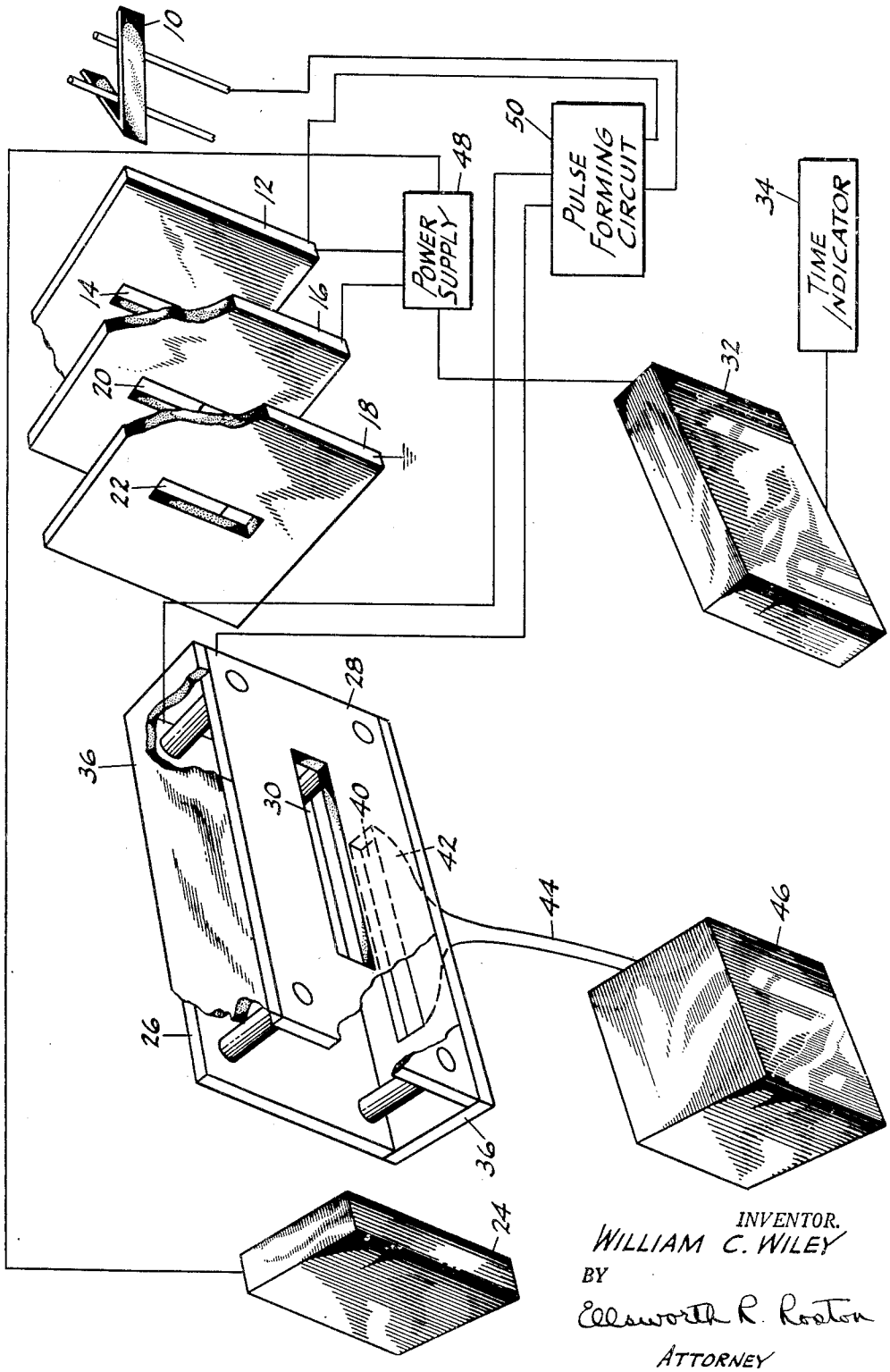
April 19, 1955 W. C. WILEY 2,706,788

ION SOURCE

Filed Oct. 1, 1951



INVENTOR.
WILLIAM C. WILEY
BY
Ellsworth R. Roston
ATTORNEY

United States Patent Office 2,706,788
Patented Apr. 19, 1955

2,706,788

ION SOURCE

William C. Wiley, Detroit, Mich., assignor to Bendix Aviation Corporation, Detroit, Mich., a corporation of Delaware

