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**Scientifique and Thomson-CSF**  
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 [33] **France**  
 [31] **916,836**  
**Pat. 1,352,167**  
**Continuation of application Ser. No.**  
**712,406, Mar. 12, 1968, Continuation-in-**  
**part of application Ser. No. 518,453, Jan.**  
**3, 1966, now abandoned, Continuation of**  
**application Ser. No. 326,566, Nov. 27,**  
**1963, now abandoned.**

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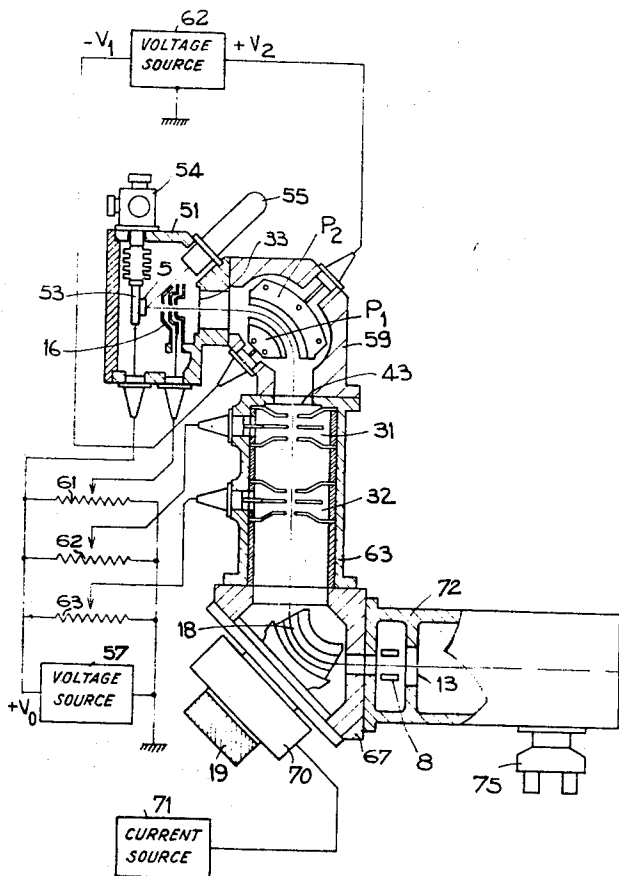
[54] **IONIC MICROANALYSERS**  
 6 Claims, 7 Drawing Figs.

[52] U.S. Cl. .... 250/49.5,  
 250/41.9

[51] Int. Cl. .... H01j 37/26

[50] Field of Search ..... 250/41.9  
 ISE, 41.9, 49.5

**ABSTRACT:** In an ionic microanalyzer, the energy filtering of the ions of the beam providing an image of a sample is effected by means of a spherical capacitor, suitably associated with the magnetic deflector used for the momentum-to-charge ratio filtering, through an intermediate lens system.











