applied to the deflecting electrodes 91, 93 in the path of the accelerated ion beam 43.

Figure 16 illustrates a system similar to those described by reference to Figs. 14 and 15 wherein a signal plate 95, or an ion collector, ion multiplier, or combination thereof, of relatively small cross-sectional area is movable in front of the target electrode 23 so that particles of each desired mass may be analyzed separately. The target electrode 23 in this instance may comprise a fluorescent screen for observing the relative atomic weights of the accelerated particles. The position of the movable target in front of the fluorescent screen may be adjusted by magnetic means, such as a solenoid 97 disposed outside of the evacuable envelope.

If desired, the system of Figure 16 may be modified, as shown in Figure 17, so that an adjustable magnetic field is applied to the device to deflect the ion stream 43 with respect to the target 23 and signal plate 95, so that ions of different atomic weight may be successively analyzed by a fixed signal plate. The magnetic field is provided by an externally disposed deflection winding 99 having its axis normal to the axis of the device. By varying the current through the winding 99, the whole ion spectrum may be shifted transversely with respect to the small signal plate target 95 so that only ions of a desired atomic weight impinge upon the signal plate. The magnetic field may be pulsed or varied in any desired manner for special purposes and for providing special indications.

If a relatively long accelerating pulse is applied to the accelerating electrode 17, a fixed axial magnetic focusing field applied to the separating space tends to spread or separate the paths of the ions of different mass, and an adjustable electrostatic deflection field applied transversely to the separating space tends to center the ion spectrum at the image screen. It should be understood that in each of the devices described heretofore by reference to Figs. 7 to 17, the target or indicating screen may be fluorescent, or an ion collector, signal plate or multiplier, whereby any desired combination of indications may be obtained.

Figure 18 is similar to Figure 17 with the exception that a relatively long accelerating pulse 35 is applied to the accelerating electrode 17, a constant axial magnetic focusing field is established in the separating space by an external winding 99 and a variable deflecting electrostatic field is established between the electrodes 91 and 93 to deflect the ions of different atomic weight with respect to the fluorescent screen 23 and the target electrode 95. The constant axial magnetic focusing field established by the winding 99 provides divergent paths for the ions of different atomic weight, thereby providing a plurality of illuminated spots upon the fluorescent screen 23. It should be understood that the target electrode 95 may be a signal plate, an ion

collector, an ion multiplier, or any desired combination thereof.

In the system of Figure 19, a relatively short duration, negative, accelerating pulse 35 is applied to the accelerating electrode 17. A similar deflecting pulse 101, of short time duration and synchronized with the accelerating pulses, is utilized to provide selective deflection of ions of a predetermined atomic weight in order that the abundance of such ions may be measured by a target electrode 95 disposed laterally with respect to the fluorescent or signal plate 23 upon which the remainder of the accelerating ions impinge. It should be understood that the voltages established upon the target electrode 23 may be utilized in any of the ways described heretofore, for example as in Fig. 7, and that the target 95 may be employed for separate use or measurement of ions of only one predetermined atomic weight. If separate measurements are desired for ions of a different atomic weight, the relative phasing of the accelerating and deflecting pulses 35 and 101 may be varied to select ions passing through the deflecting field at earlier or later relative times.

In the system of Figure 20, the ion deflecting plates 91, 93 extend substantially throughout the length of the separating space 21. A decelerating pulse 101, of relatively short duration and synchronized with the accelerating pulse 35, is applied between the target and accelerating electrodes 23 and 17 of such magnitude and duration as to stop completely all ions in the separating space 21. A unidirectional voltage applied to the deflecting plates 91 and 93 then deflects the ions to the side of the tube, from their positions at the instant of the decelerating pulse. The several differently deflected ion beams 103, 105, 107, 109 impinge upon a fluorescent screen 111 disposed parallel to and adjacent with the deflecting plate 93, whereby visual indications of the relative atomic weights of the deflected ions may be obtained in much the same manner as described heretofore by reference to the system of Figs. 14 and 15. In addition a separate target electrode 23 may be employed, if desired, to analyze ions within other mass ranges which are not deflected to the fluorescent screen 111.

The system of Fig. 21 is similar in all respects to the system of Fig. 14 with the exception that a relatively short duration deflection pulse 101 is applied to the electrostatic deflection electrodes 91, 93 to provide different deflections of accelerated ions within a predetermined velocity range for observation or measurement in response to ion impingement on the target electrode 23. It should be emphasized that the deflection system of Fig. 14 utilizing a constant deflection voltage provides deflection of all of the ions in the separating space, while the system of Figure 21 is employed for providing selective deflection only of ions within a predetermined mass range.

Thus the invention disclosed herein comprises a plurality of mass spectrometers for analyzing the composition of gaseous specimens wherein the gas is ionized, the ions are accelerated by square wave, short duration, acceleration pulses, and the accelerated ions are continuously indicated as a function of the relative abundance of said ions and the relative travel times of the ions through a fixed separating space. Direct measurements are obtained of the relative abundance

and atomic weights of the ions under observation.

I claim as my invention:

1. A mass spectrometer including, in combination, an envelope containing a source of ions of a material to be analyzed, means for intermittently and successively accelerating and decelerating said ions as a function of their respective atomic weights, means for collecting at least some of said decelerated ions at successive time intervals determined by their relative accelerations, and means for indicating the relative abundance and travel times of said collected ions.

2. A mass spectrometer including, in combination, 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, means spaced from said source and accelerating electrode for collecting at least some of said ions, a decelerating electrode intermediate said collecting means and said accelerating space for decelerating at least some of the ions accelerated through said accelerating space, means for collecting at least some of said decelerated ions at successive time intervals determined by their relative accelerations, and means for indicating the relative abundance and travel times of said ions.

3. A mass spectrometer according to claim 2 wherein a predetermined portion of said accelerated ions are decelerated for a relatively longer time interval than the accelerating interval or any of said successive time intervals.

4. A mass spectrometer including, in combination, an envelope containing 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 decelerating a portion of said accelerated ions, means for collecting at least some of said decelerated ions at successive time intervals determined by their relative accelerations, means responsive to ions collected by said collecting means for generating voltages characteristic of the quantities of said collected ions, an oscilloscope, and means for applying said generated voltages to said oscilloscope for indicating the relative travel times of said collected ions to indicate the atomic weights of said collected ions.

5. A mass spectrometer according to claim 4 wherein said ions are accelerated for intervals longer than one of said successive time intervals, and means for differentiating said generated voltages applied to said oscilloscope.

ALFRED C. SCHROEDER.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
2,331,189	Hipple	Oct. 5, 1943
2,344,042	Kallmann et al.	Mar. 14, 1944
2,387,550	Winkler	Oct. 23, 1945

OTHER REFERENCES

Atomic Energy for Military Purposes—Report by Henry D. Smyth, Princeton University Press 1945, pages 197 and 198. Copy in Div. 54.