Application October 1, 1951, Serial No. 249,080

9 Claims. (Cl. 250—41.9)

This invention relates to apparatus for, and methods of, producing pulses of ions and more particularly to apparatus for, and methods of, producing relatively sharp and strong pulses of ions. The invention is especially adapted for use in conjunction with a mass spectrometer to produce pulses of ions from the gases in an unknown mixture.

Mass spectrometers in general are used to determine the weights of different gases constituting an unknown mixture and to determine the relative abundance of the different gases in the mixture. Some mass spectrometers now in use operate on the principle of forming a pulse of ions and subjecting the ions to a predetermined force. The ions of relatively light mass are given a greater acceleration by the predetermined force than the ions of heavy mass and are collected before the ions of heavy mass after travelling through a predetermined distance. Thus, by measuring the relative times at which the ions are collected, the masses can be determined.

In order for accurate determinations to be made, the pulses of ions utilized must be formed from a relatively large number of ions and must be confined within a relatively narrow space. Until recently, apparatus did not exist for producing such sharp and strong pulses. However, in co-pending application, Serial No. 221,554, filed April 18, 1951, by me and Ian H. McLaren, an ion source is disclosed in which a relatively large number of ions is stored in a relatively small space. In the ion source disclosed in the above application, the ions are retained in the potential well created by a stream of electrons and are withdrawn in pulse form after the electron stream is cut off.

One disadvantage limiting the successful operation of the ion source disclosed in the above co-pending application is the tendency of the ions to gradually move towards the grids which accelerate the electrons. As a result of this movement, the number of ions available for withdrawal in pulse form decreases and produces a corresponding reduction in the strength and accuracy of the measurements obtained. This invention overcomes the above disadvantage by providing an ion source which confines the ions to a relatively destricted region along the length of the electron stream.

An object of this invention is to provide an ion source for producing pulses of ions having a relatively narrow width.

Another object is to provide an ion source of the above character for producing pulses of ions formed from a relatively large number of ions.

A further object is to provide an ion source of the above character for retaining the ions in a relatively confined space after they are produced so as to obtain strong and accurate measurements from the ion pulses.

Still another object is to provide a method of concentrating a maximum number of ions in a minimum space to produce a strong and sharply defined pulse.

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

The single figure is a view, partly in perspective and partly in block form, illustrating somewhat schematically an ion source constituting one embodiment of this invention and a mass spectrometer in which it may be used.

In the embodiment of the invention illustrated in the single figure, a wedge-shaped cathode **10** made from tungsten or other suitable material is provided. An accelerating grid **12** is disposed at a relatively close distance

to the cathode **10** and is provided with a vertical slot **14** whose median position is disposed at substantially the same horizontal level as the cathode **10**. A control grid **16** is positioned relatively close to the accelerating grid **12** on one side and relatively close to a shield grid **18** on the other side and is substantially in alignment with both grids. The grids **16** and **18** have slots **20** and **22** corresponding substantially in shape and position to the slot **14**. A collector plate **24** substantially in alignment with the grids is provided at a relatively great distance from the grid **18** to receive the electrons travelling past the grid.

A backing plate **26** is disposed in parallel with, and slightly to the rear of, the collector plate **24**, and an ion accelerating grid **28** having a horizontal slot **30** is positioned slightly in front of the electron stream and substantially in alignment with the plate **26**. A collector plate **32** is provided substantially in alignment with the grid **28** at a relatively great distance from the grid. A time indicator **34**, such as an oscilloscope, is connected to the collector plate **32** to indicate the relative times at which ions of different mass reach the plate.

