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[54] **DEVICE FOR DETERMINING THE ENERGY OF CHARGED PARTICLES**

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

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

[56] **References Cited**

OTHER PUBLICATIONS

"Photoelectron Spectroscopy of the Rare Gases," Samson, The Physical Review, Vol. 173, September 1968, pp. 80–85.

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Assistant Examiner—C. E. Church
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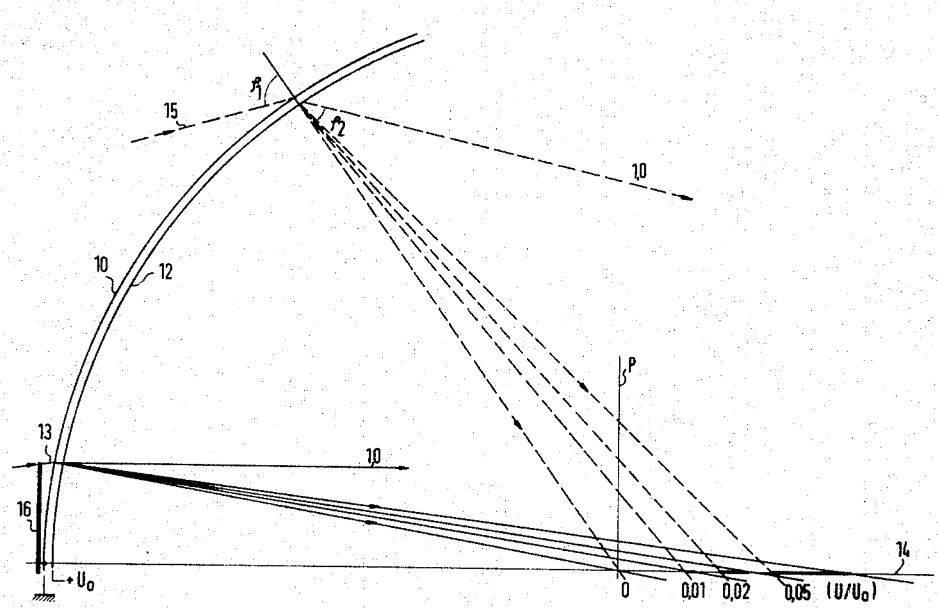
[57] **ABSTRACT**

A device for determining the energies of charged particles, as Auger electrons, comprises at least one durved or domeshaped electrode biased to converge the paths of particles which are emitted by a particle source into a solid angle spanned by said electrode. The electrode is convex toward the particle source and cooperates with a similar, fairly closely spaced second electrode, and with a bias source connected to said electrodes to produce a particle accelerating field between them, to focus particles of a predetermined energy into a particle detecting device.

