March 2, 1971 R. K. BREHM ET AL 3,567,322

SPECTROMETER

Filed Oct. 27, 1967 2 Sheets-Sheet 1

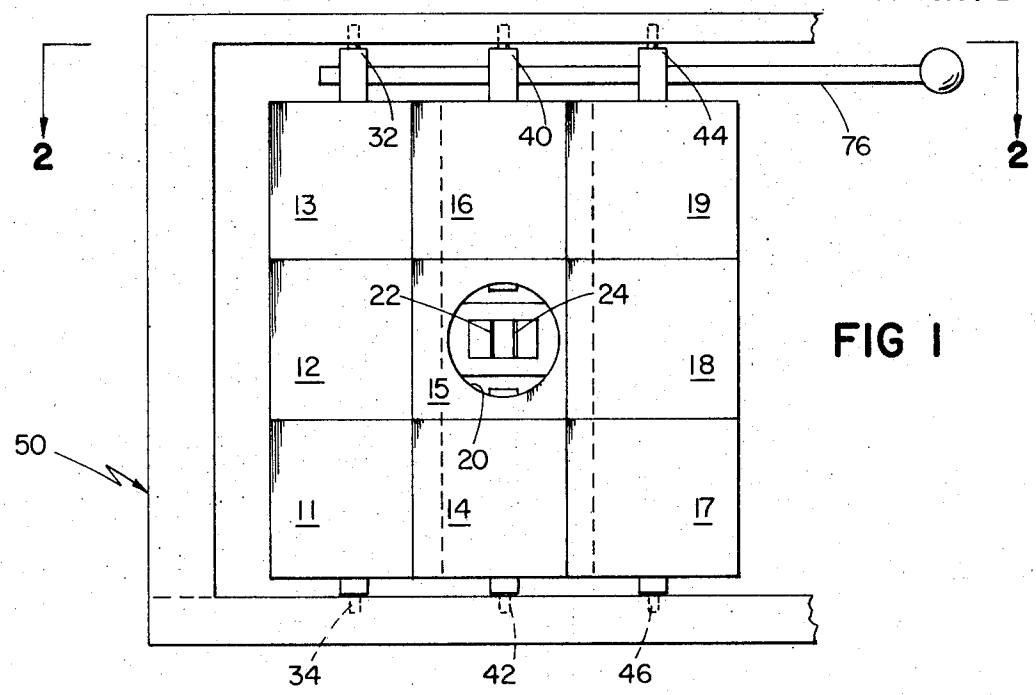


FIG 1

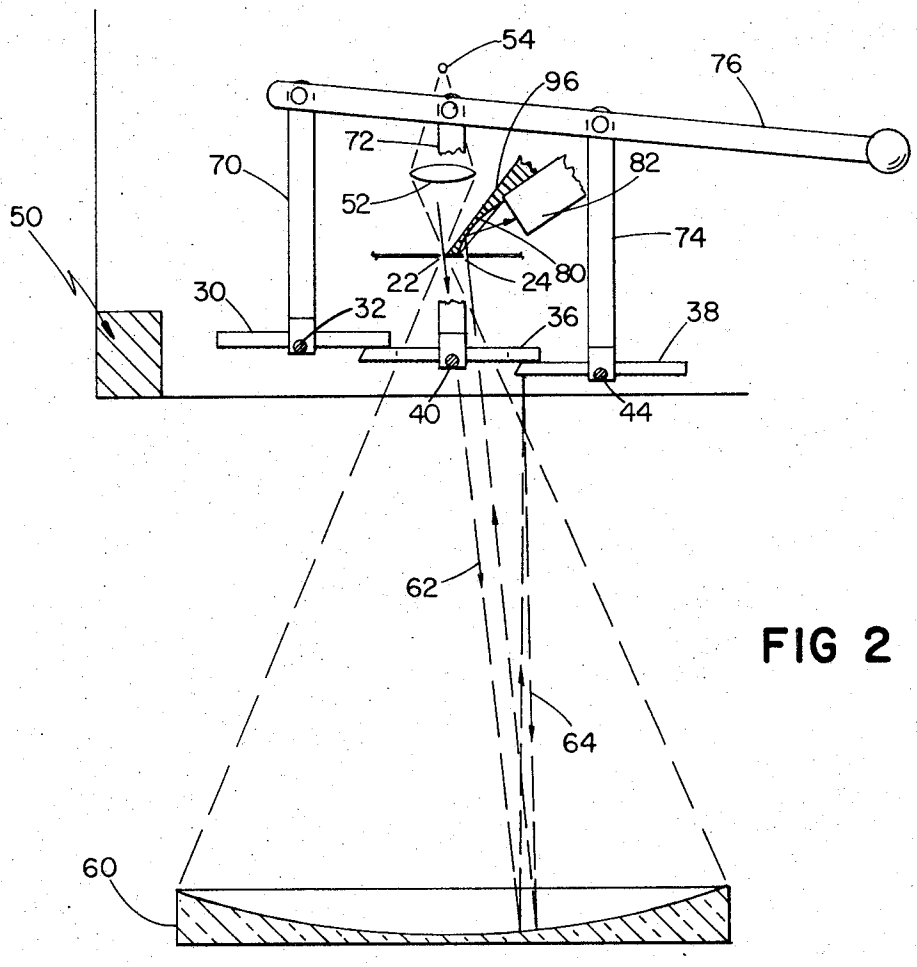


FIG 2

March 2, 1971 R. K. BREHM ET AL 3,567,322

SPECTROMETER

Filed Oct. 27, 1967 2 Sheets-Sheet 2

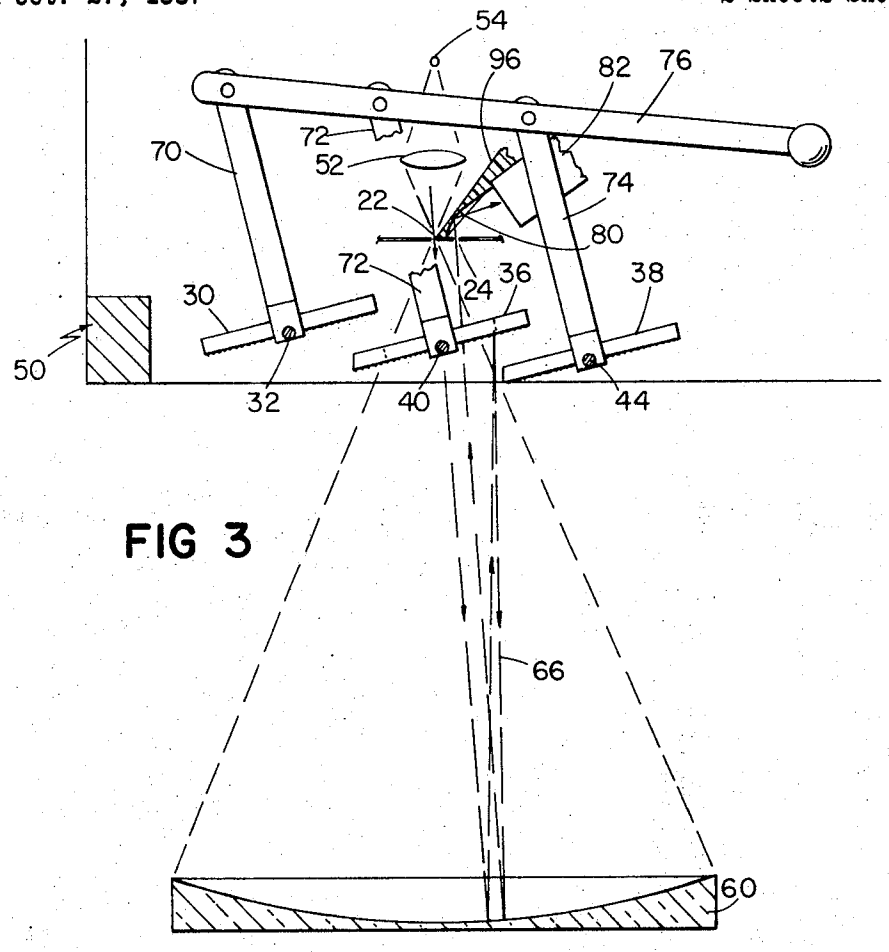


FIG 3

FIG 4

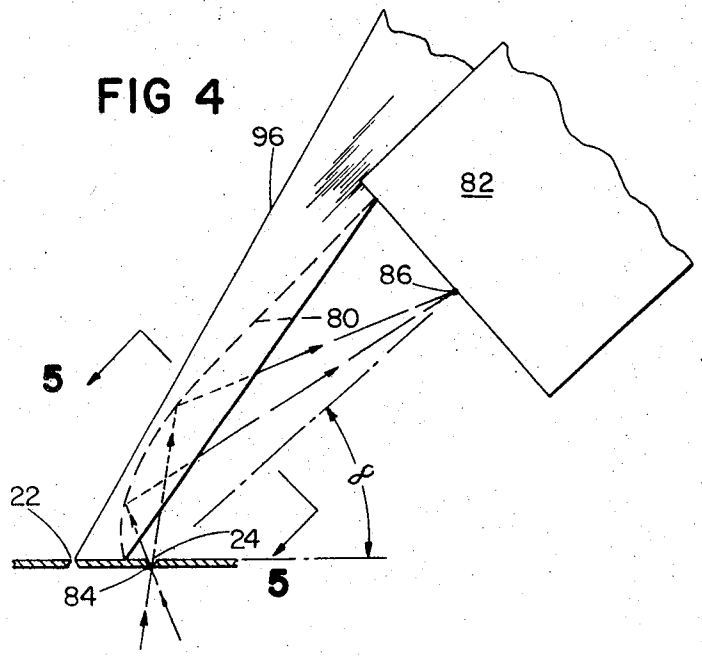
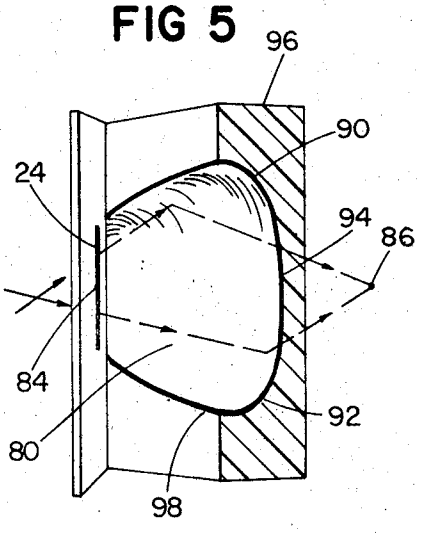


FIG 5



United States Patent Office 3,567,322 Patented Mar. 2, 1971

3,567,322

SPECTROMETER

Richard Keith Brehm, Lexington, and Charly Dany Allemand, Newtonville, Mass., assignors to Fisher Scientific Company, Pittsburgh, Pa.

Filed Oct. 27, 1967, Ser. No. 678,618
Int. Cl. G01j 3/06, 3/18
U.S. Cl. 356—98 17 Claims

ABSTRACT OF THE DISCLOSURE

An $f/1$ spectrometer has entrance and exit slits, each ten millimeters high and fifty microns wide, which are parallel to one another and spaced three millimeters apart. A parabolic collimating mirror of thirty centimeters focal length reflects light from the entrance slit onto a dispersing mosaic of nine gratings each ruled with 1200 grooves per millimeter. The gratings are mounted on three parallel axes and a drive linkage rotates all the gratings simultaneously through equal angles. The middle grating has an aperture through which light passes between the entrance and exit slits and the collimating mirror. Behind the exit slit is mounted an elliptical reflector that has focal points spaced fifty-eight millimeters apart along an axis at an angle of 34° 40′ to the plane of the entrance-exit slit optics for concentrating light passing through the exit slit on a photomultiplier.

