Nov. 26, 1968 N. J. FROIO 3,413,067

LIGHT CONDUCTING ROD ENDOSCOPIC INSTRUMENT WHICH MAKES USE OF THE PRINCIPLE OF TOTAL INTERNAL REFLECTION TO SIGHT PERPENDICULARLY TO THE ROD AXIS

Filed March 25, 1964 3 Sheets-Sheet 1

FIG. 1

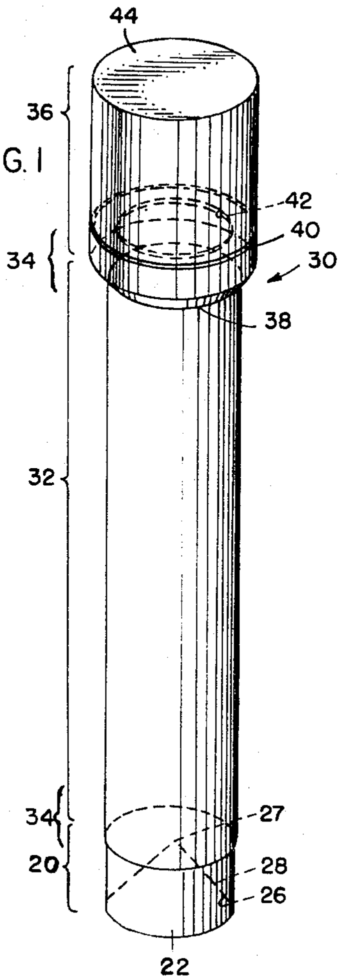


FIG. 2

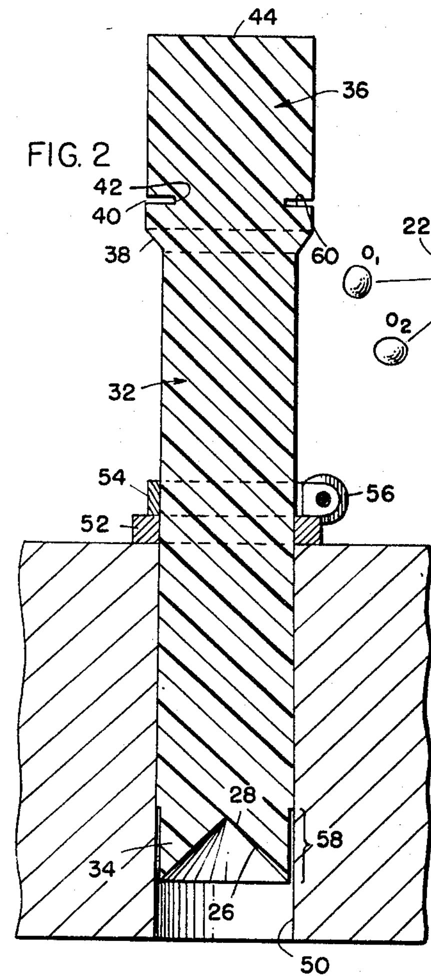


FIG. 14

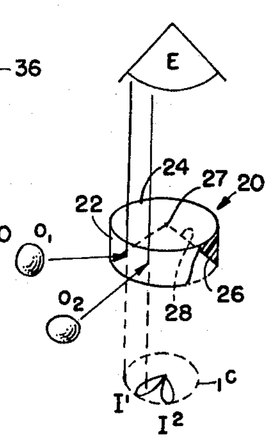


FIG. 3

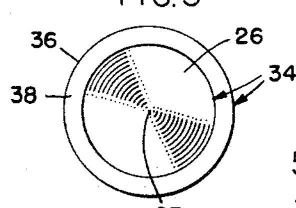


FIG. 4

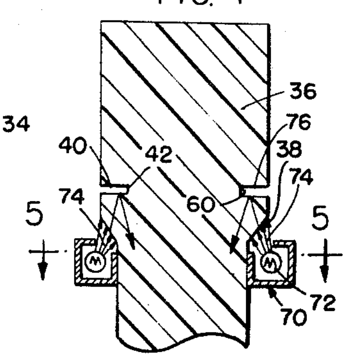
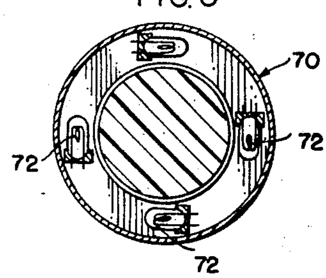


