Sept. 11, 1956 W. C. WILEY 2,762,928

MASS SPECTROMETER

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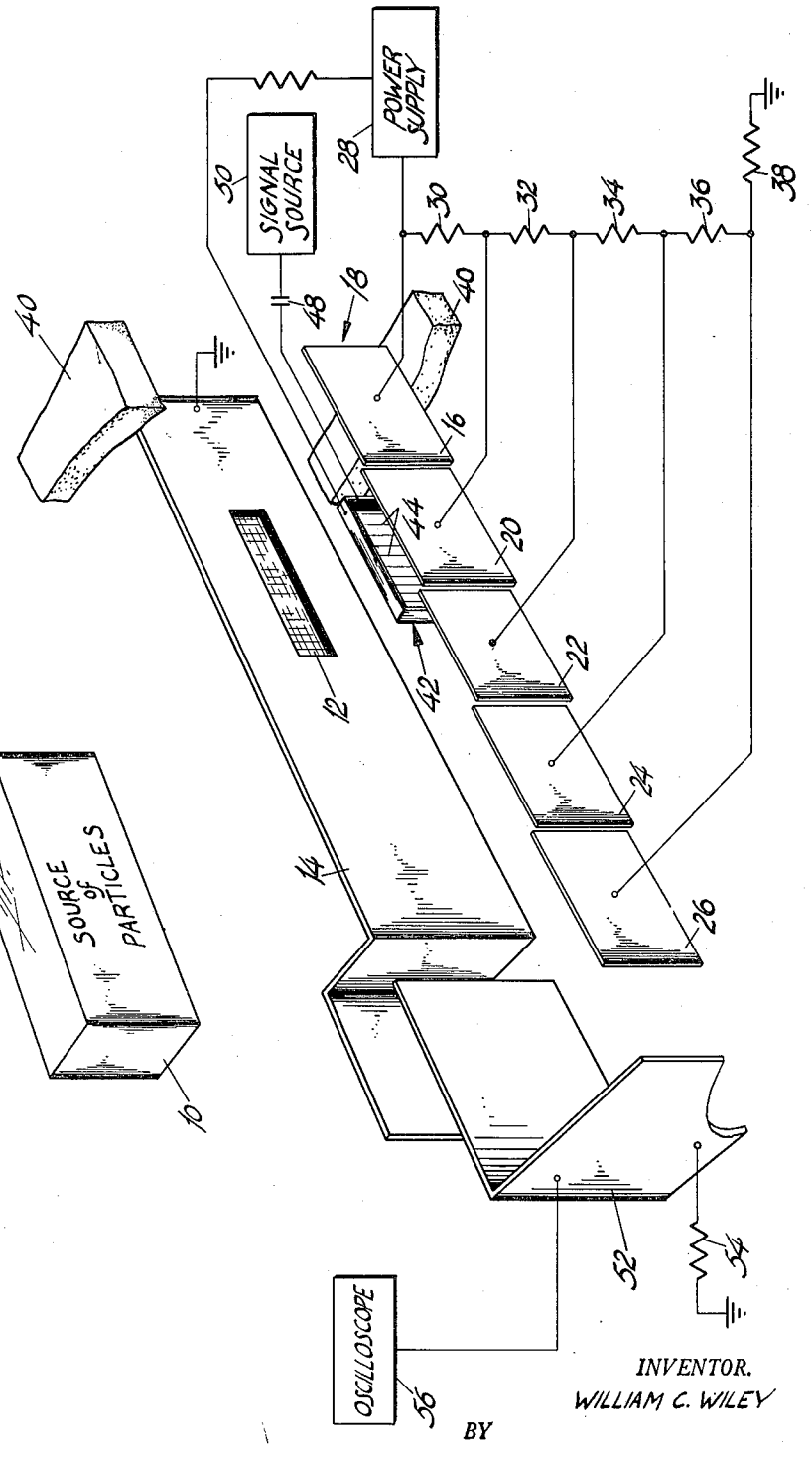



