Aug. 4, 1953 C. F. ROBINSON 2,648,009

MASS SPECTROMETER

Filed March 8, 1952 2 Sheets-Sheet 1

FIG. 1.

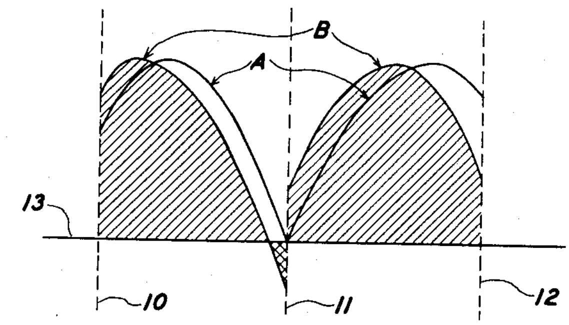


FIG. 2.

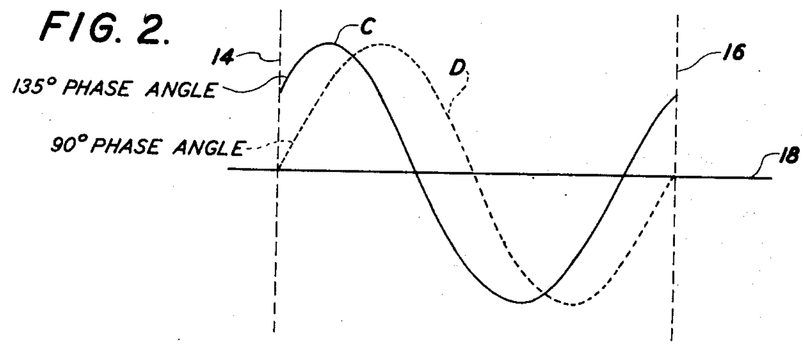
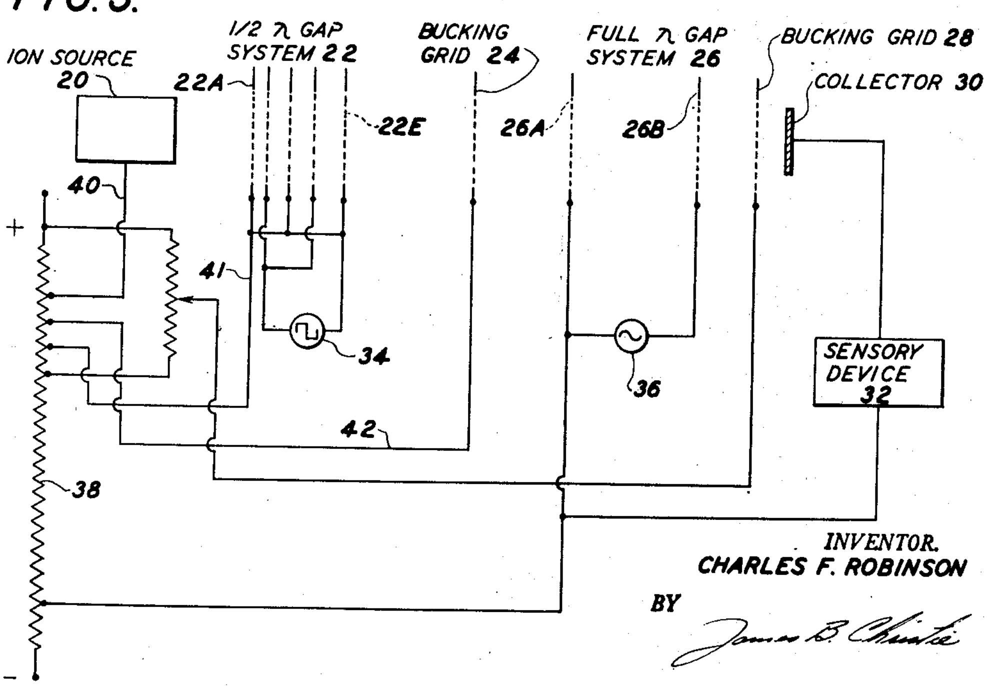


FIG. 3.



