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Halliday et al.

[11] **3,745,343**

[45] **July 10, 1973**

[54] **ION LENS SYSTEM FOR MASS SPECTROMETERS AND METHOD OF OPERATION**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.** **H01j 39/34**

[58] **Field of Search** ..... 250/41.9 G, 41.9 D, 250/41.9 ME, 49.5 P

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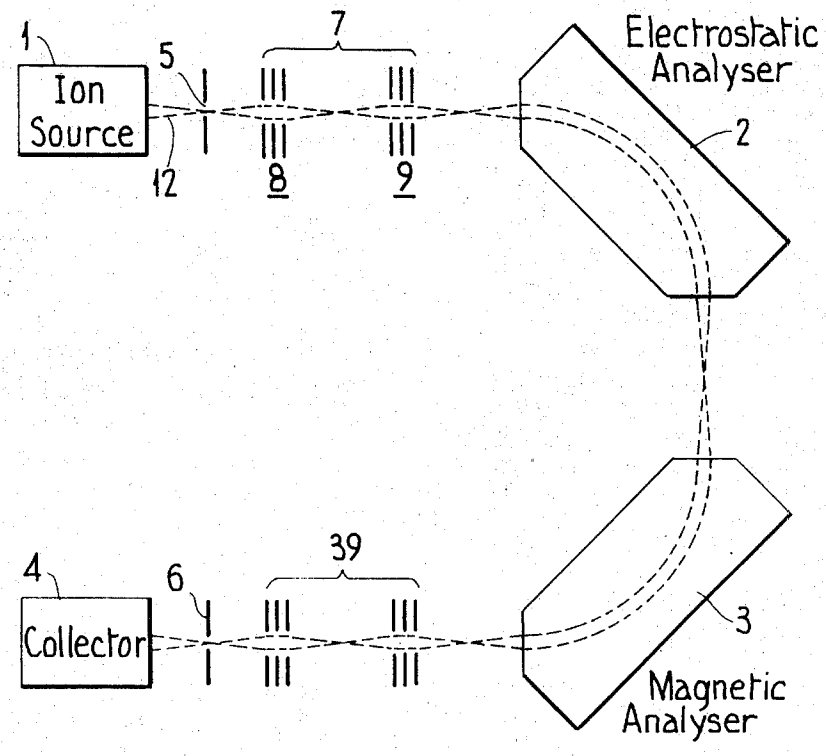
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[57] **ABSTRACT**

An ion lens system which may be utilized with a mass spectrometer for varying the width of an ion beam entering or leaving the analysis region of the spectrometer, and method of operation thereof. The lens system includes a plurality of apertured ion lenses which may be positioned between an ionization chamber and the analysis region of the spectrometer, or alternatively, may be positioned between the analysis region of the spectrometer and the collector. By varying the potentials applied to the ion lenses, the effective widths of the apertures may be altered in order to vary the width of the ion beam.

