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[54] **PLURAL BEAM MASS SPECTROMETER FOR CONDUCTING HIGH AND LOW RESOLUTION STUDIES**
25 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **250/41.9**
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[50] **Field of Search** ..... - 250/41.9(3), 41.9 (R)

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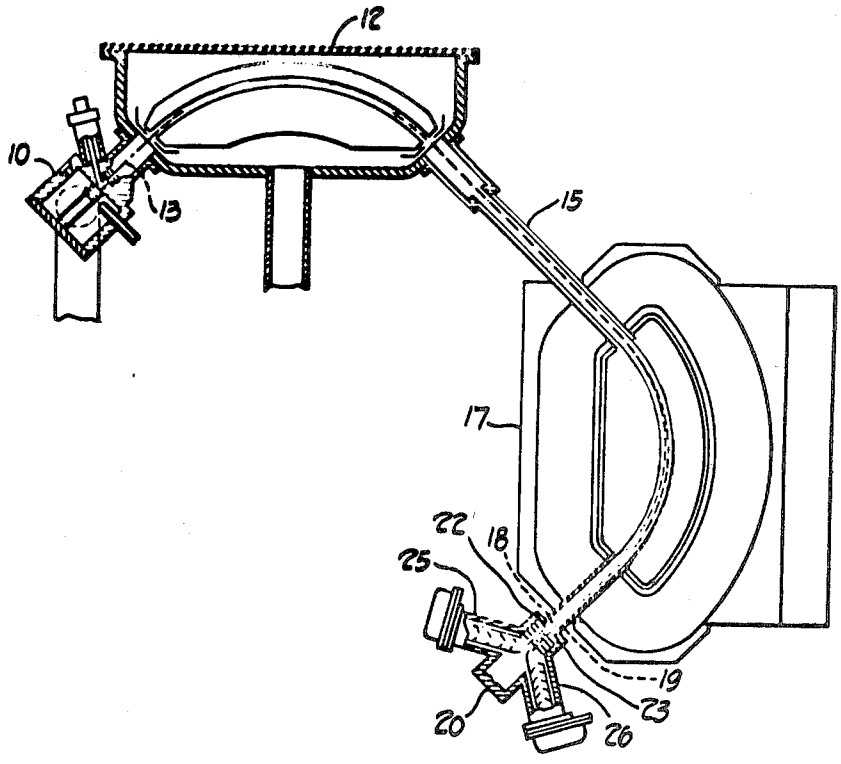
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ABSTRACT: A mass spectrometer is provided with one or two ion sources and two collectors. Slit structure is associated with each ion beam and the mass spectral range of one beam can be compared with the other beam.