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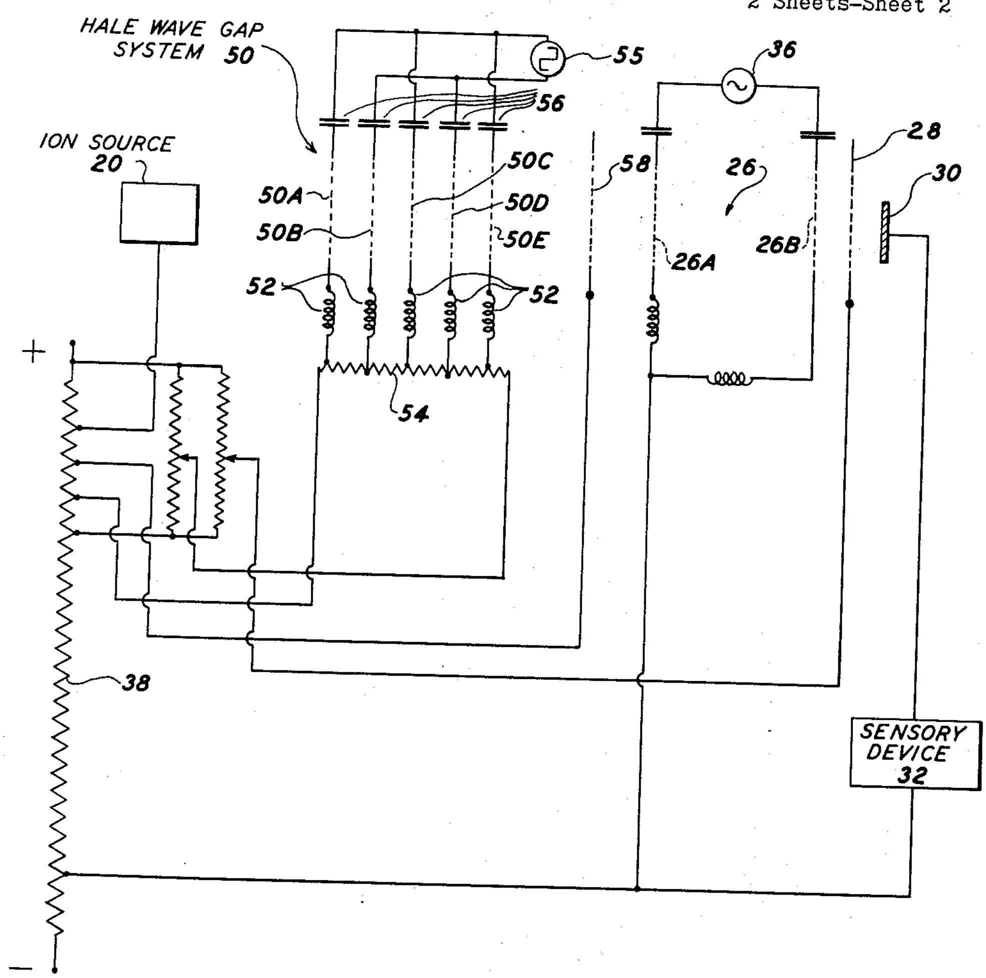

FIG. 4.

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MASS SPECTROMETER

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16 Claims. (Cl. 250—41.9)

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This invention is directed to mass separation by means of linear radio frequency fields and to an improved linear radio frequency mass spectrometer suitable for practicing the method with high resolution and efficiency.

Positive ions are characterized by the nature of their motion in electrical and magnetic fields as affected by mass. Mass separation as accomplished in the field of mass spectrometric analysis utilizes this characteristic response in order to separate ion masses and selectively measure one or another mass of the mass spectrum involved.

Mass spectrometry, in general, comprises the ionization of a sample under investigation, spatial or temporal separation of ion masses through the influence of electrical or magnetic fields or both, and selective sensing of one or more of the ion masses. Mass separation in a linear radio frequency electrical field is a branch of this science which involves segregation of the ion masses as they pursue a more or less linear path through a radio frequency alternating field or fields. To date it has been the practice to employ either a so-called half-wave R. F. field or a full-wave R. F. field for this purpose.