20 Claims, 6 Drawing Figures



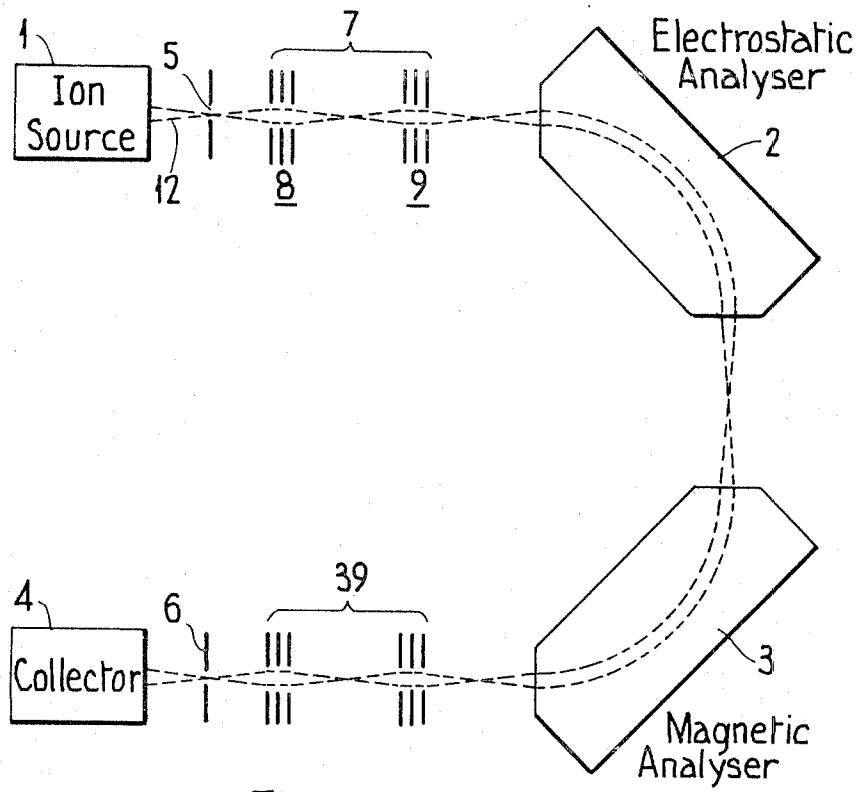


Fig. 1

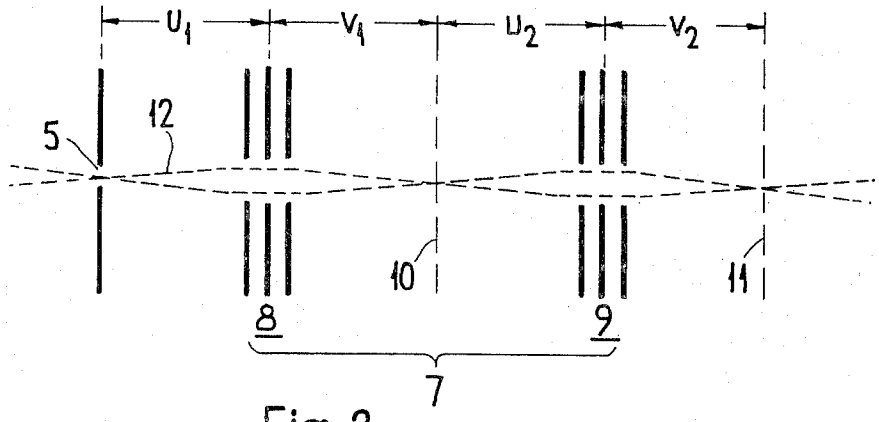


Fig. 2

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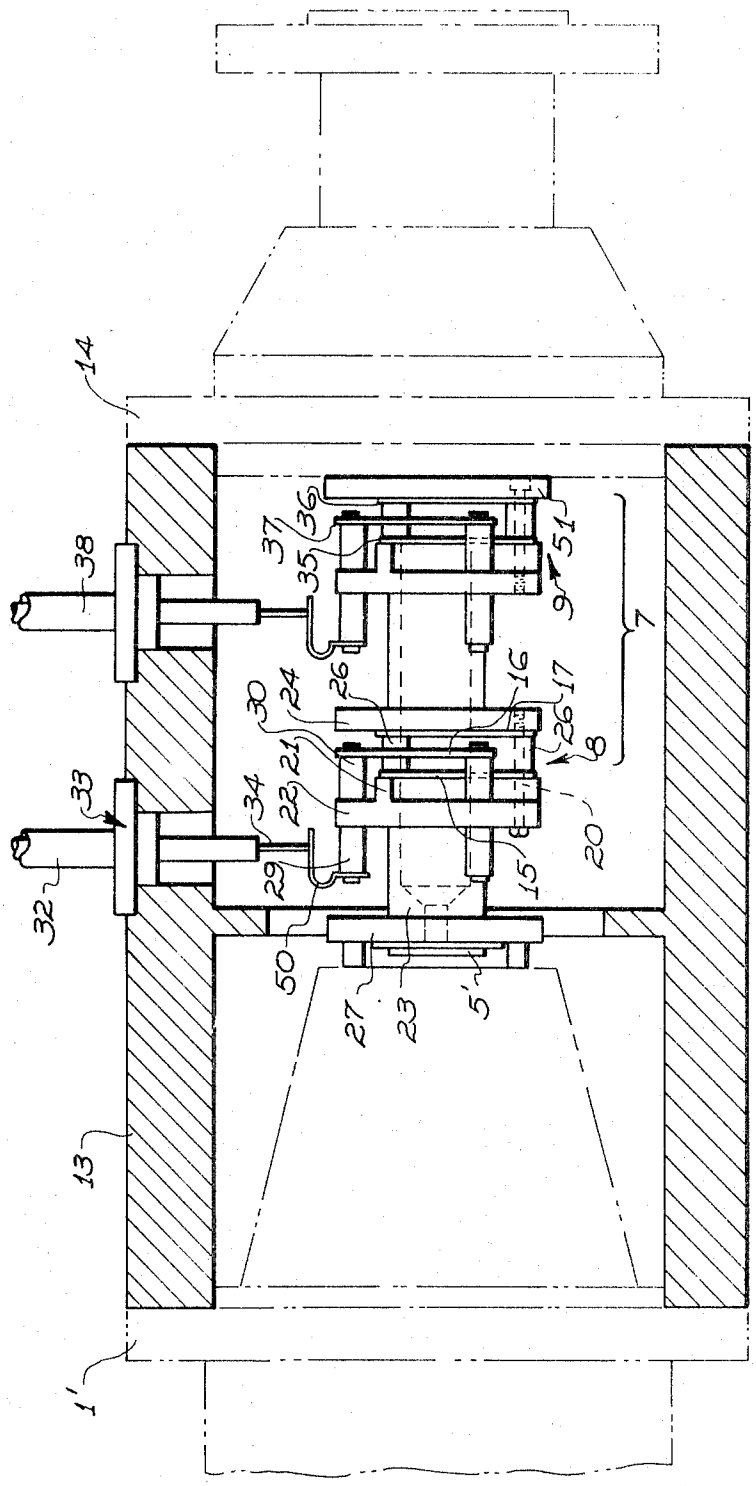