7 Claims, 6 Drawing Figures



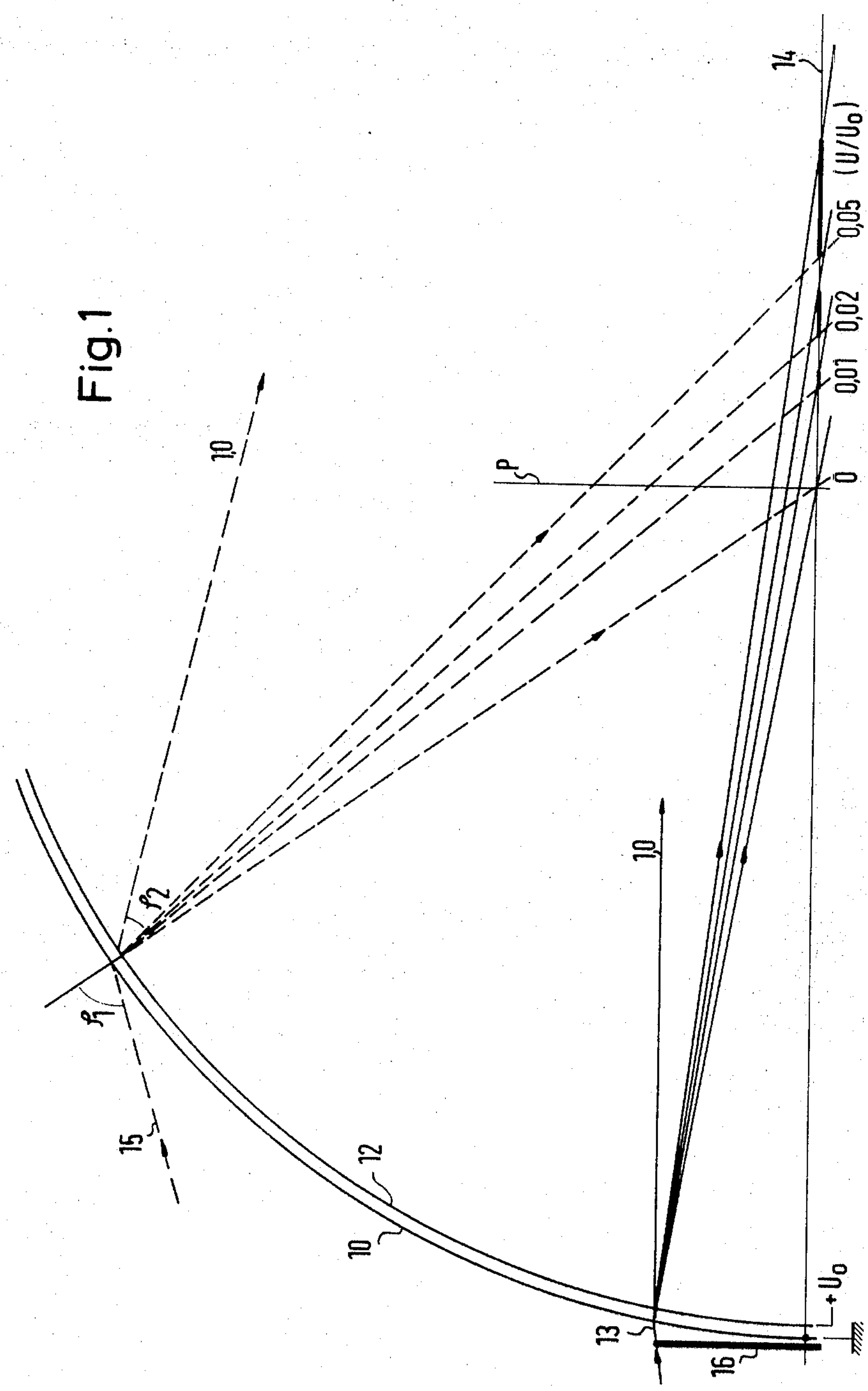


Fig.1

