

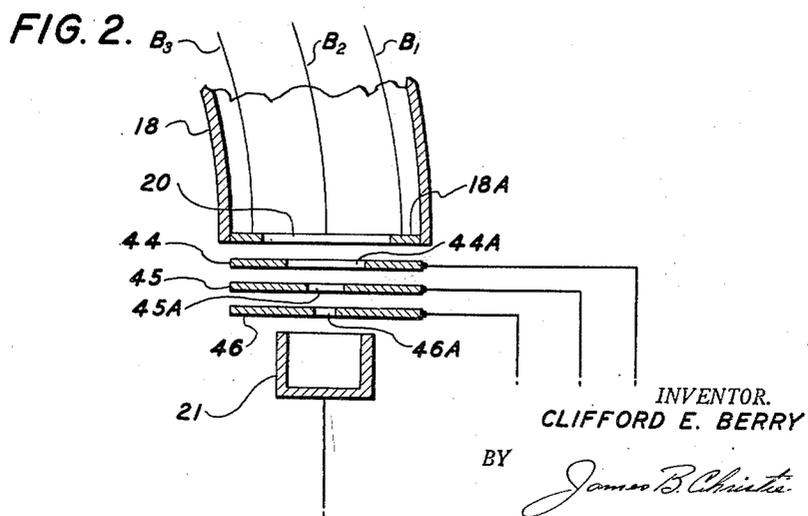
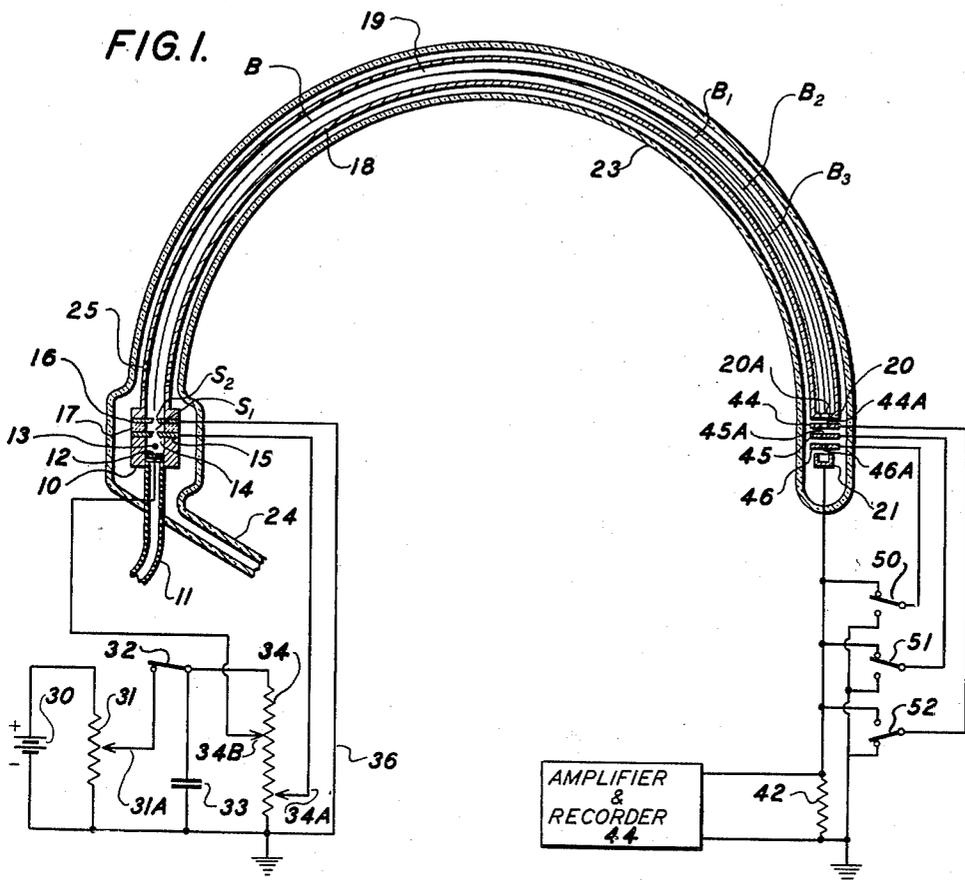
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VARIABLE RESOLUTION COLLECTOR SYSTEM

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VARIABLE RESOLUTION COLLECTOR SYSTEM

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This invention relates to mass spectrometry and particularly to simplified means for achieving variable resolution in a mass spectrometer.

