United States Patent [19]

Watson

[11] **3,783,280**

[45] **Jan. 1, 1974**

[54] **METHOD AND APPARATUS FOR CHARGED PARTICLE SPECTROSCOPY**

[75] Inventor: **John Merza Watson,** Manchester, England

[73] Assignee: **Associated Electrical Industries Limited,** London, England

[22] Filed: **Mar. 21, 1972**

[21] Appl. No.: **236,748**

[30] **Foreign Application Priority Data**

Mar. 23, 1971 Great Britain 7,594/71

[52] **U.S. Cl.** **250/305,** 250/282, 250/294

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

[58] **Field of Search** ..... 250/49.5 AE, 49.5 PE, 250/41.9 ME

[56] **References Cited**

UNITED STATES PATENTS

3,699,331	10/1972	Palmberg	250/49.5
3,617,741	11/1971	Siegbahn et al.	250/49.5
3,596,091	7/1971	Helmer et al.	250/49.5
3,609,352	9/1971	Harris	250/49.5

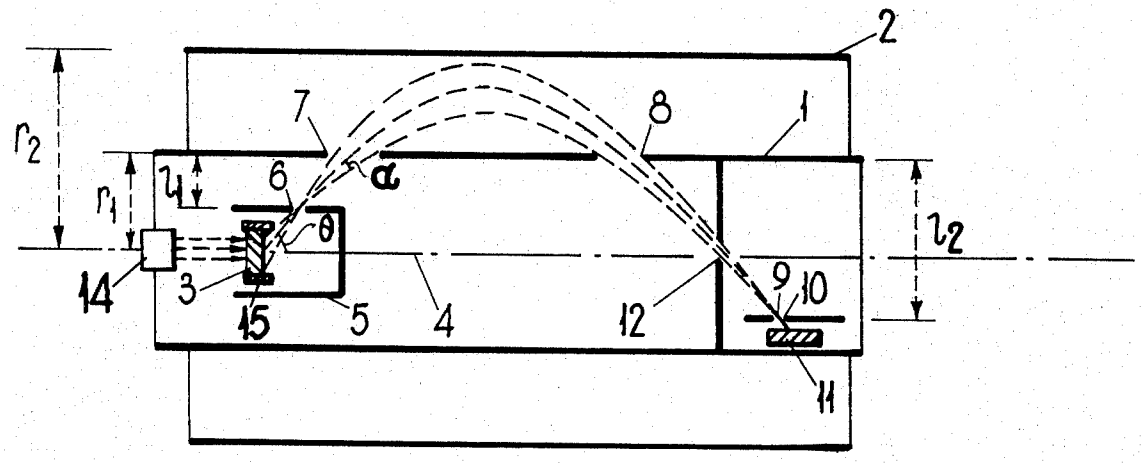
Primary Examiner—William F. Lindquist

Attorney—Thomas E. Fisher et al.

[57] **ABSTRACT**

In a cylindrical mirror analyzer, charged, particles from a source are deflected in the radial electric field between a pair of coaxial tubular electrodes, and are brought to a focus. A collector aperture positioned at the focus selects particles of predetermined energy, these particles being detected by a suitable detector. The particles cross the axis at some point between the source and the focus. An apertured member located at this point prevents skew electrons (i.e. electrons not travelling in radial planes) from reaching the focus. In this way the performance of the analyzer is improved.