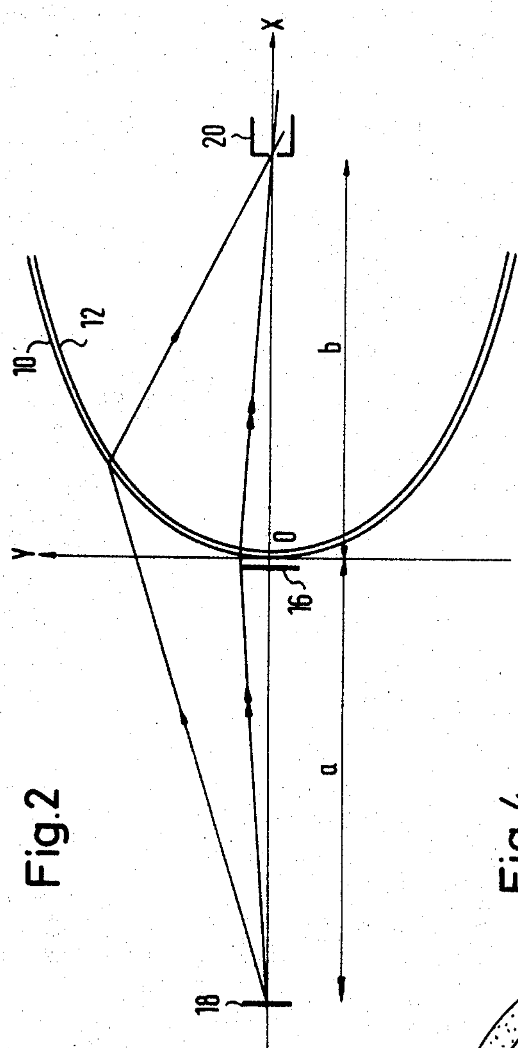


Fig.2

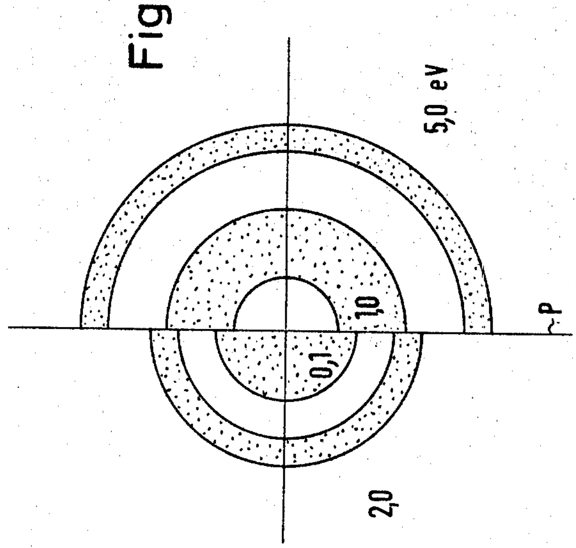