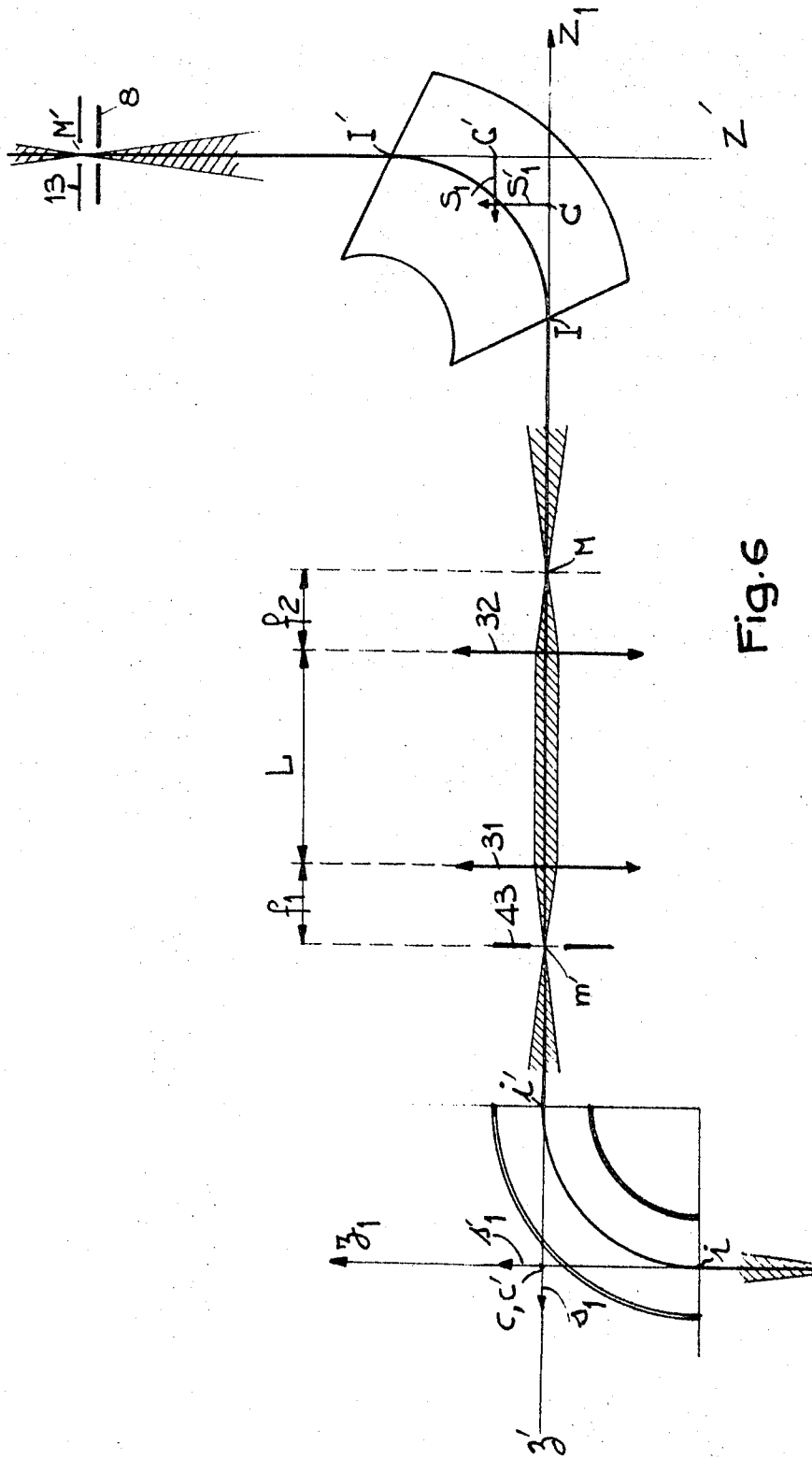


Fig. 6

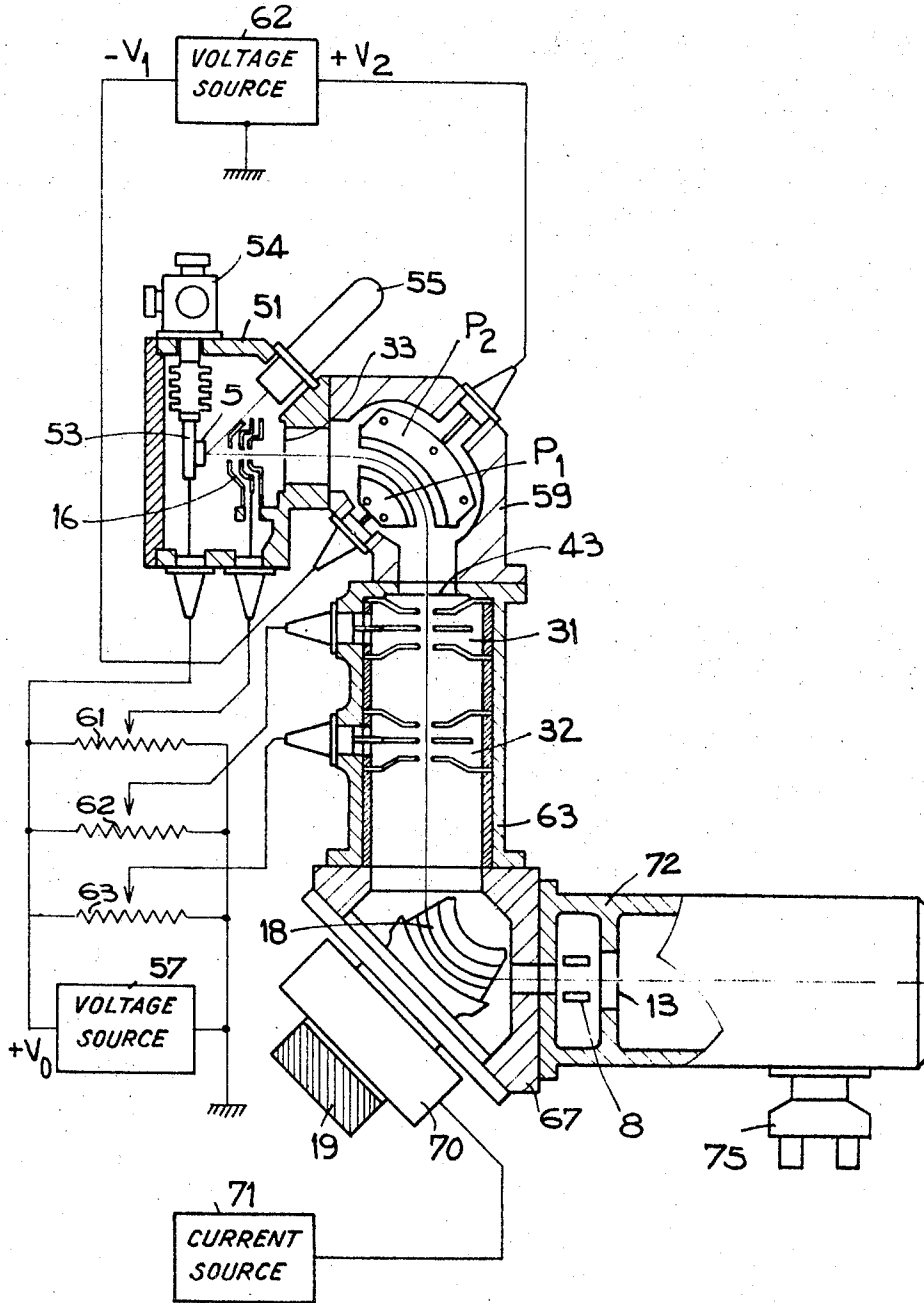


Fig. 7

### IONIC MICROANALYSERS

This application is a continuation-in-part of our application Ser. No. 712,406, filed March 12, 1968, which was a continuation-in-part of our application Ser. No. 518,453, filed Jan. 3, 1966, (now abandoned) which was a continuation of our application Ser. No. 326,566, filed Nov. 27, 1963 (now abandoned) for "Improvements in microanalyzers by secondary emission."

The present invention relates to the mass-resolving system of microanalyzers making use of the secondary ion emission for producing, by means of a particle system which combines ion optics and mass spectrometry, "characteristic images" of the surface of the sample which indicate the map of distribution of its various elements or isotopes.

Such microanalyzers are known in the art. A suitable system was described in the French Pat. No. 1,240,658.

