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Dawson

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[54] **HIGH-RESOLUTION FOCUSSING DIPOLE MASS SPECTROMETER**

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[73] Assignee: **Canadian Patents & Development Limited,** Ottawa, Canada

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[30] **Foreign Application Priority Data**

July 20, 1973 Canada 176936

[52] **U.S. Cl.** **250/290;** 250/292; 250/293

[51] **Int. Cl.**[2] **B01D 59/44**

[58] **Field of Search** 250/281, 282, 290, 291, 250/292, 293

[56] **References Cited**

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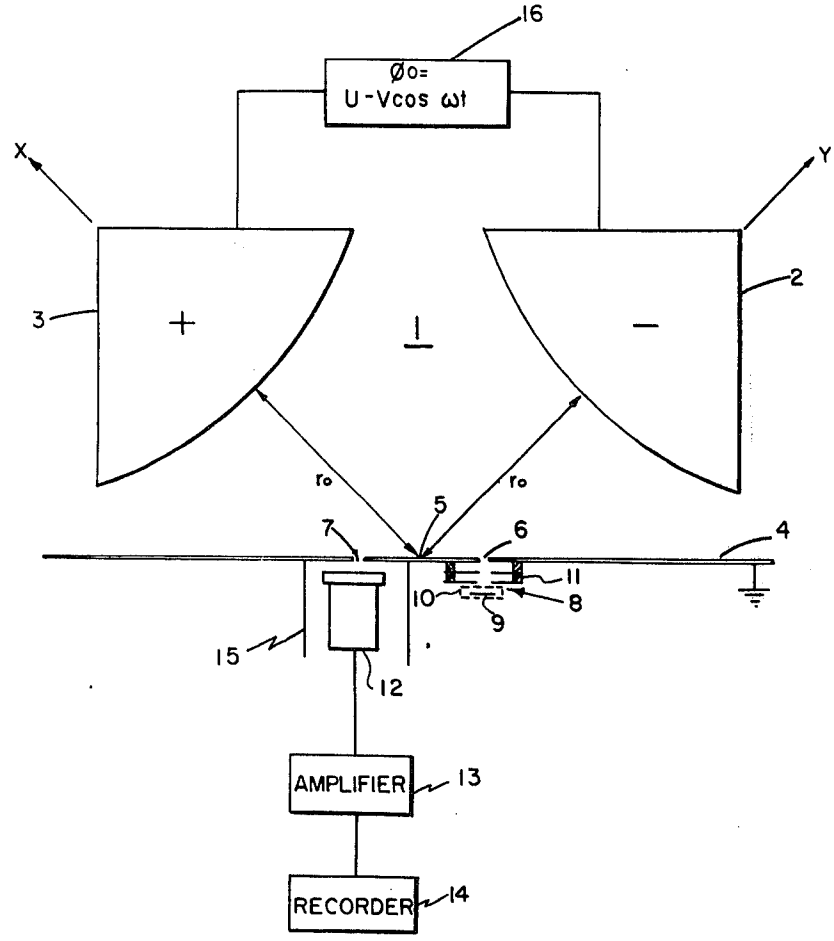
Assistant Examiner—D. C. Nelms
Attorney, Agent, or Firm—Edward Rymek

[57] **ABSTRACT**

The high-resolution focussing dipole mass spectrometer consists of two suitably spaced hyperbolic rods and a grounded plate electrode in a plane parallel to the rods. A voltage consisting of a constant voltage U and an alternating voltage V cos ωt is applied between the rods. Low energy ions are injected into the field transversely to the rods, through an entrance slit in the plate. Ions of the particular mass are focussed by the field so as to leave the device through an exit slit in the plate. By using the focussing properties of quadrupole fields, both a high resolution and a large mass range is possible while preserving the usual advantages of quadrupole mass spectrometers.

15 Claims, 12 Drawing Figures



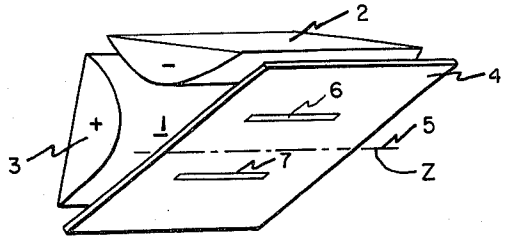

2
4
6
5
3
1
7
Z

FIG. 1

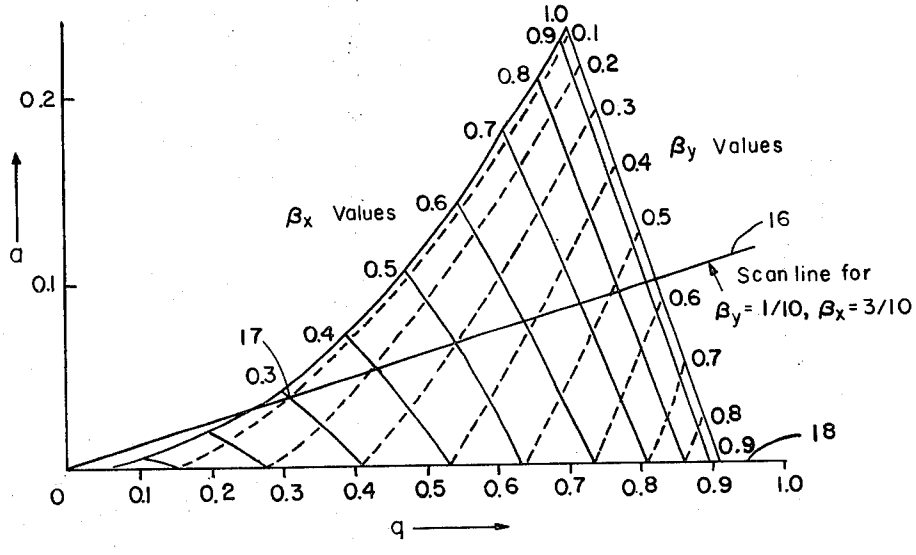

1.0
0.9
0.1
0.8
0.2
0.3
0.7
0.4
β_y Values
β_x Values
0.6
0.5
16
Scan line for
β_y = 1/10, β_x = 3/10
0.5
0.6
17
0.4
0.3
0.7
0.8
0.9
18
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
q