19 Claims, 6 Drawing Figures



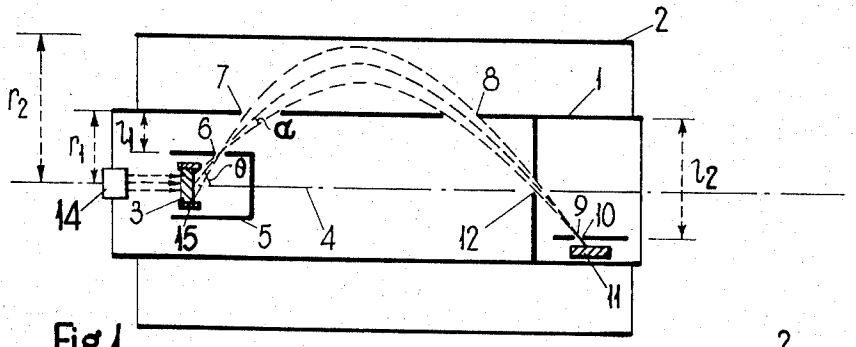


Fig.1

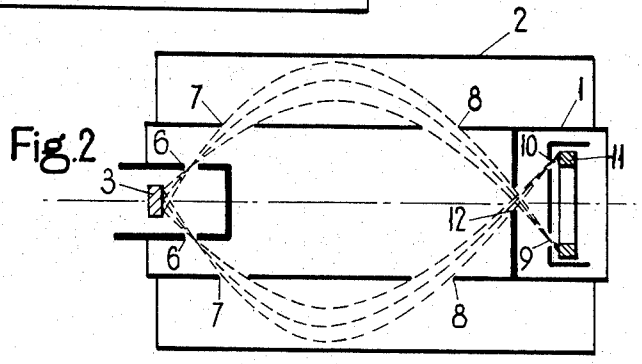


Fig.2

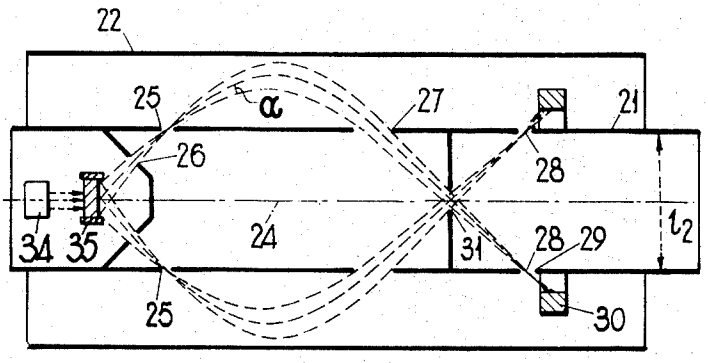


Fig.3

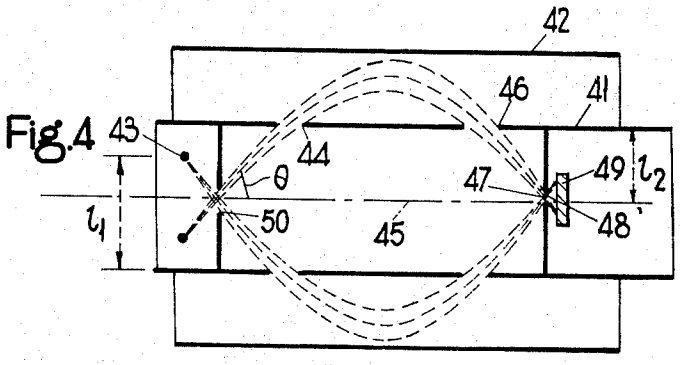


Fig.4

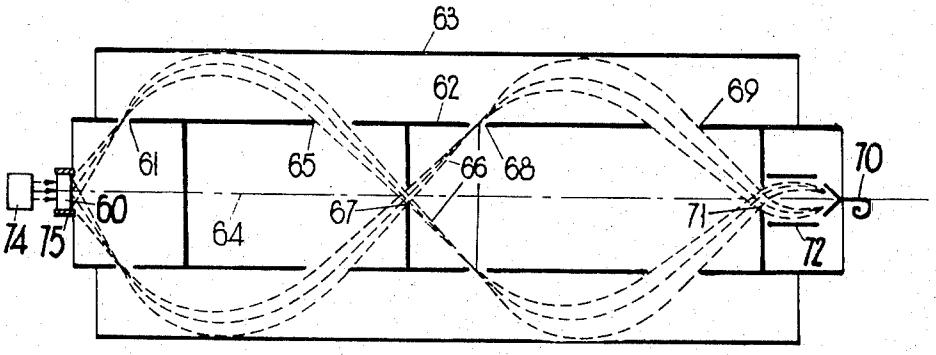

63
62
69
61
65
66
68
70
60
64
67
71
74
75
72

Fig.5

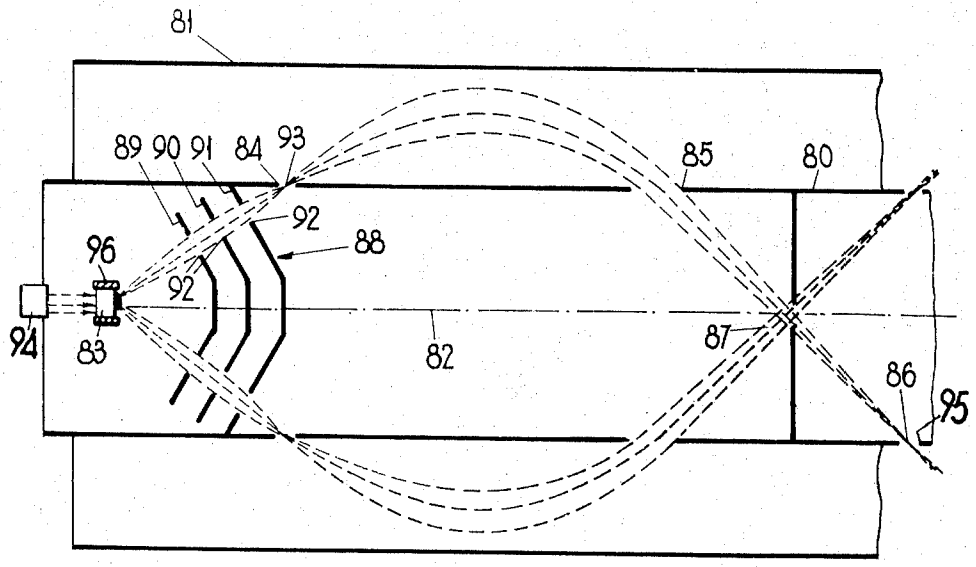

81
89
90
91
84
93
85
80
92
88
96
92
94
83
82
87
86
95

Fig.6

METHOD AND APPARATUS FOR CHARGED PARTICLE SPECTROSCOPY

CROSS REFERENCE TO RELATED APPLICATION

Electron Spectroscopy, U.S. Patent application Ser. No. 119,327, filed Feb. 26, 1971, by Brian Noel Green and John Merza Watson.

BACKGROUND OF THE INVENTION

This invention relates to charged particle spectroscopy and relates particularly, although not exclusively, to methods and apparatus for use in electron spectroscopy.

In the art of charged particle spectroscopy, devices called cylindrical mirror analyzers are known which analyze the energy spectrum of the particles by injecting the particles into a radial field produced between a pair of coaxially mounted tubular electrodes held at different potentials. Charged particles injected into the radial electric field between the tubular electrodes are deflected by the field toward the axis of the electrodes. Particles of a predetermined energy are thereby brought to a focus. By positioning a collector aperture at this focus, particles of a predtermined energy are selected by the aperture and detected as they pass through the aperture. By sweeping the voltage across the electrodes through a range of values, and detecting as a function of time such particles as pass through the collector aperture the energy spectrum of the injected particles is obtained.

Undesirable aberrations will be introduced where the source of charged particles is larger than a single point disposed along the axis of the analyzer. By way of explanation, if the source region is effectively a point disposed on the analyzer axis, all particles which emerge therefrom will travel in planes containing the axis of the analyzer. This is to say the particles will all travel in planes which are radial to the axis of the analyzer. As such, particles of the same energy will all be focused by the radial field at a common focus which is likewise along the analyzer axis.