FIG. 5



INVENTOR:
NICHOLAS J. FROIO
BY
Watson D. Harbaugh
ATT'Y

LIGHT CONDUCTING ROD ENDOSCOPIC INSTRUMENT WHICH MAKES USE OF THE PRINCIPLE OF TOTAL INTERNAL REFLECTION TO SIGHT PERPENDICULARLY TO THE ROD AXIS

Filed March 25, 1964 3 Sheets-Sheet 2

FIG. 6

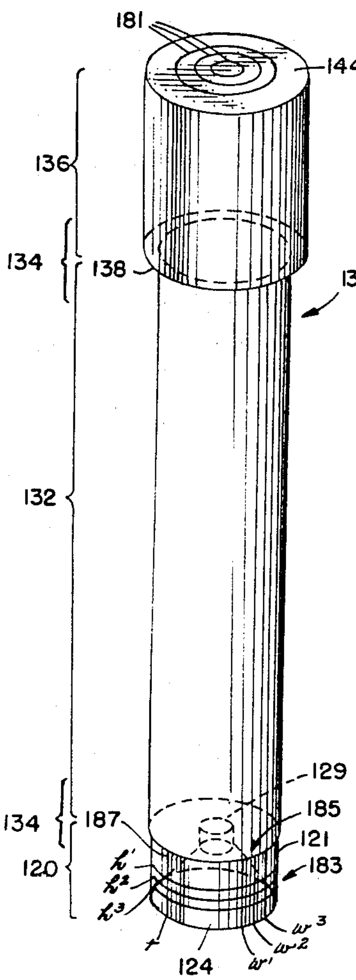


FIG. 7

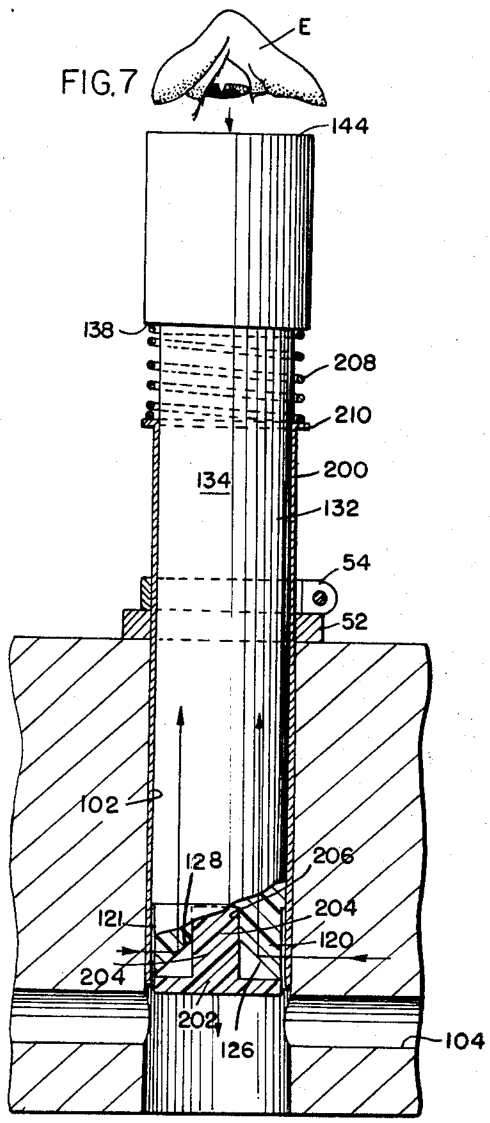
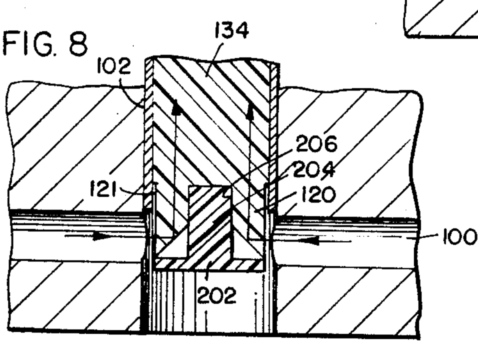