FIG. 3

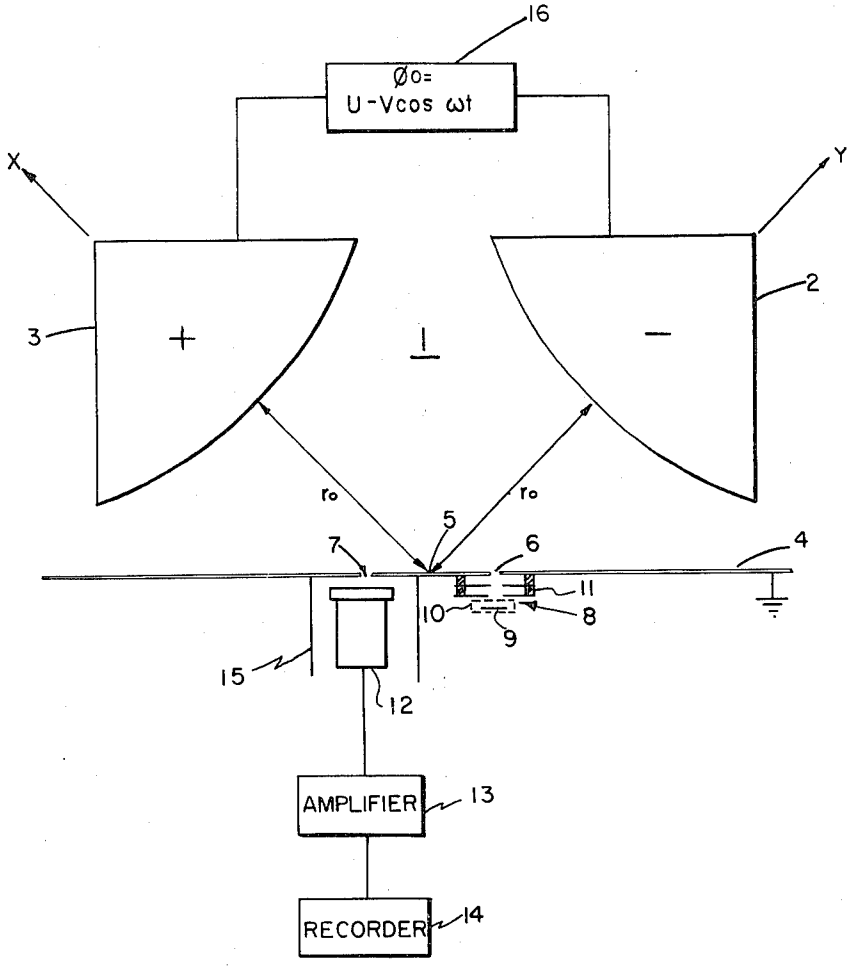

16
Ø0=
U-Vcos ωt
X
Y
3
+
1
−
2
r0
r0
5
7
6
4
11
10
8
9
15
12
AMPLIFIER
13
RECORDER
14