Where the source is not effectively a point, some of the particles introduced into the radial field will be caused to travel in paths which are askew, i.e., along paths which are not confined to a single radial plane. These skew particles will not be focused at the same place as non-skew particles of the same energy. Accordingly undesirable aberrations are introduced into the analyzer thereby reducing the resolving power of the instrument.

Although axial point sources are desirable in that they introduce no skew particles, such sources have a very small area and provide a very low sensitivity analysis.

It is known that sensitivity can be improved, at least to some extend, by shifting the source position from the axis so that the source becomes an annulus, or part-annulus, about the axis. This gives rise to an increase in source area and hence to a large increase in sensitivity. However, it also leads to a decrease in resolving power, due to the effect of skew or non-radial particle trajectories.

SUMMARY OF THE INVENTION

According to the invention, in a cylindrical mirror analyzer, said detector is so positioned that, in operation, particles of said predetermined energy from the source region, traveling in radial planes, cross the axis of the analyzer at at least one position before reaching the detector. A screen member having an aperture, hereinafter referred to as the β-aperture, is disposed at this one position so as to prevent at least the majority of particles traveling in skew paths from reaching the detector.

Preferably, said collector aperture is positioned off-axis with respect to the analyzer axis. In this way, the collector aperture does not interfere with the function of the β-aperture Conveniently, the collector aperture substantially coincides with the inner of the electrodes.

