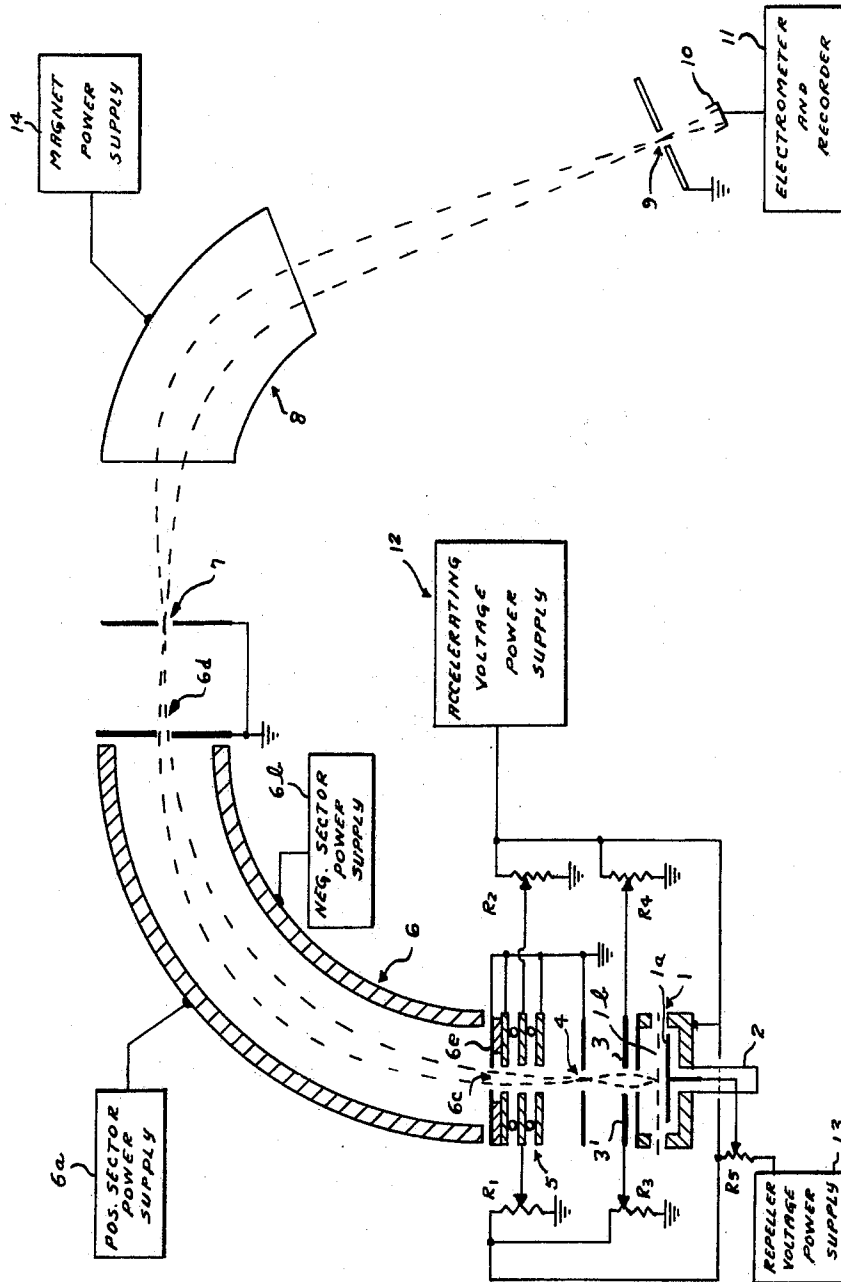


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METHOD OF IMPROVING SENSITIVITY AND RESOLUTION
OF A MASS SPECTROMETER
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**METHOD OF IMPROVING SENSITIVITY AND
RESOLUTION OF A MASS SPECTROMETER**

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1 Claim

ABSTRACT OF THE DISCLOSURE

A variable focus electrostatic lens is located between the electric sector and the object slit of the source lens assembly of a double focusing mass spectrometer, and is attached to the electric sector field termination shunt. Focusing plate electrodes providing an aperture of predetermined size are affixed between the object slit and the spectrometer ion source chamber. A common adjustable accelerating voltage power supply is in circuit with the focusing plate electrodes to control the acceleration and focusing of ions ejected from the ion source chamber on the object slit, and, in addition, both activate and provide a variable focusing action of the electrostatic lens to shift the apparent object plane in accordance with a variation in current intensity and correct for image errors at the geometric object slit.

BACKGROUND OF THE INVENTION

This invention relates generally to the field of mass spectrometers and, more particularly, to the effect of space charge defocusing of the spectrometer ion beam, which causes a shift in the effective object plane of the spectrometer optical system.