In a full-wave linear R. F. mass spectrometer, a series of grids or accelerating gaps are lined up and energized with an R. F. alternating voltage. Ions of mixed mass are injected into the grid system at a given energy so that the velocity of a particular ion is a function of its mass. The system is so arranged that ions of a particular mass of interest, commonly referred to as resonant ions, traverse each gap of the array in exactly one cycle of the R. F. field and so gain no energy from the field. Ions of non-resonant mass will either gain energy from or lose energy to the field, depending upon whether they are of lighter or heavier mass than the resonant ions and on the phase of the R. F. field at the instant the ions enter it.

The full-wave system shows no discrimination against harmonics. Ions which spend any integral number of cycles in each gap are, like the resonant ions, also passed with no change in energy. The full-wave system does, however, have the great advantage of phase insensitivity and will pass without energy change any ions which have the proper velocity no matter at what phase the ions enter the system.

In a half-wave linear R. F. mass spectrometer, a series of grids are connected to a source of R. F. voltage so that ions of interest spend approximately one-half cycle in each gap. The

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particular ions of interest, again referred to as resonant ions, are thus subject to a series of accelerating fields such that in passing through the array, they gain more energy than any non-resonant ion. This system has the advantage that there are no harmonic interferences, but unlike the full-wave system it is very sensitive to the phasing of the particles. The phase sensitivity of the half-wave system is so acute that if operated at high resolution it will reject in excess of 99% of the injected resonant ions entering at random phase.

The half-wave system has the further disadvantage that masses lighter than the resonant mass are never completely rejected by the R. F. gap system but are simply reduced in energy until their velocity matches that of the resonant particles and traverse the system thereafter without impediment.

I have now found that it is possible to utilize the advantageous features of each of the two methods described above and at the same time overcome their disadvantages by carrying out mass separation successively under half-wave and full-wave conditions.

I have developed a method of mass separation which involves sequential application of half-wave and full-wave linear R. F. fields. By means of the present method it is possible to realize the advantages inherent in both types of field and at the same time greatly mitigate the disadvantages of each. In one aspect the invention contemplates a method of mass separation which comprises ionizing a sample, subjecting the ions to a half-wave linear radio frequency electrical field, imposing a first D. C. bucking field on the ions to reject ions of kinetic energy lower than a predetermined value, subjecting the unrejected ions to a full-wave linear radio frequency field, imposing a second D. C. bucking field on the ions to again reject ions of kinetic energy lower than a predetermined value, and collecting ions emerging from the second bucking field.

The first bucking field may be superimposed on the half-wave R. F. field or may be separately developed between the half-wave and full-wave R. F. fields. The effect of the bucking fields is to reject or "stop" ions whose energy gain from the R. F. fields is less than a predetermined amount.

Preferred apparatus for carrying out the described method of mass separation comprises a half-wave linear R. F. gap system, a full-wave linear R. F. field system and a collector electrode in serial arrangement, means for ionizing a sample to be analyzed and introducing ions into the half-wave gap system, means for injecting ions passing through the half-wave gap system into the full-wave gap system, means developing a first D. C. bucking potential to prevent ions which have less than a given kinetic energy from entering the full-wave gap system, means developing a second D. C. bucking potential between the full-wave gap system and the collector electrode, and means for sensing the discharge current produced at the collector electrode by the ions passing through the full-wave gap system.

In the apparatus as described above, the half-wave gap system effectuates an initial partial segregation of the ions according to mass. Resonant ions gain a maximum amount of energy in traversing the several half-wave gaps. Ions of mass greater than resonant will acquire less than resonant energy at each gap traversal and will emerge from the system at appreciably less than resonant energy. A lighter than resonant ion will traverse such an array with an energy gain less than that of the resonant ions but can emerge at approximately the velocity of the resonant ions. By means of a suitable D. C. bucking potential established either in the gap system itself or by means of a bucking grid following the gap system, all of the ions of heavier than resonant mass are completely stopped. Only the resonant and a restricted number of lighter than resonant ions are thus available for injection into the succeeding full-wave gap system.

Because of a certain amount of velocity degeneracy in the half-wave gap system, i. e. some ions of less than resonant mass emerging therefrom at the same velocity as the resonant ions, it is necessary to effectuate some velocity dispersion before injection into the full-wave gap array. This is conveniently accomplished by means of a D. C. accelerating field imposed between the two gap systems. Alternatively, dispersion is effectuated by the bucking field alone, although ion acceleration to accomplish this end is to be preferred over ion deceleration.