Preferably, the β-aperture is disposed at a position reached by the particles after being deflected by the radial field.

In one preferred arrangement in accordance with the invention, the analyzer is so arranged that, in operation, the particles, after passing through the β-aperture, re-enter the radial electric field, and are deflected again by the field towards the detector, which is positioned on the axis.

Preferably, the particles from the source region pass through a further aperture, hereinafter referred to as the α-aperture, which restricts the angle of divergence of the paths of those particles which reach the detector. The α-aperture preferably is positioned off-axis with respect to the analyzer axis, so that it does not interfere with the function of the β-aperture, and is preferably positioned upstream of said collector aperture. Conveniently, the α-aperture substantially conicides with the inner of the electrodes.

Preferably, the collector aperture is annular and disposed symmetrically with respect to the analyzer axis. Such an annular configuration allows the sensitivity of the analyzer to be optimised for a given resolving power.

Conveniently, there is provided means selectably operable to retard the particles before they enter the radial field. A more complete discussion of electron retardation is provided in the referenced application. Such retardation enables the sensitivity of the analyzer to be improved without a corresponding loss of resolving power, as will be described. The means for retarding the particles conveniently comprises a charged particle lens.

Accordingly, one object of the present invention is to provide a cylindrical mirror analyzer in which aberrations associated with skew particles are reduced.

BRIEF DESCRIPTION OF THE DRAWINGS.

This and other objects and advantages of the invention will become more apparent from the following description of preferred embodiments of the invention as read in conjunction with the accompanying drawings, comprising FIGS. **1–6,** each of which is a schematic sectional elevation al view of a cylindrical mirror analyzer in accordance with the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS.

Referring to FIG. **1,** the cylindrical mirror analyzer shown therein comprises a pair of coaxial tubular metal electrodes **1** and **2** having radii r_1 and r_2 respectively. The electrodes **1** and **2** are mutually electrically insulated so that, in operation, the outer electrode **2** can be held at a negative potential with respect to the inner electrode **1,** thus providing a radially directed electric field in the space between the electrodes **1** and **2.**

A specimen **3** is mounted on a specimen support **15** within the inner spectrode **1**, on the common axis **4** of the electrodes. In operation of the analyzer, the specimen **3** is bombarded with radiation, such as, for example, X-rays, ultraviolet radiation, or electrons from a radiation source **14** so as to cause the specimen to emit electrons. The energies of these emitted electrons will depend on the chemical structure of the sample, and on the nature of the bombarding radiation. The specimen **3** is surrounded by a screening member **5**, having a small aperture **6** through which the electrons emitted from the specimen pass, which aperture thus effectively constitutes a point source of electrons.

After they pass through the source aperture **6**, the electrons pass through a further aperture **7**, which in this case is formed in the inner electrode **1** but may be formed in a separate member, this aperture **7** serving to restrict the angle of divergence 2α of the paths of those electrons from the source aperture **6** which pass through the aperture **7**. The aperture **7** is therefore referred to as the "α-aperture." Electrons passing through the α-aperture **7** enter the radial electric field between the electrodes **1** and **2** and are deflected by the field towards the axis **4** of the analyser. The deflected electrons pass through an exit aperture **8** in the inner electrode **1**, the exit aperture **8** being sufficiently wide as to have no limiting effect on the electrons. The electron optics of a cylindrical mirror analyser are such that electrons of a predetermined energy (depending on the strength of the radial electric field) and travelling in radial planes with respect to the analyser, are brought to a focus at a point **9**. The focus is a second order one; i.e. the focusing of the electrons at the point **9** is independent of terms in α and α^2, the principal aberration being proportional to α^3. A collector aperture **10** is positioned at this point to select electrons of the predetermined energy. Electrons passing through this aperture enter an electron detector **11**, which produces an output signal proportional to the rate at which it receives electrons.

It will be appreciated that the resolving power of the analyser (i.e. its ability to discriminate between electrons of different energies) will depend, among other things, on the extent of the collector aperture **10**, in the axial direction, and on the extent of the source aperture **6**, in the axial direction. The smaller these apertures are, the greater the resolving power. However, reducing the sizes of these apertures will also reduce the sensitivity of the analyser, so that, in practice, the sizes of the apertures must be a compromise.