SUMMARY OF INVENTION

This invention relates to spectroscopy and has for an object the provision of a new and improved monochromator system useful for spectroscopy.

More specifically, this invention relates to large aperture spectrometers (spectrometers having f numbers smaller than $f/3.5$) in which the distance between the dispersing element and collimating element approaches the dimensions of the dispersing element. Such large aperture spectrometers are useful in the analysis of weak, diffuse, or extended sources as the night sky and studies of aurora.

An object of the invention is to provide a novel and improved large aperture spectrometric instrument. Another object of the invention is to provide a novel and improved exit optics arrangement particularly useful in a large aperture spectrometer.

In accordance with the invention there is provided, in a spectrometric instrument having structure defining entrance and exit optics and a collimating element spaced from the entrance and exit optics defining structure generally along the optical axis of the instrument, a dispersing element composed of a set of similar components disposed across the optical path of the instrument. Each component is mounted for rotation about an axis parallel to the axes of rotation of the other components and perpendicular to the optical axis of the instrument. Drive structure is provided for rotating the components of the dispersing element simultaneously through equal angles. The components of the dispersing elements are adjusted so that the spectral images from the plural components are superimposed simultaneously on the exit optical system. In instruments constructed in accordance with the invention the differential in distance between the collimating element and portions of the dispersing element is reduced with consequent reduction in aberration contrasted with a comparable instrument employing a single dispersing component.

In a particular embodiment of the invention, the instrument includes a dispersing element mosaic in the form of a series of gratings mounted for simultaneous rotation by a common drive about spaced, parallel axes.

An aperture is provided in the center of the mosaic through which radiation transmitted between the entrance and exit slit optics and the collimating element passes. The entrance and exit slit optics define two closely spaced, narrow, elongated slits that are disposed parallel to one another. Further, a mirror structure, disposed immediately beyond the exit slit and configured to avoid interference with the entrance slit optics concentrates the radiation that passes through the exit slit on the input aperture of the radiation sensor of the instrument.

The invention provides a large aperture spectrometer in which optical aberrations arising from large angles of incidence of radiation on the collimating and dispersing elements employed in the spectrometer are reduced. Further, the invention provides a large aperture spectrometric system in which the projected area of the dispersing element as viewed from the collimating element (the aperture of the instrument) is maintained substantially constant within practical limits of scanning as the dispersing element is rotated.

Other objects, features and advantages of the invention will be seen as the following description of a particular embodiment progresses, in conjunction with the drawings in which:

FIG. 1 is a front view of the dispersing element structure incorporated in a spectrometer constructed in accordance with the invention;

FIG. 2 is a top diagrammatic view of the spectrometer taken generally along the line 2—2 of FIG. 1;

FIG. 3 is a view similar to FIG. 2 showing the dispersing element system in a rotated position;

FIG. 4 is a top diagrammatic view of the exit optics system employed in the spectrometer shown in FIGS. 1–3; and

FIG. 5 is a sectional view of the mirror employed in the exit optics system taken along the line 5—5 of FIG. 4.

DESCRIPTION OF PARTICULAR EMBODIMENT

With reference to FIG. 1, there is shown a spectrometer dispersing element composed of a series of nine gratings **11–19**, each grating being 100 x 100 mm. square and ruled 1200 grooves per millimeter. Grating **15** has an aperture **20** in it and immediately behind aperture **20** is positioned structure defining an entrance slit **22** and an exit slit **24**. In this embodiment each slit **22**, **24** has a height of 10 millimeters, and a width of 50 microns; and they are located parallel to one another spaced three millimeters apart.

Gratings **11**, **12** and **13** are mounted on a common support structure **30** having stub shafts **32**, **34** which define an axis of rotation for those elements **11–13** parallel to the grooves formed on their faces and coincident with the plane of those faces. These grating elements may be mounted on the support structure **30** in contact with one another or may be slightly spaced from another. Similar support structures **36** and **38** support the similar sets of gratings **14–16** and **17–19**, respectively. The axis of rotation of support structure **36** is defined by stub shafts **40** and **42** while the axis of rotation of the gratings mounted on support **38** are defined by shafts **44** and **46**. These six stub shafts are secured for rotation in a framework diagrammatically indicated at **50**.