FIG. 2

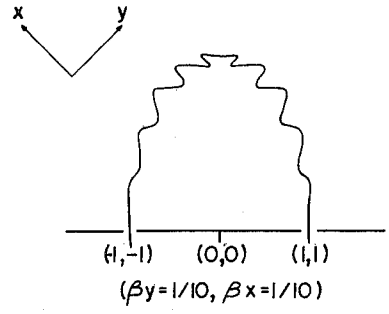


FIG. 4a

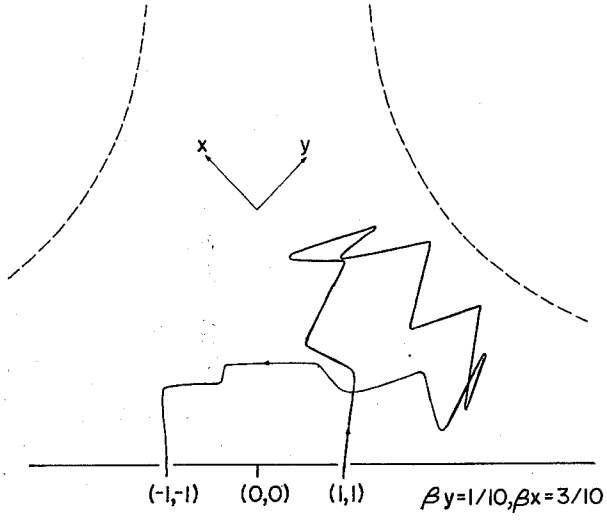


FIG. 4b

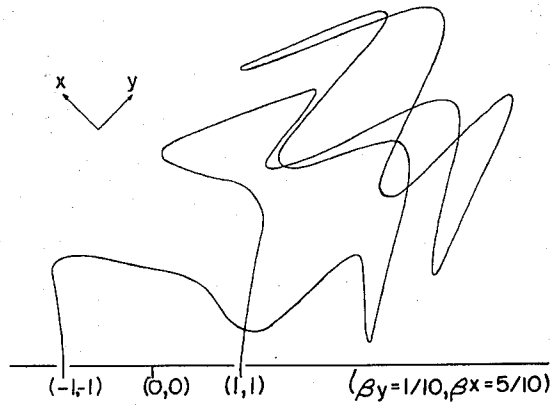


FIG. 4c

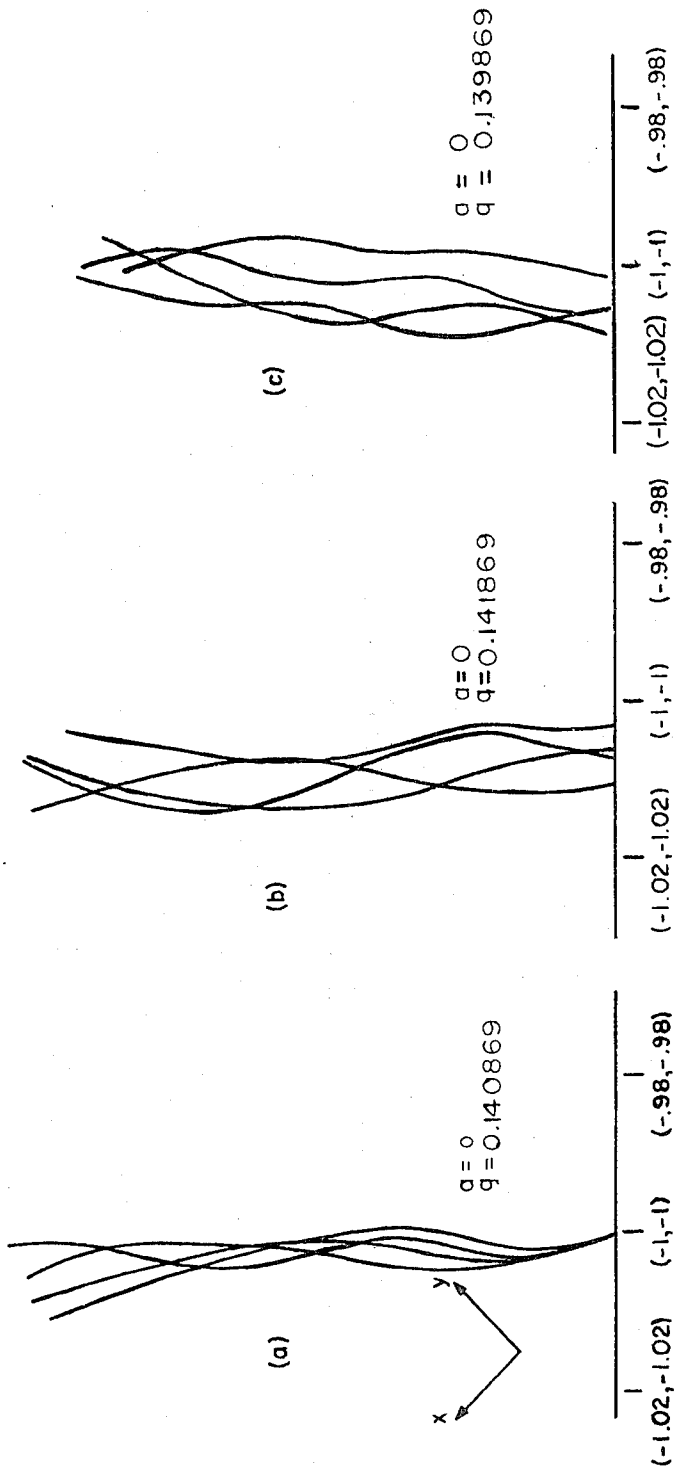


FIG. 5a

FIG. 5b

FIG. 5c

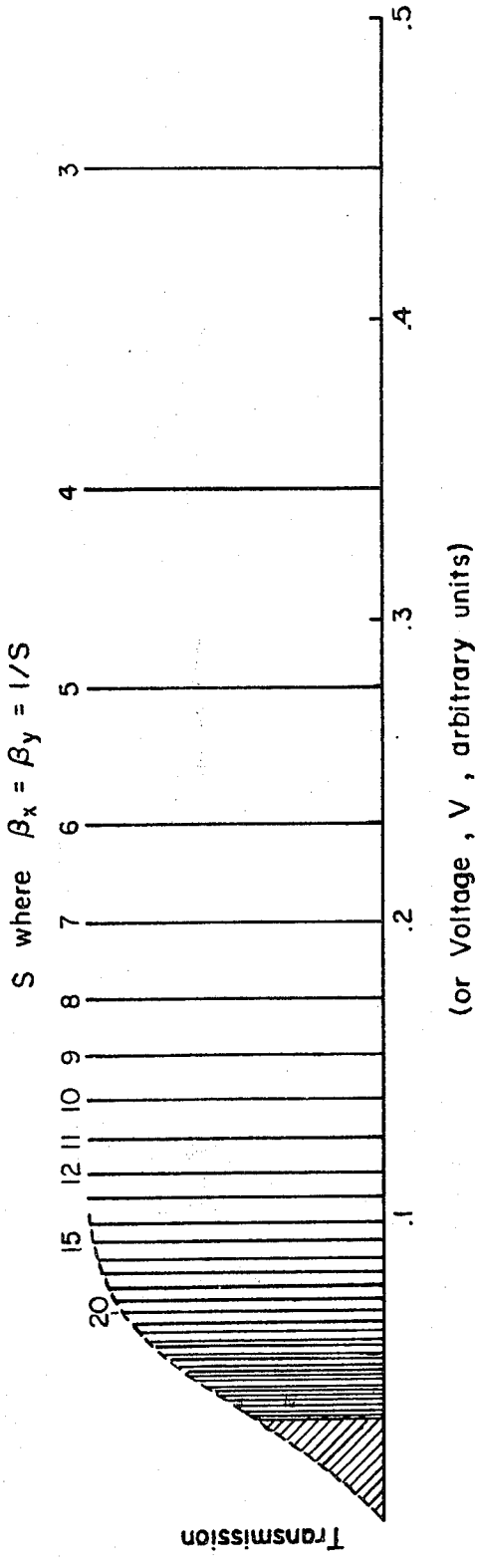

Transmission
S where $\beta_x = \beta_y = 1/S$
(or Voltage , V , arbitrary units)
.5
.4
.3
.2
.1
3
4
5
6
7
8
9
10
11
12
15
20