The radial position of the focus **9**, i.e. its radial distance l_2 from the inner electrode **1**, depends on l_1, the radial distance of the source aperture **6** from the inner electrode **1**, and also on the mean angle θ which the trajectories of the electrons make with the axis **4** before the electrons are injected into the radial electric field. For a given angle θ, the distances l_1 and l_2 are related by the equation:

$$l_1 + l_2 = nr_1 \qquad (1)$$

where n is a constant, dependent on θ. In the present example, $l_1 + l_2 = 2r_1$, i.e. $n = 2$, which corresponds approximately to an angle $\theta = 42°20'$.

It will be seen that, with this geometry, the electrons will cross the analyser axis **4** at some position between the exit aperture **8** and the focus **9**. This applies only to electrons travelling in radial planes, however, and skew electrons (i.e. those not travelling in radial planes) will not cross the axis **4**, the distance of their closest approach to the axis being a direct measure of their skewness (i.e. the angle β by which the diverge from a radial plane). A major proportion of these skew electrons is excluded from reaching the detector **11** by means of a circular aperture **12** (hereinafter referred to as the "β-aperture") located on the axis **4** at the position where the non-skew electrons cross the axis.

Clearly, the smaller the β-aperture **12** the more effective it is in excluding the skew electrons, although of course the smaller it is the smaller the number of electrons which will reach the detector **11** and hence the lower the sensitivity of the analyser. In practice, the size of the β-aperture **12** will be a compromise. The effect of the β-aperture **12** is greatly to decrease aberrations due to skew electrons, and thus to improve the performance of the analyser.

Because the source aperture **6**, α-aperture **7** and the collector aperture **10** lie off-axis with respect to the axis **4**, they do not interfere with the function of the β-aperture **12**. If, for example, the collector aperture **10** were positioned on the axis, it would, in general, restrict the flow of non-axial electrons more severely than is necessary to achieve the required resolution, and would thus unnecessarily reduce the sensitivity of the analyser.

The energy spectrum of the electrons emitted from the sample can be analysed by sweeping the voltage applied between the electrodes **1** and **2** through a suitable range of values, and recording the output of the electron detector **11** as a function of time.

Referring now to FIG. **2**, in which similar features have the same reference numerals as in FIG. **1**, in a modification of the arrangement of FIG. **1** the source aperture **6**, the α-aperture **7**, the exit aperture **8**, the focus **9** the collector aperture **10**, and the detector **11** are all annular in form extending through an azimuthal angle of 2π coaxially with the axis **4**. The electron optics of this arrangement are similar to those of the arrangement of FIG. **1**. However, it will be seen that in this case, the area of the source aperture **6** is much greater than in the case of FIG. **1**, and thus the sensitivity of the analyser is greatly increased. As before, the analyser comprises a circular β-aperture **12** at the point where the non-skew electrons across the axis.

In other modifications of the arrangement of FIG. **1**, the arrangement may be only part annular, extending through an azimuthal angle of less than 2π.

In modifications of the arrangements shown in FIGS. **1** and **2**, if the distances l_1 and l_2 are both varied, while keeping the sum $l_1 + l_2$ constant, the factor n in equation (1) above will remain constant, and therefore the angle θ required for second order focussing at the collector aperture will remain the same, i.e. approximately equal to 42° 20'. Furthermore, the aberration coefficients will remain the same, and the dispersion expression (i.e. the relation between electron energy and applied voltage) for the analyser will be retained. A limiting case of this is shown in FIG. **3**, for the case where $l_1 = 0$ and therefore $l_2 = 2r_1$.

Referring to FIG. **3**, the analyser shown therein comprises a pair of coaxial tubular electrodes **21** and **22** for producing a radial electric field. A specimen **23** is positioned by means of a specimen support **35** on the analyser axis **24**, and is arranged to be bombarded with radi-

ation from a radiation source **34** and thus to emit electrons. The emitted electrons pass through an annular aperture **25** in the inner electrode **21**, this aperture thus constituting effectively an annular source of electrons. A further annular aperture **26** is positioned between the specimen **23** and the source aperture **25**, and serves as an α-aperture, defining the angle of divergence 2 a of the electrons passing through the source aperture.

Electrons from the source aperture **25** enter the radial electric field betwen the electrodes **21** and **22**, and are deflected towards the axis **24**, passing through an annular exit aperture **27** (which is large enough to have no limiting effect on the electrons) in the inner electrode **21**. Electrons of a predetermined energy are thus brought to an annular second order focus **28**. Since in this case $l_2 = 2r_1$, the focus **28** lies on the inner electrode **21**. An annular aperture **29** is formed in the inner electrode **21**, and serves as a collector aperture, selecting the focused electrons of predetermined energy. The selected electrons are detected by an annular electron detector **30**.