Fig. 3

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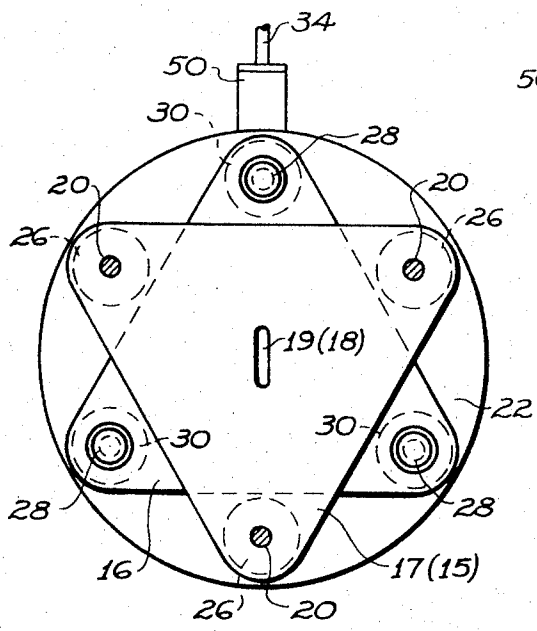


Fig. 4

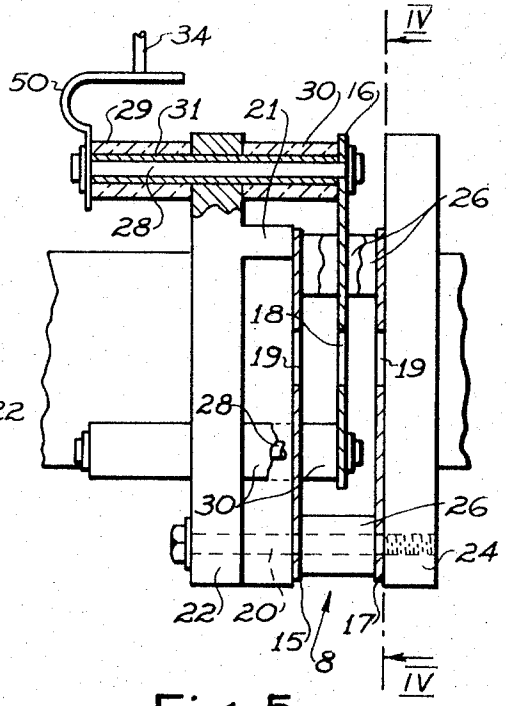


Fig. 5

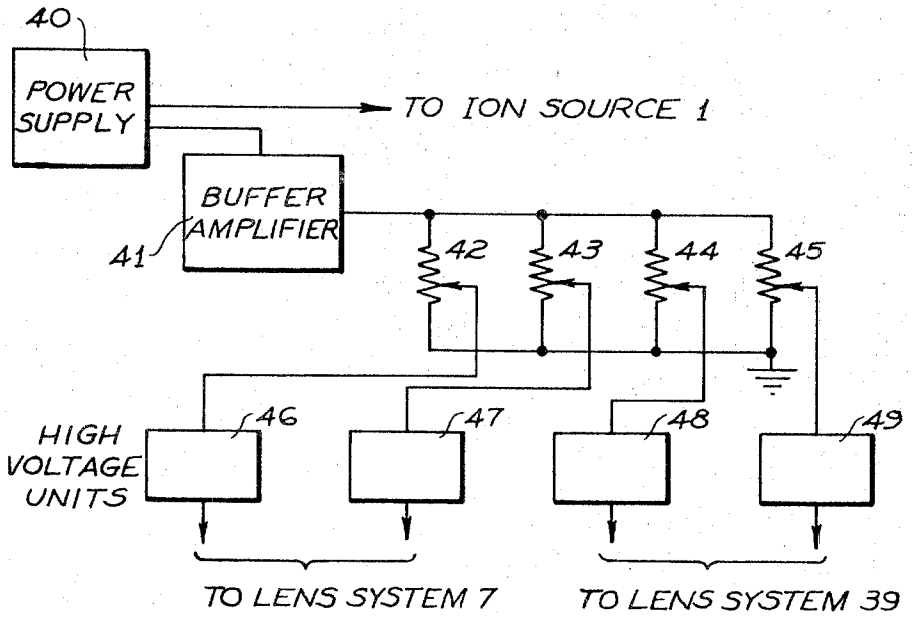


Fig. 6

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ION LENS SYSTEM FOR MASS SPECTROMETERS AND METHOD OF OPERATION

This invention relates to mass spectrometers and is more particularly, but not exclusively, concerned with mass spectrometers of the magnetic analyser type.

It is well known in mass spectrometers for the width of the ion beam to be defined by means of mechanical slits, both on entering and leaving the analysis region. These slits may be of fixed dimensions, in which case the resolving power of the instrument can be changed only by dismantling the ion source and collector systems to replace the plates carrying the slits.

More usually in high performance instruments both the slits at the source and collector ends of the analysis region are continuously adjustable from outside the vacuum enclosure. The mechanism required to provide this adjustment usually includes a micrometer screw, a bellows through the vacuum wall, and numerous levers, pivots, springs and sliding components within the vacuum system. Considerable precision is required in the manufacture of such a mechanism if accurate and reproducible characteristics are needed. A typical range of adjustments required is from a maximum slit width of say 5 thou (i.e. 0.005 inches) down to a minimum of 1/10th thou, the adjustment being continuously variable with an effective slit length of about 200 thou. In this example the slit is ideally straight and smooth to within 1/100th thou and the adjustment is required to maintain the slit edges parallel to within 1/100th thou over the slit length.

Apart from the difficulties inherent in manufacture, mechanically adjustable slits have a number of other disadvantages in use. The mechanism involved can give rise to gas traps and adsorbed gas can be released sporadically by the rubbing together of surfaces. Jerky movement can also result from lubrication problems in high vacuum, particularly in the presence of high sample concentrations with consequent surface contamination and under those conditions, physical blocking of the slit can occur due to sample build up on the slit edges.

One object of the present invention is to provide a construction of mass spectrometer in which the width of ion beam entering and/or leading the analysis region may be adjusted without the difficulties discussed above of using mechanically adjustable slits.

In a mass spectrometer according to the present invention, an ion zoom lens system is associated with an opening (for example a slit) through which is arranged to pass the ion beam of the spectrometer, this lens system being arranged to vary the effective width of said opening.