In mass spectrometry a mixture to be analyzed is ionized at least in part by electron bombardment. The ions are then segregated in accordance with their mass-to-charge ratio and all of the ions of a given mass-to-charge ratio are discharged at a collector electrode. The ion segregation may be accomplished in various ways. One common technique, and one with which the present invention is concerned, involves propelling the unsegregated ions as a heterogeneous beam through a magnetic field, the direction of the field being transverse to the direction of ion travel.

In the magnetic field, the path of the ion beam is bent with the ions of differing mass-to-charge ratio assuming different radii of curvature so that the heterogeneous beam is separated into a plurality of essentially homogeneous beams. A single ion beam is focused on and discharged at a collector electrode, the discharge current being a function of the partial pressure in the original sample of the particles from which the ions of the beam are derived. Frequently the mass spectrum is scanned by successively focusing several spatially separated or dispersed beams on the collector electrode.

In the conventional instrument, the final resolution of the several beams is accomplished by a barrier placed in front of the collector electrode and having a narrow slit through which ions must pass to reach the collector. This slit is commonly referred to as the resolving slit and is oriented with its major axis parallel to the magnetic field, resolution being a function of the width of the slit, i. e. the length of its minor axis. Ions of differing mass-to-charge ratio are focused on the resolving slit by varying the magnitude of the ion propelling field or by varying the magnetic field strength, which procedure is commonly referred to respectively as electric or magnetic scanning.

The resolving power of such an instrument depends upon the ion beam width, the resolving slit width as mentioned above, and the dispersion or separation of adjacent masses. For a given ion beam width, which is determined independently of the collector system, the maximum practical resolving power is obtained when the resolving slit width equals the beam width. Under these conditions, the maximum mass that can be resolved is that for which the dispersion is equal to twice the beam width, or, in other words,

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the beam width plus the resolving slit width is equal to the dispersion. Hence, the wider the resolving slit, the lower the resolving power.

To adapt a mass spectrometer for analysis of components of wide mass differential there is need of means for varying the resolving power of the instrument for different mass ranges. The dispersion or separation between the ion beams is given by the function $r \frac{dm}{m}$ where r is the radius of the ion path, dm the mass difference between ions of adjoining beams, and m the mass of the ions in the focused beam. For a given instrument radius and mass differential, beam dispersion therefore is inversely proportional to mass. Thus, the lower the mass under investigation, the lower the required resolving power.

Since maximum permissible recording speed, i. e. scanning speed, is inversely proportional to resolving power, ideally the resolving power should be variable so that only the minimum necessary resolving power is employed for any mass separation. In this fashion maximum recording speed is assured throughout a mass range. In short, the resolving power necessary to resolve between closely adjacent masses in the mass range 400 to 500, for example, is excessive if employed in the mass range 50 to 100, for example, and unnecessarily reduces the recording speed otherwise possible for this lower mass range. This reduction in recording speed is so appreciable that a mass spectrometer suitable for analysis of components of mass in the 400 to 500 range is not suited to rapid analysis of lower mass components if the resolving power is fixed at that required to resolve the components of the higher mass. To construct a mass spectrometer suitable for use over a very wide mass range, it is necessary to provide variable resolution in the instrument.

Others have recognized this problem and have advanced various solutions for achieving variable resolution. Such prior art techniques involve physical substitution of a barrier having a different size slit or mechanical adjustment of the slit size in a fixed barrier. The first of these expedients has the disadvantage of requiring shut down of the instrument and breaking the vacuum seal to replace the barrier, while the second of these expedients involves complicated mechanism necessitating additional vacuum seals to accommodate the actuating parts thereof.