FIG. 1

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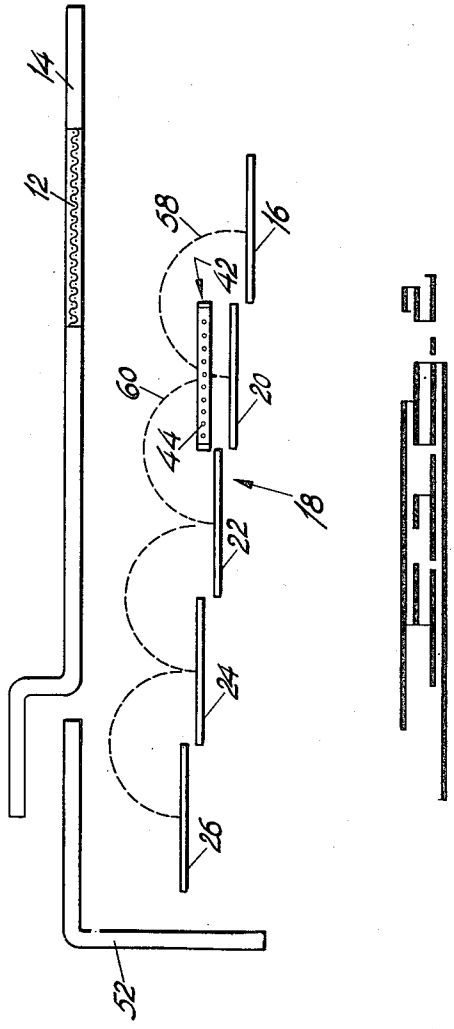
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MASS SPECTROMETER

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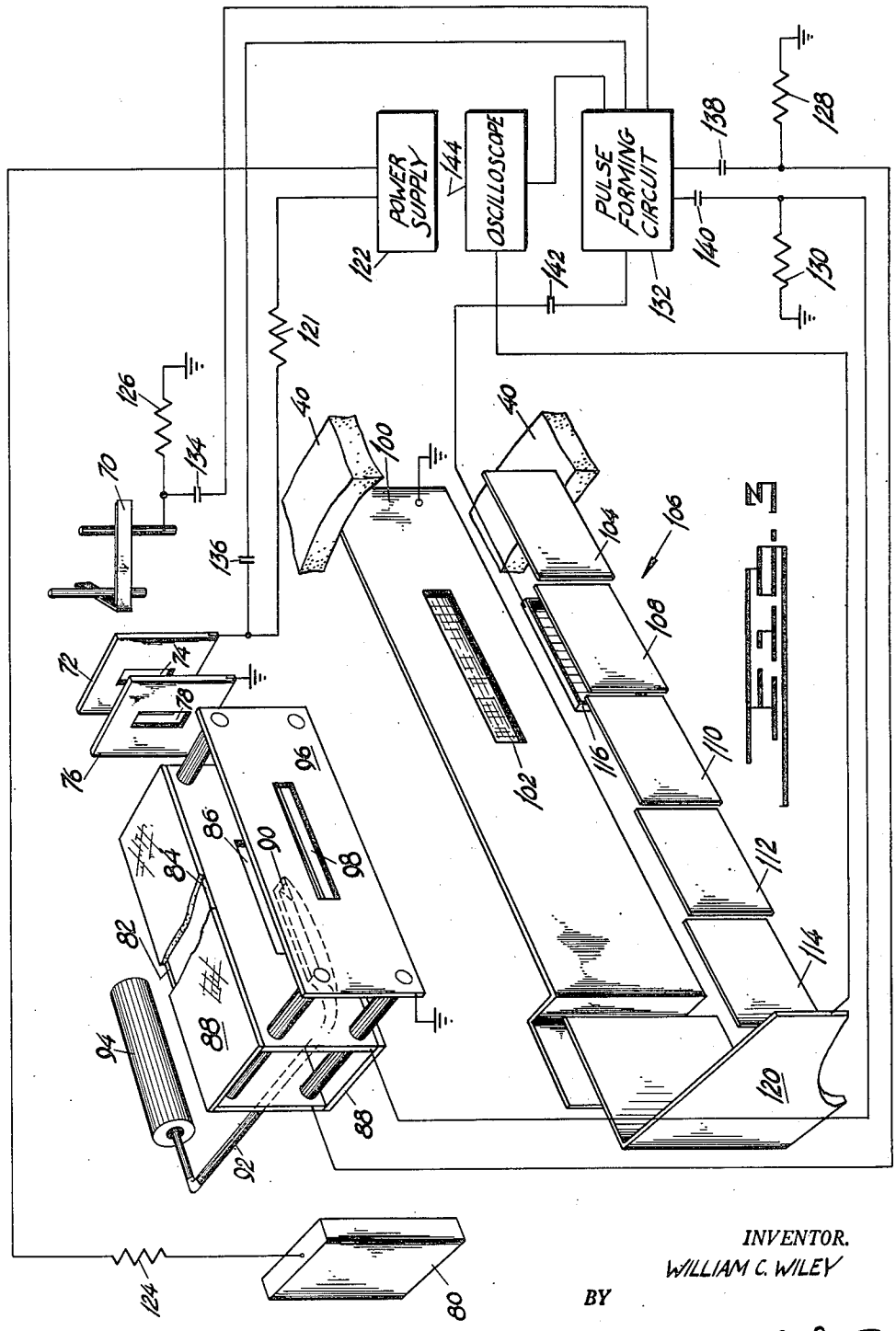
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MASS SPECTROMETER