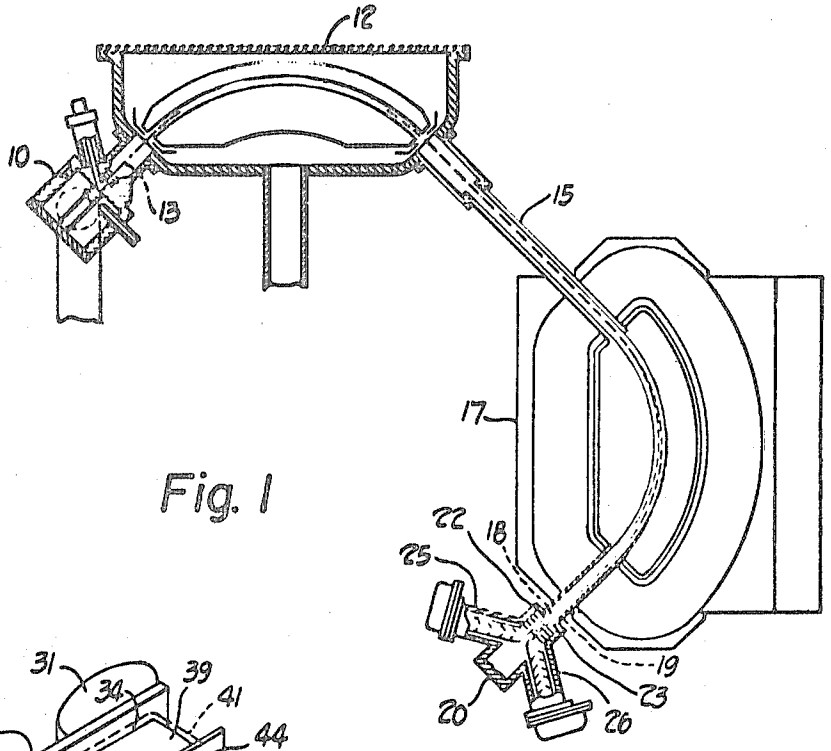


Fig. 1

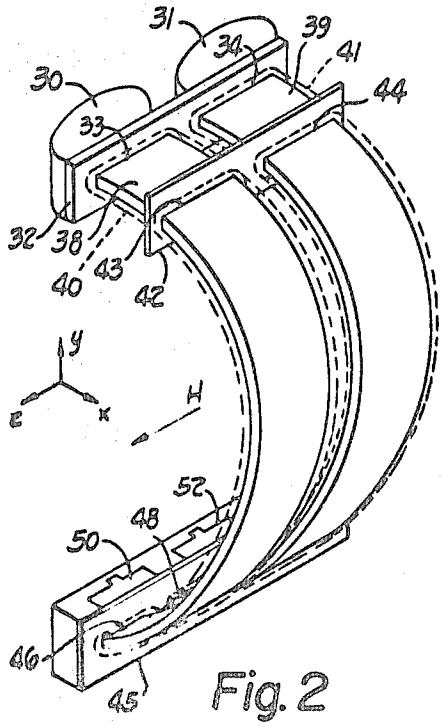


Fig. 2

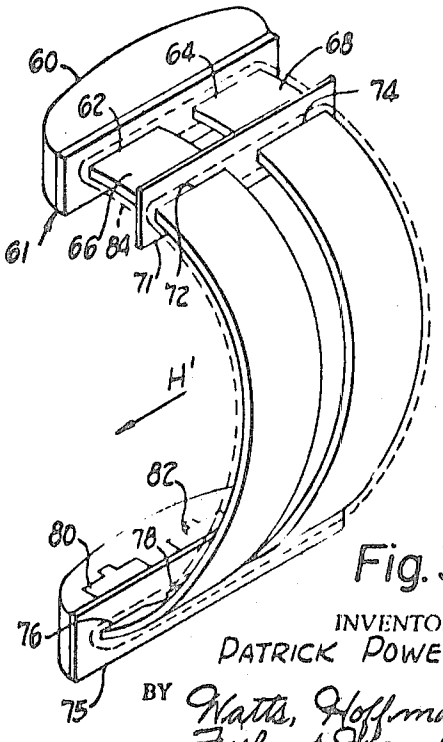


Fig. 3

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PLURAL BEAM MASS SPECTROMETER FOR CONDUCTING HIGH AND LOW RESOLUTION STUDIES

CROSS-REFERENCE TO RELATED APPLICATION

1. "Improvement Relating to Mass spectrometers," Ser. No. 557,272, filed Jun. 13, 1966 by John Stephen Halliday, et al. now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to mass spectrometers and more particularly to a mass spectrometer for conducting high and low resolution studies of a substance or substances.

2. Description of the Prior Art

In the analysis of a given compound with a mass spectrometer, ions of a material to be studied are generated in a source and accelerated as an ion beam toward a collector. In a so-called single focusing mass spectrometer, the ions pass through a magnetic analyzer. In a so-called double focusing instrument, the ions pass through an electrostatic analyzer before passing through the magnetic analyzer and then to the collector.

During a given analytical study, the magnetic analyzer or the accelerating potential of an ion source may be scanned, so that during the scan ions of different mass-charge ratios are focused on the collector at different times as the analyzer is scanned. By scanning of the analyzer, it is meant that the energy in the analyzer is changed so that the amount of deflection of ions passing through the analyzer is varied, thereby focusing ions of varying constructions and mass-charge ratios on the collector at different times during the scan.