The plate **26** and grid **28** form a compartment with the grid **18** and the collector plate **24**, the upper and lower limits of the compartment being defined by horizontal insulating plates **36**. The lower plate **36** has a horizontal slot **40** which communicates with the flared mouth **42** of a conduit **44**. The conduit in turn extends from a receptacle **46** adapted to hold molecules of the different gases constituting an unknown mixture.

In the steady state condition, positive voltages of substantially equal magnitude are applied to the grids **12** and **16** from a suitable direct power supply **48**. In addition, slightly positive voltages are applied to the collector plates **24** and **32**. The cathode **10**, the grid **18**, the backing plate **26** and the ion accelerating grid **28** are all substantially at ground potential in the steady state condition.

During the steady state operation of the mass spectrometer, electrons emitted by the cathode **10** are accelerated towards the control grid **12** because of the positive voltage on the grid relative to the cathode. The electrons are not further accelerated after they have travelled past the grid **12**, since the grid **16** is at approximately the same voltage as the grid **12** and the grid **18** is substantially at ground. Therefore, any electrons which do reach the region between the collector plate **26** and the grid **28** do not have a sufficient force to produce ionization of a material number of gas molecules.

To produce a heavy flow of electrons towards the collector plate **24**, voltage pulses of approximately equal magnitude and of negative polarity are applied on the cathode **10** and the grid **12** from a pulse forming circuit **50**. Upon the application of the negative pulse on the grid **12**, the grid **16** becomes positive with respect to the grid **12** and considerably accelerates the electrons as they travel towards it. Because of this additional acceleration, the electrons travel into the region between the plate **26** and grid **28** with sufficient energy to ionize many of the gas molecules introduced into the region from the receptacle **46**. The electrons flowing from the cathode **10** and the electrons produced by the ionization of gas molecules are collected by the plate **24**.

Because of their positive charge, the ions produced by the action of the electron stream on the gas molecules are retained within the stream. The ions are retained in a space having a relatively narrow width in the direction perpendicular to the electron stream because of the collimating action which is provided on the stream by the slots **14**, **20** and **22**. Furthermore, a relatively large number of ions can be, and is, retained within the electron stream, or negative potential well, before the negative charge of the stream becomes neutralized. This causes the ion pulse withdrawn from the stream to have a strength considerably greater than ion pulses formed by previous sources.

The ion pulses which are formed by the ion source disclosed above have a relatively great strength for another reason. Because of the positive voltage on the collector plate **24** and the grid **16** during the electron stream, the ions are retained within the stream in the region adjacent the slot **30**. Since the ions cannot drift down the electron

stream towards the grids **18**, **16** and **12**, practically all of the ions formed from gas molecules are included in the ion pulse which is withdrawn towards the collector plate **32**. The action of the positive voltage on the grid **16** serves to materially increase the number of ions available for withdrawal in pulse form towards the collector plate **32**.

When the electron stream has become substantially saturated by positive ions, the voltage pulses on the cathode **10** and grid **12** are cut off and the electron stream is discontinued. A negative voltage pulse may also be applied to the grid **16** upon the discontinuance of the voltages pulses on the cathode **10** and grid **12** to insure that the electron stream remains cut off even with the attractive forces produced by the positive voltage pulses which may be applied to the plate **26** and the grid **28**. Since the ions are no longer retarded by the negative voltage produced by the electron stream, they are easily accelerated towards the grid **28**. This acceleration is produced by the application of an electric field between the plate **26** and the grid **28** at substantially the instant that the electron stream is cut off or at a slightly later time. The electric field is imposed on the ions by the application of a positive voltage pulse on the plate **26** relative to the voltage on the grid **28** or by the application of a negative pulse on the grid **28** relative to the voltage on the plate **26**.

The electric field imposed upon the ions causes the ions of relatively light mass to be given a greater acceleration than the ions of heavy mass. As a result, the ions of relatively light mass reach the collector plate **32** before the ions of heavy mass. By indicating the relative times at which the ions of different mass reach the collector plate, the masses of the ions can be determined. The relative abundance of the different gases in an unknown mixture can also be determined by measuring the amplitudes of the signals produced at the collector plate **32** when the ions of different mass impinge on the plate.