In previous research generally involving use of the analytical type mass spectrometer and, in particular, while optimizing the performance of a small double focusing type mass spectrometer during operation at high ion current levels, a serious loss in resolution was encountered. The latter loss was particularly emphasized as the signal intensity was increased by increasing the source pressure or the ionizing current. It was apparent that this effect was caused by space charge defocusing of the image resulting from coulombic repulsion of the charged particles in the ion beam. This defocusing effect, which seriously degraded the resolution and sensitivity of the spectrometer during its operation at low ion accelerating voltages and with currents of the same magnitude as that typically used in analytical mass spectrometers, caused the apparent object plane to shift closer to the electric sector of the spectrometer than is the actual location of the physically fixed object slit.

One solution to the above problem was to manually shift the object slit by shimming the mounting plate assembly. However, although an optimum resolution was found in this manner, it was achieved only after empirically shifting the object slit perhaps several times before the correct image focus was obtained. Moreover, the position so obtained was correct only for one particular total ion current and, therefore, the same empirical shifting of the object slit would be required for each change in the operating conditions of the mass spectrometer. Therefore, in view of the obvious difficulties and time consumption inherent in the mechanical shifting of the object slit to a new location each time a change in operating conditions occurred, the double focusing mass spectrometer of the present invention was developed with an improved variable focusing means incorporated therein in a manner to be described in detail hereinafter.

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SUMMARY OF THE INVENTION

The principal object of the present invention, therefore, is to provide an improved mass spectrometer having means to resist the inherent loss of sensitivity and resolution occurring particularly under certain operating conditions.

A further object of the invention resides in the provision of a novel mass spectrometer equipped with an auxiliary lens system to counteract defects in image at the object slit as a result of the apparent shift in object plane caused by the phenomenon known as space charge defocusing.

A still further object of the invention is in the use of a unique mass spectrometer incorporating an electrostatic lens combined with a variable accelerating voltage power supply easily adjustable in potential to nullify the effect of varying degrees of space charging defocusing by electrically shifting the apparent position of the spectrometer object slit a corresponding amount.

Other objects and advantages of the invention will become apparent from the following description, taken in connection with the single figure of the drawing, which represents a partly sectional and schematic diagram of the present mass spectrometer incorporating the improved auxiliary lens of the invention.

**DESCRIPTION OF THE PREFERRED
EMBODIMENT**

Referring to the single figure of the drawing, a double focusing mass spectrometer is illustrated as generally including an ion source chamber 1, a gas inlet tube 2 attached in communication with chamber 1, a pair of ion source lens assembly focusing plates or electrodes 3 and 3', a first object slit 4 for the electric sector 6, a second object slit 7 for the magnetic sector 8, a mass resolving slit 9, and a collector, and electrometer and recorder at 10 and 11, respectively. Electric sector 6 is shown as having positive and negative sector power supplies, applied as indicated at 6a and 6b, respectively, an entrance slit at 6c and an exit slit at 6d. Magnetic sector 8 is also shown as having a magnet power supply at 14 for the electromagnet (not shown) used therewith.

The ion source chamber 1 is equipped or formed with a repeller plate at 1a in circuit with a repeller voltage power supply at 13. An adjustable potentiometer tap R5 is used therewith to adjust the potential applied to repeller plate 1a. An electron beam is shown by the dashed lines at 1b as crossing ion source chamber 1 and positioned immediately in front of the repeller plate 1a. Forwardly of, and nearly adjacent the exit slit for chamber 1, are the focusing plate electrode at 3 and 3' of the source lens assembly. These focusing plate electrodes, which may be trimmed to a predetermined aperture width for a particular system to make tuning less critical, are powered by the accelerating voltage power supply at 12 through means of a pair of potentiometers having adjustable potential taps at R3 and R4, respectively, for a specific purpose to be explained hereinafter in detail with reference to the operation of the present mass spectrometer.

To improve the sensitivity and resolution of the present mass spectrometer by countering the inherent effect of space charge defocusing, a three element unipotential lens 5 is interposed between the object slit 4 and electric sector 6 and is mounted on the electric sector field termination shunt 6e. The operation of the unipotential lens 5 will be explained hereinafter in connection with the following description of the overall operation of the present mass spectrometer. The gas to be analyzed is introduced into ion source chamber 1 by way of the gas inlet tube 2, and is ionized by the electron beam indicated by the dashed lines at 1b. The repeller plate 1a is powered by the repel-

ler voltage power supply 13 by means of its connection to the tap of ion repeller potential R5. Ions produced by collision between the gas being introduced into chamber 1 by inlet tube 2 and the electron beam at 1b are repelled by repeller plate 1a, as controlled by the adjustment of ion repeller potential R5, and ejected through the exit slit of chamber 1. The ejected ions are then focused and accelerated by the adjustable potentials R3 and R4, which apply a fraction of the accelerating voltage to the focus plate electrodes 3, 3'. Ions are focused by this means on the object slit 4 of electric sector 6.