The full-wave gap system is operated so that resonant particles spend exactly one cycle in each gap and hence pass through the array without any gain or loss in energy. Any lighter then resonant particles can be made to lose energy to the system by proper phasing of the instant of entry so that an appreciable energy spread is realized in the emergent ions even between those ions of resonant mass and lighter ions of adjacent mass. These latter together with all other lighter ions can be rejected by a second D. C. bucking field so that only resonant ions reach the collector. Although a full-wave gap system is sensitive to harmonic masses, there is no problem presented since all harmonic masses are excluded by the half-wave system.

Thus the combination of the half-wave and full-wave gap systems arranged serially to function in a complementary fashion accomplishes what neither system separately will do. The combination provides high resolution free of spurious masses and a relatively high efficiency in passing a much higher fraction of the total number of injected resonant ions than would the half-wave gap system alone if operated at anywhere near the same effective resolution.

The invention will be more clearly understood with reference to the following detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a graphic illustration in explanation of the phase sensitivity of a half-wave gap system;

Fig. 2 is a graphic illustration in explanation of the phase insensitivity of a full-wave gap system;

Fig. 3 is a schematic diagram of one form of apparatus in accordance with the invention; and

Fig. 4 is a schematic diagram showing an alternative configuration of the half-wave gap system.

Referring to Fig. 1, curve A represents the traversal of an in-phase resonant particle through a half-wave gap system represented by the grids **10**, **11** and **12**. Curve B represents the traversal of an out-of-phase resonant particle through the same gap system. The in-phase particle represented by the curve A gains energy as represented by the area included within the curve and zero line **13**, whereas the out-of-phase particle represented by the curve B gains energy to the extent represented by the shaded area defined by the curve above the zero line **13** and loses energy to the extent represented by the cross hatched area defined by the curve below the zero line **13**.

From Fig. 1 it is apparent that if the half-wave gap system is operated at high resolution, only those resonant particles which are injected in optimum phase will gain maximum energy while passing through the system, and any bucking potential employed to eliminate non-resonant particles will likewise eliminate those resonant particles which have entered the system at other than optimum phase. With two consecutive gaps the optimum transit angle is approximately 135° as shown in Fig. 1. With three or more consecutive gaps, the optimum transit angle depends on the number of gaps, but the optimum phase is still critically defined and only particles which pass through at optimum phase will gain maximum energy.

In Fig. 2 the phase characteristics of a full-wave gap system are illustrated. Curve C represents a resonant particle entering a full-wave gap system defined by grids **14** and **16** at a phase angle of say 135°, and curve D represents a resonant particle entering at a different phase angle. Since each curve defines equal areas above and below base or zero line **18**, it follows that the resonant particles of different phase as represented by the two curves pass through the full-wave gap system without any net energy change.

Fig. 3 is a schematic diagram of one form of apparatus in accordance with the invention and includes an ion source **20**, a half-wave gap system **22** comprising spaced grids **22A** through **22E**, a bucking grid **24**, a full-wave gap system **26** comprising spaced grids **26A** and **26B**, a second bucking grid **28** and a collector electrode **30**. A sensory device **32** of conventional nature such as a D. C. amplifier and recorder, provides means for sensing the discharge currents produced at the collector electrode. A first oscillator **34** is connected to the half-wave gap system and is adapted to apply an R. F. voltage, preferably a square wave, to the system. A second oscillator **36** is connected to the full-wave gap system to apply an R. F. voltage, preferably a sine wave, to this system.

A voltage source **38**, shown schematically as a voltage divider, provides suitable operating potentials to the ion source, a D. C. bias to the grids of the half-wave and full-wave arrays and suitable bucking potentials on the grids **24** and **28**, the polarity shown in Fig. 3 being chosen for mass separation of positively charged ions.

The operation of the half-wave gap system **22** is to impart more energy to certain ions than to others, the ions receiving the maximum energy being those injected with a certain velocity and phase. A single half-wave gap will act as a high pass velocity filter. With a square wave on the gap, all masses which enter with optimum phase and which are lighter than the critical mass are passed with maximum energy. A particle heavier than the resonant mass will require more than a half period to cross any gap and will thus acquire less than resonant energy at any gap traversal. Impression of a sine wave oscillation on the half-wave gap system changes the detailed shape but not the general characteristics of the response.