The images must be selective with respect to the mass  $m$  of the secondary ions. In fact, as in mass spectrometry, the selectivity can be obtained only as a function of the ratio  $m/q$ , where  $q$  is the charge of the ion. This being understood, it will be assumed hereinafter that the ions utilized for forming the images are positive ions, with a single charge; this will not be a restriction as to the use of the arrangement described since an ion with a mass  $m$  and a charge  $2q$  behaves in an electric or a magnetic field as an ion with a mass  $m/2$  and a charge  $q$ .

It is known that in an ionic microanalyzer, the secondary ions, obtained by the impact of primary particles, are emitted from the sample surface with a certain amount of energy dispersion.

As in a mass spectrometer, these secondary ions are thereafter accelerated by a fixed voltage  $V_0$ , which is applied between the specimen and an accelerating electrode, and imparts to each of the ions an energy  $E_0$  equal to  $V_0$  electronvolts, the total energy of the ion being then  $V_0 + \Delta V$ , where  $\Delta V$  is the initial energy, in electron volts, of the ion.

In order to minimize the ratio  $\Delta V/V_0$ ,  $V_0$  should be high. However, for practical reasons,  $V_0$  cannot be chosen as high as it would be desirable in this respect, and the energy dispersion of the secondary ion beam is never negligible.

Since the magnetic filtering of the ions is not selective with respect to the mass  $m$  of the ions, but to their momentum  $mv$ , where  $v$  is the ion velocity ( $m v/q$  if all the ions have not the same charge) a satisfactory mass filtering of the ions requires, as is often the case in mass spectrometry, the adjunction of a filtering with respect to energy, in addition to the filtering with respect to momentum, so as to retain in the useful beam only those ions whose initial energy is lower than a given threshold, or lies in a predetermined energy band, the threshold, or the band, being a function of the mass of the ions used for the image and of the masses of the other ions present in the secondary ion beam.

In a microanalyzer, this energy filtering raises however problems which are not encountered in mass spectrometry and which are due to the following factors:

In mass spectrometry, the energy filtering needs only to preserve the image of a narrow slit, generally considered as a one-dimensional aperture. In a microanalyzer strict conditions must be respected for two two-dimensional images, i.e. the image of a two-dimensional aperture, and the image of the sample surface.

One solution of this problem consists in effecting the energy filtering with the help of an electrostatic mirror.

This system, however, can be used only for imparting a maximum threshold (and not a minimum one) to the energy of the ions, which energy filtering is generally, but not always sufficient. On the other hand, where very high ion currents are used, the operation of the mirror may be perturbed by space charge in the vicinity of the reflecting electrode, where the velocity of the noneliminated ions is zero.

According to the present invention, which eliminates the above-mentioned drawbacks, the energy filtering is effected by means of a spherical capacitor associated with auxiliary

lens means, the spherical capacitor having optical properties which, in the problem considered here, can compare with those of the mirror, and allowing a high degree of achromaticity in the image finally obtained.

It is recalled here that in particle optics, the term achromaticity as applied to an image is used to indicate the absence of aberrations due to the fact that the particles used for forming the image have different velocities.

The invention will be better understood and other characteristics thereof will appear, from the following description and appended drawings, in which:

FIG. 1 is a diagram illustrating the principle of the operation of a magnetic prism used in a known microanalyzer;

FIG. 2 illustrates the optical properties, used in the present invention, of a spherical capacitor;

FIGS. 3 to 6 are the optical diagrams of various preferred embodiments of the double filtering system according to the invention;

FIG. 7 is a detailed embodiment of an ionic microanalyzer using the optical diagram of FIG. 6.

The apparatus of the invention uses two deflectors having a common radial plane. Each of those deflectors has a pair of conjugate real stigmatic-points for ions having a predetermined mass and velocity, and entering it along a given axis.

A convenient magnetic deflector of this type, already used in known microanalyzers, is a magnetic prism. It is known that a magnetic prism or sector is a space region limited, along two faces, by a dihedron, with, disregarding edge effect, a uniform magnetic induction parallel to the line of intersection of the planes of the dihedron, which line will be assumed here to be vertical. It is generally obtained by means of an electromagnet whose pole pieces, of adequate design, having parallel plane inner faces, separated by a gap the width of which is small as compared with the dimension of the pole pieces. A radial plane of a magnetic deflector being a plane perpendicular to the magnetic induction, a magnetic prism has more than one radial plane. The radial plane more particularly considered here is the plane of symmetry of the two pole pieces.

FIG. 1 shows the section in the radial plane of a magnetic deflector **I**, which is a 90° deflector, i.e. a deflector deflecting by an angle of 90° the center ray of the beam of particles which it is desired to select. Two axes  $ZZ_1$  and  $Z'Z'_1$ , contained in this plane and normal to each other, intersect each other at **H** and the two faces of the prism respectively at **I** and **I'**,  $HI$  being equal to  $HI'$ .

$\epsilon$  and  $\epsilon'$  are the oriented acute angles of the normals at **I** and **I'** respectively with the straight lines  $ZZ_1$  and  $Z'Z'_1$ .

An ion  $P_0$ , with a mass  $m_0$ , and a velocity  $v_0$  directed along  $ZI$ , entering the prism at **I** has its trajectory inside this prism incurved along an arc of a circle, tangent at **I** to  $ZI$ , the radius  $R$  of this circle being proportional to  $m_0 v_0/B$  where  $B$  is the magnetic induction inside the prism.

$B$  may be adjusted so that  $R=IH$ ; the ion  $P_0$  then leaves the prism at **I'**, and its trajectory follows the half-line  $I'Z'_1$ , tangent at **I'** to the arc  $II'$ .