A typical mass spectrometer will be equipped with a slit structure at the outlet of the ion source and another slit structure at the entrance to the collector. By adjusting the slit structures, one is able to vary the resolution of the mass spectrometer. Thus, when one wishes to vary high resolution of a given ion that is present, the slit structure is adjusted so that only a very small range of mass-charge ratios are focused through the slit and onto the collector. With so-called low resolution studies, the range of mass-charge ratios passing through the slit structure at any one time is considerably increased. In mass spectral analysis, high resolution is used to identify the components of a given compound while low resolution assists in identifying the metastable spectra of the compound, thereby assisting in sorting out the molecular structure of a given compound,

In the past, it has been necessary to study sequentially first high resolution and then low resolution at different times during an analysis with a mass spectrometer.

Mass spectrometers have been used to conduct isotope ratio studies and the like. Such studies are performed by using a mass spectrometer having two collector electrodes, one electrode for collecting an isotope of greater abundance and the other collector electrode for collecting an isotope of lower abundance. The isotope ratio is then determined by comparing the relative abundance of the respective isotopes.

Calutrons, having two separate collector structures, have also been used to separate the isotopes of a particular element. Deposits of a particular isotope accumulate on one collector and are then scraped off for further use. Neither of these devices are appropriate for simultaneous high and low resolution studies of material.

There are certain applications in mass spectrometry, such as the examination of chemical structures, in which it is necessary to measure the mass of each fragment peak in the mass spectrum to a high degree of accuracy. This may require using high resolution conditions so that the various chemical possibilities for each fragment can be determined. However, several chemical possibilities exist, and it is frequently necessary to also use an overall spectrum at low resolving power to observe broad peaks due to metastable transitions. Examination of these broad peaks can be helpful in confirming fragmentation processes, but cannot, however, be easily detected and measured during a high resolution scan. For example, with automatic operation of a mass spectrometer, the mass spectrum may be tape recorded during one or more scans at high resolving power, but the record will not contain full information relating to metastable changes occuring during the study. That is, the study will not include a low resolution study as well. Thus, a further study was required for low resolution analysis. Similarly with manual operation, two separate processes of analysis were required at separate times, one at low and one at high resolving power, to obtain all the necessary information.

SUMMARY OF THE INVENTION

The present invention comprises apparatus and a method for analyzing substances with a mass spectrometer by obtaining in a simultaneous scan two or more resolution spectra of the ions of a substance to be analyzed.

If N ion beams are to be recorded and analyzed simultaneously, there will be N sets of focusing slits and collectors. Thus, one may have two or more simultaneously produced spectra. With, for example, two sets of focusing slits and two collectors, one may use either one or two ion sources, either one or two electrostatic analyzers, and either one or two ion tubes. This permits a number of novel processes and studies to be conducted.

For example, one may simultaneously obtain high and low resolution spectra of a given compound. In that situation where one source, one analyzer, and one tube are used with two collector slits and collectors, the two recorded spectra will be offset in time, nonetheless the information may be fed to a computer, simultaneously recorded and compared by the computer to produce an analysis of the material of the sample.

In many mass spectrometer studies, a reference compound is introduced into the ionization chamber simultaneously with the sample to be analyzed. In known studies of this character, the reference compound is selected so that it will have easily recognizable regularly spaced peaks, which peaks are spaced considerably from the peaks of the sample compound. With the apparatus used in this invention, a single magnetic analyzer is employed in all embodiments.

In that situation where a reference compound is employed, one advantage of the invention where two ion tubes and two sources are used in that the reference compound may be identical to the sample so that, for example, one may monitor a continuous production process and adjust the process whenever differences between the references compound and the sample are detected.

Accordingly, an object of the present invention is to provide a novel and improved mass spectrometer and process of operating a mass spectrometer for improved analysis of substances.