Two gaps in series driven 180° out-of-phase still function principally as a high pass velocity filter. With a square wave potential the effect of the second gap is to restrict the part of the beam which acquires maximum energy from the system to particles which cross the gap interface at the instant the field changes sign and thus to sharpen the response characteristics. With three or more consecutive gaps there is appreciable true velocity separation. Particles which have optimum transit times and optimum entrance phase angle gain appreciably more energy than any others, and all others can, in principle, be rejected from the emergent beam by a simple bucking potential. It is possible to derive mathematically an expression for the total energy acquired by a resonant particle as it passes through a three-gap system driven by square waves. The expression is:

$$\Delta W = 3aE_1 \qquad (1)$$

where

ΔW=particle energy acquired from the gap system.

a=gap width.

E_1=the peak magnitude of the electric field in the gap.

By way of explanation of the performance of a charged particle, the traversal time through a gap is given by the following expression:

$$t=\sqrt{\frac{m}{q}}\left[\sqrt{2(W_0/E_1^2+a/E_1)}-\sqrt{\frac{2W_0}{E_1}}\right] \qquad (2)$$

where

$\frac{m}{q}$=specific mass W_0=initial ion energy

From Equation 2 it is possible to derive the fact that a particle lighter than resonant by one mass unit in fifty which crosses the interface between the first and second gaps at the optimum instant will cross the interface between the second and third gaps 1% too soon and will, in the third gap, move against a bucking field for 1% of the cycle and will move with an accelerating field for only 99% of the cycle. Such a particle will acquire from such a three-gap system 99.3% of the energy acquired by a resonant particle. The conditions discussed above hold approximately true with a sine wave configuration on the three-gap array. A fourth gap is somewhat more effective in the elimination of non-resonant particles and the effectiveness of a gap system increases with increasing number of gaps. Clean separation by the half-wave gap system operated with a square wave driving voltage requires that at least three consecutive gap positions be energized.

The half-wave system is self-chopping. It will reject all masses which fail to satisfy the conditions on entrance phase and transit angle which are imposed by the requirement of maximum energy transfer. Hence the intensity is inversely dependent upon resolving power and, if operating such a system at high resolution, much less than 1% of the ions of resonant mass which are available will actually reach the collector. It is because of this extremely low efficiency of the half-wave system when operated at high resolution that the apparatus of the invention is superior to the linear R. F. mass spectrometers based solely on half-wave gap systems.

It has been shown that particles heavier than the resonant particles will gain less energy than the resonant mass in traversing every gap of the half-wave gap system; whereas the resonant particles will emerge with the largest energy gain. The particles that are lighter than the resonant particles are discriminated against only until their velocity matches that of the resonant particles, so that they emerge from the gap system with approximately the velocity of the resonant ions. It is essential, of course, that the fractional energy spread in the injected beam must be maintained less than the fractional mass resolution desired. If separation between mass **99** and mass **100** is sought, the most energetic particle of mass **99** may not have an energy greater than 1% of the nominal injection energy, for if it did it would be in velocity match with the resonant ions of mass **100** and would never be rejected by the half-wave system.

The bucking grid **24** following the half-wave gap system is maintained at a D. C. potential which will completely reject any ions heavier than the resonant mass. Resonant ions will pass through the bucking grid as will a limited number of the lighter than resonant ions which have been slowed down by the half wave gap system until their velocity matches that of the resonant ions. It is possible to bias bucking grid **24** so as to reject lighter-than-resonant ions as well, but such operation also rejects a great many resonant ions and gives a reduction in efficiency for resonant ions which it is a principal object of this invention to alleviate.

The full-wave gap system **26** should be designed and driven such that the product

$$nE_0d \sin \alpha/W_0 \qquad (3)$$

is as high as possible, where the field strength (E_2) in the gap is given by

$$E_2=E_0 \sin (\omega t+\alpha) \qquad (4)$$

where

n=number of cycles the resonant particles spends in the gap;

E_0=peak electric field strength across the gap;

d=the gap width;

ω=the angular frequency of the r. f. voltage on the gap;

W_0=the ion injection voltage; and

α=the entrance phase angle of the ion.