This trajectory  $ZII'Z'$  is defined as the "optical axis" of the prism for a bundle of trajectories in the vicinity thereof. The surface normal to the radial plane along the optical axis is called the transverse section of the prism.

It is convenient to indicate the optical properties of the prism considering only the rectilinear portions of the trajectories, outside the prism, and their virtual prolongations into the prism.

These trajectories will thus be related to the two axes  $ZHZ_1$  and  $Z'HZ'_1$ , which will be respectively designated as the object axis, and the image axis. The origins of the ordinates on those two axes are respectively **I** and **I'**, and the positive directions thereof are from **Z** to  $Z_1$  and  $Z'$  to  $Z'_1$  respectively.

The focusing properties of the prism for trajectories contained in the radial plane are well known and applied in mass spectrometers to conjugate the entrance slit and the exit slit optically.

In particular, there exists, for the trajectories of the radial plane in the vicinity of the optical axis, an object-side focal point  $F$ , an image-side focal point  $F'$  and a focal distance  $f_p$ , such that any point  $N$ , real or virtual, of the object axis has a conjugate image point  $N'$ , real or virtual, of the image axis,  $N'$  being such that

$$FN \cdot F'N' = -f_p^2.$$

The focusing properties of the prism for trajectories lying in the transverse section also find an application in a microanalyzer. As is known these properties, which are based on the existence of a small radial component, due to an edge effect, of the magnetic induction in the vicinity of the prism edges, exist only if the optical axis of the prism is at an angle with the normal to the prism at the entrance or/and at the emergence face thereof. The horizontal component, which is normal to the prism face, is zero in the radial symmetry plane of the prism, and increases, with opposite directions, above and under this plane, and, if it is at an angle with the velocity vector of the ions, produces a force, a component of which is vertical.

The trajectories lying in the transverse section and crossing under these conditions a face of the prism are correspondingly inverted; this results in focusing properties of the prism in the transverse section.

However, the focal points and the focal distance for the transverse section are generally different from those pertaining to the radial plane.

More precisely, to any object point with an abscissa  $\zeta$  on the object axis, there corresponds on the image axis, a first image point, conjugate of the object point in the radial plane, with an abscissa  $\zeta'_1$ , and another image point, conjugate of the object point in the transverse section, with an abscissa  $\zeta'_2$ .

For reasons, which will be set forth hereinafter, it is preferred to have a symmetrical design of the prism system, i.e. to have  $\epsilon = \epsilon'$ .  $ZZ_1$  and  $Z'Z'_1$  are then symmetrical with respect to the vertical plane bisecting the prism.

Under those conditions, the formulas giving  $\zeta'_1$  and  $\zeta'_2$ , given in the general case by the Cotte theory (Maurice Cotte, doctorate thesis "Recherches sur l'optique electronique," Masson et Cie Paris, 1938), become

$$\begin{aligned} \frac{\zeta'_1}{R} &= \frac{-1 + (\tan \epsilon) \frac{\zeta}{R}}{-\tan \epsilon - (1 - \tan^2 \epsilon) \frac{\zeta}{R}} \\ \frac{\zeta'_2}{R} &= \frac{-\frac{\pi}{2} + \left(1 - \frac{\pi}{2} \tan \epsilon\right) \frac{\zeta}{R}}{-\left(1 - \frac{\pi}{2} \tan \epsilon\right) - \left(2 \tan \epsilon - \frac{\pi}{2} \tan^2 \epsilon\right) \frac{\zeta}{R}} \end{aligned}$$

In the known ionic microanalyzer, angle  $\epsilon = \epsilon'$  is chosen so as to ensure the coincidence of the two image points  $M'$ , relative to one and the same object point  $M$  symmetrically located with  $M'$  relatively to the prism. This is possible for a theoretical value of  $\frac{1}{2}$  for  $\tan \epsilon$  ( $\epsilon$  being then equal to about  $27^\circ$ ), the corresponding values of  $\zeta$  and  $\zeta' = \zeta'_1 = Ah'_2$  being

$$\epsilon = -2R$$

$$\epsilon'_1 = \epsilon' A_2 = 2R$$

A beam of revolution with its apex in  $M$  and its axis along  $ZI$  will thus become after the crossing of the prism a beam substantially converging in  $M'$  and which, by reason of symmetry, will be a beam of revolution about  $I'Z'_1$ . The advantage of making  $\epsilon' = \epsilon$  is thus clearly seen, since it avoids aberrations of the images through preserving the symmetry of revolution of the beam.

On the other hand, among all the couples of points  $N$  and  $N'$ , conjugate in the radial plane, and respectively lying on the object and the image axis, there exists a couple of points  $C$  and

$C'$  such that a plane beam of the radial plane, having its apex in  $C$  and its axis along  $CI$  is converted by the prism into a beam converging in  $C'$ , not only for ions  $P_0$ , but also, disregarding first order terms, for all those ions whose momentum is slightly different from  $m_0 v_0$ , in other words, as concerns ions with the mass  $m_0$ , for a certain velocity band including  $v_0$ . Point  $C'$  will be called hereinafter the achromatic focal point of the prism. For the particular prism considered above,  $C$  and  $C'$  are respectively given by

$$\zeta = 2R/3 \text{ and } \zeta'_1 = -2R/3$$

In the absence of an energy filtering, the microanalyzer of the known type operates as follows (FIG. 1):

A magnetic prism of the above type is used.

The surface of the specimen  $S$  to be analyzed is placed normally to the axis  $ZI$ .