It should be realized that the relationship between the voltages on the grids **12**, **16** and **18** during the application of the voltage pulses can be varied from that disclosed above without materially affecting the performance of the ion source. However, in any such variations the grid **16** must have a positive voltage during the time that the ion pulse is being formed so as to confine the ions in the region adjacent the slot **30**. It should also be realized that other means than the plate **26** and the grid **28** can be employed to withdraw in a pulse the ions that are formed. As previously disclosed, first pulses are initially applied to the cathode **10** and the grid **12**, and second pulses are subsequently applied to the backing plate **26** and the grid **28**. Equipment for producing two groups of pulses separated from each other by a relatively short time is known to persons skilled in the art and may be either purchased or built. For example, Model 902 of the double pulse generator manufactured by the Berkeley Scientific Company of Richmond, California, may be used to produce two groups of pulses having a variable time separation relative to each other. This model generator is fully described in a publication entitled "Instruction Manual, Berkeley Double Pulse Generator, Model 902" issued by the Berkeley Scientific Company in August, 1950. Equipment for producing a pair of pulses having a variable time separation may be built in accordance with the principles outlined on pages 223 to 238, inclusive, of Volume 20 entitled "Electronic Time Measurements" of the Radiation Laboratory Series prepared by the Massachusetts Institute of Technology.

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. An ion source, including, means for forming a plurality of electrons, a collector plate having a positive voltage to attract the electrons, means operative upon the application of voltage pulses to produce a channeled acceleration of the electrons towards the collector plate, the last mentioned means including a grid having a positive voltage to confine any ions that are formed within a particular region between the grid and the collector plate, means for introducing molecules of gas to the electron channel for the production of ions and the retention of the ions in the electron channel, and means operative at the end of the voltage pulses on the electron accelerating means to withdraw the ions in a pulse.

2. An ion source, including, means for producing a plurality of electrons, means, including a grid, for channeling the flow of electrons, means for introducing a plurality of molecules into the electron channel for ionization by the electrons and for retention of the ions in the electron channel, means for applying a positive voltage to the grid during the flow of electrons to accelerate the electrons through the channel and to confine the ions within a particular portion of the channel, means for cutting off the flow of electrons when the number of ions in the channel approaches saturation, and means operative at a particular time relative to the cut-off of the electron flow to remove the ions in a bunch from the electron channel.

3. An ion source, including, a compartment, means for introducing a plurality of gas molecules into the compartment, means for forming a plurality of electrons, a collector plate located at one end of the compartment and having a positive voltage applied to it, a grid located at the other end of the compartment and having a positive voltage applied to it, the collector plate and grid operating in conjunction to retain in the center of the compartment any ions that are formed, means, including the grid, for producing a channeled flow of a pulse of electrons towards the collector plate with sufficient energy to produce ions from the gas molecules, and means for withdrawing ions of the gas molecules from the center of the compartment after the flow of the electron pulse through the compartment.

4. An ion source, including, a cathode for emitting a plurality of electrons, a first grid spaced from the cathode, there being a hole in the grid for the passage of the electrons from the cathode in a directed stream, a second grid spaced from the first grid, there being a hole in the second grid substantially in alignment with the hole in the first grid, a third grid spaced from the second grid, there being a hole in the third grid substantially in alignment with the hole in the second grid, a collector plate for collecting the electrons, means for applying voltage pulses between the cathode and the first grid and between pairs of successive grids to accelerate the electrons past the grids, the second grid having a positive voltage applied to it to repel any ions that are formed, means for introducing molecules of gas into the stream for the production of ions and the retention of ions in the stream, and means for withdrawing the ions from the electron stream in a pulse.

5. An ion source, including, a cathode for emitting a plurality of electrons, a first grid spaced from the cathode, a second grid spaced from the first grid, a third grid spaced from the second grid, a collector plate spaced from the third grid, there being slots in the first, second and third grids to produce a beam of electrons from the cathode, means for applying voltage pulses at particular instants between the cathode and the first grid and between pairs of successive grids to produce an acceleration of a pulse of electrons towards the collector plate, means for introducing a plurality of molecules into the potential well created by the electron beam for ionization by the beam and for retention in the space occupied by the beam, means for applying a positive voltage on the second grid during the acceleration of the electron beam towards the collector plate to prevent a drift of the ions along the beam towards the grids, and means for withdrawing the ions in a pulse at a particular time relative to the pulse of electrons.