The unipotential lens 5 of the present invention is utilized to correct defects in the ion image at the object slit 4 by incorporating split potentials on the central element of the lens through use of the pair of potentiometers indicated at R1 and R2, respectively. Although these split potentials may be adjusted to a slightly unbalanced condition to correct for slight misalignments in the ion beam and, also, permits correction for mass discrimination by various factors, the main function of the lens 5 to correct for image error due to space charge defocusing is achieved, however, by keeping potentiometers R1 and R2 at approximately the same potential. Changing their potential with reference to ground causes the focusing of lens to become stronger or weaker, without changing any of the other characteristics of the ion beam. Thus, by a suitable adjustment of the potentials at R1, R2, the position of the virtual object may be matched with the actual position of the geometric object slit which represents the theoretical optimum design point for the particular mass spectrometer, for any arbitrary set of conditions, for example, of ion current, voltage and mass. Furthermore, whenever any of the latter mentioned parameters may be changed in the course of an experiment, it is only necessary to make a simple corresponding electrical adjustment in the potentiometers R1 and R2, external to the mass spectrometer vacuum system, to thereby correct for any change in the degree of space charges defocusing resulting therefrom.

The unipotential lens 5 and the electric sector 6 may be considered together as a compound lens system which provides a properly focused image at the object slit 7, commonly termed the β slit in the Nier-Johnson configuration mass spectrometers. The object image at object slit 7 is then transmitted to magnetic sector 8 and refocused by the electromagnet incorporated therewithin to thereby form ions of the proper mass-to-charge ratio at the mass resolving slit 9, and these ions are collected at the collector 10 and recorded by the electrometer and recorder 11. A mass spectrum is developed in a well known manner by sweeping the magnetic field intensity provided by the electromagnet in magnetic sector 8 and its associated power supply.

In the preferred embodiment of the present invention, a double focusing mass spectrometer is used; however, the unipotential lens 5 has equal application to a single focusing instrument. In the latter case, the electric sector 6 would be eliminated, and the object slit for the ion source lens assembly would be the present object slit 7 with the lens 5 located between slit 7 and the magnetic sector 8. Moreover, although the use of such a unipotential lens as at 5 was initially developed for application with mass spectrometers operating under a low accelerating voltage and at ion currents comparable to those of most analytical type mass spectrometers, it is equally

clear that the present invention would have general application to accelerating voltages more typically used with mass spectrometry and at substantially increased ion currents. For example, it is considered that the trend towards the development of the so-called "bright" sources for gas analysis will likely lead to similar problems of space charge defocusing, and that the solution of the present invention will have direct application thereto.

In addition to the above mentioned development, other more recent developments in high resolution mass spectrometry have involved the study of the use of a toroidal condenser rather than the usual cylindrical condenser configuration for the electric sector of a stigmatic focusing mass spectrometer. This type of condenser, which provides focusing in the Z direction of the ion beam as it passes through the condenser, increases the intensity of the ions at the final detector by a factor of about 20. However, it has been concluded that such a toroidal type condenser is obviously very difficult to manufacture and align and, in addition, a particular configuration would have a fixed focal length in the Z direction. In any event, it is readily apparent that, with the use of a unipotential lens in conjunction with the electric sector, many of the required stigmatic corrections associated with the toroidal condenser configuration would be accomplished. Furthermore, although the optimum position for such a lens would be at the approximate midpoint of the sector; nevertheless, a Z-axis unipotential lens placed anywhere within the sector region would probably involve both a considerable gain in intensity and correction in image error, as compared to that of the cylindrical condenser configuration.

We claim:

1. In a double focusing mass spectrometer having an electric sector, a magnetic sector, an ion source, accelerating means receiving ions from said source and forming a beam of accelerated ions emanating from an exit slit which serves as the object slit for the electric sector, means providing an object slit for the magnetic sector situated between the electric and magnetic sectors in which slit the electric sector normally forms an image of its object slit, and means providing a mass resolving slit in which said magnetic sector normally forms an image of its object slit for ions of a given mass, apparatus for correcting the defocusing of the image at the magnetic sector object slit caused by the apparent shift of the electric sector object slit nearer to the electric sector as a result of the mutual repulsion of like charged ions in the beam at high beam currents, said apparatus comprising a converging electrostatic lens situated between the electric sector and its object slit for producing a virtual object slit displaced from the actual object slit for the electric sector in a direction away from the electric sector by an amount sufficient to cause the apparent object slit for the electric sector to coincide with the actual object slit.

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