A plurality of electrodes  $6$ , forming with the specimen surface an immersion lens, through suitable voltages being applied to the sample and to the electrodes, accelerates the ions and imparts thus to them a supplemental energy  $E_0 = \frac{1}{2} m_0 v_0^2 = V_0$  electron-volts, and is so located that its crossover  $Q$  is centered on  $M$ . The convergence of the lens is so adjusted that the secondary ions extracted from the specimen under the impact of primary particles, for example primary ions, are concentrated into a beam giving a real magnified image  $S_1$  of the analyzed sample surface (i.e. a small portion of the surface of the specimen), which image, in the absence of the prism would be centered on point  $C$ .

Under those conditions, the prism gives in  $C'$  an image  $S'_1$  of  $S_1$ , and consequently of the analyzed surface, and, in  $M'$ , an image  $Q_1$  of the crossover  $Q$ , the latter being stigmatic, while the former, which is conjugate of  $S_1$  only as concerns the radial focusing, is astigmatic.

Two diaphragms  $3$  and  $13$ , with circular apertures, are respectively located in  $M$  and  $M'$ . These diaphragms, as concerns their selectivity in the radial plane, play the part of the selection slits of a conventional mass spectrometer and ensure the momentum filtering of the secondary ion beam.

The vertical image  $S'_1$ , practically achromatic for ions with mass  $m_0$  and a velocity comprised in a velocity band including  $v_0$  is converted into a real image by means of a lens  $7$ . However, this image, as indicated above, may be contaminated by ions having a mass different from  $m_0$ .

On the other hand, the image  $S'_1$  is astigmatic in the transverse direction, but this is a defect which it is easy to correct on the final image by means of a conventional stigmator  $8$  placed in the vicinity of the diaphragm  $13$ , so that it will not substantially perturb the stigmatism obtained for  $Q_1$ .

FIG. 2 shows the operation, considered per se, of a spherical capacitor used in particle optics.

It will be recalled that, in the case of an electric field, and of a plane optical axis, the radial plane is that plane which contains both the field and the axis, in other words the unique plane containing the optical axis, where the latter is incurved.

In FIG. 2 a spherical capacitor, with two electrodes  $P_1$  and  $P_2$ , has been shown by its section in a diametral plane, assumed to be horizontal, this capacitor being limited by two vertical planes  $\omega X$  and  $\omega Y$ . An arc  $K$  of a circle, having the same center  $\omega$  as the electrodes  $P_1$  and  $P_2$ , and a radius  $r$  which is the half-sum of the radii of  $P_1$  and  $P_2$ , has also been shown.

Suitable voltages are applied to electrodes  $P_1$  and  $P_2$  to make the potential along  $K$  equal to the potential outside of the capacitor, the potential difference between  $P_2$  and  $P_1$  being such that ions with a mass  $m_0$ , penetrating into the capacitor in  $i$ , intersection of the arc  $K$  with  $\omega X$ , with a velocity  $v_0$  directed along the tangent  $zi$  to the arc  $K$ , describe this arc  $K$  inside the capacitor and consequently leave it along the tangent  $i'z'_1$  to the arc  $K$ ,  $i'$  being the intersection of this arc with  $\omega Y$ .

The system with the optical axis  $z i' z'_1$  has in a radial plane optical properties similar to those of a magnetic prism in a radial plane, and which will be set forth in the same way, using

the virtual prolongations into the capacitor of the rays penetrating therein, as well as the oriented axes  $ziz_1$  and  $z'i'z'_1$ , which are the object axis and the image axis of the system.

In this system, an object-side focal point  $f$  and an image-side focal point  $f'$  may be respectively determined on the object axis and the image axis, and the optical properties indicated for the radial plane of the magnetic prism hold for the capacitor, if  $f, f', z_1, z'_1$  are substituted for  $F, F', ZZ_1$  and  $Z'Z'_1$ , and a constant  $f_0$  for the constant  $f_p$ .

But the spherical capacitor has in addition the property that what has been said for the radial focusing holds for the focusing in the transverse section, i.e. the vertical surface cutting the radial plane along the optical axis, with the same focal points and the same focal length  $f_0$ . It is to be noted that this latter property is specific of spherical capacitors and does not belong to the cylindrical capacitors generally used in mass spectrometry.

Lastly the Applicants have established that two conjugate points  $c$  and  $c'$  may be defined, for which the direction focusing, as well as the radial as the transverse one, is substantially independent of the energy of the ions. There is thus obtained a focusing for an energy band centered on  $m_0 v_0^2/0$ , and consequently, as concerns the ions with the mass  $m_0$ , for a certain range of velocities centered on  $v_0$ . Point  $c'$  will be called hereinafter the achromatic focal point of the capacitor.

It is thus possible, with a spherical capacitor, to obtain an achromatic energy filtered ionic image, in the same way as an achromatic momentum filtered image may be obtained with a magnetic prism. It suffices to chose two conjugate real points  $m$  and  $m'$ , points  $m, m', c$  and  $c'$  playing then the part previously played by points  $M, M', C$  and  $C'$ . But the stigmator is here necessary only to correct the edge effect in the capacitor.

The two deflecting sectors, i.e. the prism and capacitor, are serially located, preferably so that the first sector (prism or capacitor) supplies an achromatic filtered image of the sample, which image is taken up by a conventional optical system to be projected, with a suitable magnification, onto the point which is the conjugate, at least in the radial plane, of the achromatic focal point of the second sector, the latter supplying thus an achromatic double filtered image.

Of course, the vertical astigmatism correction must be effected on the image supplied by the magnetic sector.

There is thus obtained a purely mass-filtered image, which is achromatic for a velocity band including  $v_0$ .

This image is again taken up by a conventional optical system to be projected onto an observation screen, preferably through an ion-electron image converter.