6. An ion source, including, a cathode for emitting a plurality of electrons, a first grid disposed relative to the cathode to pass a stream of electrons emitted by the cathode, a second grid disposed relative to the first grid to pass the stream of electrons moving past the first grid, a third grid disposed relative to the second grid to pass the stream of electrons moving past the second grid, means for collecting the electrons moving past the third grid, means for introducing a plurality of molecules into the electron stream for ionization of the molecules and for retention of the ions within the stream, an electrical circuit for imposing negative voltages of relatively short duration on the cathode and the first grid for the movement of the electrons to the collecting means, an electrical circuit for imposing positive voltages of relatively moderate magnitude on the second grid and the collecting

means to retain the ions in a particular region along the length of the stream, and an electrical circuit for applying an electrical field upon the ions in a direction transverse to the electron stream to withdraw the ions in a pulse from their place of retention.

7. An ion source, including, means for forming a plurality of electrons, electrical means for withdrawing the electrons in a stream, electrical means for collecting the electrons after their movement through a particular distance, a backing plate disposed in substantially parallel relationship to the electron flow, a first grid disposed in substantially parallel relationship with the backing plate on the far side of the electron stream relative to the backing plate, means for introducing a plurality of molecules into the region between the backing plate and the first grid for the ionization of the molecules and for the retention of the ions within the stream, a second grid disposed on the far side of the backing plate and the first grid relative to the collecting means, an electrical circuit for applying slightly positive voltages to the collecting means and to the second grid to retain the ions in a concentrated region in the electron stream, and an electrical circuit for applying an electrical field between the backing plate and the first grid to withdraw the ions in a pulse from their place of retention.

8. An ion source, including, a cathode for emitting a plurality of electrons, a grid disposed at a particular distance from the cathode and shaped to channel into an electron stream the electrons emitted by the cathode, a collector disposed at a particular distance from the grid and in substantially parallel relationship to the grid to receive the electrons, a backing plate disposed between the grid and the collector in substantially perpendicular relationship to these members and on one side of the electron stream, a second grid disposed in substantially parallel relationship to the backing plate on the other side of the electron stream, an electrical circuit for applying a voltage pulse on the cathode relative to the voltage on the first grid to produce a movement of the electrons through the region between the backing plate and the second grid to the collector, means for introducing a plurality of molecules into the region between the backing plate and the second grid for ionization of the molecules and for retention of the molecules within the electron stream, an electrical circuit for imposing positive voltages of moderate magnitude on the first grid and the collector to restrain any movement of the ions towards these members, and an electrical circuit for applying an electrical force between the backing plate and the first grid to produce a movement of the ions in a pulse from their place of retention.

9. An ion source, including, a cathode for emitting a plurality of electrons, a first grid disposed at a particular distance from the cathode and shaped to pass the electrons from the cathode in a stream, a second grid disposed at a particular distance from the first grid and shaped to pass the electrons from the cathode in a stream, a third grid disposed at a particular distance from the second grid and shaped to pass the electrons from the cathode in a stream, a collector disposed at a particular distance from the third grid to receive the electrons flowing past the third grid, a backing plate disposed between the third grid and the collector in substantially perpendicular relationship to these members and on one side of the electron stream, a fourth grid disposed at a particular distance from the backing plate on the other side of the electron stream, an electrical circuit for producing electrical fields between the cathode and the first grid and between the first and second grids to produce a movement of the electrons to the collector, means for introducing a plurality of molecules into the electron stream in the region between the backing plate and the fourth grid for ionization of the molecules and for retention of the ions within the stream, an electrical circuit for positively biasing the second grid and the collector to prevent the movement of the ions along the stream towards these members, and an electrical circuit for producing an electrical field between the backing plate and the fourth grid to withdraw the ions in a pulse from their place of retention.

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