As before, the electrons cross the analyser axis **24** at a point intermediate the exit aperture **27** and the focus **28**, and a circular aperture **31** is positioned on the axis at this point so as to exclude the majority of skew electrons and therefore reduce the aberrations from this cause.

In a modification of the arrangement shown in FIG. **3**, the aperture **27** may be arranged to act as the α-aperture, effectively limiting the divergence of the electron beam. In this case the aperture **26** will be chosen to be large enough to have no limiting effect on the electrons, or may be omitted altogether, thus leaving more working space around the specimen **23**.

In other modifications of the arrangements shown in FIGS. **1** and **2**, the distances l_1 and l_2 may be modified independently of each other, so that the factor n in equation (1) no longer remains equal to 2. It will be appreciated that, in such an arrangement, in order to achieve second order focussing, the angle θ must be other than 42° 20′.

One such modification is shown in FIG. **4**, which shows a cylindrical mirror analyser comprising, as before, a pair of coaxial tubular metal electrodes **41** and **42**, and an annular source **43** of electrons, which may comprise a source aperture such as aperture **6** in FIGS. **1** and **2**. Electrons from the source **43** pass through an annular α-aperture **44** in the inner electrode **41**, are deflected by the radial electric field between the electrodes towards the analyser axis **45** through an annular exit aperture **46** (having no limiting effect on the electrons) in the inner electrode, electrons of a predetermined energy and travelling in radial planes being brought to a second order focus **47**. In the particular example shown, the angle θ and the distance l_1 are so chosen that this focus **47** is a point focus, lying on the axis **45**. However, in other arrangements, this focus could be annular or part annular. A circular collector aperture **48** is disposed at the focus **47**, and selects focused electrons having the predetermined energy. The selected electrons pass into an electron detector **49**.

It will be seen that in this arrangement, the electrons cross the axis **45** at a point between the source **43** and the α-aperture **44** i.e. before they enter the radial electric field. A circular β-aperture **50** is located on the axis at this point, in order to prevent the majority of skew electrons from reaching the detector **49**.

In the particular example shown in FIG. **4**, it will be seen that l_1 is greater than r_1 and $l_2 = r_1$, so that the factor n in equation (1) is greater thus 2. For example, if $l_1 = 1.5r_1$, $n = 2.5$

Referring to FIG **5**, a preferred analyser in accordance with the invention comprises a pair of coaxial tubular electrodes **62** and **63** for producing a radial electric field. A specimen **60** is positioned by means of a specimen support **75** on the analyser axis **64**, and is arranged to be bombarded with radiation from a radiation source **74** and thus to emit electrons. The emitted electrons pass through an annular source aperture **61** in the inner electrode **62**, this aperture thus effectively constituting an annular source of electrons.

Electrons from the source aperture **61** enter the radial electric field between the electrodes **62** and **63**, and are deflected towards the axis **64**. The electrons pass through an annular aperture **65** in the inner electrode **62**, this aperture serving as an α-aperture defining the effective angle of divergence 2α of the electrons from the source aperture **61**.

The radial electric field focuses electrons of a predetermined energy to an annular second order focus **66**, which lies coincident with the inner electrode **62**. An annular collector aperture **68** in the inner electrode selects focussed electrons of the predetermined energy.

The electrons cross the analyser axis **64** at a point intermediate the α-aperture **65** and the focus **66**, and a circular β-aperture is positioned on the axis of that point, so as to exclude the majority of skew electrons and therefore reduce the aberrations from this cause.

As described so far, the arrangement of FIG. **5** is similar to that of FIG. **3**. However, in FIG. **5**, the electrons do not enter an annular detector after passing through the collector aperture **68**. Instead, the electrons reenter the radial electric field between the electrodes **62** and **63**, and are deflected by the field again towards the axis **64**, so that they pass through an exit aperture **69** in the inner electrode **62**. The electrons converge on to, and pass through, a circular detector aperture **71**, on the axis **64**, and are deflected by a tubular electrode **72** into an electron detector **70**. Neither the exit aperture **69** nor the detector aperture has any limiting effect on the electrons.