Moreover, the invention has for its object more particular associations of the two deflecting sectors, such that ions with a mass  $m_0$  penetrating into the first sector with a velocity vector directed along the object axis of this sector leave the second sector along the image axis thereof, independently, disregarding terms of the second order, of the value of this velocity.

There is thus obtained an "achromatic system" allowing a still larger contribution of the ions with the mass  $m_0$  to the final image, while still avoiding the intrusion, in the final image, of ions with a different mass. In addition, the system is achromatic not only for the ions of mass  $m_0$ , but also for the ions whose mass is slightly different from  $m_0$ , which ensures a very high resolving power of the apparatus.

Before describing associations of the two sectors, the electric sector which is preferably used will be more accurately determined. Again here, it is preferred to use, as shown in FIG. 2, an optical axis whose circular portion is a  $90^\circ$  arc, for reasons of convenience, and also because it facilitates the preferred association modes of the two sectors.

In order to obtain this  $90^\circ$  arc, it obviously suffices that (FIG. 2)  $\omega X$  and  $\omega Y$  should be perpendicular to each other, the two focal points  $f$  and  $f'$  then coincide with  $i$  and  $i'$  respectively, and the conjugation relation is

$$i'm'i'm' = -r^2$$

The achromatic focal point  $c'$  (which is accurate disregarding second order terms) coincides with the point of intersection of the object and image axes, as well as with its conjugate  $c$ .

FIGS. 3 to 6 show several embodiments of the association of the preferred type. On those Figures, the same elements are designated by the same symbols as in FIGS. 1 and 2.

On the other hand, the plane of all the Figures is the symmetry radial plane of the magnetic sector and a radial plane of the electric sector; the object axis of the second sector coincides with the image axis of the first one, those two superimposed axes being hereinafter designated as the "common axis." This being so, either of the two sectors may occupy a position derived from that of FIGS. 1 or 2, not only through a displacement in which the radial plane slides on itself, but also through a  $180^\circ$  rotation around its object or image axis, which of course does not alter its properties in the least way.

According to whether the two optical axes lie or not on one and the same side of the common axis, the assembly will be called an assembly of the "C" type or of the "S" type.

Lastly, for all the described assemblies, the term "angle of dispersion" will mean that angle which is formed between the image axis of the second sector and the emergence rectilinear trajectory of an ion of mass  $m_0 + \Delta m$  and energy  $V_0 + \Delta V$ , having penetrated into the first sector with a velocity vector directed along the object axis of the first sector.

In FIG. 3, an assembly of the "C" type has been shown, wherein the first sector is the magnetic prism. The prism of FIG. 1 and all the elements preceding it are again present in the assembly of FIG. 3.

But the lens 7 is no longer there and is substituted by a lens 9, which is, like the stigmator 8, located in the vicinity of point  $M'$ . The diaphragm 13 is, as previously, centered on point  $M'$ . The lens 9 is very near  $M'$  so that it is possible, for the sake of simplicity in the language and formulas, to consider that the image which it gives of point  $M'$  practically coincides with  $M'$ .

Point  $i$  of the electric sector is at a distance  $D$  from  $M'$ . Image point  $M'$  of the prism optical system may also be considered as an object point  $m$  of the capacitor optical system, and is thus called point  $M', m$  in the Figures. The convergence of the lens 9 is adjusted to give of the virtual image  $S'_1$ , given by the prism, a real image  $s_1$  centered on point  $c, c'$  of the spherical capacitor, the latter image playing the part of a virtual object for the capacitor, which gives thereof a virtual image  $s'_1$ , also centered on point  $c, c'$ , but normal to its image axis. On the other hand, the capacitor gives of the crossover in  $M', m$  a further image centered on point  $m'$ , conjugate of point  $M', m$  in the capacitor optical system, i.e. defined by  $i'm' = -r^2$  ( $-D$ , ( $D$  being a positive length).

At this point  $m'$ , a further diaphragm 23 is located. The lens 18, which forms the ultimate ion image is centered on this object axis, beyond the diaphragm 23.

Such a structure allows the obtention of an "achromatic system": Calculation shows that the angle of dispersion  $\alpha$  of the system is

$$\alpha = \left(1 - \frac{2R}{D+r}\right) \frac{\Delta V}{V_0} - \frac{2R}{D+r} \cdot \frac{\Delta m}{m_0}$$

It suffices to make  $D+r=2R$  to have a system, which is dispersive with respect to mass, without being dispersive with respect to energy or velocity, since in that case

$$\alpha = -\frac{\Delta m}{m_0}$$

In particular, as shown in FIG. 3, this relation obtains for

$$D=rR.$$

Under those conditions, the velocity "pass-band" of the ions of mass  $m_0$  is optimum.

FIG. 4 shows an assembly of the "C" type, wherein the capacitor precedes the prism.

Point  $m$  lies on the half-axis  $z_i$ . The specimen 5 and an accelerating lens 16 are placed normally to the axis  $z_1$ , and the lens adjusted so as to give a crossover Q centered on  $m$  and the real image  $s_1$  of the sample surface. This real image acts as a virtual object for the capacitor which gives thereof a virtual image  $s'^1$ .

A diaphragm 33 is centered on  $m$  to delimitate the crossover

The magnetic sector is so located that the point M of its optical axis coincides with the point  $m'$ , which is the conjugate of point  $m$  in the electric sector and whose position on the object axis thereof is given by  $i'm' = -r^2/m = D$ .

At point  $m'$ , M, as at point  $M'$ ,  $m$  of FIG. 3, a diaphragm 43 is located, and, in the immediate vicinity thereof, a lens 9, which allows the projection, onto point C of the prism, of a real image  $S_1$  of the virtual image  $s'_1$  given by the capacitor; the image  $S_1$  is for the prism a virtual object.