The present invention overcomes the disadvantages of both of these prior art techniques and contemplates in a mass spectrometer having an ionization chamber, an analyzer chamber,

means including a voltage source for propelling ions from said ionization chamber through the analyzer chamber, means for sorting ions in the analyzer chamber according to specific mass, a collector electrode mounted externally of said analyzer chamber, and an amplifier connected to receive and amplify signals from said collector electrode, the combination comprising a conductive barrier disposed at the end of said analyzer chamber and having an aperture therein through which ions must pass to reach the collector electrode from the analyzer chamber, an auxiliary electrode disposed between the barrier and the collector electrode and having an aperture therein narrower than the aperture in the barrier, and means for alternately connecting said auxiliary electrode to the negative side of said voltage source and to the amplifier in parallel with the collector electrode.

In the described embodiment the auxiliary electrode functions either as the final resolving slit for the collector electrode when it is connected to the negative side of the voltage source supplying accelerating potentials, such connection conveniently being through ground, or as an auxiliary collector electrode when connected to the amplification system in parallel with the main collector electrode. The fact that the aperture in the auxiliary electrode is narrower than that in the barrier has no effect on the resolving power of the instrument when the auxiliary electrode is connected in parallel to the collector electrode, since under such circumstances the auxiliary electrode and collector electrode function as a single collector to discharge and sense all ions passing through the barrier. However, when the auxiliary electrode is connected to the negative side of the accelerating voltage source the resolving power of the instrument is determined by the dimensions of the aperture in the auxiliary electrode and not in the barrier.

The variation in resolving power is accomplished simply by electrical linkage requiring no movable mechanical elements sealed into the spectrometer tube. In preferred practice a plurality of such apertured auxiliary electrodes are interposed between the barrier and the collector electrode in substantially parallel and evenly spaced relationship, with the apertures in the succeeding electrodes from the barrier to the collector having progressively smaller minor axes. This construction permits step-wise variation in the resolving power of the spectrometer through a number of steps equal to one more than the number of auxiliary electrodes and adapts the spectrometer to use over a wide mass range at maximum efficiency. The invention is described in greater detail in relation to the accompanying drawing in which:

Fig. 1 is a schematic diagram of a mass spectrometer illustrating modifications therein in accordance with the invention; and

Fig. 2 is an enlarged schematic diagram of the collection end of the mass spectrometer of Fig. 1 showing more clearly the arrangement of auxiliary electrodes and aperture dimensions therein.

Referring to Fig. 1, the spectrometer there shown comprises a cylindrical head 10 which connects with the sample inlet tube 11 generally constructed of an insulating material. Within the head, and in the path of gas entering the head from the inlet tube, there is a pusher or repeller electrode 12 in the form of a conductive plate insulated from the rest of the apparatus

conveniently by a gap. An electron beam 13 is produced within the head in the space immediately following the electrode 12 and by means of an electron gun (not shown). The region of the electron beam is referred to as the ionization chamber 14 since gas molecules entering the head from the inlet tube 11 are ionized by the electron beam in this region.

The front of the ionization chamber, i. e. opposite the gas inlet, is formed by an intermediate propelling or collimating electrode 15 which is electrically connected to the head and is provided with a slit S1 substantially in line with the pusher electrode and with the path of the electron beam. A second propelling or collimating electrode 16 is spaced in front of the first electrode by a ring 17 of insulating material and is provided with a slit S2 aligned with the slit S1 and the electron beam. The head 10 opens into an analyzer tube 18 through the slit S2. The analyzer tube in the illustrated type of spectrometer is semi-circular in shape and defines an analyzer chamber 19. The end of the analyzer tube 18 opposite the head 10 is provided with a barrier 20 having an aperture 20A therein which gives access to the collection system including the principal collector or target 21, as hereinafter described in greater detail.