Fig.4

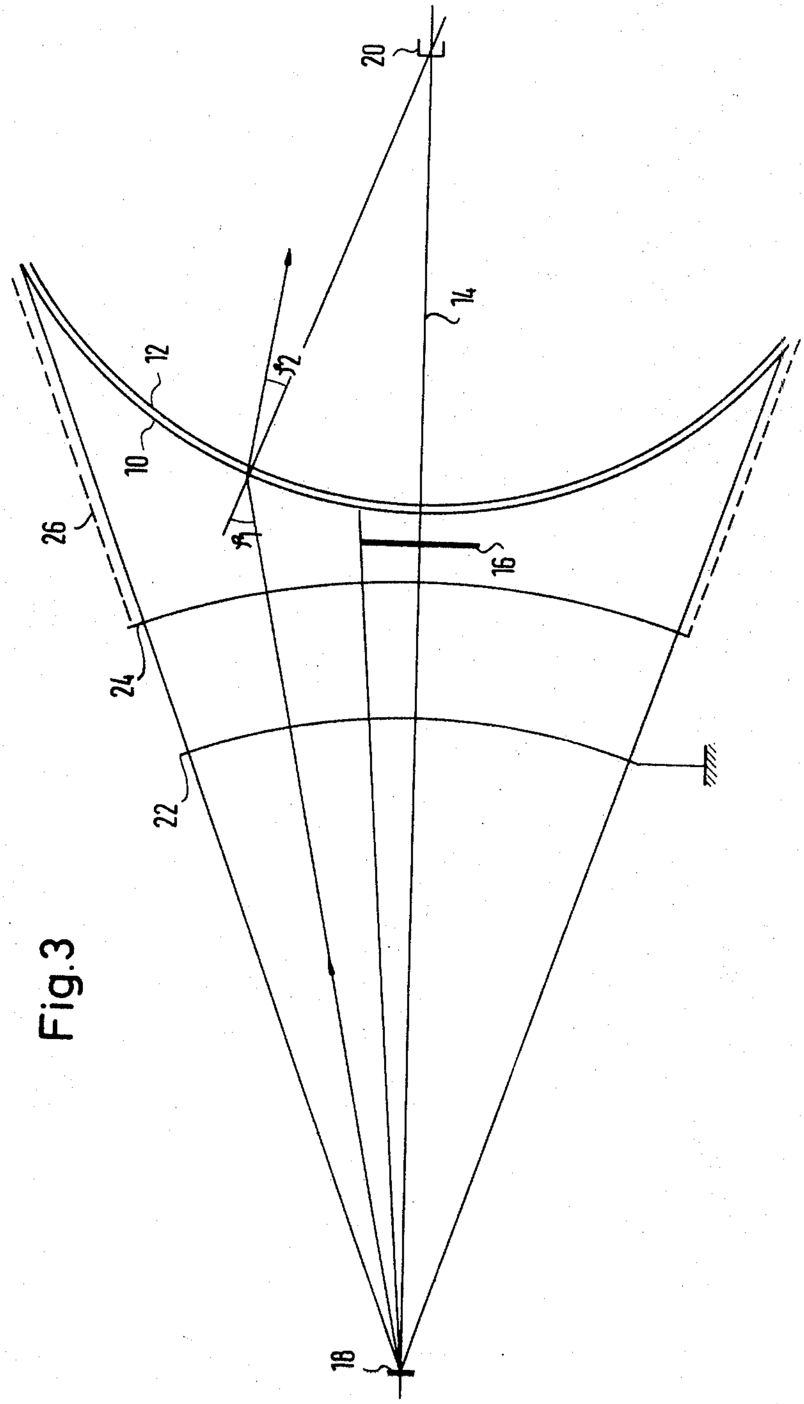
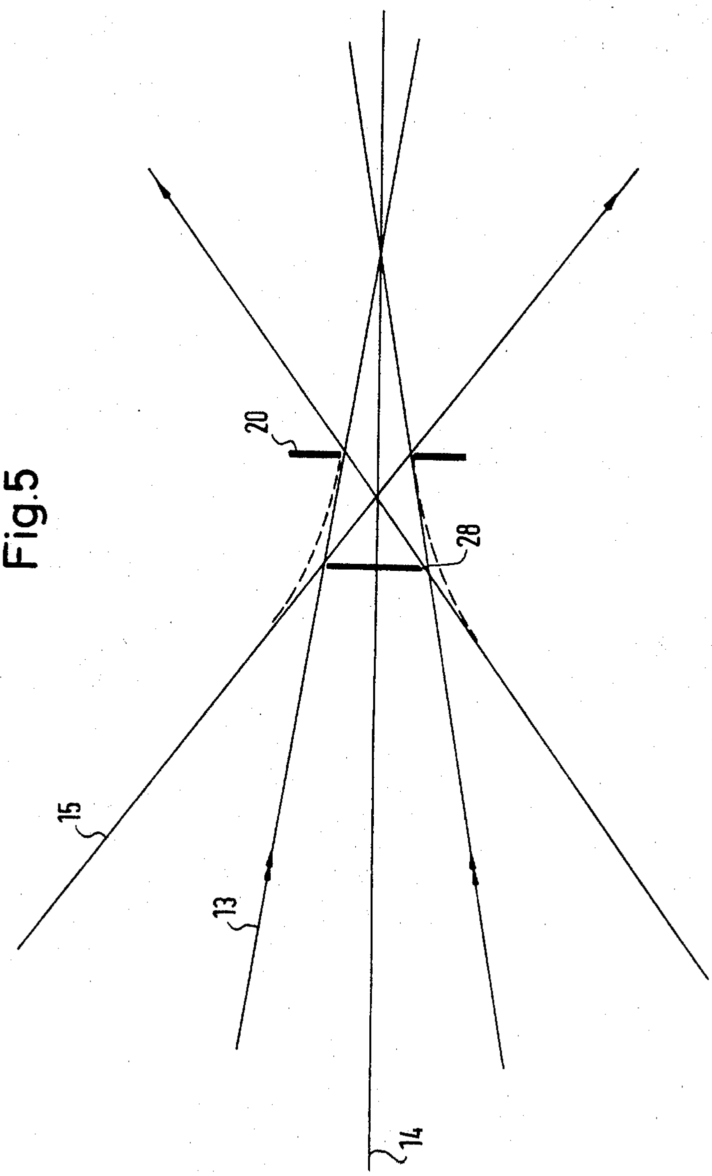