The conditions are now again those which were described, with the help of FIG. 1, for the obtention of an image filtered only as to the momentum of the ions. The corresponding elements have not been shown again in FIG. 4.

The angle of dispersion of the assembly of FIG. 4 is

$$\alpha = \frac{3}{4} \left( \frac{D+r}{2R} - 1 \right) \frac{\Delta V}{V_0} + \frac{3}{4} \frac{\Delta m}{m_0}$$

An achromatic system is thus obtained for

$$D+r=2R$$

The mass dispersion being then

$$\alpha = \frac{3}{4} \frac{\Delta m}{m_0}$$

In particular this condition obtains, as shown in FIG. 4, for

$$D=r=R.$$

It has been assumed, hereinabove, that the optical center of the lens 9 (FIGS. 3 and 4) practically coincided with the center of the diaphragm, 13 or 43, respectively. In fact, this condition is not easily met with a very good degree of accuracy, because the lens is generally an electrostatic one, and it is difficult to place a diaphragm very near its center without perturbing its operation.

Besides, the lens considered here has a comparatively large focal length, and its dimensions are large.

It is thus preferred to substitute for the single lens centered on the common axis a group of two lenses, each of which has then a smaller focal length than that of the single lens.

As will be shown, it is thus possible to realize assemblies of the "S" type, which from the point of view of dispersion and achromatism, have properties respectively similar to those of the "C" type assemblies with a single intermediate lens, this being due to the fact that the passage from the "C" type to the "S" type is associated with the change of an inverted image to a noninverted image as concerns the sample image given by the intermediate lens system.

FIG. 5 shows an arrangement of the "S" type where the prism precedes the capacitor. The structure is the same as that of FIG. 3 between the sample and point  $M'$ .

The diaphragm 13 delimiting the first image of the initial crossover is centered on  $M'$ .

A first convergent lens 31, with a focal length  $f_1$ , has its object-side focal point in  $M'$ , and a second convergent lens 32, with a focal length  $f_2$ , is placed, relatively to the capacitor, so that its image-side focal point coincides with point  $m$  of the capacitor optical system. There is thus obtained in  $m$  an image of the crossover in  $M'$ .

The distance L between the two lenses is determined so that the points  $C'$  of the prism optical system and  $c$  of the capacitor optical system are conjugate with respect to the two-lens system.

The conditions are now the same, for obtaining the final image, as in the case of FIG. 3.

The angle of dispersion of this system is

$$\alpha = \left[ 1 - \frac{2R}{D+r} \frac{f_2}{f_1} \right] \frac{\Delta V}{V_0} - \frac{2R}{D+r} \frac{f_2}{f_1} \frac{\Delta m}{m_0}$$

An achromatic system is obtained for

$$\frac{f_1}{f_2} = \frac{2R}{D+r}$$

The mass dispersion being then

$$\alpha = - \frac{\Delta m}{m_0}$$

If  $f_1=f_2$ , an achromatic system is obtained for

$$D+r=2R.$$

FIG. 6 is an arrangement of the "S" type, with two intermediate lenses, wherein the electric sector precedes the magnetic sector.

Nothing is changed, relatively to FIG. 4, between the sample and point  $m'$ .

The intermediate optical system may be the same as that of FIG. 5, the diaphragm 43 being centered on  $m'$ , where the object-side focal point of lens 31 is also located, while the image-side focal point of the lens 32 coincides with the point M of the prism optical system, and the distance L between the two lenses being such that the point  $c'$  and C are conjugate with respect to the two-lens system.

The conditions are now the same as those which prevailed in the case of FIG. 4 for the obtention of the final image.

The angle of dispersion is

$$= \frac{3}{4} \left[ \frac{D+r}{2R} \frac{f_1}{f_2} - 1 \right] \frac{\Delta V}{V_0} + \frac{3}{4} \frac{f_1}{f_2} \frac{\Delta m}{m_0}$$

The system is achromatic for

$$\frac{f_1}{f_2} = \frac{2R}{D+r}$$

The angle of dispersion being then

$$= \frac{3}{4} \frac{f_1}{f_2} \frac{\Delta m}{m_0}$$

With  $f_1=f_2$ , the condition  $D+r=2R$  is again obtained.

The apparatus shown in FIG. 7 is a practical embodiment of a microanalyzer according to the optical diagram of FIG. 6. It comprises five main parts connected so as to build up a vacuumtight enclosure in which a vacuum is maintained with the help of a pumping system not shown in the Figure.

The first part is the specimen chamber 51 wherein the specimen 5 to be analyzed is placed on a support 53, which may be displaced along three directions, each of which is perpendicular to the other two, by means of a mechanism 54, the controls of which are outside the specimen chamber.

An ion gun 55, fixed in the specimen chamber generates the beam of primary ions for the bombarding of the sample. The secondary ions, which will be assumed to be positive ions, are accelerated and focused by means of a three-electrode lens 16 forming with the sample an immersion lens. To this end, the sample is brought, by means of a voltage source 57, to a potential  $V_0$  which is positive relatively to the ground potential of the apparatus. Three potentiometers 61, 62 and 63 are connected across this voltage source; the first and third electrodes of the lens 16 are grounded, while the second electrode is brought by means of the potentiometer 61 to an adjustable positive potential less than  $V_0$  in order to adjust the convergence of the lens. A diaphragm 33 is placed at the crossover of this lens.

The second part of the apparatus is an enclosure 59 comprising the electric sector, built up by the spherical electrodes

$P_1$  and  $P_2$ , respectively brought to potentials  $-V_1$  and  $+V_2$  by means of a voltage source 162.