FIG. 8



INVENTOR:
NICHOLAS J. FROIO
BY
Watson D. Harbaugh
ATT'Y

FIG. 9

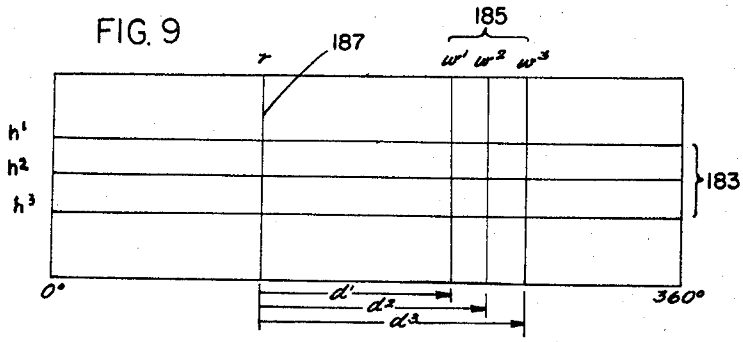


FIG. 10

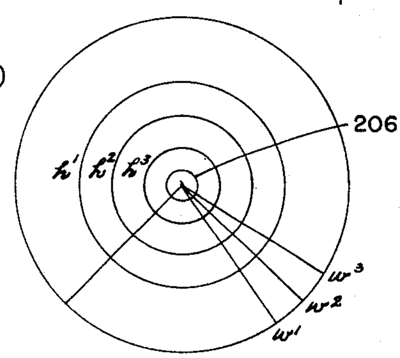


FIG. 12

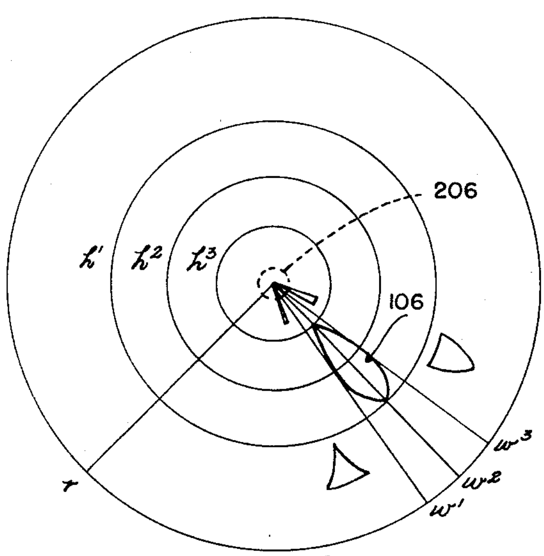


FIG. 11

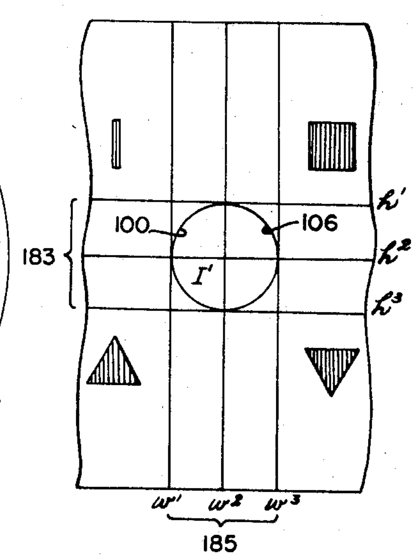
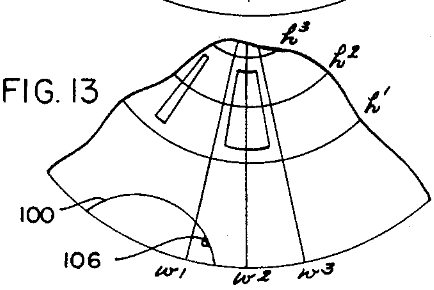


FIG. 13



INVENTOR:
NICHOLAS J. FROIO
BY
Watson D. Harbaugh
ATT'Y

United States Patent Office 3,413,067
Patented Nov. 26, 1968

3,413,067

LIGHT CONDUCTING ROD ENDOSCOPIC INSTRUMENT WHICH MAKES USE OF THE PRINCIPLE OF TOTAL INTERNAL REFLECTION TO SIGHT PERPENDICULARLY TO THE ROD AXIS

Nicholas J. Froio, Harvey, Ill., assignor to Froio Corporation, a corporation of Illinois

Filed Mar. 25, 1964, Ser. No. 354,529
6 Claims. (Cl. 356—241)

ABSTRACT OF THE DISCLOSURE

The disclosure describes an endoscope having in one embodiment an elongated rod like light-transmitting solid body with a concave conical face at the distal end which provides an internal convex reflecting face radially opposite a clear coaxial side face. The viewing end is enlarged to provide an annular frusto-conical shoulder with an annular groove thereabove whose lower planar wall provides an internal reflecting surface for circumferentially directed light to increase ambient lighting therethrough. Auxillary light means at the shoulder, a radially recessed side face, a distal end cap and cylindrical protective sheath are provided in other embodiments.