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2,762,928

# MASS SPECTROMETER

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Application June 4, 1953, Serial No. 359,491

10 Claims. (Cl. 250—41.9)

This invention relates to electron multipliers and more particularly to an electron multiplier for producing strong and accurate output signals in accordance with the introduction of relatively weak input signals.

Electron multipliers are often utilized to provide amplification of electrical signals. The multiplier includes a plurality of plates, each of which is made from a suitable material to secondarily emit electrons when particles strike it. The plates are so arranged relative to one another that each plate receives the electrons emitted by a preceding plate and emits a proportionately increased number of electrons. By utilizing a plurality of plates in an electron multiplier, the multiplier may produce output signals having amplitudes as much as one million times greater than the amplitudes of input signals.

In order to amplify signals through the use of an electron multiplier, the signals must be converted into a stream of charged particles varying in intensity in accordance with the amplitude of the input signal. Such a conversion has often been difficult and has largely negated the increased amplifications provided by the electron multiplier.

This invention provides an electron multiplier in which the amplification produced by the multiplier is controlled by a gate positioned in contiguous relationship to one of the plates in the multiplier. The gate is formed from a plurality of laterally spaced wires. The gate has a signal applied to it to control the number of electrons flowing from the adjacent plate past the gate to the next plate. Because of this control, the intensity of electrons emitted by the last plate in the multiplier is dependent at every instant upon the amplitude of the signal applied to the gate.

An object of this invention is to provide an electron multiplier for producing output signals of relatively large amplitude in accordance with the introduction of a relatively weak control voltage.

Another object is to provide an electron multiplier of the above character having a gate which controls the flow of electrons from the plates in the multiplier in accordance with a voltage applied to the gate.

A further object is to provide an electron multiplier of the above character having a gate formed from a plurality of spaced wires disposed in contiguous and parallel relationship to one of the plates in the multiplier.

Still another object is to provide an electron multiplier of the above character for use in a mass spectrometer to provide an instantaneous indication as to the presence of ions of a particular mass in an unknown mixture.

A still further object is to provide an electron multiplier of the above character for use in a mass spectrometer to produce an output signal only when ions of a particular mass are present in an unknown mixture.

Other objects and advantages will be apparent from a detailed description of the invention and from the appended drawings and claims.

In the drawings:

Figure 1 is a somewhat schematic view, partly in block form and partly in perspective, illustrating one embodiment of an electron multiplier constituting this invention;

Figure 2 is a plan view schematically illustrating the operation of the electron multiplier shown in Figure 1; and

Figure 3 is a somewhat schematic view, partly in block form and partly in perspective, illustrating a mass spectrometer which utilizes the electron multiplier shown in Figure 1.



In the embodiment of the invention shown in Figure 1, a source **10** of charged or uncharged particles is provided. For example, the source **10** may be an ion source for a mass spectrometer, such as is shown in Figure 3 and disclosed in detail hereinafter. When the source emits ions, the ions may be directed through a slot **12** in a grounded electrode **14** towards the first plate **16** in an electron multiplier, generally indicated at **18**.

In addition to the plate **16**, the electron multiplier includes a plurality of other plates such as plates **20**, **22**, **24** and **26**. Each of the plates may be made from a suitable material so as to secondarily emit electrons when electrons or other particles strike it. For example, the plates may be made from beryllium copper having approximately two percent by weight of beryllium.