Fig.3

Fig.5



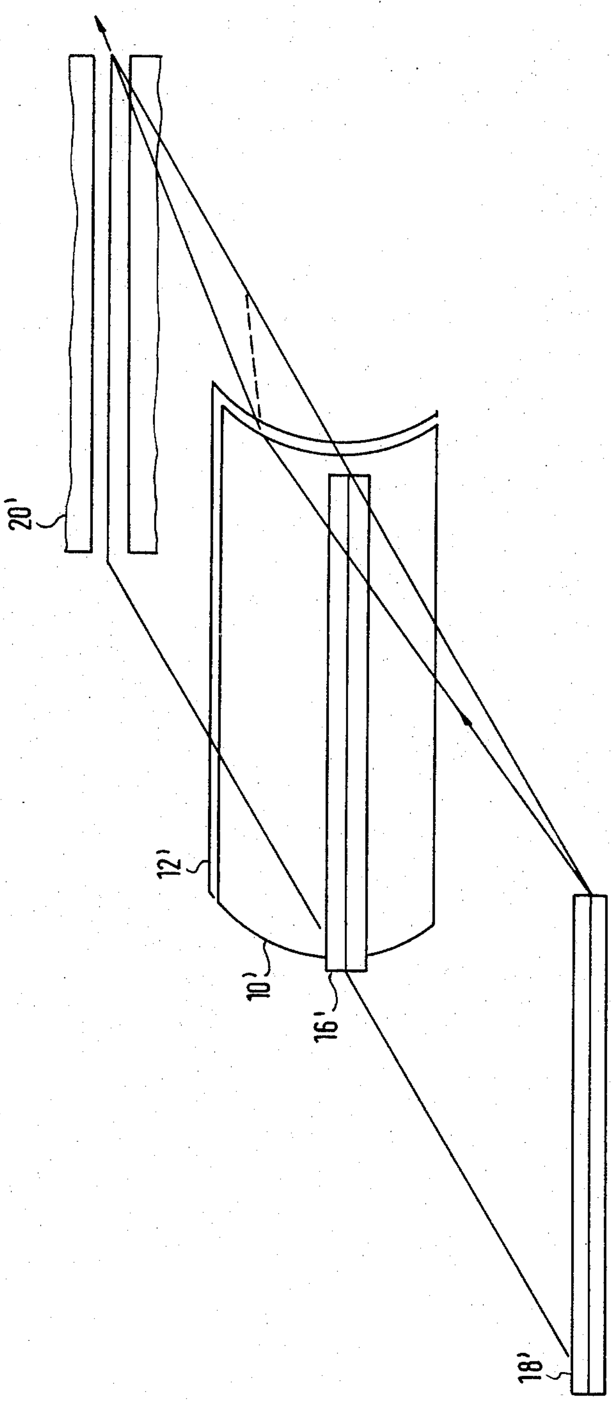


Fig.6

DEVICE FOR DETERMINING THE ENERGY OF CHARGED PARTICLES

BACKGROUND OF THE INVENTION

The present invention relates to a device for determining the energy of charged particles, especially electrons, emitted from a source of particles into a given solid angle, with an arrangement of electrodes which includes at least one electrode, spanning the solid angle, curved and perforated and connected to one terminal of a bias source, and which generates an electrical field that produces a convergent beam from the particles diverging from the source; with a particle-detecting device, arranged on the side of the electrodes away from the source of particles, at the point of smallest cross-section of the beam of particles; and with a diaphragm arranged between the source of particles and the particle-detecting device, which prevents particles from the source reaching the particle-detecting device on a straight orbit.