The head 10 of the spectrometer, analyzer tube 18 and the collector electrode 21 are enclosed within an envelope 23 through a wall of which the sample inlet tube 11 projects. A high degree of vacuum is maintained within the envelope by means of vacuum pumps (not shown) connected to a gas outlet 24, the analyzer chamber being evacuated through the envelope by interconnecting apertures 25 in the tube 18.

The entire instrument, by means of a magnet (not shown) is maintained in a magnetic field transverse to the direction of travel of the ion beam through the analyzer.

A battery or other direct current supply 30 is connected in an energizing network across a potentiometer 31. The positive end of this potentiometer is connected through a slider 31A and switch 32 to a capacitor 33 connected between the switch 32 and the negative side of the battery 30. A potential dividing network is connected across this capacitor and takes the form of a potentiometer 34. A lead 36 is connected to the terminal propelling electrode 16 and to the negative side of the potentiometer 34. Since the terminal propelling electrode 16 is electrically connected to the analyzer tube, the latter, including the barrier 20, is also at the potential of the negative side of the voltage source, in this case ground. Potentiometer 34 has a first slider 34A connected to the intermediate propelling electrode 15 imparting to this electrode a positive potential with respect to the terminal accelerating electrode 16. Pusher electrode 12 is connected to the potential dividing network between the slider 34A and the positive end of the potentiometer 34 by means of a slider 34B so that this electrode is at positive potential with respect to both the intermediate accelerating electrode 15 and the terminal accelerating electrode 16.

Collector electrode 21 is connected to ground through a high resistance 42. This resistance is shunted by an amplifying and indicating or recording apparatus 44, which is preferably of negative feed back type. A series of auxiliary electrodes 44, 45, 46 are interposed between the barrier 20 and the collector 21 in parallel spaced relationship, each being provided with apertures 44A, 45A, 46A, respectively.

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As shown in the enlarged view of Fig 2, the apertures in the auxiliary electrodes are of successively smaller width (minor axis) in the direction of the collector electrode. The minor axis within the meaning of the present specification and claims is assumed to be that axis coinciding with the direction of dispersion of the ion beams, i. e. perpendicular to the magnetic field in the illustrated mass spectrometer. Thus, the apertures 44A in electrode 44 adjacent barrier 20 is narrower than the aperture 20A in the barrier. Aperture 45A in the intermediate auxiliary electrode 45 is narrower than the aperture 44A in the leading electrode 44 and the aperture 46A in electrode 46 adjacent collector 21 is narrower than the aperture 45A in the intermediate electrode 45. The electrodes 44, 45 and 46 are connected respectively to switches 50, 51, 52. One terminal in each of these switches is connected to the lead from collector electrode 21 to resistor 42, the other terminal in each of these switches being connected directly to the negative side of the voltage source 30, in this case through ground.

In the operation of the spectrometer, a sample of gas to be analyzed is admitted to the ionization chamber through the gas inlet tube. Molecules of gas are ionized in the ionization chamber by the electron beam and the resulting ions are propelled as an unsorted ion beam B into the analyzer tube by means of the electrical potentials established between the pusher and the two collimating electrodes. Thus, slits S1, S2 in the propelling electrodes 15, 16, respectively, through which the ions pass, cause the ions to immerge into the analyzer as a thin heterogeneous ribbon B, a cross section of which is defined approximately by dimensions of these slits. In the analyzer the heterogeneous ion beam is separated into a plurality of a diverging homogeneous beams B1, B2, B3 under the influence of the magnetic field established by a magnet (not shown) transverse to the travel of the beams. The number of diverging beams formed under the influence of the magnetic field will, of course, be a function of the number of components in the sample undergoing analysis, three beams being illustrated as representative of the phenomenon that takes place in the analyzer tube.

If the beams B1, B2 and B3 are of comparatively low specific mass, the resolution effected by aperture 20A in the barrier 20 will be sufficient to resolve the beams to the desired accuracy. In such event electrodes 44, 45 and 46 are connected through the respective switches to the collector electrode and hence to the amplifier and recorder 44. Under these circumstances a beam, say the beam B2 passing through the aperture 20A in barrier 20, will be collected in part on each of the electrodes 44, 45, 46 and on the collector electrode 21, a combined discharge current being applied to resistor 42 from which a proportionate voltage is amplified and recorded.