FIG.6

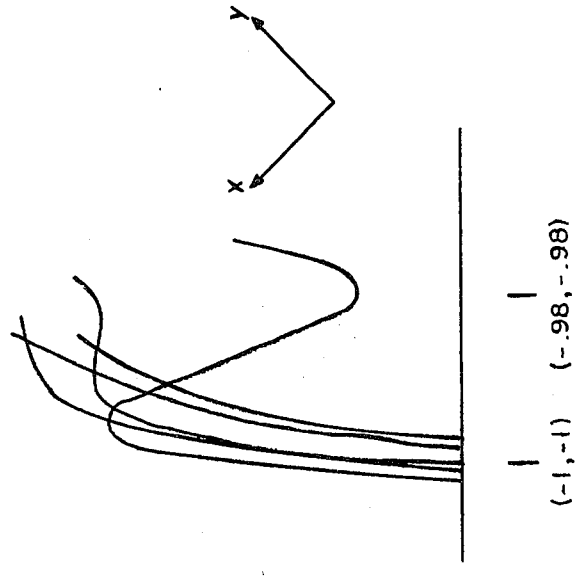


FIG.8

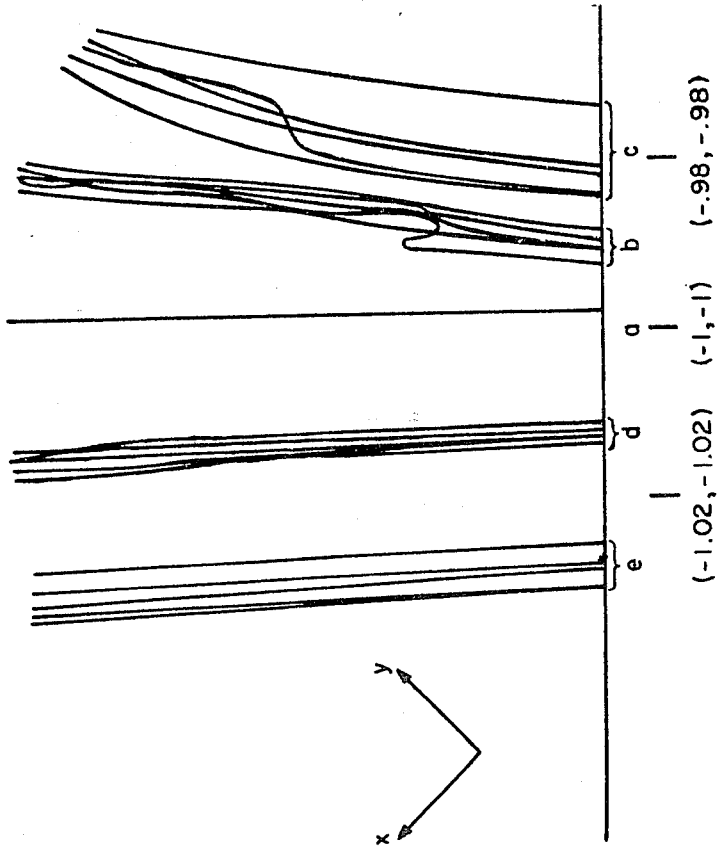


FIG.7

HIGH-RESOLUTION FOCUSSING DIPOLE MASS SPECTROMETER

This invention relates to a novel mass spectrometer and in particular to a dipole device which uses the focussing properties of quadrupole fields.

The use of quadrupole fields in mass spectrometry has been extensively studied and in particular, the quadrupole mass filter has found wide application. The mass filter, as implied by the name, transmits only ions of a small range of m/e values. Other ions have unstable trajectories so that their amplitudes of transverse oscillation become large and the ions are lost from the device. There is a filtering rather than a focussing action. The principal advantages of the mass filter have been the absence of a magnetic filed, the compactness, rapid electronic scanning and, in some cases, the relative independance of instrument performance on initial ion energy. The limitations have been (a) the difficulties of achieving resolving powers greater than 1000 without a great loss of sensitivity due to the rapid increase in oscillation amplitudes as the stability boundary is approached and (b) the high rf voltages required at high masses. The amplitude of the required high frequency voltage between opposite pairs of rods is proportional to the m/e ratio.
i.e.

$$V = \frac{q}{2} \frac{m}{e} r_o^2 \omega^2 \qquad (1)$$

where r_o is half the rod separation, ω is the angular frequency of the applied field and $q \approx 0.706$ at high resolution. The requirements of a high V at high masses could be eased by a lower frequency. However, the mass filter resolving power depends, in part, on the number of cycles an ion spends in the field, n. For an ion of a given mass and a given injection energy, the maximum resolving power attainable is proportional to ω^2. Therefore the problem of very high voltages for high masses can only be overcome by sacrificing resolution or building longer instruments.

The mass filter merely uses the path stability properties of quadrupole fields as expressed in the Mathieu equation of motion; ions of a m/e higher than those transmitted are unstable in the x direction and ions of a lower m/e are unstable in the y direction. However, the exact focussing properties of quadrupole fields under certain well-defined (a, q) conditions are well known. An attempt was made to utilize these properties with the invention of the monopole by U. von Zahn as described in the Review of Scientific Instruments 43 (1963) 1. The monopole no longer depends on stability properties near the tip of the stability diagram but uses a lower ratio a/q as a scan line. The mass separation depends on the nature of ion trajectories near the y stability boundary. von Zahn considered the possibility of utilizing focussing in both x and y directions simultaneously but subsequent computer simulations have shown that the monopole, as commonly used with ion injection parallel to the instrument axis, only involves a partial focussing in the y direction and none in the x direction. Recently the importance of fringing fields in achieving high performance with this mode of operation has been demonstrated.