An energy analyzer of this type is described in the journal "Applied Physics Letters," Vol. 16, no.9, May 1 1970, pages 348 to 351. It represents a further development of the so-called LEED retarding-field apparatus and, like it, has the advantage over deflecting-field system energy analyzers, as used in mass spectrometers, of substantially higher transmission.

The energy analyzer described in the above-quoted publication consists of a high-resolution opposing-field section with two spherical-cap-shaped grids, concave in relation to the source of particles, having a separation of 6.25 cm and an average radius of approximately 40 cm. This geometry comprehends a solid angle of 0.08 π with a source area of 2 cm^2. Behind the opposing-field section a potential trough is produced which operates only on the low-energy electrons (e <10 eV). By this means, noise is greatly reduced by comparison with the LEED opposing-field apparatus, which represents a high-pass filter, because most of the faster electrons (E >10 eV) are not detected. The depth of the potential trough should not be too great, in order that not too many electrons with an energy of a few eV reach the detecting system, but it should be deep enough for a satisfactory percentage of low-energy electrons to be detected.

SUMMARY OF THE INVENTION

An object of the present invention is to improve the resolving power and the transmission of the above-mentioned, known energy analyzer, especially for small particle-energies.

According to the invention, this and other objects are achieved in that the curved electrode is convex in relation to the source of particles and is so biassed in relation to a second perforated electrode, which lies between it and the particle-detecting device, that there prevails between these electrodes an electrical field which accelerates the particles.

The second electrode should preferably be curved concentrically with the first electrode.

An energy analyzer of this kind can be arranged with advantage in the orbit of the rays behind a LEED retarding-field apparatus.

The device according to the invention is especially but not exclusively suitable for determining the energy of Auger electrons and photoelectrons in the context of non-destructive chemical analysis by electron spectroscopy.

Other objects, features and advantages of the invention will be apparent from the following detailed description of preferred embodiments thereof, reference being made to the accompanying drawings, in which:

FIG. 1 is a diagrammatic representation of a method by which the invention is to be performed which is especially suitable for determining the energy of low-energy electrons;

FIG. 2 is a diagrammatic representation of a modification of the method according to FIG. 1;

FIG. 3 is a diagrammatic representation of a further method by which the invention is to be performed;

FIG. 4 is a diagrammatic representation of various cross-sections of beams of radiation in a plane P in FIG. 1;

FIG. 5 is an axial section which shows the relations in the area of the smallest cross-section of the beam in the device according to FIG. 1 or 3 and

FIG. 6 is a diagrammatic perpsective view of a method by which the invention is to be performed with cylindrical geometry.

FIG. 1 shows in diagram form an energy analyzer according to the invention, which consists essentially of two concentric, sperical-cap-shaped wire-mesh grids **10,12**, arranged in separation (proportion of separation to average radius preferably more than 0.01, e.g. 0.03 – 0.5; especially 0.05 to 0.1) between a source of particles, e.g. electrons, placed in FIG. 1 to the left of the grids and a particle-detecting device, not shown in FIG. 1, arranged to the right of the grids, preferably a secondary electron multiplier. If an energy spectrum is to be collected, the particle-detecting device can be moveable along the axis **14** of the system so that its entry diaphragm can be brought into various planes perpendicular to the axis, of which one plane P is shown in the drawing. Another possibility for the collection of an energy spectrum consists in altering the voltage U_0 at the grid **12** while keeping the particle-detecting device fixed.

In what follows, it should be assumed for the sake of simplicity that the particles, whose energy is to be determined are electrons. The present invention is of course also applicable to other charged particles, e.g. positive ions and in this case the signs simply have to be reversed.

The grid **10** is in practice at the potential of the source of particles, while the grid **12**, by a positive bias U_0, is biassed in relation to the said grid **10** which is grounded. The bias U_0 is large in comparison with the voltage V corresponding to the energy $E = eU$ (e = elementary charge) of the electrons and, in the analysis of low-energy electrons with eneriges of a few tenths of an eV, amounts to e.g. about 10 V.