Said opening may be a slit defining the width of the ion beam entering the analysis region of the spectrometer or alternatively it may be a slit defining the width of ion beam leaving the analysis region that is passed to an ion collector. In a preferred arrangement, separate source and collector slits are provided each with an associated ion zoom lens system so that the width of ion beam entering the analysis region and the width of ion beam leaving that region may be separately adjusted.

According to a feature of the present invention, a mass spectrometer has two ion lenses, which are of variable magnification and which together form an ion zoom lens system, disposed between an analysis region of the spectrometer and a source or collector slit, the arrangement being such that the effective width of the slit through which the ion beam passes during use of the spectrometer may be varied by electrically changing the magnification of said lenses.

Preferably each of said ion lenses is formed by a plurality of apertured elements through which the ion beam is arranged to pass and there is provided means to supply variable potential to at least one element of each of these lenses to control the magnification thereof.

One example of a mass spectrometer in accordance with the present invention will now be described with reference to the accompanying drawings in which

FIG. 1 shows the complete mass spectrometer diagrammatically,

FIG. 2 is an explanatory drawing of the ion zoom lens system,

FIG. 3 shows the construction of the ion zoom lens system in more detail,

FIGS. 4 and 5 show enlarged views, partly in section, of part of the lens system of FIG. 3, FIG. 4 being a cross-section at the line IV — IV in FIG. 5, and

FIG. 6 shows an electric circuit.

Referring first to FIG. 1, the mass spectrometer comprises an ion source 1 including an ionization chamber (not shown) containing an ion accelerating electrode, an electrostatic anaylser 2, a magnetic analyser 3, and an ion collector 4 in known manner. (Although not shown in the drawing, the collector 4 is preferably connected to an electron multiplier and output signals from the multiplier are passed through an amplifier to a suitable read-out device.) Two slits 5 and 6 are respectively associated with the ion source 1 and the collector 4, the ion source slit 5 limiting the width of the ion beam entering the analysis region of the spectrometer and the collector slit 6 limiting the width of ion beam passed to the collector 4. During use the magnetic field to which the ion beam is subjected in the magnetic analyser 3 is scanned through a range of values and during such a scan ions of different mass reach the collector 4. As so far described the mass spectrometer is quite conventional.