As described by R. E. Lever — IBM J. Res. Dev. 10 (1966) 26, it has been shown that a two-directional-focussing monopole (that is, using both x and y directions), should be possible with ion injection at a small angle to the instrument axis. He suggested that application of this principle should make possible the achievement of very high resolution in a small device. The exact focussing in two directions occurs only for certain specific pairs of (a,q) values some of which Lever tabulated. Ions are focussed after an exact number of rf cycles within the field. This means that since ions are travelling along the axis of the instrument, they must all have precisely the same velocity in order to be focussed on the exit hole and to produce a high resolution. Hence, one of the attractive features of the mass filter is sacrificed in return for the promise of high resolution in a short device. However, the circular entrance aperture would have to be small to retain the high resolution, the small area thus limiting instrument sensitivity. In magnetic sector instruments, for example, the very narrow rectangular entrance and exit slits necessary for high resolution still have appreciable aperture area. Recently a resolution better than 300 in a 30 cm long device has been attained in the operation of a monopole in the mode suggested by Lever.

It is therefore an object of this invention to obtain a very high resolution in a compact instrument.

A further object of the invention is to retain the quadrupole mass filters relative independance from initial ion energy to render a velocity selector unnecessary.

Yet another object of this invention is to provide a device which will operate at lower rf frequencies without loss of resolution resulting in lower voltage requirements at high masses.

A further object is to provide a device having a rectangular entrance and exit slit system such that aperture area reamins appreciable with narrow slits.

These and other objects are achieved by a dipole device having two suitably spaced rods and a grounded plane electrode in a plane parallel to the rods. Ions entrance and exit slits are symmetrically located in the grounded plane electrode. A voltage consisting of a d.c. voltage U and rf voltage V cos ωt is applied between the rods. Low energy ions are injected into the field through the entrance slit, transversely to the rods. Ions of a particular mass will be focussed and will leave the device through the exit slit.

In the drawings:

FIG. 1 is a perspective view of the dipole spectrometer,

FIG. 2 is a cross-section of the dipole spectrometer;

FIG. 3 is the a,q stability diagram for ion motion in a quadrupole field;

FIGS. 4*a*, 4*b* and 4*c* are examples of ion trajectories for various values of β_y and β_x.

FIGS. 5*a*, 5*b* and 5*c* illustrate the variation of the focussing properties at the exit slit when q is varied.

FIG. 6 represents the transmission characteristic for ions of a particular mass as the voltage V is scanned when the d.c. voltage U is zero,

FIG. 7 illustrates ion trajectories near the exit slit for the scan line passing through the point $\beta_y = 1/10$, $\beta_x = 3/10$, each set showing five initial phases of the alternating field; and

FIG. 8 illustrates the results of an error in the choice of a q/a ratio.

The basic spectrometer **1** shown in FIGS. **1** and **2** consists of three electrodes, two rods **2** and **3** and a grounded plate **4,** which are symmetrically spaced with regard to centerline **5** on plate **4** which is taken as the *z* axis for rectangular co-ordinates. The *x* and *y* axes run from point **5** through the center of rods **2** or **3** (FIG. **2**). Rods **2** and **3** may have a circular cross-section however for best operation a hyperbolic face is desired. The electrodes may be made from stainless steel, molybdenum, metallic coated ceramic or any other material commonly used for electrodes in mass spectrometers. The hyperbolic rods are required to be of sufficient length to minimize "end effects" caused by fringing fields. A practical length would be approximately 3 r_o where r_o is the minimum distance from the point **5** to the hyperbolic rod. Ion entrance and exit slits **6,** and **7** respectively, are symmetrically located in the grounded plate **4** equidistant from centerline **5.** Slit width should be kept to a minimum to achieve high resolution i.e. approximately 1/10 mm for high performance, however slit length may be up to 2 cm. for greater sensitivity.

Also shown in FIG. **2** is a typical ion source **8** consisting of a hot filament electron beam source **9,** an electron beam trap **10** and an ion focussing electrode **11,** mounted on plate **4** so as to provide a low energy ion beam to the device through entrance slit **6.** The ions could have an energy of 1–5 eV but are typically in the range of 1–2 eV.

The ion beam should enter the field perpendicular to the grounded plate **4.** However, due to the difficulty of forming low energy ions beams, some ions will enter the field at slight angles in the *x–y* plane, this may be tolerated as it will not effect spectrometer focussing. Other ions may have a slight velocity in the *z* direction. As the field will not effect this velocity, these ions will be focussed along a line running through the length of the exit slit, and will either leave the device along the length of slit **7** or will hit the grounded plate.

Block **12** represents an ion detector mounted over the exit slit **7.** A Faraday cup collector or, for greater sensitivity, an electron multiplier may be used. The detector signal is fed to an ion current amplifier **13** which is coupled to a mass spectrum recorder **14. 15** represents a shield normally used with ion detector. This entire electrode system which ion source and detector is mounted in a vacuum system (not shown) with an auxiliary system to permit entry of the gas to be analysed. Typical vacuums used are in the order of 10^{-5} to 10^{-8} Torr.

Finally the device is provided with a scanning power supply **16** which provides the rods **2** and **3** with a voltage $\phi_o = U - V(t)$. *U* is a d.c. potential with the negative pole connected to rod **2** and the positive pole connected to rod **3.** The voltage midpoint between the two rods is at ground potential. $Vf(t)$ is an alternating potential with a zero to peak voltage *V*. Under typical operation, $Vf(t)$ is a sinusoidal voltage and is represented by $V \cos \omega t$.