The third part is the intermediate enclosure 163 containing the energy selection diaphragm 43, and the two three-electrode lenses 31 and 32, whose convergences are adjusted by means of the potentiometers 62 and 63, whose sliders are connected to the second electrode of those two lenses respectively.

The fourth part is the enclosure 67, containing the pole pieces the lower one of which, 68, is visible in the Figure, of an electromagnet 19 generating the magnetic prism. The coils 70 of this electromagnet are located outside the enclosure 67 and connected to an adjustable current source 71 for the adjustment of the magnetic induction.

The fifth part is the enclosure 72 containing the stigmator 8, the diaphragm 13 and the image converter, the latter and the electric supply thereof not being shown in the Figure. A binocular-viewing device 75 is used to observe the image appearing on the luminescent screen of the image converter.

Of course, the invention is not limited to the embodiment shown and described.

In particular, it is possible to use for the electric sector as well as for the magnetic sector optical axes whose circular portions are built up by arcs other than  $90^\circ$  arcs, it being always possible to determine on the former as well as on the latter an achromatic focal point.

Also, it is of course possible to use a "C" type assembly with a two-lens intermediate system, or an S-type assembly with a one-lens intermediate system; however, the degree of achromaticity thus obtained is not so satisfactory as in the described embodiments.

It should be noted that the stigmator which is necessary in the described embodiments to correct the image of the sample surface given by the prism is not, in fact, a drawback of the embodiments described, since anyhow a stigmator is always necessary in such complex optical systems to correct minor astigmatisms such as those resulting from edge effects, and since, generally, the different astigmatisms may be corrected by means of a suitably designed single stigmator.

In this connection, it should be noted that the stigmator should be, for the reason hereinabove indicated, located in the vicinity of one of the crossovers.

We claim:

1. An ionic microanalyzer for providing a selective ionic image of a surface of a sample, said microanalyzer comprising: means for bombarding a surface of a sample with primary particles, thereby extracting secondary ions from said surface;

first lens means, having an axis, for accelerating said ions and concentrating them into a beam having a crossover centered at a predetermined point of said axis of said lens means and providing a first image of said surface, said first image being centered at a further point of said axis; means for filtering the ions of said beam with respect to their mass-to-charge ratio, said filtering means comprising;

a first and a second deflector, one of which is a magnetic deflector having two pole pieces defining a gap having lateral faces normal to said pole pieces, and the other of which is a spherical capacitor,

said deflectors having a common radial plane with respect to which said two pole pieces are symmetrical with each other,

each of said deflectors having in said radial plane an optical axis comprising, inside the considered deflector, an arc of a circle having two ends, which arc is preceded and followed respectively by a first and a second rectilinear portion, respectively tangent to said arc at said two ends thereof, and respectively lying on a first and second rectilinear axis, respectively referred to as the object axis and the image axis of the considered deflector,

each of said deflectors having first and second conjugate real stigmatic points respectively lying on said object axis and said image axis of the considered deflector, said first deflector being located to have its object axis along said axis of said first lens means, and its first stigmatic point at said predetermined point of said axis of said lens means,

said second deflector being located to have its object axis along the image axis of said first deflector, the superimposed last two-mentioned axes being referred to as the common axis of said filtering means,

said filtering means further comprising a diaphragm centered on said common axis at said second conjugate stigmatic point of said first deflector and second lens means, having an axis coinciding with said common axis, for forming in an image plane a further image of the image formed by said first deflector, at least as far as radial focusing is concerned, of said first image of said surface and for forming, at said first conjugate real stigmatic point of said second deflector, an image of said second conjugate real stigmatic point of said first deflector;

a screen, and further lens means having an axis coinciding with said image axis of said second deflector, for projecting said selective ionic image onto said screen;

said further image in said image plane being inverted or erect according to whether said first lens means and said further lens means lie on one and the same side or on opposite sides of that plane, normal to said radial plane, which passes through said axis of said second lens means.

2. An ionic microanalyzer as claimed in claim 1 wherein, each of said deflectors having for said optical axis thereof an achromatic focal point located on the image axis thereof, and said further point of said axis of said first lens means coinciding with the conjugate relatively to said first deflector, at least as far as radial focusing is concerned, of said achromatic focal point of said first deflector, said second lens means being further such that said image plane intersects said axis of said second lens means at a point which, in relation to the second deflector, is the conjugate, at least as far as radial focusing is concerned, of said achromatic focal point of said second deflector.

3. An ionic microanalyzer as claimed in claim 2, wherein said first lens means and said further lens means lie on one and the same side of said plane normal to said radial plane and wherein said second lens means comprise a single lens.

4. An ionic microanalyzer as claimed in claim 2, wherein said first lens means and said further lens means respectively lie on opposite sides of said plane normal to said radial plane and wherein said second lens means comprise a first and a second lens.

5. An ionic microanalyzer as claimed in claim 1, wherein: said axis of said first lens means and said axis of said further lens means are parallel to each other and perpendicular to said axis of said second lens means; said axis of said second lens means and that one of the two axes of said first and further lens means which is intersected by one of said lateral faces of said gap make angles equal in absolute value to  $\text{Arc tan } \frac{1}{2}$  with the normals at said lateral faces of said gap at their respective points of intersection with said lateral faces; and a stigmator is provided for correcting the astigmatism of the image of said surface provided by said magnetic deflector.

6. An ionic microanalyzer as claimed in claim 5, wherein said diaphragm is centered on said axis of said second lens means at a point located at the distance  $D=2R-r$  from the point at which said last-mentioned axis is tangent to said arc of a circle of said optical axis of said spherical capacitor,  $R$  and  $r$  being respectively the radii of said arcs of a circle of said optical axes of said magnetic deflector and of said electrostatic deflector respectively.