The slit 5 is of fixed width and for the purpose of controlling the width of ion beam entering the analysis region there is provided an ion zoom lens system 7 between the slit 5 and the electrostatic analyser 2. The lens system 7 consists of two ion lenses 8 and 9 which will subsequently be described in more detail.

The operation of the ion zoom lens system 7 will now be considered with reference to FIG. 2 of the accompanying drawings. As shown in this figure, the lens 8 is arranged to affect the ion beam 12 so as to produce an intermediate image of the slit 5 in a plane 10 between that lens and the lens 9 while the lens 9 produces a final image of the slit 5 in a plane 11 on the opposite side of that lens, this latter plane being the object plane of the electrostatic analyser 2 (FIG. 1). In respect of the ion beam 12 the lenses 8 and 9 satisfy the usual lens formula and it can easily be shown that the overall magnification m of the lens system 7 is given by the following expression:

$$m = (v_1 v_2)/(u_1 u_2)$$

where

u_1 = the distance between the source ion slit 5 and the lens 8,

v_1 = the distance between the lens **8** and the intermediate image plane **10**,

u_2 = the distance between the plane **10** and the lens **9** and

v_2 = the distance between the lens **9** and the final object plane **11**.

Since the lenses **8** and **9** are fixed relative to the ion slit **5** and the rest of the mass spectrometer, it follows that u_1 and v_2 are constant and that $v_1 + u_2$ is also constant. However by suitably varying the focal length of the lenses **8** and **9** v_1 and u_2 may be varied so as to vary the overall magnification of the lens system **7**.

By way of example, if $u_1 = v_1 = 1$ and $u_2 = v_2 = 0.2$ (so that $v_1 + u_2 = 1.2$), an overall magnification of unity is obtained. If however the lenses **8** and **9** are modified so that $v_1 = 0.2$ and $u_2 = 1$, the overall magnification is then 1/25.

The ion zoom lens system **7** may be used in practice to effect de-magnification of the ion source slit **5** from 1:1 to more than 100:1 so that if the ion source slit has a width of 5 thou, the width of the ion beam at the object plane **11** may be varied continuously between 5 thou and 1/20 thou. In other words the effective width of the ion source slit may be varied between these limits.

The preferred construction of the ion zoom lens system **7** will now be described with reference to FIGS. **3, 4** and **5** of the accompanying drawings. The lens system **7** is contained within a generally cylindrical metal housing **13** which is secured by way of vacuum seals between the ion source assembly **1'** (which constitutes the ion source of FIG. **1**) and a coupling unit **14** which is connected to the electrostatic analyser **2** (FIG. **1**). (It may be mentioned here that the form of mass spectrometer herein described is a modification of a commercially available mass spectrometer in which the lens system **7** is not provided and the housing **13** is replaced by a housing which is somewhat shorter in length and to which the assembly **1** and the unit **14** are connected.)

The lens **8** is formed by three apertured metal plates **15, 16** and **17** with their apertures **18** and **19** (see FIGS. **4** and **5**) each having their major dimension in the plane of FIGS. **3** and **5**. By means of three bolts **20**, the plates **15** and **17** are clamped so as to abut respectively projections **21** from the flange **22** of a metal support member **23** and the flange **24** of another metal support member **25**, tubular metal spacers **26** being provided between the plates **15** and **17**. The plates **15** and **17** are maintained at earth potential as will subsequently be described.

The plate **16** is supported by three studs **28** to lie midway between the plates **15** and **17** and parallel thereto. Each stud **28** also carries quartz spacers **29** and **30** and a tube **31** of ceramic insulating material so that the plate **16** is electrically insulated from the plates **15** and **17**. The end of one of the studs **28** remote from the plate **16** is connected to a spring contact **50**. During use, the plate **16** is maintained at a high potential supplied over a cable **32** which passes through the housing **13** by way of a high voltage seal **33**, the conductor **34** pressing against the spring contact **50**.

The lens **9** is of essentially the same construction as the lens **8** and will accordingly not be described in detail. The member **51** is however secured to the unit **14** by means of bolts (not shown) so as to provide an electrical connection to maintain the plates **35** and **36** at earth potential (and also the plates **15** and **17** of the lens **7** as previously mentioned). The apertured plate **37** is maintained at a high potential supplied over a cable **38**.