In operation ions are injected transversely to the rods from a position $x_o = y_o$ with initial velcoities y_o and $-x_o$. The z_o velocity will generally be close to zero. The ions leave the instrument at the position $-x_o, -y_o$ with velocities (when focussed) of $-y_o$ and x_o. That is, the field is required to produce an inverted "image" in both *x* and *y* directions. If r_o is the minimum distance from the centre of the field to the rods, the equations of motion in the *x* and *y* directions are expressed by the Mathieu equation

$$\frac{d_u^2}{d\xi^2} + (a - 2q \cos 2(\xi - \xi_o))u = 0 \qquad (2)$$

where $\xi = \omega t/2$ and ξ_o represents the initial phase of the alternating voltage when the ion enter the field where from equation (1),

$$q_y = -9_x = 2eV/mr_o^2\,\omega^2 \qquad (3)$$

$$a_y = -a_x = 4eU/mr_o^2\,\omega^2 \qquad (4)$$

The properties of the Mathieu equation are described by the stability diagram as shown in FIG. **3.** This is made up of superimposed stability diagrams for the *x* and *y* directions. For (*a,q*) values inside the triangular area, the ion trajectories are stable (of limited amplitude) in both *x* and *y* directions. The nature of ion motion is defined by the $\beta_{x,y}$ values. The fundamental frequency of the ion oscillation in a particular coordinate direction is given by

$$\omega_o = \beta/2.\omega \qquad (5)$$

and other superimposed frequencies by

$$\omega_1 = \left(1 - \frac{\beta}{2}\right)\omega,\ \omega_2 = \left(1 + \frac{\beta}{2}\right)\omega \text{ etc.} \qquad (6)$$

As pointed out by Lever in the article referred to above, an inverted image is formed after S field cycles when $\beta_y = 1/S$ and *S* is an integer. An inverted image will also be formed after S cycles when $\beta_x = P/S$ and *P* is an odd integer ($1 \leq P < S$).

Therefore ions will be transmitted by the instrument for (*a,q*) conditions where $\beta_y = 1/S$ and $\beta_x = P/S$ ($1 \leq P < S$ and *P* is odd) subject to the condition that at all times $y > x$ so that the ion does not prematurely strike the ground electrode **4.** Ions with a mass related to the *a* and *q* of 0.037966 and 0.309820 as defined in equation (3) and (4) will be focussed on the slit, all other ions of different mass will either hit the ground electrode at a point some distance from the slit or will be lost.

One scan line **16** for $\beta_y = 1/10$ and $\beta_x = 3/10$ is shown on FIG. **3.** Table 1 below taken from the work of Lever, lists some possible *a,q* operating points. Values for P close to S can be excluded because the rapid oscillation in the *x* direction causes the ion to strike the grounded plane.

TABLE 1

Values of a (upper) and q (lower) satisfying the condition $\beta_y(a,q) = 1/s$, $\beta_x(-a, -q) = P/S$ as calculated by Lever

Values of S	Values of P 1	3	5
5	.000000	.126186	
	.278436	.575816	
6	.000000	.095019	
	.233150	.495503	
7	.000000	.073030	.175636
	.200422	.432374	.633358
8	.000000	.057492	.147256
	.175699	.382516	.576545
9	.000000	.046272	.123236
	.156378	.342500	.525286
10	.000000	.037966	.103772
	.140869	.309820	.480593
11	.000000	.031673	.088154
	.128150	.282696	.441966
12	.000000	.026802	.075590
	.117532	.259856	.408554

FIGS. **4***a*, **4***b* and **4***c* illustrate the general nature of the trajectories involved and the influence of the choice of the P value. FIG. **4***a* is a trajectory for $\beta_y = \beta_x$

$= 1/10$ when the initial phase of the field ξ_o equals 2.356 (the optimum for ion transmission). The equations of motion are linear with respect to u (that is, x and y) and therefore ion motion can be arbitrarily scaled. The initial displacements x_o and y_o are always taken as unity. The initial velocities, in order to be readily scaled, are best expressed in terms of $[\xi]^{-1}$. In each case, for FIG. **4**, the x and y velocities were -0.05 and $+0.05$ respectively. FIG. **4***b* shows a trajectory ($\xi_o = 2.356$) for $a_y = 0.037966$, $q_y = 0.309820$ or $\beta_y = 1/10$ and $\beta_x = 3/10$. FIG. **4***c* is a similar plot for $a_y = 0.103772$, $q_y = 0.480593$ or $\beta_y = 1/10$, $\beta_x = 5/10$. This illustrates the kind of trajectories involved. Generally there is ion transmission with these types of trajectory only during half the *rf* cycle when $a = 0$ ($\beta_x = \beta_y$) and one quarter the *rf* cycle when $a > O$. At other parts of the cycle the field is unfavorable to ion entry into the device or the ions are quickly repulsed by the field and strike the grounded electrode ($x > y$).

The properties of the dipole mass spectrometer may be further detailed by observing its operation under two sets of conditions, (1) when $\beta_x = \beta_y$ and (2) when $\beta_x > \beta_y$.