There is nothing to be gained at the full-wave gap system by having more than one gap, a single gap being illustrated in the drawing. If additional gaps are employed they must be driven in phase. The ion beam entering the full wave gap system should be chopped in such a way as to exclude harmonic ions and to ensure that sin α is of one sign only. In the instant apparatus this is accomplished automatically by the half-wave gap system.

As mentioned above, the action of the half-wave system is to split the incident ion beam into two parts, with the resonant particles at the dividing line. Particles heavier than resonant will lose energy at every gap traversal until they are finally stopped either in the gap system itself (see Fig. 4 and description thereof) or by the bucking grid **24** in the embodiment of Fig. 3. The lighter particles lose energy until their velocity matches that of the resonant ions and thereafter proceed with no hindrance. Since the half-wave gap system passes resonant ions and any non-resonant ions of the same velocity as that of resonant ions, a succeeding gap system would ordinarily be helpless to effect any further separation. This velocity degeneracy is removed by the action of a D. C. field following the half-wave gap system whether the action of the field is to accelerate or decelerate the beam, so that the use of the bucking grid **24** in Fig. 3 or grid **58** of Fig. 4 removes the degeneracy, but in doing so it slows down the ion beam to such an extent that space charge effects are very objectionable. Consequently, the preferred embodiment is one in which the D. C. potential difference between the full-wave gap system **26** and the half-wave gap system **22** of Fig. 3 or **50** in Fig. 4 is such as to accelerate the ion beam. This arrangement serves both to remove the velocity degeneracy and to minimize the effects of space charge. It can be shown mathematically that this arrangement will develop a velocity difference between resonant and lighter non-resonant ions of adjacent mass even though there was complete velocity degeneracy in the beam emerging from the half-wave gap system.

If velocity degeneracy is removed by a net acceleration of the ions between gap systems **22** and **26**, the entrance phase in **26** should be controlled such that sin α (Equation 4) is positive.

The foregoing emphasizes the fact that in the apparatus of the invention there is no requirement that the half-wave gap system operate at high resolution in the sense of requiring that the energy of lighter than resonant particles be reduced as far as possible. In fact the velocity degeneracy referred to above results from the fact that the resolution, for some particles, is already too high.

In the system shown in Fig. 3 in which the grids of the half-wave gap system are provided with no D. C. bias, grid spacing is increased uniformly in the direction of ion travel. In this system rejection of the heavier than resonant ions and most of the lighter than resonant ions is accomplished at the bucking grid **24**. An alternative arrangement is shown in Fig. 4 in which a bucking potential is applied to the grids of the half-wave gap system.

Referring to Fig. 4, the mass spectrometer there shown is identical to that of Fig. 3 to the extent of ion source **20**, full-wave gap system **26**, bucking grid **28**, collector electrode **30**, sensory circuit **32** and a D. C. voltage source **38**. A half-wave gap system **50** is oriented in the same manner as the corresponding gap array **22** of the apparatus of Fig. 3. Each of the grids **50A, B, C, D**, and **E** are connected through respective R. F. chokes **52** to a voltage divider **54**, which is in turn connected across a suitable portion of the voltage source **38**. In this fashion a bucking field is developed across the half-wave array which, if properly distributed, permits uniform spacing of the grids. An oscillator **55** is connected across the grid system through capacitors **56**.

The following example of the operation of the instrument illustrated in Fig. 4 will facilitate an understanding of the invention. A gas sample from which a range of ion masses in the neighborhood of mass **100** is derivable, is ionized in the ion source **20** and is propelled from the source by conventional accelerating means to be injected at grid **50A** of the half-wave gap system **50** with 100 volts energy. The several gaps in the half-wave gap system are spaced one centimeter apart and a square wave driving voltage of a frequency of 725 kilocycles and a 40 volt peak to peak amplitude is impressed on the grid system from the oscillator **55**. A D. C. bucking potential of 20 volts is impressed on each gap from the source **38**. Under these conditions a particle of mass **100** emerges from grid **50E** with 100 volts energy (energy unchanged) at a velocity of 1.38×10^6 centimeters per second. The particles of mass **101** or heavier emerge from **50E** with a kinetic energy somewhat less than a maximum of 97 volts. A particle of mass 99 emerges at a maximum energy of 99 volts and at a velocity equal to that of the resonant particle of mass **100**. The bucking grid **58** is biased at −3 volts (with respect to the source) to reject all particles with mass **101** and over. This grid will at the same time reject all particles of less than the resonant mass which emerge from the half-wave system with less than 97 volts kinetic energy. Hence the ions pass through the bucking grid **58** with a kinetic energy spread from 0 to 3 electron volts.