The slit **5** (FIG. **1**) is provided by a plate **5'** that is secured to the flange **27** of the member **23**, the slit which is not shown in FIG. **3** lying in the plane of that figure.

It will be appreciated that the focal lengths of the lenses **8** and **9** may be changed to vary the overall magnification of the lens system **7** merely by altering the voltages supplied over the cables **32** and **38**.

Reverting now to FIG. **1** of the accompanying drawings, the collector slit **6** has an associated ion zoom lens system **39** which is essentially the same as the lens system **7** described above. It will be appreciated that the mass spectrometer operates so that ions emerging from the magnetic analyser **3** effectively form an image (hereinafter termed the "analyser image") of the source ion slit **5** shortly after leaving that analyser and the object plane of the lens system **39** is arranged to coincide with the plane of this image. The lens system **39** serves to produce a reduced image of the slit **6** in its object plane. Looked at another way, the lens system **39** results in a magnified image of the analyser image being produced in the plane of the collector slit **6**, this magnified image being of substantially the same width or wider than the slit **6** so that ions in all or part of the analyser image are passed to the collector **4** (depending upon the particular operating conditions). As in the case of the lens system **7**, it is possible to adjust the effective width of the collector slit **6** by varying the magnification of the lens system **39**.

During use of the mass spectrometer described above, the lens system **7** associated with the ion source slit **5** is utilised to control the effective width of the source ion beam while the lens system **39** associated with the collector slit **6** is utilised to control the ion transmission to the collector **4** to obtain optimum sensitivity for a given resolving power.

With this arrangement, rapid variation of resolution may be obtained merely by altering the appropriate potentials supplied to the lens systems **7** and **39**. Thus, when the magnetic field of the magnetic analyser **3** is scanned through a range of values (as aforesaid) for the purpose of detecting ions of different mass, very high resolution may be used over only a small selected part of the total mass range being investigated while the remainder of the scan may be carried out at a lower resolution and consequently higher sensitivity.

The potentials applied to the lenses **8** and **9** of the lens system **7**, for example, to effect a given demagnification of the ion source slit **5** are dependent on the energy of the ion beam. In order to compensate automatically for changes in the ion source potential, it is convenient for the lens potentials to be dependent upon the ion source potential. A suitable circuit for effecting this is shown in FIG. **6**. In this circuit, a small fraction of the voltage supplied by the power supply **40** to the ion source **1** (FIG. **1**) is passed to a buffer amplifier **41** which in turn supplies to four potentiometers **42** to **45** a voltage proportional to the ion source potential. High voltage units **46** to **49** are connected respectively to the tapping points of the potentiometers **42** to **45** and these units thus supply to the lens systems **7** and **39** potentials that are dependent upon the ion source potential. During use of the mass spectrometer, the magnification of the lens system **7** may therefore be changed merely by

movement of the tapping points of the potentiometers **42** and **43** while the lens system **39** may similarly be changed by means of the potentiometers **44** and **45**.

Preferably the arrangement described may be modified so that there is only a single control for each of the lens system **7** and **39**. Thus, for the lens system **7**, the potentiometer **43** may be replaced by a function generator which responds to the voltage supplied by the potentiometer and which supplies the appropriate voltage to the unit **47** for correct operation of the lens system **7** at all settings of the potentiometer **42**.

Instead of the potentials supplied to the lens systems **7** and **39** being continuously adjustable, as provided for by the circuit of FIG. **6**, they may be selected from a plurality of predetermined values. In this case the resolving power of the spectrometer is only adjustable in known steps.

In an alternative arrangement, the mass spectrometer may be arranged automatically to control its resolving power. This may be done by causing the spectrometer to scan a single ion mass (of a sample introduced by way of said ion source) and to pass back to the lens controls an electric signal that is a measure of the width (i.e. time duration) of the resulting "peak" measured at the collector. Having set the resolving power in this way, the ratio of the magnifications of the two lens systems is then automatically set to give the optimum transmission conditions (i.e. automatically to adjust for maximum peak height at the selected peak width).

Although in the embodiment of the invention described herein the slit **5**, for example, is of fixed width, it is to be understood that the invention is not restricted to mass spectrometers having slits of fixed physical width. In practice, the overall range of the effective width of the slit **5**, for example, may be increased if the slit **5** is adjustable or is arranged to be replaced by an alternative slit of different width.