The path of the ion beams with respect to the ultimate resolving slit may be altered to focus one or more of the other ion beams therein by varying either the magnetic field or the propelling potentials. The latter method, i. e. electric scanning, is employed in the particular spectrometer illustrated. To accomplish electric scanning, the switch 32 in the energizing network is closed and capacitor 33 is charged to an appropriate level. The switch is then opened and the capacitor is permitted to discharge through the potential dividing network 34 and through the propelling electrodes in the head of the spectrometer. In this fashion the propelling potentials between

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these several electrodes gradually decay while maintaining constant relative values. The potentials between the propelling electrodes may be adjusted relative to each other by suitable adjustment of sliders 34A, 34B of the potentiometer 34.

If the particular sample under analysis includes components of an appreciably higher specific mass than the ions of the beam B2, or if the entire sample is in a higher mass range, it may be desirable to increase the resolving power of the spectrometer coincident with the focusing of ions of such higher mass on the aperture 20A in barrier 20. Assuming this to be the case, one or more of electrodes 44, 45 or 46 may be progressively connected through respective switches to the negative side of voltage source 30 instead of to the collector electrode 21 as above described. In Fig. 1, electrode 44 immediately following barrier 20 is illustrated as thus connected, while electrodes 45 and 46 remain connected to the collector electrode 21. With this orientation the resolving power of the spectrometer is determined not by the aperture 20A in the barrier 20 but by aperture 44A in the electrode 44, since all ions which now strike the barrier 44 are discharged independently of the collection system. If even greater resolution is required, electrode 45 and finally electrode 46 may be connected in the manner of electrode 44 as shown in Fig. 1, in which event the resolving power of the instrument will be determined by the dimensions of the aperture 46A in the final auxiliary electrode 46.

By way of example of the relative dimensions of the apertures in the barrier 20 and in the auxiliary electrodes, assume an instrument of a five inch radius and an ion beam width of .005 inch. The ion beam width is, of course, determined independently of the collection system and in part by the dimensions of the apertures in the accelerating and collimating electrodes 15 and 16. If it is desired to adapt the illustrated spectrometer to analysis of components up to a specific mass of 500, aperture 46A in the electrode 46 may have a minor axis dimension of approximately .005 of an inch conforming approximately to the width of the ion beam. As discussed above, such aperture width furnishes maximum practical resolving power as will be required for the resolution of such high mass. Aperture 45A in electrode 45 will have a minor axis dimension of approximately .0092 of an inch and will be used to determine the resolving power of the instrument for separation of masses in the range of about 350. Aperture 44A in electrode 44 will be approximately .028 of an inch in width and will be connected to determine the resolving power of the instrument for the analysis of components of specific mass of approximately 150. Aperture 20A in the barrier 20 will be approximately .095 of an inch in width and will be used to determine the resolving power of the instrument when analyzing components of a mass in the neighborhood of mass 50. Thus, with the electrodes connected as shown in Fig. 1 with the resolving power of the instrument being determined by the aperture 44A in electrode 44, the spectrometer is set up for analysis of components having a mass up to about mass 150. If components of higher or lower mass are introduced into the spectrometer or are included in the same sample, the resolution of the instrument can be increased or decreased as indicated by the simple expedient of grounding additional ones of the auxiliary electrodes or of connecting all of the auxiliary electrodes to the collector.

The invention as described has the very considerable advantage of simplification in construction, operation and maintenance of a variable resolving power mass spectrometer. No down time is required in order to vary the resolving power of the instrument and no complex vacuum seals are required for accommodating mechanical slit adjusting means in the collector system. It is, of course, understood that any number of auxiliary electrodes having apertures of varying size may be employed between the so-called barrier and the collector electrode to achieve any desired flexibility in the resolving power. The only requirement of the present invention is that the several succeeding auxiliary electrodes progressing from the barrier to the collector have apertures of progressively smaller minor axis dimensions.