The first grid **26A** of the full-wave gap system is biased at 500 volts negative with respect to the bucking grid **58** so as to establish in the region between the bucking grid and the grid **26A** a D. C. accelerating field for the purposes heretofore described. With this accelerating field the ions passing through the grid **58** at substantially complete velocity degeneracy will enter the full-wave system through grid **26A** with a velocity spread of from approximately 3.095 to 3.167×10^6 centimeters per second for masses **98, 99** and **100**. A sine wave of frequency 1.45 megacycles is imposed across grids **26A** and **26B** by the oscillator **36**, the grids being spaced 10.9 centimeters apart. Under these conditions the resonant mass (mass **100**) requires five complete cycles to traverse this gap. If the full-wave gap system is driven at 150 volts, the system results in an energy separation of approximately 3.8 volts between the resonant mass and the adjacent mass **99**. The bucking grid **28** easily separates between masses of this energy spread so that only mass **100** strikes upon and discharges at collector **30** at the conditions stated.

By raising the number of half-wave gaps to six or seven, dividing the frequencies of the driving voltages applied to the half and full-wave gap systems by a factor of the square root of 2 and approximately doubling the spacing between the grids **26A** and **26B** and also the D. C. accelerating voltage between the grids **58** and **26A**, selective separation of mass **200** is feasible.

The invention is not limited to the particular embodiments illustrated, it being obvious from the foregoing discussion that variations in operating conditions and in the number of gaps provided in each of the half-wave and full-wave systems are feasible.

I claim:

1. A method of mass separation which comprises ionizing a sample, subjecting the ions to a half-wave linear ratio frequency electrical field, imposing a first D. C. bucking field on the ions to reject ions of kinetic energy lower than a pre-

determined value, subjecting the unrejected ions to a full-wave linear ratio frequency field, imposing a second D. C. bucking field on the ions to again reject ions of kinetic energy lower than a predetermined value, and collecting the ions emerging from the second bucking field.

2. A method of mass separation which comprises ionizing a sample, injecting the ions into a half-wave linear radio frequency electrical field, imposing a first D. C. bucking field on the ions to reject ions of kinetic energy lower than a predetermined value, injecting the unrejected ions into a full-wave linear radio frequency field, imposing a second D. C. bucking field on the ions to again reject ions of kinetic energy lower than a predetermined value, and collecting ions emerging from the second bucking field.

3. A method of mass separation which comprises ionizing a sample, injecting the ions into a half-wave linear radio frequency electrical field, imposing a first D. C. bucking field on the ions emerging from the half-wave field to reject ions of kinetic energy lower than a predetermined value, injecting the unrejected ions into a full-wave linear radio frequency field, imposing a second D. C. bucking field on the ions emerging from the full-wave field to again reject ions of kinetic energy lower than a predetermined value, and collecting ions emerging from the second bucking field.

4. A method of mass separation which comprises ionizing a sample, injecting the ions into a half-wave linear radio frequency electrical field, imposing a first D. C. bucking field on the ions within the half-wave field to reject ions of kinetic energy lower than a predetermined value, injecting the ions emerging from the half-wave field into a full wave linear radio frequency field, imposing a second D. C. bucking field on the ions emerging from the full-wave field to again reject ions of kinetic energy lower than a predetermined value, and collecting ions emerging from the second bucking field.

5. A method of mass separation which comprises ionizing a sample, injecting the ions into a half-wave linear radio frequency electrical field, imposing a first D. C. bucking field on the tions to reject ions of kinetic energy lower than a predetermined value, inducing velocity dispersion among the ions unrejected in the first bucking field, injecting these unrejected ions into a full-wave linear radio frequency field, imposing a second D. C. bucking field on the ions emerging from the full-wave field to again reject ions of kinetic energy lower than a predetermined value, and collecting the ions emerging from the second D. C. field.