The plates **20**, **22**, **24** and **26** are disposed in lateral relationship to the plates **16**, **20**, **22** and **24**, respectively, such that the right extremity of each plate is contiguous to the left extremity of an adjacent plate. Each of the plates **16**, **20**, **22**, **24** and **26** are slightly displaced with respect to the other plates. For example, the plate **16** may be positioned approximately one inch from the electrode **14**, and the plates **20**, **22**, **24** and **26** may be approximately 0.97, 0.94, 0.91 and 0.88 inch away from the electrode **14**.

Voltages are applied to the plates **16**, **20**, **22**, **24** and **26** through a resistance network from a power supply **28**. The resistance network includes resistances **30**, **32**, **34**, **36** and **38** connected in series between the power supply and ground. The voltages are applied on the different plates to produce a substantially uniform electrical field between the plates and the electrode **14**. For example, voltages of approximately —6200, —6000, —5800, —5600 and —5400 volts may be respectively applied to the plates **16**, **20**, **22**, **24** and **26**.

In addition to the electrical field produced between the electrode **14** and the electrodes **16**, **20**, **22**, **24** and **26**, a magnetic field is also imposed on the electrons emitted by the electrodes. The magnetic field is produced in a vertical direction substantially parallel to the faces of the electrodes and is imposed by pole pieces **40** shown partially broken away for purposes of convenience. In the above example, a magnetic field of approximately 300 gauss may be applied by the pole pieces.

A gate generally indicated at **42** is disposed in contiguous and parallel relationship to one of the first plates in the electron multiplier such as the plate **20**. The gate is formed from a plurality of wires **44** which are laterally separated by substantially equal distances from one another. For example, the wires **44** may be separated by approximately 0.01 inch from one another and by approximately 0.01 inch from the plate **20**. A biasing voltage is applied to the wires **44** from the power supply **28**. The biasing voltage has a value approximating the voltage applied on the adjacent plate **20**. For example, a voltage such as —6000 volts may be applied to the gate **42** to control the electrons flowing from the plate **20**.

An input signal is applied to the gate **42** through a coupling capacitance **48** from a suitable signal source **50**. The signal from the source **50** may have a repetitive pattern such as a sine wave or may vary in a non-recurring pattern to simulate a phenomenon such as noise.

A collector **52** has a first portion laterally aligned with

the electrode 14 and disposed in substantially parallel relationship with the plate 26. The collector also has a second portion extending in substantially perpendicular relationship to the first portion at a position to the left of the first portion, as seen in Figures 1 and 2. The collector is electrically connected through a suitable resistance 54 to ground. An indicator such as an oscilloscope 56 is connected to the collector 52 to show the pattern of the electrons received by the collector.

The ions are directed by the source 10 through the slot 12 in the electrode 14 and are received by the plate 16. When the ions strike the plate 16, they cause electrons to be secondarily emitted from the plate. The number of electrons secondarily emitted from the plate 16 is dependent upon the number of ions which impinge upon the plate.

The electrons emitted by the plate 16 are subjected to a cycloidal movement because of the composite operation of the electrical field between the electrode 14 and the plate 16 and the magnetic field between the pole pieces 40. This cycloidal movement is illustrated by broken lines at 58 in Figure 2. As a result of their cycloidal movement, the electrons impinge on the plate 20 in a direction substantially perpendicular to the face of the plate.

The electrons impinging on the plate 20 cause a proportionately increased number of electrons to be secondarily emitted from the plate. An increased number of electrons is secondarily emitted from the plate 20 because of the particular voltages applied to the plates 16 and 20 and because of the material from which the plates are made. The electrons emitted from the plate 20 are subjected to a cycloidal movement 60 by the combined electrical and magnetic fields so as to be directed towards the plate 22. In this way, each of the plates 22, 24 and 26 produces a number of electrons which are proportionately increased over the number of electrons that strike the plate. The electrons emitted by the plate 26 are collected by the collector 52 to produce amplified output signals.

The number of electrons moving in a cycloidal path from the plate 20 towards the plate 22 may be controlled by the voltage applied to the gate 42. Normally the gate 42 is biased by the power supply 28 at a potential for producing a moderate flow of electrons from the plate 20 towards the plate 22. When the voltage on the gate 42 is increased by the application of a positive signal from the source 50, its voltage becomes more positive relative to the voltage on the plate 20. This causes an increased number of electrons to be attracted from the plate 20 for a cycloidal movement past the gate and towards the plate 22.