As indicated in FIG. 2, disposed behind the entrance slit **22** is a lens **52** which focuses light from source **54** for passage through slit **22** for impingement on collimating mirror **60**. The mirror has a diameter of 42.4 centimeter and a focal length of thirty centimeters so that the effective aperture of this collimating-dispersing system is approximately $f/1$. A beam of light **62** passing through entrance slit **22** impinges on mirror **60** and is reflected onto the dispersing matrix of gratings **11–19** and a component **64** of the resulting spectrum from the gratings mounted

on structure **38** (as a function of the angle of rotation of the angle of rotation of gratings **11–19**) is reflected by mirror **60** through exit slit **24**.

The gratings **11–19** are connected to a pantograph mechanism which includes arms **70**, **72** and **74** which are pinned to a common link **76** which in turn is driven by monochromator drive which may be of conventional type. The arm **70** is connected to the grating support **30**, the arm **72** is connected to the grating support **36**, and the arm **74** is connected to the grating support **38**, so that the pantograph mechanism, in response to the monochromator drive, rotates the mosaic of gratings simultaneously through equal angles. A rotated position of the gratings as moved by the pantograph structure, is shown in FIG. 3 and it will be noted, that at that grating angle, as is well known in the art, a different component **66** of the dispersed spectra produced by the gratings mounted on structure **36** in response to beam **62** is reflected back to mirror **60** and from there through exit aperture **24**. It will be noted that, in this embodiment, the grating axes define a plane not perpendicular to the system axis such that the gratings have a limiting position at zero angle (FIG. 2). As the mosaic of gratings rotate the grating forming a spectral image in response to a particular incident beam changes, as in the above example, and the range of path lengths, for a given maximum angle of grating rotation, of all the radiation incident on mirror **60** is much less than the range of path lengths that result in an instrument of the same aperture employing a single grating or other dispersing element.

Mounted immediately behind the exit aperture **24** is a mirror **80** which reflects light from the exit slit **24** into the radiation sensing photomultiplier **82**. As shown in greater detail in FIGS. 4 and 5, the mirror 80, in horizontal cross section, is an ellipse having one focal point **84** at exit aperture **24** and a second focal point **86** at the entrance aperture of photomultiplier **82**. In vertical cross section (in a plane perpendicular to the axis of the ellipse) the mirror has two quarter circle section **90**, **92** joined by a straight section **94** ten millimeters in length (the length of the exit slit **24**) thus providing a cylindrical section joining two ellipsoid sections. (The cylindrical section **94** may be replaced by a toroidal section to adjust the concentration of the light beam.) Focal points **84** and **86** are 58 mullimeters apart and their axis lies at an angle α of 34°, 40′ to the plane of the entrance-exit slit optics. The mirror **80** is formed in a molding operation in a body **96** of epoxy resin and a reflective coating **98** is applied to the formed mirror cavity.

While a particular embodiment of the invention has been shown and described, various modifications thereof will be apparent to those skilled in the art and therefore it is not intended that the invention be limited to the disclosed embodiment or to details thereof and departures may be made therefrom within the spirit and scope of the invention as defined in the claims.

What is claimed is:

1. In a spectrometic instrument having structure defining entrance and exit optics and a collimating element spaced from the entrance and exit optics defining structure generally along the optical axis of the instrument, a dispersing system composed of at least two similar components disposed across the optical path of the instrument so that each said component disperses a portion of the radiation directed onto said dispersing system by said collimating element, said two components simultaneously dispersing the radiation directed on them by said collimating element, means for mounting said at least two components in overlapping relation for rotation about axes parallel to and in spaced relation from one another and perpendicular to the optical axis of the instrument, and structure for rotating said components of the dispersing system about their individual axes of rotation simultaneously through equal angles while maintaining said overlapping relation so that the surface area of said dispersing components projected upon a plane perpendicular to the mean ray of the radiation incident on said dispersing system from the collimating element is continuous.