Through the voltage U_0 between the two grids **10, 12**, the inner space of the spherical mesh is related as a sphere with the refraction index

$$n = (1 + eU_0/eU)^{1/2} \tag{1}$$

The relation between the angle of incidence ϕ_1 and the angle of reflection ϕ_2 is determined by the optical refraction law

$$\sin \phi_1 = n \sin \phi_2 \qquad (2)$$

Where $U << U_O$ n alters very quickly depending on U and where $U \rightarrow O$ it approaches infinity, and this corresponds to a large dispersion of energy on the symmetrical axis **14.** In FIG. 1*a* few refracted rays are shown for various values of U/U_O and for the inner and outer peripheral rays. The paraxial area is screened off by a circular disc **16.** The spherical aberration is small where values of $U/U_O < 0.01$ and the beams formed by monoenergetic electrons intersect the symmetrical axis **14** within a small area. The combination of these two properties, namely high dispersion of energy and sharp focus images, is highly advantageous.

The energy of the detected electrons depends on the position of the entry aperture of the radiation detecting device on the axis **14** and on the applied voltage U_O. This will be examined in more detail later.

The resolving power of the energy analyzer according to FIG. **1** is principally determined by the diameter of the source and the spherical aberration. The spherical aberration can be excluded if the mesh grids are given the form not of a spherical cap but of a cartesian oval. The equation for an area of this kind reads in the system of coordinates according to FIG. **2**

$$\sqrt{(x + a)^2 + y^2} + n \sqrt{(x - b)^2 + y^2} = a + nb \qquad (3)$$

When a grid of this form is used, the resolving power is then primarily determined by the diameter of the source and by coma error. Estimate shows that a resolving power of the order of 1 percent can be obtained.

In FIG. **2** the source of radiation is marked **18** and the entry diaphragm of the radiation-detecting device **20.**

As shown in FIG. **3,** the present energy analyzer can be combined with a LEED retarding-field apparatus. Between the source of electrons **18** and the grids **10,12,** represented in the form of a sperical cap, two concentric, spherical-cap-shaped grids **22, 24** are correspondingly arranged, concave in relation to the source, between which a particle-retarding field is generated. The space between grid **10** and grid **24** is radially cut off by a truncated-cone-shaped (or cylindrical) grid **26.** In FIG. **3,** by way of example, the biasses for the various electrodes are given when the system is to be used for the analysis of electrons with energies of the order of approximately 0.1 to 10^2 eV.

A mesh lens causes dispersion of the beam of particles. This dispersion is practically only observable at electrode **24** of the retarding-field section formed by electrodes **22** and **24,** because the energies of the particles extend to zero here on account of the retarding effect, and the angle of dispersion increases rapidly as the energy of the particles decreases. Owing to the high value of the refraction index of the mesh lens, formed by the mesh electrodes **10,12,** for low-energy electrons, these angles of dispersion are very sharply reduced after refraction. The cross-sections in the plane P (FIG. **1**) for an arrangement of the kind shown in FIG. **3,** taking the dispersion into account, are shown in FIG. **4** for the inner peripheral rays ($U_O = 100$ V).

For small particle-energies (approx. 0.1 eV after retarding), these cross-sections are circles, whose radii

increase with the energy. When the energy increases further, the cross-sections of the rays become ring-shaped, as shown by the cross-sections for 1.0 eV, 2.0 eV and 5.0 eV in FIG. **4.** The detecting device has, correspondingly, an entry diaphragm **20** (FIG. **5**) with a circular aperture, the centre of which lies on the symmetrical axis **14** of the rotation-symmetrical system. Where a diaphragm with an aperture radius r is used, all electrons up to an energy of E_O are detected, as shown in the following equation:

$$E_O \approx (r/R)^2 eU_O \qquad (4)$$

In this equation, R represents the average radius of the electrodes **10,12.** With higher energies the cross-sections increase and the measured intensity decreases. Particles whose energy is so great that the inner peripheral ray determined by the disc **16** no longer passes through the diaphragm aperture, are not detected.