It will be seen that by passing the electrons through the radial field for a second time, the electrons can be directed on to a relatively localised region, so that a single detector can be used. This avoids the use of an annular detector, as required in FIGS. **2** or **3**.

In a modification of the arrangement of FIG. **5**, the collector aperture may be positioned where the electrons emerge from the radial field for the second time i.e. may replace exit aperture **69**.

In the arrangements described above the various apertures, such as the apertures **61**, **65** and **68** in FIG. **5** are defined by the inner electrode of the analyser. However, in modifications of these arrangements, the apertures may be defined by separate plates, which are mounted adjacent the inner electrode. This allows the apertures to be replaced if it is desired to change their dimensions. Such separate plates may be held at the same potential as the inner cylinder, or may be held at a slightly different potential, such as to effect small corrections to the injection angle θ and to compensate for the effect of fringing fields at the apertures.

In the particular embodiments described above the effective source of electrons is defined by an aperture,

such as the aperture **6** in FIG. **1.** However, in modifications of these arrangements, the effective source may be the area of the surface of a specimen after which the electrons actually originate. Alternatively, the apparatus may include an electron optical lens, arranged to bring electrons to a focus, (which may be a point focus, or an annular or part annular focus), which focus then constitutes the effective source of electrons for the apparatus. The electron optical lens, in addition to focusing the electrons, may also retard them i.e. decrease their energies. The advantage of retarding electrons in apparatus for electron spectroscopy is, as explained in the referenced application, that in certain circumstances it allows the sensitivity of the apparatus to be increased, at least for relatively high energy electrons, without loss of resolving power.

Referring now to FIG. **6,** in one such embodiment of the invention there is again provided a cylindrical mirror analyser comprising two tubular electrodes **80** and **81** disposed coaxially with respect to a common axis **82,** between which a radial electric field can be produced. A specimen **83** is mounted in a specimen support **96** on the axis **82,** and is arranged to be bombarded with radiation from a radiation source **94** so as to emit electrons. These electrons pass through an annular source aperture **84** in the inner electrode **80,** are deflected towards the axis **82** by the radial electric field and pass through an annular α-aperture **85** in the inner electrode. Electrons of a predetermined energy are thus brought to an annular focus **86** coincident with the inner electrode **80.** Electrons of this predetermined energy are selected by a collector aperture **95** formed in the inner electrode **80.** Electrons selected by the collector aperture **95** either enter an annular electron detector (not shown) as in the case of FIG. **3,** or pass for a second time through the radial field and are converged on to a detector (not shown) on the axis **82,** as in the case of FIG. **6.** As before, a β-aperture **87** is positioned at a point where the electrons cross the axis **82** before arriving at the focus **86,** in order to prevent the majority of skew electrons from reaching the focus **86.**

Between the specimen **83** and the aperture **84** is positioned an electron optical lens arrangement **88,** comprising three metal components, **89, 90, 91** each of which is in the shape of a truncated cone coaxial with the electrodes **80, 81,** and each of which has an annular aperture **92** through which the electrons pass successively. It will be seen that by applying suitable potentials to the components **89, 90, 91,** the lens arrangement **88** can be made to focus electrons emitted from the specimen **83** to an annular focus **93** at the aperture **84,** and may also be arranged to retard the electrons before they enter the radial field. Thus, it will be seen that this focus **93** acts effectively as an annular source of electrons.

The lens arrangement is selectably operable by changing the electrical connections thereto, either to produce or not to produce retardation, and either to produce a substantially unit electron optical magnification, or to produce an electron optical magnification substantially greater than unity. Retardation is produced by setting the potentials of components **89, 90, 91** such that the potential of the last component **91** is more negative than that of the specimen **83.**

Retardation is used when analysing relativey high energy electrons, for the reason explained above, while no retardation is used for analysing relatively low energy electrons.

A magnification greater than unity is used in one of two circumstances. First, where the specimen is irradiated with a fine probe of radiation, (i.e. a "microprobe") the area of the specimen which emits electrons is very small, and the use of a magnification substantially greater than unity allows a greater number of the electrons emitted from this small area to pass through the analyser, thereby increasing the sensitivity of the analyser. Secondly, where the specimen is flooded with radiation, the use of a magnification substantially greater than unity means that the electrons which pass through the source aperture **84** come only from a very small area of the specimen. This latter arrangement provides in effect a "virtual microprobe" and can be used in a similar manner to conventional microprobe arrangements.