2. The instrument as claimed in claim **1** wherein each said dispersing system component is a ruled grating.

3. In a spectrometric instrument having structure defining entrance and exit optics and a collimating element spaced from the entrance and exit optics defining structure generally along the optical axis of the instrument, a dispersing system composed of a set of similar components disposed across the optical path of the instrument so that each said component disperses a portion of the radiation directed onto said dispersing system by said collimating element, said dispersing element components being arranged in a mosaic with an aperture in the center of the mosaic through which radiation from said entrance optics passes for impingement on said collimating element, means for mounting said components for rotation about axes parallel to and spaced from one another and perpendicular to the optical axis of the instrument, and structure for rotating said components of the dispersing system about their individual axes of rotation simultaneously through equal angles.

4. The instrument as claimed in claim **3** wherein said collimating element is a mirror.

5. The instrument as claimed in claim **4** wherein the aperture of said instrument is greater than *f*/3.5.

6. A spectrometric instrument comprising an entrance optics system, a collimating system for receiving light passed through said entrance system from a source and forming it into substantially parallel rays, a grating system for dispersing light received from said collimating system, said grating system comprising: a set of grating members, each member having a series of identically spaced parallel rulings, and means for mounting each member for rotation about a fixed axis parallel to said rulings and each member being positioned to receive light from said collimating system in parallel with the other grating members, said axes being parallel to one another and so spaced that said grating members overlap, and structure for rotating said grating members while maintaining the ruled surfaces thereof parallel from said overlapping position through equal angles to a series of positions exposing more of said ruled surfaces to said collimating system, while maintaining the surface area of the ruled surfaces of said members projected upon a plane perpendicular to the mean ray of light incident on said grating members from said collimating system continuous through said series of positions, and an exit optics system for directing light from said grating system to an energy collector.

7. The instrument as claimed in claim **6** wherein said entrance optics system includes a narrow elongated aperture, disposed parallel to the rulings on said grating members, said exit optics system includes a slit corresponding to said entrance slit, and disposed in laterally spaced, aligned proximity thereto.

8. A spectrometric instrument comprising an entrance optics system, including a narrow elongated aperture, a collimating system for receiving light passed through said entrance system from a source and forming it into substantially parallel rays, a grating system for dispersing light received from said collimating system, said grating system comprising: a set of reflection grating members, each member having a series of identically spaced parallel rulings, and means for mounting each member for rotation about a fixed axis parallel to said rulings and each member being positioned to receive light from said collimating system in parallel with the other grating members, said axes being parallel to one another and so spaced that said grating members overlap, and structure for rotating said grating members while maintaining the ruled surfaces thereof parallel from said overlapping position to a series of positions exposing more of said ruled sur-

faces to said collimating system, while maintaining the surface area of the ruled surfaces of said members projected upon a plane perpendicular to the mean ray of light incident on said grating system continuous through said series of positions, and an exit optics system including a slit corresponding to said entrance slit and disposed in laterally spaced, aligned proximity thereto for directing light from said grating system to an energy collector, said grating system being interposed between said collimating system and said slits, and including a central aperture, at least as large as the area defined by the opposite outer edges of said laterally spaced slits, for passing light from said entrance slit onto said collimating system and light reflected back from said reflection grating members onto said collimating system to said exit slit.