6. A method of mass separation which comprises ionizing a sample, subjecting the ions to a half-wave linear radio frequency electrical field, imposing a first D. C. bucking field on the ions to reject ions of kinetic energy lower than a predetermined value, subjecting the ions to a D. C. accelerating field, injecting ions passing through the D. C. accelerating field into a full-wave linear radio frequency field, imposing a second D. C. bucking field on the ions to again reject ions of kinetic energy lower than a predetermined value, and collecting ions emerging from the second bucking field.

7. A mass spectrometer comprising a half-wave linear radio frequency gap system, a full-wave linear radio frequency gap system and a collector electrode in serial arrangement, means for ionizing a sample to be analyzed and introducing ions

into the half-way gap system, means for injecting ions passing through the half-wave system into the full-wave gap system, means developing a first D. C. bucking potential to prevent ions having less than a given kinetic energy from entering the full-wave gap system, and means developing a second D. C. bucking potential between the full-wave gap system and the collector electrode.

8. A mass spectrometer comprising a half-wave linear radio frequency gap system, a full-wave linear radio frequency gap system and a collector electrode in serial arrangement, an ion source including means for injecting ions into the half-wave gap system, means for injecting ions passing through the half-wave gap system into the full-wave gap system, means developing a first D. C. bucking potential to prevent ions having less than a given kinetic energy from entering the full-wave gap system, and means developing a second D. C. bucking potential between the full wave gap system and the collector electrode.

9. A mass spectrometer comprising a half-wave linear radio frequency gap system, a full-wave linear radio frequency gap system and a collector electrode in serial arrangement, an ion source including means for injecting ions into the half-wave gap system, means for superimposing a D. C. bucking potential across the half-wave gap system to reject ions which fall below a given kinetic energy, means for injecting ions passing through the half-wave gap system into the full-wave gap system, and means developing a second D. C. bucking potential between the full-wave gap system and the collector electrode.

10. A mass spectrometer comprising a half-wave linear radio frequency gap system, a full-wave linear radio frequency gap system and a collector electrode in serial arrangement, an ion source including means for injecting ions into the half-wave gap system, a first bucking grid disposed between the half and full-wave gap systems, means for impressing a D. C. bucking potential on the first bucking grid, means for injecting ions passing through the first bucking grid into the full-wave gap system, a second bucking grid disposed between the full-wave gap system and the collector electrode, and means for impressing a D. C. bucking potential on the second bucking grid.

11. A mass spectrometer comprising a half-wave linear radio frequency gap system, a full-wave linear radio frequency gap system and a collector electrode in serial arrangement, and an ion source including means for injecting ions into the half-wave gap system.

12. A mass spectrometer comprising a half-wave linear radio frequency gap system, a full-wave linear radio frequency gap system and a collector electrode in serial arrangement, an ion source including means for injecting ions into the half-wave gap system, means for establishing a first D. C. bucking field to prevent ions of less than a given kinetic energy from entering the full-wave gap system, velocity dispersion means for developing a velocity dispersion among the ions passing through the first D. C. bucking field, and means developing a second D. C. bucking potential between the full-wave gap system and the collector electrode.

13. Apparatus according to claim 12 wherein the means developing first and second D. C. bucking fields comprise first and second buck-

ing grids disposed respectively between the half-wave and full-wave gap systems and between the full-wave gap system and the collector electrode, and means for impressing a D. C. potential on the first and second bucking grids.

14. Apparatus according to claim 12 wherein the means developing a first D. C. bucking field and the velocity dispersion means comprise a grid disposed between the half-wave and full-wave gap systems, and means for impressing on the grid a D. C. voltage in opposition to ion passage through the grid whereby ions of less than a predetermined kinetic energy will not pass through the grid and other ions will be decelerated as a function of mass.

15. Apparatus according to claim 12 wherein

the means developing a first D. C. bucking field comprises a bucking grid disposed between the half-wave and full-wave gap systems and means impressing a D. C. bucking voltage on the grid and the velocity dispersion means comprises means for biasing the first grid of the full-wave gap system with a D. C. voltage of such polarity as to develop an ion accelerating gap between the bucking grid and said first grid.

16. Apparatus according to claim 12 wherein the means developing a first D. C. bucking field comprises means for superimposing on the half-wave gap system a D. C. potential in opposition to ion travel through the gap system.

CHARLES F. ROBINSON.

No references cited.