I claim:

1. In a mass spectrometer having an ionization chamber, an analyzer chamber, means including a voltage source for propelling ions from said ionization chamber through the analyzer chamber, means for sorting ions in the analyzer chamber according to specific mass, a collector electrode mounted externally of said analyzer and an amplifier connected to receive and amplify signals from said collector electrode, the combination comprising a conductive barrier at the end of said analyzer chamber adjacent said collector electrode and having a first aperture therein, an auxiliary electrode disposed between said barrier and said collector electrode and having a second aperture therein, the minor axis of said second aperture being smaller than that of the first aperture, and means for alternately connecting said auxiliary electrode to the negative side of said voltage source and to said amplifier in parallel with said collector electrode.

2. In a mass spectrometer having an ionization chamber, an analyzer chamber, means including a voltage source for propelling ions from said ionization chamber through the analyzer chamber, means for sorting ions in the analyzer chamber according to specific mass, a collector electrode mounted externally of said analyzer and an amplifier connected to receive and amplify signals from said collector electrode, the combination comprising a conductive barrier at the end of said analyzer chamber adjacent said collector electrode and having a first aperture therein, a plurality of auxiliary electrodes disposed between said barrier and said collector electrode in spaced parallel relationship, each of said auxiliary electrodes having an aperture therein aligned with the first aperture, the apertures in succeeding electrodes from the barrier to the collector being of progressively decreasing width, and means for alternately and separately connecting said auxiliary electrodes to the negative side of said voltage source and to said amplifier in parallel with said collector electrode.

3. In a mass spectrometer having an ionization chamber, an analyzer chamber, means including a voltage source for propelling ions from said ionization chamber through the analyzer cham-

ber, means for sorting ions in the analyzer chamber according to specific mass, a collector electrode mounted externally of said analyzer and an amplifier, the combination comprising a resistor connected at one end to said collector electrode and at the other end to the negative side of said voltage source, the amplifier being connected across a portion of said resistor, a conductive barrier at the end of said analyzer chamber adjacent said collector electrode and having a first aperture therein, the barrier being connected to the negative side of said voltage source, an auxiliary electrode disposed between said barrier and said collector electrode and having a second aperture therein, the minor axis of said second aperture being smaller than that of said first aperture, and means for alternately connecting said auxiliary electrode to the negative side of said voltage source and to said resistor in parallel with said collector electrode.

4. In a mass spectrometer having an ionization chamber, an analyzer chamber, means for propelling ions from said ionization chamber through the analyzer chamber, means for sorting ions in the analyzer chamber according to specific mass, a collector electrode mounted externally of said analyzer and an amplifier connected to receive and amplify signals from said collector electrode, the combination comprising a conductive barrier at the end of said analyzer chamber adjacent said collector electrode and having a first aperture therein, an auxiliary electrode disposed between said barrier and said collector electrode and having a second aperture therein, the second aperture having a smaller minor axis than the first aperture, and means for alternately connecting said auxiliary electrode to be at the same potential as said barrier and to said amplifier in parallel with said collector electrode.

5. In a mass spectrometer having an ionization chamber, an analyzer chamber, means including a voltage source for propelling ions from said ionization chamber through the analyzer chamber, means for sorting ions in the analyzer chamber according to specific mass, a collector electrode mounted externally of said analyzer and an amplifier connected to receive and amplify signals from said collector electrode, the combination comprising a conductive barrier at the end of said analyzer chamber adjacent said collector electrode and having an aperture therein, a plurality of apertured auxiliary electrodes disposed between said barrier and said collector electrode in spaced parallel relationship, the apertures in said auxiliary electrodes being aligned with the aperture in said barrier and being progressively narrower in succeeding electrodes between the barrier and the collector, and a plurality of switches separately connected to each of said auxiliary electrodes for alternately connecting said electrodes to the negative side of said voltage source and to said amplifier in parallel with said collector electrode.

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No references cited.