Similarly, the imposition of a negative signal on the gate 20 causes the voltage on the gate to become more negative relative to the voltage on the plate 20. Because of its increased negative bias, the gate 42 acts to restrict the number of electrons flowing past the gate towards the plate 22. In this way, the number of electrons flowing to the plate 22 is controlled by the signal imposed on the gate 42 from the source 50. Since the number of electrons emitted by the plate 26 is dependent upon the number of electrons flowing to the plate 22, the collector 52 produces a signal having an amplitude dependent upon the signal from the source 10.

The electron multiplier disclosed above has several important advantages. It utilizes a relatively weak input signal to control the gain in signal strength produced by the multiplier. It produces an output signal having an amplitude which varies in accordance with the amplitude of the input signal and which has a considerable gain over the amplitude of the input signal. By introducing the input signal to a gate such as the gate 42 to control the electrons emitted by the plate contiguous to the gate in the multiplier, any need for apparatus to vary the amplitude of the ion stream produced by the source 10 is eliminated.

The electron multiplier disclosed above may be adapted for use with different types of apparatus. For example, the electron multiplier may be utilized in the mass spectrometer shown in Figure 3 to provide an indication as to whether or not ions of a particular mass are present in an unknown mixture of gases and vapors. The mass spectrometer includes a wedge-shaped filament 70 made from a suitable material such as tungsten to emit electrons when heated. An electrode 72 is disposed at a relatively short distance, such as ¼ milimeter, from the tip of the filament 10 and is provided with a vertical slot 74, the median position of which corresponds to the level of the filament 70.

An electrode 76 is positioned in parallel relationship with the electrode 72 and at a relatively short distance such as one millimeter from the electrode 72. The electrode 76 is provided with a slot 78 corresponding substantially in shape and position to the slot 74. A collector 80 is positioned at a moderately great distance, such as four centimeters, away from the electrode 76 and in substantially parallel relationship to the electrode.

A backing plate 82 is disposed between the electrode 76 and the collector 80 in substantially perpendicular relationship to these members. The backing plate 82 is positioned slightly to the rear of an imaginary line extending from the tip of the filament 70 through the slots 74 and 78 to the collector 80. An electrode 84 is substantially parallel to the backing plate 82 at a relatively short distance, such as two millimeters, in front of the electrode. The electrode 84 is provided with a horizontal slot 86.

Top and bottom slats 88 made from a suitable insulating material extend from the plate 82 to the electrode 84 to form a compartment with these members. A horizontal slot 90 is provided in the bottom slat 88 at a position directly below the imaginary line disclosed above. A conduit 92 communicates at one end with the slot 90 and at the other end with a receptacle 94 adapted to hold molecules of the different gases and vapors in an unknown mixture.

An electrode 96 is positioned a relatively short distance, such as two millimeters, in front of the electrode 84 and in substantially parallel relationship to the electrode. The electrode 96 has a slot 98 corresponding substantially in shape and position to the slot 86. An electrode 100 corresponding to the electrode 14 in Figure 1 is positioned a relatively great distance such as 40 centimeters in front of the electrode 96. The electrode 100 is provided with a horizontal slot 102 corresponding substantially in shape and position to the slot 98. The slot 102 is covered with a suitable wire mesh.

A first plate 104 is an electron multiplier, generally indicated at 106, is positioned directly in front of the slot 102. Other plates 108, 110, 112 and 114 are disposed relative to the plate 104 in a manner similar to that disclosed for the electron multiplier shown in Figure 1. A gate 116 corresponding to the gate 42 shown in Figure 1 is positioned in contiguous and parallel relationship to the plate 108. A collector 120 is positioned in back of the plate 114 in substantially the same relative positioning to the plate as the relative positioning between the collector 52 and the plate 26 shown in Figure 1.

A positive voltage is applied to the electrode 72 through a resistance 121 from a suitable power supply 122. A slightly positive potential is also applied to the collector 80 through a suitable resistance 124 from the power supply 122. The collector 80 has a slightly positive potential to attract back to it electrons secondarily emitted from it upon the impingement of electrons from the filament 70. The filament 70, the backing plate 82 and the electrode 84 are grounded through suitable resistances 126, 128 and 130, respectively, and the electrodes 76, 96 and 100 are directly grounded. Since the different plates in the electron multiplier receive voltages corresponding to the voltages applied to the different plates shown in Figure 1, the connections to the plates are not shown.