The present invention, in its broadest aspect, relates to an optical system for producing a stereopanoramic image, the image presenting a view from a central position in all radial directions of circumferentially arranged objects, or of the visible portions of a single surrounding or encompassing object. More specifically, the stereopanoramic image which is produced by the optical system of the present invention is a lemniscular distortion of a rectangular panoramic image, the distortion being roughly on the order of a Mercator's Projection based on conical considerations rather than on spherical, as will be further explained presently. The optical system of the present invention, when employed for viewing objects or portions of an object which present themselves for viewing in three dimensions (for example circumferentially arranged objects), will produce a stereopanoramic image of such objects or portions of an object, the stereographic depth of which is equal to the depth dimensions of the objects or portions. When viewing objects or portions of an object which present themselves in only two dimensions (for example markings or other characteristics on the inner surface of a cylinder), the optical system will produce a planopanoramic image. Whether the optical system be employed for viewing objects that present themselves for viewing in three dimensions, or objects that present themselves for viewing in two dimensions, the optical system remains unchanged, the images produced in either case flowing merely from the character of the objects being viewed.

Briefly, the optical system of the present invention embodies an optically transparent body which functions partially in the manner of a lens, partially in the manner of a prism, and partially in the manner of a reflecting mirror, although, strictly and technically speaking, it does not meet the definition of any one of these fundamental optical devices. Considering only the effective image-forming surfaces of the optical system, these surfaces are three in number, namely an outer cylindrical surface, an inner affectively convex conical surface coaxial with the cylindrical surface, and a planar viewing surface normal to the common axis of the cylindrical and conical surfaces and positioned in opposition to the small base of the conical surface. These three optical surfaces are embodied in a single optically transparent body in the form of a true cylinder having one planar circular end face, the other

end face of the cylinder being recessed on a truly conical bias. The net optical effect of such a transparent body is the provision of a prismatic body having a cylindrical surface of light incidence, an internal convex reflective conical surface which receives the incident light and totally reflects the same, and a plane surface of light emergence for viewing the totally reflected light emanating from the convex conical surface. By such a prismatic arrangement of surfaces, the aforementioned lemniscular distortion of a stereopanoramic image is attained upon viewing the light emerging from the plane surface of the optically transparent body.

The lemniscular distortion above referred to is not an undesirable image distortion. On the contrary, it is a desirable one and it constitutes one of the principal features of the present invention in that it presents the entire stereopanoramic image in a small circular viewing area directly in the line of vision of the viewer, the size of the viewing area being no greater than the area of the large base of the conical reflecting surface. Furthermore, the entire 360° field of view, which is represented by the height of the cylindrical surface of incidence, and which is a function of the surface area of the cylinder, is, by reason of this lemniscular distortion, reduced to such a size that the image thereof falls wholly within the small circular viewing area. Finally, advantage is taken of this lemniscular distortion of the panoramic image for novel and convenient surface marking of the optically transparent body to the end that image measurements may be made and readings obtained which are indicative of such things as object size, specific object dimensions, and relative positioning of objects with respect to one another, as well as to the optical system itself. Although image distortion involves an over-all object-to-image size reduction, the optical system is such that by relative movement of the system bodily with respect to the object or objects undergoing viewing, any selected visible portion of an object may be brought under surveillance and the image thereof viewed at an image magnitude which is no less than the full magnitude of the portion thus selected.