DESCRIPTION OF THE DRAWING

FIG. 1 shows a single ion source in a double focusing mass spectrometer with collector structure for collecting two ion beams;

FIG. 2 shows two ion sources producing two separate ion beams with separate slit structure for each ion beam and two collectors; and

FIG. 3 shows a single ion source with slit structure for separating the ion into two separate beams and two collectors.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

One form of the invention, shown in FIG. 1 is incorporated in a double focusing mass spectrometer including an ion source 10 for producing ions of a substance to be analyzed. The ions are accelerated and are directed toward an electrostatic analyzer 12 as an ion beam 13. The ion beam 13 is delineated by slit structure in the ion source and other slit structure along its path of travel. After entering and emerging from the electrostatic analyzer 12, the ion beam 13 enters an ion tube 15 which passes between the coils of a magnetic

analyzer 17, only one coil of which is shown. As the ion beam progresses through the ion tube 15 it becomes two separate beams 18, 19 which are deflected by a magnetic field directed substantially transverse to the path of travel of the ion beams. In FIG. 1, the magnetic field would be directed normal to the plane of the drawing. The ion beams 18, 19 emerge from the magnetic analyzer 17 and each will include ions over a particular portion of the mass spectral range. In other words, the masses of the ions in the ion beam 18 will differ somewhat from the masses of the ions in the ion beam 19, and the mass composition of ions in the respective beams will vary during a scan.

The beams 18, 19 are collected in a collector unit designated generally by the numeral 20. The collector unit 20 includes slit structure 21 defining a plurality of slits 22, 23 for delineating the ion beams 18, 19. The slits 22 have larger dimensions than the slits 23 so that a low resolution study may be conducted on the ion beam 18 and a high resolution study may be conducted on the ion beam 19. That is, the mass spectral range of ions in the ion beam 19 is restricted with respect to the mass spectral range of ions in the ion beam 18 due to the smaller dimensions of the slits 23 relative to the slits 22. The ion beams 18, 19, after passing through the slits 22, 23 impinge on collectors comprising electron multipliers 25, 26 which provide indications of the respective compositions of the ion beams 18, 19.

In operation, the magnetic analyzer 17 is scanned so that the ion beam 19 may be analyzed at high resolution and the ion beam 18 may be analyzed at low resolution. During the scan, it can be seen that the mass composition of ions in the beam 18, 19 will be changing due to the variation in magnitude of the magnetic field in the magnetic analyzer 17. Thus, for example, as the magnitude of the magnetic field is increased during a scan, the mass composition of the ion beams 18, 19 will be changing and high and low resolution studies of the beams 18, 19 may be accomplished. With the particular apparatus shown in FIG. 1, low and high resolution studies may be conducted simultaneously, however, it should be realized that the low resolution study of ions in a particular mass spectral range will be displaced somewhat in time from the high resolution study of similar ions within a segment of the same mass spectral range already having been studied at high resolution.

Another form of the invention shown schematically in a single focusing mass spectrometer in FIG. 2 includes two ion sources 30, 31 producing ions of the same or similar substances. A member 32 has two source slits 33, 34 lying in a common plane for delineating ion beams 38, 39, respectively, originating from the ion sources 30, 31, respectively. The ion beams 38, 39 may be surrounded by ion tubes 40, 41 respectively, indicated by the dotted lines. However, it may be desirable to use only a single ion tube to surround both of the ion beams 38, 39.

The magnetic analyzer (not shown) of the mass spectrometer is located near the region of the source slits 33, 34 for producing a varying magnetic field *H* aligned parallel to the slits and transverse to the paths of travel of the ions in the ion beams 38, 39, as indicated by the arrow, which shows the direction of the field for deflecting positive ion beams.

A member 42 has collimating slits 43, 44 arranged in a common plane, which are provided to delineate the ion beams 38, 39 and to perform the important function of preventing the interaction between the ion beams 38, 39. The collimating slits 43, 44 may be arranged to intercept the beam in a *y* direction as well as a *z* direction, of the mutually perpendicular axes *x*, *y*, and *z* shown if there is need for such collimating to obtain the required resolution.

The magnetic field *H* will deflect the beams as shown diagrammatically, and if varied, will focus ions of respective different masses successively at fixed positions toward a member 45 having collector slits 46, 48. In the disclosed embodiment, the slits 46, 48 are disposed in a common plane. The ions passing through the collector slits 46, 48 may be collected on respective collectors 50, 52, which, for example, may comprise electron multipliers, amplifiers, and recorders.