The filament 70 and the electrode 72 are connected to a suitable pulse forming circuit 132 through coupling capacitances 134 and 136. Pulses are also respectively applied to the plate 82 and the electrode 84 through suitable coupling capacitances 138 and 140 from the pulse forming circuit 132. As will be disclosed in detail hereinafter, the pulses are applied to the plate 82 and the electrode 84 a relatively short time after the imposition of the pulses on the filament 70 and the electrode 72.

Pulses of voltage are also applied to the gate 116 through a suitable coupling capacitance 142 from the pulse forming circuit 132. These pulses are applied relatively short times after the imposition of pulses on the plate 82 and the electrode 84. An indicator such as an oscilloscope 144 is also connected to the pulse forming circuit 132 to have its sweep triggered at the instant that pulses are applied to the gate 116. The oscilloscope is also connected to the collector 120 to indicate the electrons received by the collector.

Although the pulse forming circuit 132 is shown in block form in Figure 3, its construction and operation will be apparent to persons skilled in the art. For example, Model 902 of the Double Pulse Generator manufactured by the Berkeley Scientific Company of Richmond, California, may be used to produce a plurality of pulses separated from one another by variable periods of time. The pulse forming circuit disclosed in co-pending application Serial No. 288,104 filed May 16, 1952, by Macon H. Miller and William C. Wiley may also be conveniently adapted for use.

The electrons emitted by the filament 70 are attracted towards the electrode 72 because of the positive potential on the electrode relative to the voltage on the filament. In the steady state operation, the electrons are decelerated in the region between the electrodes 72 and 76 since the electrode 76 is at substantially the same potential as the filament 70. This prevents electrons from traveling through the region between the plate 82 and the electrode 84 with a sufficient energy to ionize molecules of gas and vapor introduced into the region.

Upon the imposition of negative pulses of voltage on the filament 70 and the electrode 72, the voltage on the electrode 72 becomes negative with respect to the voltage on the electrode 76. This causes the electrons traveling through the slots 74 to be further accelerated in the region between the electrodes 72 and 76 and to pass through the slot 78 with a considerable amount of energy. The electrons then enter into the region between the backing plate 82 and the electrode 84 and strike molecules of gas or vapor with sufficient energy to ionize them. Most of the molecules that are ionized have only a single electron split off from them so that positive ions having only a single charge are produced.

The positive ions are retained in the electron stream because of their opposite charge relative to that of the stream. When a relatively large number of ions have collected in the electron stream, the electron stream is interrupted by cutting off the voltage pulses on the filament 70 and the electrode 72. The ions are then withdrawn in a group by the imposition of the voltage pulses on the backing plate 82 and the electrode 84.

The voltage pulses applied to the backing plate 82 and the electrode 84 cause a field of moderate intensity to be produced in the region between the plate 82 and the electrode 84 and an electrical field of considerably increased intensity to be produced in the region between the electrodes 84 and 96. For example, pulses of approximately +400 and +380 voltage may be applied to the plate 82 and the electrode 84, respectively. Upon the imposition of the voltage pulses on the plate 82 and the electrode 84, the ions are accelerated in a group through the slots 86 and 98.

Because of the particular values of the voltage pulses on the plate 82 and the electrode 84, compensation is provided for differences in the positioning of different ions during their retention in the electron stream. Compensation is also provided for differences in random motion that individual ions may have as a result of thermal and other energy in the ions. The differences in random motion cause some of the ions to be traveling towards the backing plate 82 and the other ions to be traveling towards the electrode 84 at the instant that the ions become accelerated by the imposition of the voltage pulses on the plate 82 and the electrode 84. The compensatory actions provided by the imposition of the particular voltage pulses on the plate 82 and the electrode 84 is fully disclosed in co-pending application Serial No. 249,318, filed October 2, 1951, by William C. Wiley, now Patent No. 2,685,035.

Since the ions of relatively light mass have a greater acceleration imparted to them in the region between the plate 82 and the electrode 96 than the ions of heavy mass, they travel through the region between the electrodes 96 and 100 faster than the ions of heavy mass. This causes the ions of different mass to become separated into groups dependent upon their mass as they travel in the field-free regions between the electrodes 96 and 100. When each group of ions impinges on the plate 104, it causes a proportionate number of electrons to be emitted by the plate. The relative times at which the plate 104 emits electrons provides an indication of the ions of different mass.