According to the present invention, a wide variety of environmental aspects for the basic optical system briefly outlined above are contemplated, but in all of them, and without exception, the system remains unchanged. However, various auxilliary features may be incorporated in the optical system to enhance the efficiency thereof as, for example, the provision of a viewing extension in the form of a transilluminating rod, which may either be separate from or integral with the prism-like transparent body, and which operates upon the principle of internal reflection from the side walls thereof for conducting light from the stereo or planar image to a remote point for visualization thereof. Another auxilliary feature which may be incorporated with the basic optical system of the present invention is a novel means for applying artificial external light to and conducting the same through the optical system for object and, consequently, image-illumination and subsequent reflection of the image light toward the eye of the observer. An additional and mechanical adjunct to the optical system resides in the provision of a combined protective sheath and guide for the transilluminating rod portion when the latter is incorporated in the system and which normally, when the system is not in use, serves as a protective shield for the cylindrical and conical optical surfaces but which, when the system is in use, affords a guide for the transilluminating rod so that the position of the various optical surfaces may be shifted bodily as a unit with respect to the object or objects undergoing viewing for various purposes such as object selection, object size comparison, object size or dimension determination, or image position shifting when desired.

The optical system of the present invention, and as briefly described above, has been designed for use primarily in connection with depth probing operations and, toward this end, the system is embodied at one terminal end of a cylindrical transilluminating rod, as described above, preferably as an integral portion of the rod. More aptly, the transilluminating rod may be described as an integral extension of the optical system which is comprised of a body of optically transparent material having the aforementioned cylindrical surface of light incidence and the convex conical reflecting surface associated therewith. The integral body, thus constructed, is generally in the form of a conventional endoscope and which may be inserted into a bore or other cavity for lateral viewing purposes simultaneously in all radial directions. When so constructed, the resultant device may be found useful as a bore inspection instrument useful, for example, in connection with inspection of the inside cylindrical bores of valve or pump casings in order to ascertain the nature of the surface finish thereof, or to detect the presence of flaws or other defects, in which case the resultant circular lemniscular image produced will present itself as a planar two dimensional image, or the inspection of an intersecting radial bore, in which case a stereo or three dimensonal image will be produced. Such a device may also find medical or surgical uses for examining or observing the functions involved in connection with human or animal body cavities; for example, as a bronchoscope or a laryngoscope. When thus used in the manner of an endoscope, the device is not limited to optical viewing of the image which is produced by the optical system associated therewith inasmuch as it is contemplated that the optical system may be employed for photographic exposure purposes or for the transmission of certain types of electron beams. Irrespective however of the particular use to which the present invention may be put, the essential features thereof are at all times preserved.

The provision of a novel optical system and its incorporation in an endoscopic type of instrument or device as set forth above being the principal object of the invention, it is a further object to provide such a device wherein the transparent body which provides the optical system may be formed of a transparent or optically clear plastic material such as Lucite, and which, moreover, may be machined as an integral unit from cylindrical rod stock, thereby contributing toward economy of manufacture.

The provision of a depth probe inspection device which can be devoid of moving parts and in which the optical surfaces of light incidence, reflection and emergence are permanently fixed with respect to one another so that the system cannot get out of proper focus or collamination; one which oherwise is rugged and durable and therefore is unlikely to get out of order; one which by reason of such ruggedness is able to withstand comparatively rough usage; one which is of compact design and of small proportions so that it may conveniently be transported on the person of the physician, surgeon, mechanic, inspector or other user; one which has a shape characteristic which is conducive toward ease of manipulation; and one which, otherwise, is well adapted to perform the services required of it, are further desirable features which have been borne in mind in the production and development of the present invention.

Numerous other objects and advantages of the invention, not at this time enumerated, will readily suggest themselves as the following description ensues, and, although for the sake of convenience and quick apprenhension of the invention the invention is sometimes described and defined herein in connection with vertical and horizontal orientations, it is to be noted that the invention contemplates use in all orientations as required without limitation with respect to any particular one.

In the accompanying three sheets of drawings forming a part of this specification, several illustrative embodiments of the invention have been shown.

In these drawings:

FIG. 1 is a perspective view of a depth probing device or endoscope constructed according to the principles of the present invention and embodying the novel optical system thereof;

FIG. 2 is a sectional view taken substantially centrally and longitudinally through the device of FIG. 1 and showing the same operatively installed in a bore for surface inspection purposes;

FIG. 3 is an end view of the device of FIG. 1;

FIG. 4 is a fragmentary sectional view taken substantially centrally and longitudinally through the upper region of the device of FIG. 1 and illustrating the manner in which an external source of artificial light may be applied thereto, the view representing a modified form of the invention;

FIG. 5 is a sectional view taken substantially along the line **5—5** of FIG. 4 in the direction indicated by the arrows;

FIG. 6 is a perspective view, similar to FIG. 1 showing a slightly modified form of depth probing device or endoscope embodying the optical system of the invention;