The apertures of the source and collector slits for one of the beams are larger than those for the other beam. With such an arrangement, the spectra obtained form the respective collectors will be of different resolution. In addition, the source and collector slits for the high resolution beam are preferably adjustable, while those for the low resolution beam may either be fixed or adjustable. Suitable adjustable slit structure is disclosed in the referenced copending application of John Stephen Halliday, et al.

It should be realized that with this arrangement, a low resolution study of ions in a particular mass spectral range may be conducted simultaneously with a high resolution study of similar ions within a segment of the mass spectral range studied at low resolution. This differs from the operation of the apparatus shown in FIG. 1 with which the respective high and low resolution studies of ions of similar composition will be spaced somewhat in time.

Another form of the invention shown schematically in FIG. 3 is similar to the arrangement shown in FIG. 2 except that a single ion source 60 is used rather than two separate ion sources. A member 61 having source slits 62, 64 receives ions from the ion source 60. The ions produced in the ion source 60 are established by the source slits 62, 64 to emerge as separately delineated ion beams 66, 68. A member 71 has collimating slits 72, 74 lying in a common plane to delineate and to prevent interaction of the ion beams 66, 68 respectively. The ion beams 66, 68 are deflected by a magnetic field *H'* directed transversely to their path of travel and ultimately reach a member 75 having collector slits 76, 78. The ion beam 66, 68 pass through collector slits 76, 78 and are collected on collectors 80, 82. A single ion tube 84, indicated by the dotted lines, surrounds both of the ion beams 66, 68. However, a separate ion tube may surround each of the ion beams 66, 68. In this arrangement, the source and collector slits may be constructed according to the description of the source and collector slits shown in FIG. 2 to obtain somewhat similar results.

Although the magnetic analyzer section described in conjunction with FIGS. 2 and 3 is assumed to be for a single focusing spectrometer which uses magnetic deflection only, the method of analysis accomplished with such structure is also of importance with double focusing spectrometers which use both electric and magnetic deflection systems. In a single focusing spectrometer shown in FIGS. 2 and 3, the plane in which the source slits are situated corresponds to the interanalyzer position in a double focusing spectrometer. That is, the location of the source slits in the single focusing case corresponds to a position between the electric analyzer and the magnetic analyzer. Also, it is not necessary for the corresponding slits of the respective beams to be in line or even in a common plane, but positioning them in this way makes for easier correlation of the two mass spectra.

In carrying out a method of analysis with the apparatus shown and described, the positions of broad metastable peaks can be more easily located than hitherto, using the reference peaks in the high resolution spectrum. This operation can be performed by a computer accompanying the mass spectrometer and the high resolution and low resolution results can be plotted as an output.

In the description, means for simultaneously analyzing two separate beams of similar mass composition have been described. However, it is recognized that the present invention may be modified to accommodate the analysis of more than two ion beams.

Many modifications and variations of the invention will be apparent to those skilled in the art in view of the foregoing disclosure. Therefore, it is to be understood that, within the scope of the appended claims, the invention can be practiced otherwise than as specifically shown and described.

I claim:

1. A plural beam mass spectrometer for plural spectral analysis comprising:

a. an ion source for producing ions of like polarity of a material to be analyzed;
b. means for delineating plural ion beams along a path and for restricting the mass spectral range of ions in at least one ion beam relative to at least another ion beam;
c. analyzer means for applying like deflecting forces to each beam for deflecting the path of the plural ion beams; and
d. collector means for respectively collecting the plural ion beams.

2. The apparatus of claim 1 wherein said means for delineating plural ion beams along a path and for restricting the mass spectral range of ions is adjustable.

3. The spectrometer of claim 1 wherein the means for delineating plural beams includes means to prevent beam interaction.