The electrons emitted by the plate 104 travel to the plate 108 and cause the plate 108 to emit a proportionately increased number of electrons in a manner similar to that disclosed above for the multiplier shown in Figure 1. Because of the bias on the gate 116, the electrons emitted by the plate 108 are prevented from moving past the gate 116 to the plate 110. When a positive pulse of voltage is applied to the gate 116, the potential on the gate changes sufficiently for the gate to pass the electrons emitted by the plate 108. By applying voltage pulses to the gate 116 at substantially the instant that ions of a particular mass are expected to reach the plate 104, an instantaneous indication can be provided on the oscilloscope 144 as to the presence or absence of ions of that mass.

Although this invention has been disclosed and illustrated with reference to particular applications, the principles involved are susceptible of numerous other applications which will be apparent to persons skilled in the art. The invention is, therefore, to be limited only as indicated by the scope of the appended claims.

What is claimed is:

1. In combination, a plurality of plates arranged in staggered relationship with respect to one another, each plate being disposed to receive the electrons from a preceding plate and to produce a correspondingly increased number of electrons, means for introducing a plurality of particles to a first plate in the plurality to produce an emission of electrons from the plate corresponding to the number of particles, means for providing a signal, a gate disposed in contiguous relationship to a particular one of the plates and adapted to receive the signal to produce a pattern in the flow of electrons from the contiguous plate corresponding to the pattern of the signal, and means connected to the last plate in the plurality to provide an indication of the number of electrons emitted by the plate at any instant.

2. In combination, a plurality of plates arranged in staggered relationship to one another to receive the electrons emitted by a preceding plate in the plurality and to emit a correspondingly increased number of electrons, means for introducing a plurality of particles to a first plate in the plurality to produce an emission of electrons by the plate corresponding to the number of particles, a gate formed from a plurality of spaced wires, the gate being disposed in contiguous relationship to a particular one of the plates in the plurality to control the number of electrons traveling from the contiguous plate to the next plate in the plurality in accordance with the voltage applied to the

plate, means for introducing a control voltage to the gate to produce a corresponding flow of electrons from the contiguous plate, and means connected to the last plate in the plurality to provide an indication of the number of electrons emitted by the plate at any instant.

3. In combination, a plurality of plates arranged in staggered relationship to one another to receive the electrons emitted by a preceding plate in the plurality and to emit a correspondingly increased number of electrons, means for introducing a plurality of particles to a first plate in the plurality to produce an emission of electrons by the plate corresponding to the number of particles, a gate formed from a plurality of wires spaced from one another by regular intervals, the gate being disposed in contiguous and parallel relationship to a particular one of the plates in the plurality to control the number of electrons traveling from the contiguous plate to the next plate in the plurality in accordance with the voltage applied to the gate, means for introducing a control voltage to the gate to produce a corresponding flow of electrons from the contiguous plate, and means connected to the last plate in the plurality to provide an indication of the number of electrons emitted by the plate at any instant.

4. In combination, a plurality of plates arranged in staggered relationship with respect to one another, each plate being disposed to receive the electrons from a preceding plate and to produce a correspondingly increased number of electrons means for introducing a plurality of particles to a first plate in the plurality to produce an emission of electrons from the plate corresponding to the number of particles, a gate disposed in contiguous relationship to a particular one of the plates to control the number of electrons flowing from the contiguous plate to the next plate in the plurality, a circuit for biasing the gate with a voltage relative to the voltage on the contiguous plate to limit the number of electrons flowing from the plate past the gate, a circuit for imposing pulses of voltage on the gate to provide for the flow of a relatively large number of electrons from the plate past the gate, and means associated with the last plate in the plurality to produce signals indicative of the time at which electrons are emitted by the plate.

5. In combination, means for providing a plurality of particles, a plurality of plates disposed in lateral relationship to one another and in a progressively longitudinal relationship, at least one plate in the plurality being disposed to receive the particles and to produce a number of electrons dependent upon the number of particles that it receives, other plates in the plurality being adapted to receive the electrons from a preceding plate in the plurality and to produce a proportionately increased number of electrons, a gate formed from a plurality of spaced wires disposed in contiguous and parallel relationship to a particular plate in the plurality, a circuit for biasing the gate with a voltage relative to the voltage on the contiguous plate to prevent the flow of electrons from the plate and past the gate, a circuit for imposing pulses of voltage on the gate to provide for the passage of electrons from the contiguous plate past the gate, and an indicator for providing a determination of the electrons emitted by the last plate in the plurality.