The first is a special case which occurs when $a = 0$; that is, when no constant voltage is applied between the rods. For a given applied voltage V cos ωt ions of different mass will be spread out along the scan line **18**, $a = 0$, (FIG. **3**) with the lighter masses farthest from the origin. For any ion with $\beta_y = \beta_x = 1/S$, where S is an integer, there will be exact focussing on the exit slit after a trajectory of the type shown in FIG. **4***a*. FIG. **5***a* shows this focussing in detail for the case $S = 10$, $q = 0.140869$ for assumed initial velocities of $\pm 10^{-1}$. The initial phases $\xi_o = 0.6\pi$, 0.7π, 0.8π and $0.9\pi$are shown. The ions are focussed at the same point $x = -1$, $y = -1$, for all these phases are exactly 10 cycles after the ions entered the field. This focussing is independent of the initial velocities, although the ions exit with velocities $\dot{x}_o$ and $-\dot{y}_o$. If slightly different q values are examined, the results are as illustrated in FIGS. **5***b* and **5***c*. The ions are no longer focussed on the point $(-1, -1)$ and cross the plane $x = y$ at different points, at different times and with differing velocities, even for this small change in q. The change in q corresponds, of course, to a change in the voltage amplitude V for an ion of a given mass m or to an ion of a slightly different mass at that same fixed voltage amplitude V. It is evident that a spectrometer operating with the scan line $a = 0$, cannot be used for mass analysis in a simple way. As a "spectrum" is scanned by varying q an ion of a given mass will be transmitted each time $\beta_x = \beta_y = 1/S$. At low q values (or high S), β is very approximately proportional to q, so that the transmitted signal as q is varied would be a series of peaks spaced according to $1/S$ for a given ion. Trajectories similar to those of FIG. **5** but for $\beta = 1/20$ ($q = 0.070644$) show that there is a similar displacement from the exit position for a given percentage variation in q when β is smaller. In fact, about the same absolute variation in q is required to give the same displacement of the mean exit position. This suggests an overall transmission characteristic for a given ion would be as illustrated in FIG. **6**, each transmission peak being roughly of equal width. The diminished intensity at high S suggests qualitatively the loss of sensitivity at low voltages due to the too large amplitudes of the ion oscillations.

The special case of $\beta_y = \beta_x = 1/S$ would be useful in conjunction with very narrow slits to give high resolution but computer processing would be necessary to transform the complex spectra into a simple form in a similar way to the use of Fourier transform methods in optical spectroscopy. The characteristic multiple peak transmission characteristic gives an advantage in sensitivity at the expense of computer processing the spectra.

When $\beta_x > \beta_y$ a simpler, more directly useful situation exists. For example, under operating conditions such that $\beta_y = 1/10$ and $\beta_x = 3/10$ which corresponds to a scan line passing through the point $a = 0.037951$ $q = 0.309700$. It is to be noted that there are some very slight differences in the values found here for exact focussing by examination of ion trajectories and the values calculated by Lever as given in Table 1. Only when the a,q value is at or near this value is the ion transmitted. That is, the transmission characteristic is now a single peak as in a normal mass spectrometer.

As previously stated, transmission can only occur during about 25% of the *rf* cycle, when the field is favorable for ion entry. The resolving power for an instrument of a given size (given initial x and y displacements) can be estimated by examining ion trajectories at different points along the scan line. FIG. **7** shows some examples for $\beta_y = 1/10$, $\beta_x = 3/10$ for five initial phases of the alternating field. ($\xi_o = 2.042$ t**0** 2.670). At $q = 0.309700$, the focussing is not quite at the desired spot but all the phases are similar, the arrival time is about 10.04 periods after injection and the arrival velocities in the x and y directions are close to the initially assumed values of 0.05. The 0.1% change q, produced, for example, by a 0.1% change in the ion mass, gives a separation of about 1% in x and y positions when the initial displacements are unity as illustrated by the groups of trajectories (*b*) and (*d*). The trajectories are no longer focussed. For (*b*), the arrival time at the plane $x = y$, is roughly 10.12 periods and the arrival velocities are phase dependent, but of the order of 0.1. For (*d*) the arrival time is about 9.92 periods after injection and the arrival velocities are roughly 0.12. Clearly, the device gives an excellent mass resolution in relation to the initial displacements. However, the overall size of the device depends largely on the maximum y amplitude of the trajectories as can be seen in FIGS. **4***b* and **4***c*. Table 11 compares the percentage separation of the mean exit position from the unity for several different choices of β_y and β_x for a 0.1% variation in q in each case. The maximum y deflection is also given. The assumed initial x and y velocities were ± 0.05 in each case.

TABLE 2

β_y	β_x	a	q	$\Delta x_{0.1}\%$	$\Delta y_{0.1}$	maximum y deflection
1/10	3/10	0.0380	0.3097	1		4.2
1/10	5/10	0.1038	0.4806	5		7.2
1/12	3/12	0.0268	0.2598	1.4		4.5
1/12	5/12	0.0756	0.4085	5.9		7.0

The performance is seen to improve as both S and P become larger. However, it is to be noted that for $\beta_y = 1/12$, $\beta_x = 7/12$, the x oscillation is such that the ions strike the ground electrode ($x > y$) after only 1.9 periods. Even higher performance could be achieved by choosing higher S values, with only small increases in the device size. The higher S values would also be associated with somewhat lower voltages for a given mass.

The focussing in this device does not depend on the initial x and y velocities, although transmission may be reduced if $\dot{x}_o > \dot{y}_o$. However, the maximum amplitudes will depend on the initial velocities as illustrated in Table 111.

TABLE 3

Dependance of maximum y amplitude on the initial x and y velocities (expressed in terms of ξ) the case $\beta_y = 1/10, \beta_x = 5/10$. The initial displacements were unity in each case.

INITIAL VELOCITIES	MAXIMUM AMPLITUDE
(see text)	
0	6.47
0.05	7.15
0.075	7.48
0.10	7.81
0.20	9.26

Initial x and y velocities up to about 0.1 are possible in these circumstances without a substantial increase in device size.

To obtain the exact focussing, the q/a ratio must be precisely controlled to the desired value. FIG. **8** illustrates the results of an error in the choice of scan line, i.e. a 0.1% shift in the q/a ratio to 4.62611 from 4.63124 the latter being the correct value for $\beta_y = 1/10$, $\beta_x = 5/10$. The position of best focussing at the exit aperture is illustrated. The resolving power is obviously degraded. The mean arrival time of the ions is about 10.14 periods and the arrival velocities are about 0.2 compared with the initial velocities of 0.05.