4. A plural beam mass spectrometer for plural spectral analysis comprising:
a. an ion source for producing ions of like polarity and of a material to be analyzed;
b. slit means for delineating plural ion beams along a path;
c. means for restricting the mass spectral range of ions in at least one ion beam relative to at least another ion beam;
d. analyzer means for applying like deflecting forces to each beam for deflecting the path of the plural ion beams; and
e. collector means for respectively collecting the plural ion beams.

5. The apparatus of claim 4 wherein said means for restricting the mass spectral range of ions is adjustable.

6. A double beam mass spectrometer for conducting high and low resolution studies of material comprising:
a. an ion source for producing ions of a material to be analyzed;
b. first means having first and second source slits through which a portion of said ions may pass as first and second ion beams respectively, said first source slit having larger dimensions than said second source slit;
c. second means having first and second collector slits through which said first and second ion beams respectively may pass, said first collector slit having larger dimensions than said second collector slit;
d. third means disposed in said first and second ion beams and interposed between said first means and said second means having first and second collimating slits through which said first and second ion beams may pass, said third means including means to inhibit ion beam interaction;
e. analyzer means for deflecting the path of the first and second ion beams; and
f. first and second collectors adapted for receiving said first and second ion beams respectively after having passed through said first and second collector slits.

7. The apparatus of claim 6 wherein said second source slit and said second collector slit are adjustable.

8. The apparatus of claim 6 wherein said first source slit and said first collector slit are adjustable.

9. A method of analyzing material in a mass spectrometer comprising the steps of:
a. producing ions of like polarity and of material to be analyzed;
b. establishing plural beams of the ions;
c. applying like analyzer deflective forces to each beam to deflect the beams;
d. restricting the mass spectral range of at least one ion beam relative to at least another ion beam; and
e. collecting said plural beams on plural collectors.

10. The method of claim 9 wherein plural ion beams including ions of a common mass are collected simultaneously.

11. The method of claim 9 wherein at least two separate samples of material are used to produce ions and wherein the plural ion beams include some ions of a common mass.

12. A mass spectrometer comprising:
a. source means for establishing two distinct beams of ions of like polarity;
b. first and second collector means adapted to receive ions from first and second beams respectively when focused on the collectors;
c. means establishing an ion path of travel from the source means to the collector means;
d. a magnetic analyzer along said path and positioned to apply like magnetic flux to each of said distinct ion beams; and
e. beam delineating means along said path for restricting the mass spectral range of the ions in each of said paths.

13. The spectrometer of claim 12 wherein the beam delineating means includes means to prevent interaction of the two beams.

14. The spectrometer of claim 12 wherein the ion source means comprises two separate sources.

15. The spectrometer of claim 12 wherein the means establishing the ion beam path includes a pair of separate ion tubes.

16. The spectrometer of claim 12 wherein the source means is a single source.

17. The spectrometer of claim 12 wherein the means establishing the ion path includes a tube through which both beams travel.

18. The method of analyzing material in a mass spectrometer comprising the steps of:
a. establishing a plurality of ion beams of ions of like polarity;
b. deflecting the ion beams with an analyzer by applying like deflective forces to both beams; and
c. collecting focused ones of the ions with a plurality of collectors.

19. The method of claim 18 including the steps of forming one of the beams from a material to be analyzed and the other from a reference compound.

20. The method of claim 18 wherein one of said beams is resolved to a relatively high resolving power and resolving the other beam to a relatively low resolving power.

21. The method of claim 18 including the steps of simultaneously conducting a high resolution study of the mass spectrum of a sample and a metastable ion analysis of the sample.

22. A mass spectrometer comprising:
a Ion source means for producing ions of a material and establishing produced ions into beams;
b. collector means for receiving ions in such beams;
c. means establishing ion beam paths from the source means to the collector means;
d. an analyzer along said paths and positioned to apply ion deflecting forces to ions passing along each path; and
e. the means establishing the ion beam paths including a pair of curved ion tubes each extending over at least a portion of one of said paths whereby two ion beams may be formed and analyzed simultaneously.

23. The spectrometer of claim 22 wherein the curvature of the two tubes is equal.

24. The spectrometer of claim 22 wherein the ion source means comprises two separate sources.

25. The spectrometer of claim 22 wherein the source means is a single source.