A substantially unit magnification, on the other hand, is used if the sample were flooded with radiation to cause it to emit electrons over an extended area.

It will be appreciated that in modifications of the arrangement shown in FIG. **6** the lens **88** may comprise more than three components or may alternatively comprise only two components. Furthermore the components of the lens may have substantial thickness, so that the apertures **92** become channels of significant length.

It should be appreciated that while the particular embodiments of the invention described herein, by way of example, are for electron spectroscopy, the invention is equally applicable to other forms of charged particle spectroscopy, e.g. ion spectroscopy.

Although the invention has been shown in connection with preferred embodiments it will be readily apparent to those skilled in the art that various changes in the form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention as defined by the appended claims.

I claim:

1. A cylindrical mirror analzer comprising:

a pair of at least partially tubular electrodes mounted coaxially with respect to a common axis and mutually electrically insulated so that when a voltage is applied between said electrodes a radial electrical field is established between said electrodes;

source means for injecting charged particles into said radial field whereby particles emanating from said source means are deflected by said field toward said axis and particles of a predetermined energy are directed toward a focal point;

a first apertured means having a collector aperture formed therein and positioned at said focal point to permit passage of substantially only said particles of predetermined energy;

a detector means for detecting particles which pass through said collector aperture; and,

a second apertured means having an aperture formed therein and positioned at a point where said particles of said predetermined energy which are traveling in radial planes with respect to said analyzer axis cross said analyzer axis.

2. A cylindrical mirror analyzer according to claim **1** wherein said collector aperture is positioned off-axis with respect to the analyzer axis.

3. A cylindrical mirror analyzer according to claim **2** wherein said collector aperture substantially coincides

in diameter with the diameter of the inner of said electrodes.

4. A cylindrical mirror analyzer according to claim **2** wherein said collector aperture is annular and disposed symmetrically with respect to said axis.

5. A cylindrical mirror analyzer according to claim **1** wherein said second apertured means is positioned between said source means and said collector aperture.

6. A cylindrical mirror analyzer according to claim **5,** wherein said second apertured means is disposed at a position reached by said particles after being deflected by said field.

7. A cylindrical mirror analyzer according to claim **6,** wherein, said detector means is positioned along said axis and said particles, after passing through said second apertured means, re-enter the radial field and are deflected again by the field towards said detector means.

8. A cylindrical mirror analyzer according to claim **1,** further including a third apertured means having an aperture formed therein for restricting the angle of divergence from said source means of the paths of those particles which reach said detector means.

9. A cylindrical mirror analyzer according to claim **8** wherein said aperture in said third apertured means is positioned off-axis with respect to said analyzer axis.

10. A cylindrical mirror analyzer according to claim **9** wherein said aperture in said third apertured means substantially coincides in diameter with the diameter of the inner of said electrodes.

11. A cylindrical mirror analyzer according to claim **8** wherein said third apertured means is positioned upstream of said collector aperture.

12. A cylindrical mirror analyzer, according to claim **1** further including means selectably operable to retard said particles before they enter said field.

13. A cylindrical mirror analyzer according to claim **12,** wherein said means to reatrd the particles comprises a charged-particle lens.

14. A cylindrical mirror analyzer according to claim **13,** wherein said lens is an electrostatic lens comprising a plurality of metal components having respective apertures through which the particles pass successively.

15. A cylindrical mirror analyzer according to claim **14,** wherein said metal components are generally conical in shape.

16. A method of operating a cylindrical mirror analyzer having a pair of tubular electrodes mounted coaxially with respect to a common axis and mutually electrically insulated, comprising the steps:

a. injecting charged particles between said electrodes;

b. applying a voltage between said electrodes so as to deflect said particles towards said axis thereby bringing particles of a predetermined energy to a focus;

c. selecting said particles of said predetermined energy at said focus;

d. positioning a member having an aperture on said axis at a said sai particles of predetermined energy, travelling in radial planes, cross said axis, so as to prevent at least the majority of particles travelling in skew paths from reaching said focus; and

e. detecting the particles so selected.

17. The method of claim **16** wherein said step of selecting particles is carried out by inserting an apertured means having a collector aperture formed therein at said focus.

18. The method of claim **16,** including the further step of retarding said particles before they enter said field.

19. The method of claim **18,** wherein said step of retarding said particles is carried out by operating a charged-particle lens.

* * * * *