9. A spectrometric instrument comprising an entrance optics system, a collimating system for receiving light passed through said entrance system from a source and forming it into substantially parallel rays, a grating system for dispersing light received from said collimating system, said grating system comprising: a set of grating members, each member having a series of identically spaced parallel rulings, and means for mounting each member for rotation about a fixed axis parallel to said rulings and each member being positioned to receive light from said collimating system in parallel with the other grating members, said axes being parallel to one another and so spaced that said grating members overlap, and structure for rotating said grating members while maintaining the ruled surfaces thereof parallel from said overlapping position to a series of positions exposing more of said ruled surfaces to said collimating system, while maintaining the surface area of the ruled surfaces of said members projected upon a plane perpendicular to the mean ray of light incident on said grating system continuous through said series of positions, and an exit optics system including a narrow elongated exit aperture for directing light from said grating system to an energy collector, said energy collector including an entrance aperture, and a reflecting surface disposed between said exit and entrance apertures, said reflecting surface being generated by the translation of a conic section along an ellipsoidal path, said surface being so sized and spaced relative to said exit aperture as to have a first focal point at said exit aperture, and a second focal point at said entrance aperture of said energy collector.

10. The instrument claimed in claim **9** wherein said reflecting surface has a portion of an ellipsoid of revolution at each end.

11. The instrument as claimed in claim **10** wherein said exit aperture is a longitudinal slit and said reflecting surface includes a cylindrical section joining said two ellipsoids of revolution.

12. The instrument as claimed in claim **11** wherein said entrance optics system includes a narrow elongated aperture, disposed parallel to the rulings on said grating members, said exit optics system includes a slit corresponding to aid entrance slit, and disposed in laterally spaced, aligned proximity thereto, and said grating system comprises a set of reflection grating members, and is interposed between said collimating system and said slits, said grating members being arranged to define a central aperture, at least as large as the area defined by the opposite outer edges of said laterally spaced slits, for passing light from said entrance slit onto said collimating system and light reflected back from said reflection grating members onto said collimating system and through said exit slit for reflection by said reflecting surface to said energy collector.

13. The instrument as claimed in claim **12** wherein the aperture of said instrument is greater than *f*/3.5.

14. In a spectrometer comprising

a collimating system, a dispersing system, and entrance optics for directing radiation from a source onto said collimating system,

an exit optics system comprising

a narrow elongated exit aperture,

an energy collector including an entrance aperture,

and a reflecting surface disposed between said exit and entrance apertures, said reflecting surface being generated by the translation of a conic section an ellipsoidal path, said surface being so sized and spaced relative to said exit aperture as to have a first focal point at said exit aperture, and a second focal point at said entrance aperture of said energy collector.

15. The system claimed in claim **14** wherein said reflecting surface has a portion of an ellipsoid of revolution at each end.

16. The system as claimed in claim **15** wherein said exit aperture is a longitudinal slit and said reflecting surface includes a cylindrical section joining said two ellipsoids of revolution.

17. A spectrometric instrument comprising an entrance optics system, a collimating system for receiving light passed through said entrance system from a source and forming it into substantially parallel rays, a dispersing system for dispersing light received from said collimating system, said dispersing system comprising: a set of dispersing members, means for mounting each member for rotation about a fixed axis and each member being positioned to receive light from said collimating system in parallel with the other dispersing members, said axes being parallel to one another and so spaced that said dispersing members overlap, and structure for rotating said dispersing members from said overlapping position through equal angles to a series of positions exposing more of their surfaces to said collimating system, while maintaining the surface area of said members projected upon a plane perpendicular to the mean ray of light incident on said dispersing members from said collimating system continuous through said series of positions, and an exit optics system for directing light from said dispersing system to an energy collector.

References Cited

UNITED STATES PATENTS

3,390,604	7/1968	Makabe	356—96
2,453,164	11/1968	Swings	356—79
2,995,973	8/1961	Barnes et al.	356—99
3,218,914	11/1965	Bartz et al.	356—97
3,279,308	10/1966	Bartz et al.	356—51
3,428,391	2/1969	Newcomer	356—100UX

OTHER REFERENCES

Makabe et al.: "Proceedings of the Conference on Photographic and Spectrographic Optics, 1964" Japanese Journal of Applied Physics, vol. 4, supplement I, 1965, pp. 385–389.

RONALD L. WIBERT, Primary Examiner

F. L. EVANS, Assistant Examiner

U.S. Cl. X.R.

356—100; 350—162