6. In combination in a mass spectrometer, means for providing a plurality of ions, means for accelerating the ions to produce a separation of the ions on the basis of their mass, a plurality of plates disposed in lateral relationship with respect to one another, at least one of the plates in the plurality being disposed to receive the ions after their travel through a relatively great distance and to produce a corresponding number of electrons, other plates in the plurality being disposed to receive the electrons emitted by a preceding plate in the plurality and to produce a proportionately increased number of electrons, a gate disposed in contiguous relationship to a particular one of the plates in the plurality to control the number of electrons flowing from the plate past the gate, a circuit for biasing the gate with a voltage relative to the voltage on the particular plate to limit the flow of electrons from the plate past the gate, a circuit for applying a pulse of voltage to the gate at a time corresponding to the reception by the first plate of the ions of a particular mass to provide for the movement past the gate of the electrons produced as a result of the reception of the ions, and means for indicating the emission of electrons from the last plate in the plurality.

7. In combination in a mass spectrometer, means for providing a plurality of ions, means for accelerating the ions longitudinally to produce a separation of the ions on the basis of their mass, a plurality of plates disposed in lateral and in longitudinally staggered relationship with respect to one another, at least one of the plates in the plurality being disposed to receive the ions after their travel through a relatively great distance in a longitudinal direction and to produce a corresponding number of electrons, other plates in the plurality being disposed to receive the electrons emitted by a preceding plate in the plurality and to produce a proportionately increased number of electrons, a gate formed from a plurality of laterally spaced wires disposed in contiguous and parallel relationship to a particular plate in the plurality to control the number of electrons flowing from the plate past the gate, a circuit for biasing the gate with a voltage relative to the voltage on the contiguous plate to control the flow of electrons from the plate past the gate, a circuit for applying pulses of voltage to the gate at times corresponding to the reception by the first plate of the ions of a particular mass to provide for the movement past the gate of the electrons providing a signal representing the ions, and means for indicating the emission of electrons from the last plate in the plurality.

8. In combination in a mass spectrometer, means for providing a plurality of ions, means for accelerating the ions longitudinally to produce a separation of the ions on the basis of their mass, a plurality of plates disposed in lateral relationship, each plate being displaced from its adjacent plate by a relatively short distance in the longitudinal direction, at least one plate in the plurality being disposed to receive the ions after their travel through a relatively long distance and to emit a number of electrons substantially proportionate to the number of ions reaching the plate, second plates in the plurality being disposed relative to one another and to the first plate to receive the electrons emitted by a preceding plate and to emit a proportionately increased number of electrons, means for providing voltages on each of the plates dependent upon the longitudinal disposition of the plates, means for providing a magnetic field operative in conjunction with the electric field produced by the voltages on the plates to advance the electrons emitted by each plate towards a successive plate, a gate formed from a plurality of wires laterally separated from one another and disposed in contiguous and parallel relationship to a particular one of the second plates, means for biasing the gate with a voltage relative to the voltage on the contiguous plate to prevent the flow of electrons from the plate past the gate, means for applying pulses of voltage to the gate at substantially the instant that ions of a particular mass are expected at the first plate, the voltage pulses being of a polarity and magnitude to provide for the movement of electrons past the gate, and means for indicating the emission of electrons from the last plate in the plurality.

9. In an electron multiplier, a plurality of plates, each plate disposed to receive electrons emitted by a preceding plate in the plurality and to emit an increased number of electrons, means for introducing a plurality of particles to a first plate in the plurality to produce an emission of electrons from the plate, a gate disposed adjacent to a particular plate in the plurality, means for applying a signal to the gate to control in accordance with the amplitude of the signal the number of electrons flowing

from the particular plate to the succeeding plate in the plurality, and means for indicating the emission of electrons from the last plate in the plurality.

10. In an electron multiplier, a plurality of plates arranged in staggered relationship to one another to receive electrons emitted by a preceding plate in the plurality and to emit an increased number of electrons, means for introducing a plurality of particles to the first plate in the plurality to produce an emission of electrons by the plate, a gate disposed adjacent to a second plate in the plurality to pass to the second plate the electrons emitted by the first plate and to pass to a third plate in the plurality the electrons emitted by the second plate, means for applying a signal to the gate to control in accordance with the amplitude of the signal the number of electrons flowing through the gate from the second plate to the third plate, and means for indicating the electrons emitted from the last plate in the plurality.



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