Having thus described our invention, we claim:

1. In a mass spectrometer an ionization source for ionizing a sample to be analyzed, said source having an ion exit slit for the passage of a beam of ions, analyzer means disposed to apply a deflection field to a said beam of ions, and detection means positioned to receive at least a portion of the ions in said beam of ions in order to analyze said ions, wherein the improvement comprises:

an ion lens system disposed between said ion exit slit and the entire analyzer means and including;

first and a second electrostatic lens means each having an aperture therein for the passage of a said beam of ions, said first and second electrostatic lens means disposed between said ion exit slit and the entire analyzer means to form a focused image of said ion exit slit in a focal plane between said lens means and said analyzer means;

control means for varying the focal lengths of said first and second electrostatic lens means in a manner to vary the width of a said image of said slit in a said focal plane while maintaining the image focus in the plane whereby the lens means function in the manner of an adjustable slit.

2. An apparatus as defined in claim **1** wherein said first electrostatic lens means includes first, second, and third apertured members positioned in spaced relationship with respect to each other, said first and third apertured members being connected to ground potential.

3. An apparatus as defined in claim **1** wherein each of said first and second electrostatic lens means comprises first, second and third apertured members positioned in spaced relationship with respect to each other, each of said first and third apertured members being coupled to a constant source of potential and the second apertured members of said first and second electrostatic lens means being coupled to variable sources of potential.

4. An apparatus as defined in claim **1** including a second ion lens system disposed between the entire analyzer means and said detection means and including;

first and second electrostaitc lens means each having an aperture therein for the passage of a said beam of ions, said first and second electrostatic lens means disposed between said ion exit slit and said detection means to thereby form an image of said ion exit slit in a second plane between said lens means and said detection means;

control means for varying the focal lengths of said first and second electrostatic lens means in a manner to vary the width of a said image of said ion exit slit in a said second plane.

5. A method of varying the width of an ion beam in a mass spectrometer including an analyzer section, and an ion source, comprising the steps of:

ionizing a sample to be analyzed to thereby form ions;

directing the ions into a beam;

passing the beam of ions through a first and second electrostatic lens means to form a focused image of a source slit in a focal plane between the lenses and the entire analyzer section; and,

electrically varying the focal lengths of the first and second electrostatic lens means in coordinated manner so as to vary the size of said image in said focal plane while maintaining the focus of the image in said plane.

6. A method of varying the width of an ion beam as set forth in claim **5** including the steps of:

applying first and second potential signals respectively to a first and a second apertured member in said first electrostatic lens means; applying third and fourth potential signals respectively to a first and a second apertured member in said second electrostatic lens means; and, varying the value of both of said first and third potential signals in order to vary the width of the ion beam by changing the focal lengths of both the first and second electrostatic lenses while maintaining the focal length of the beam substantially constant.

7. In a mass spectrometer including an ionization source for ionizing a sample to be analyzed, said source having an ion exit slit to pass a beam of ions from the ionization source, analyzer means, detection means positioned to receive at least a portion of the ions in said beam of ions after passage through said analyzer means, and an ion collector slit disposed between said analyzer means and said detection means wherein the improvement comprises:

an ion lens system disposed between one of said ion slits and the entire analyzer means and including;

first and second electrostatic lens means each having an aperture therein for the passage of a said beam of ions; said first electrostatic lens means disposed such that this lens means provides a first image in a cross over plane situated between said first elec-

trostatic lens means and one side of said second electrostatic lens means, and said second electrostatic lens means disposed such that this lens means provides a second image in a focal plane which is positioned on the opposite side of said second electrostatic lens means; and,

control means for varying the focal length of both said first and second lens means in a manner such that the location of the cross over plane is shifted longitudinally of the beam while the image plane of the second image is at a constant position to thereby vary the magnification of said ion lens system whereby to cause the lens means to function in the manner of an adjustable slit.

8. An apparatus as defined in claim **7** wherein said one ion slit is said ion exit slit of said ionization source.

9. An apparatus as defined in claim **8** including a second ion lens system disposed between said analyzer means and said detection means and including:

third and fourth lens means each having an aperture therein for the passage of a said beam of ions and for forming a third image in a third plane between said second lens system and said detection means; and,

control means for varying the focal lengths of said third and fourth lens means in a manner such that the plane of the third image is at a constant position to thereby vary the magnification of said ion lens system.

10. An apparatus as defined in claim **7** wherein said one ion slit is said ion collector slit.

11. In a double focusing mass spectrometer an ionization source for ionizing a sample to be analyzed, said source having an ion exit slit for the passage of a beam of ions, double focusing analyzer means including an electrostatic analyzer disposed to apply an electrostatic deflection field to a said beam of ions and a magnetic analyzer disposed to apply a magnetid deflection field to a said beam of ions, detection means positioned to receive at least a portion of the ions in said beam of ions after passage through said double focusing analyzer means, and an ion collector slit disposed between said double focusing analyzer means and said detector means wherein the improvement comprises:

an ion lens system disposed between one of said ion slits and said double focusing analyzer means and including;

first and second electrostatic lens means each having an aperture therein for the passage of a said beam of ions, said first and second electrostatic lens means disposed between one of said ion slits and said double focusing analyzer means to thereby form an image in an image plane;

control means for varying the focal lengths of said first and second electrostatic lens means in a manner to vary the width of said image in said image plane while maintaining the overall focal length of said lens system substantially constant whereby the lens system functions in the manner of an adjustable slit.