If spherical-cap-shaped mesh electrodes **10,12** are used, the resolving power can be improved by a disc **28,** arranged in front of the entry diaphragm **20** of the detecting aperture, the exact position of which can be seen from FIG. **5.**

The invention is not confined to rotation-symmetrical geometries. It is also, for example, possible to work with a cylindrical symmetry, as shown in FIG. **6.** In FIG. **6,** the corresponding parts are designated with the same reference numbers as in FIG. **2,** with the addition of an accent. The source of radiation **18'**, the diaphragm **16'** for screening off the paraxial rays, and the entry diaphragm **20'** of the radiation-detecting device are elongated and strip-shaped, while the mesh-electrodes **10', 12'** are cylindrical in form. Depending on the type of modification wanted, the electrodes in a plane intersecting the axis of the cylinder at right-angles can have the form of a circle, an ellipse, a parabola or a section of the above-mentioned cartesian oval.

The second grid electrode **12** can also be arranged in greater separation behind the grid electrode **10** and in certain circumstances even be reduced to a relatively small, flat grid electrode or diaphragm directly in front of the particle-detecting device (e.g. multiplier or capture-apparatus).

Various modifications of the above described embodiments of the invention will be apparent to those scilled in the art, and it is to understood that such modifications can be made without departing from the scope of the invention if they are within the spirit and tenor of the accompanying claims.

I claim:

1. A device for determining the energy distribution of charged particles, especially electrons, emitted from a source of particles in a given solid angle, comprising:

an arrangement of electrodes which includes potentials least a first perforated electrode **(10,10')** spanning said solid angle, which electrode is convex towards said source of particles **(18),** and a second perforated electrode **(12,12'),** likewise convex towards said source, radially spaced from said first electrode on the side of said first electrode farthest from said source;

electric potential bias means for applying otentials to said first and second electrodes such as to generate an electric field that causes said particles diverging from said source to converge after passing through said first and second electrodes;

a particle detecting device located on the median of the arrangement of said electrodes and said source at a greater distance from said source than said electrodes, said particle detecting device having an entrance diaphragm (**20**) with an aperture of such restricted size and shape as to exclude particles converging on said median at more than a predetermined small distance behind said diaphragm;

a baffle (**16,28**) centered on said median and located between said source of particles and said diaphragm, said baffle being of a size and shape at least approximately including the direct projection from said source of said diaphragm aperture, so that particles with little or no divergence from said median are blocked from said particle detecting device; and

scanning means for enabling said particle detecting device to scan over a range of particle emission energies of said source.

2. A device as defined in claim **1** in which the curvature of said first and second electrodes is concentric.

3. A device as defined in claim **1** in which said scanning means includes means for moving said particle detecting device towards or away from said source along said median.

4. A device as defined in claim **1** in which said median is an axis passing through said source and said first and second perforated electrodes are rotation-symmetrical with respect to said axis, and in which, further, said diaphragm aperture of said particle detecting device is circular and located so that said axis passes therethrough.

5. A device as defined in claim **4** in which said baffle is a disc (**28**) disposed between said second electrode and said diaphragm.

6. A device as defined in claim **1** in which the proportion of the spacing of said first and second perforated electrodes to the average radius of curvature of said electrodes is between 0.01 and 0.5.

7. A device as defined in claim **1** in which said scanning means includes a retarding-field analyzer disposed between said source of particles and said first perforated electrode, said retarding-field analyzer comprising at least a third and a fourth perforated electrodes (**22,24**) concave towards said source and connected to an electric bias source so as to produce a particle-retarding electric field between said third and fourth electrodes, and in which further the space between said retarding-field analyzer and said first perforated electrode (**10,10'**) is bounded by a fifth electrode (**26**) of cylindrical or truncated-cone shape.

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