As described above, the q/a ratio must be precisely controlled to enable focussing of the spectrometer. In order to scan masses, either of two parameters in equation (3) and (4) may be scanned, the amplitudes of the voltages U and V, or the frequency of the voltage V. It is preferred to scan the amplitudes of U and V maintaining the q/a ratio constant which means that the ratio V/2U must remain constant for a chosen q/a scan. A zero to peak voltage V of up to 6000 v. may be necessary for ions in the order of 5,000 mass units. However in addition, the instrument may be provided with a number of mass ranges by varying the frequency of V in the steps from approximately 1Mhz to approximately 15 khz for ions with large masses, i.e. in the order of 5000 mass units.

Finally, r_o may vary from one instrument to another depending on the desired mass range. It has been determined that the lower limit for r_o will be governed by the minimum practical distance between the entrance and exit slits **6** and **7** required for mounting the ion source **8** and detector **12.** (see FIG. **2**). The upper limit for r_o will in turn be governed by power limitations on the voltage compoment V cos ωt. However a range for r_o from 5 to 20 cm. appears to be well within these practical limitations. In addition, it has been determined that for normal operation, r_o should be approximately four times the distance between the slits

I claim:

1. A mass analyser for focussing ions of a particular mass-to-charge ratio in an ion beam comprising:

a plane electrode;

parallel entrance and exit slits located in the plane electrode;

first and second elongated electrodes positioned in parallel to one side of the plane electrode such that the electrodes are symmetrically located with respect to a plane normal to the plane electrode and containing a centerline located between the slits;

a voltage source having a d.c. component and an rf component connected across the first and second electrodes to provide an electrostatic field for focussing ions in a beam entering the field through the entrance slit such that ions of a particular mass-to-charge ratio will exit the field through the exit slit.

2. A mass analyser as claimed in claim **1** wherein the plane electrode is at ground potential.

3. A mass analyser as claimed in claim **2** wherein a segment of each of the first and second electrodes facing the centerline are hyperbolically shaped, each segment being symmetrical about a plane containing the centerline and the electrode axis.

4. A mass analyser as claimed in claim **2** wherein the entrance and exit slits are rectangular.

5. A mass analyser as claimed in claim **2** wherein the negative pole of the d.c. component is connected to the elongated electrode nearest to the entrance slit and the positive pole of the d.c. component is connected to the elongated electrode nearest to the exit slit.

6. A mass analyser as claimed in claim **2** which further includes ion source means mounted on the other side of the plane electrode to direct a beam of ions through the entrance slit transverse to the first and second electrodes.

7. A mass analyser as claimed in claim **6** which further includes detector means adjacent to the exit slit.

8. A mass analyser as claimed in claim **7** wherein the detector means comprises:

an electron multiplier mounted to face the exit slit;

amplifier means coupled to the multiplier output; and

recording means coupled to the amplifier output.

9. A mass analyser for focussing ions of a particular mass-to-charge ratio in an ion beam comprising:

a plane grounded electrode;

parallel entrance and exit slits located in the plane electrode;

first and second elongated electrodes positioned in parallel to one side of the plane electrode and symmetrical to each other with respect to a plane normal to the plane electrode and containing a centerline located between the slits, each of said electrodes having a hyperbolically shaped face, each face being symmetrical about a plane containing the centerline and the electrode axis;

a voltage source having a d.c. component and an rf component connected across the first and second electrode to provide an electrostatic field for focussing ions in a beam entering the field through the entrance slit such that ions of particular mass-to-charge ratio will exit the field through the exit slit.

10. A mass analyser as claimed in claim **9** wherein the negative pole of the d.c. component is connected to the elongated electrode nearest the entrance slit and the positive pole of the d.c. component is connected to the elongated electrode nearest to the exit slit.

11. A mass analyser as claimed in claim **9** wherein the voltage source further includes means to vary the voltage source to provide a mass scan of the ion beam.

12. A mass analyser as claimed in claim **10** wherein the source varying means scans the amplitude of the d.c. component U and the zero-to-peak amptitude of the r.f. component V in the ratio 2 U/V.

13. A mass analyser as claimed in claimed **11** wherein the source varying means varies the frequency of the r.f. component.

14. A mass analyser for focussing ions of a particular mass-to-charge ratio in an ion beam comprising:

a plane electrode;

parallel entrance and exit slits located in the plane electrode;

first and second elongated electrodes positioned in parallel to one side of the plane electrode such that the electrodes are symmetrically located with respect to a plane normal to the plane electrode and containing a centerline located between the slits; and

a *rf* voltage source connected across the first and second electrodes to provide an electrostatic field for focussing ions in a beam entering the field through the entrance slit such that ions of a particular mass-to-charge ratio will exit the field through the exit slit.

15. A mass analyser for focussing ions of a particular mass-to-charge ratio in an ion beam comprising:

a plane electrode;

parallel entrance and exit slits located in the plane electrode;

first and second elongated electrodes positioned in parallel to one side of the plane electrode such that the electrodes are symmetrically located with respect to a plane normal to the plane electrode and containing a centerline located between the slits; and

a voltage source having a d.c. component and a *rf* component connected across the first and second electrodes to provide an electrostatic field having the parameters $\beta_y = 1/S$ and $\beta_x = P/S$ where $1 \leq P < S$ and P is odd for focussing ions in a beam entering the field through the entrance slit such that ions of a particular mass-to-charge ratio will exit the field through the exit slit, with $\beta_x = 2\omega_{ox}/\omega$ and $\beta_y = 2\omega_{oy}/\omega$

where

ω = angular frequency of the applied voltage;

ω_{ox} = fundamental frequency of ion motion in the x direction;

ω_{oy} = fundamental frequency of ion motion in the y direction;

S = an integral number of field cycles, and

P = an odd integer.

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