12. An apparatus as defined in claim **11** wherein said one ion slit is said ion exit slit of said ionization source.

13. An apparatus as defined in claim **12** including a second ion lens system disposed between said analyzer means and said detection means and including:

third and fourth electrostatic lens means each having an aperture therein for the passage of a said beam of ions, said third and fourth electrostatic lens means disposed between said analyzer means and said detection means to thereby form a second image in a second plane between said third and fourth lens means and said detection means;

control means for varying the focal lengths of said third and fourth electrostatic lens means in a manner to vary the width of said second image in said second plane while said second image plane remains at a constant position.

14. An apparatus as defined in claim **11** wherein said one ion slit is said ion collector slit.

15. In a double focusing mass spectrometer including an ionization source for ionizing a sample to be analyzed, said source having an ion exit slit to pass a beam of ions from the ionization source, double focusing analyzer means including an electrostatic analyzer disposed to apply an electrostatic deflection field to a said beam of ions and a magnetic analyzer disposed to apply a magnetic deflection field to a said beam of ions, detection means positioned to receive at least a portion of the ions in said beam of ions after passage through said double focusing analyzer means, and an ion collector slit disposed between said double focusing analyzer means and said detector means wherein the improvement comprises:

an ion lens system disposed between one of said ion slits and said double focusing analyzer means and including;

first and second electrostatic lens means each having an aperture therein for the passage of a beam of ions; said first electrostatic lens means disposed such that this lens means provides a first image in a cross over plane situated between said first electrostatic lens means and said second electrostatic lens means, and said second electrostatic lens means disposed such that this lens means provides a second image in an image plane; and,

control means for varying the focal length of both said first and second electrostatic lens means while maintaining the total focal length of both of said electrostatic lens means substantially constant to thereby vary the magnification of said ion lens system in the image plane whereby the lens system functions in the manner of an adjustable slit.

16. An apparatus as defined in claim **15** wherein said one ion slit is said ion exit of said ionization source.

17. An apparatus as defined in claim **16** including a second ion lens system disposed between said analyzer means and said detection means and including:

third and fourth electrostatic lens means each having an aperture therein for the passage of a said beam of ions, said first and second electrostatic lens means disposed between said analyzer means and said detection means to thereby form an image in a second image plane between said third and fourth lens means and said detection means;

control means for varying the focal lengths of said third and fourth electrostatic lens means in a manner to vary the width of said image in said second image plane.

18. An apparatus as defined in claim **15** wherein said one ion slit is said ion collector slit.

19. In a mass spectrometer an ionization source for ionizing a sample to be analyzed, said source having an ion exit slit for the passage of a beam of ions, analyzer means, detection means positioned to receive at least

a portion of the ions in said beam of ions after passage through said analyzer means, and an ion collector slit disposed between said analyzer means and said detector means wherein the improvement comprises:

a. a first ion lens system disposed between said ion exit slit and the analyzer means and including:

i. first and second lens means each having an aperture therein for the passage of a said beam of ions and for forming an image in an image plane;

ii. control means for varying the focal lengths of said first and second lens means in a manner to vary the width of said image in said image plane while maintaining the focal length of said beam substantially constant;

b. a second ion lens system disposed between said analyzer means and said detection means and including:

i. third and fourth lens means each having an aperture therein for the passage of a said beam of ions and for forming a second image in a second image plane between said third and fourth lens means and said detection means; and,

ii. control means for varying the focal lengths of said third and fourth lens means in a manner to vary the width of said second image in said second image plane while maintaining the focal length of said beam substantially constant.

20. A method of varying the width of an ion beam in a mass spectrometer which includes an analyzer section, an ion source to supply a beam of ions to said analyzer section, a detector positioned to receive at least a portion of the ions in said beam of ions that emerge from said analyzer section after passage therethrough, and a slit disposed between the analyzer section and the detector, comprising the steps of:

passing the ions of said beam that emerge from said analyzer means through first and second electrostatic lens means to form a focused image in the plane of said slit; and,

electrically varying the focal lengths of the first and second electrostatic lens means in co-ordinated manner so as to vary the size of said image in said slit plane while maintaining the image focused in said plane.

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