FIG. 7 is a sectional view similar to FIG. 2 showing a further modified form of depth probing device or endoscope together with a retractible protective shield for the optical system of the device, the device being operatively insertable in a bore with the optical system thereof in retracted and protected position;

FIG. 8 is a fragmentary sectional view of the depth probing device of FIG. 7, showing the optical system projected into its operative position preparatory to inspection of an intersecting bore;

FIG. 9 is a panoramic chart of a cylindrical light incident surface employed in connection with the form of endoscope shown in FIG. 6 and illustrating certain reference graduations associated therewith;

FIG. 10 is a composite diagram representing the field of view of the endoscope of FIG. 6, no image being present, and illustrating the composite optical effect of the reference graduations;

FIG. 11 is a fragmentary panoramic chart of the inside cylindrical surface of a large diameter bore having a plurality of defects therein, and showing the intersection of such bore with a small diameter bore, the two bores being within the field of view of the optical system of the endoscope of FIG. 6;

FIG. 12 is a composite diagram of the visible image represented by the field of view shown in FIG. 11 and as viewed through the endoscope of FIG. 6;

FIG. 13 is a fragmentary composite diagram similar to FIG. 12, showing the effect of a shift of the optical system bodily to a position wherein one of the defects being examined is brought into collamination with certain of the reference graduations for size and symmetry determination; and

FIG. 14 is a perspective view, schematic in its representation, illustrating the basic optical system of the present invention.

Referring now to the drawings in detail and in particular to FIG. 14 wherein the basic optical system which underlies the various forms of the invention illustrated herein has been portrayed, this system is predicated upon the provision of a solid prism-like or prismatic body of optically clear material such as optical glass or a suitable plastic material such as Lucite. Such a body has been designated in its entirety at **20**. The body **20** is of cylindrical design and is smooth and polished on all surfaces thereof. The body **20** is provided with a cylindrical side face **22**, an upper planar circular end face **24**, and a lower or underneath concave conical end face **26** having a slant angle of 45° and the vertical axis of which is equal in height to the height of the side face **22** so that the apex **27** of the cone lies on and at the center of the end face **24**. The lower concave conical end face **26** establishes an effectively convex internal optical face **28** (see also

FIGS. 1 and 2) within the transparent body **20** itself. The three faces **22**, **24** and **28** of the body **20** cooperate optically with one another to provide a compound lens-prism combination wherein the faces **22** and **24** function in the manner of lenses and the internal face **28** functions in the manner of a totally reflecting prism involving internal reflection. Because the body **20** does not possess two planar faces it cannot be defined as a prism, and because it affords neither light convergence nor divergence, it does not fit the ordinary definition of a lens. Suffice it then, for purposes of discussion herein and for purposes of claim terminology subsequently, to refer to this body **20** as an effectively prismatic or prism-like body.

The prismatic body **20** embodies the entire basic optical system of the present invention and, in the use thereof, it is positioned centrally of a series of circumferentially arranged objects O^1 and O^2 and coaxially of the series. The cylindrical side face **22** thus constitutes a surface of light incidence as indicated by the horizontal arrows in FIGS. 8 and 14. The light issuing from the circumferentially arranged objects such as the two exemplary objects O^1 and O^2 passes radially inwardly of the side face **22** and, since the angle of entry is truly radial or normal to the surface of the cylindrical face **22**, there is no deflection in the direction of the light rays as they enter the body **20** regardless of the index of refraction of the material involved. The radial inwardly directed rays, after entering the body **20** through the cylindrical side face **22**, then are reflected upwardly from the internal convex conical face **28** due to the phenomenon of total internal reflection as indicated by the vertical arrows. The end face **24** constitutes a surface of light emergence and it is this surface which is viewed by the eye E of the observer from a central point above the surface. The resultant composite image which is seen by the observer will be of a circular nature, this composite image being schematically represented by the dotted circle labelled I^c. The individual images I^1 and I^2 appearing within this composite image I^c will be distorted, the distortion being of a lemniscular nature due to well known phenomenon which is attendant upon the reflection of light from a convex conical mirror wherein object width is reduced and object height remains the same. The composite image I^c and the individual images I^1 and I^2 associated therewith are virtual, inverted and reduced, as is the case in connection with all concave mirrors or reflecting surfaces, whether the same be spherical, conical or cylindrical. Thus, these images which are in the form of individual lemniscates appear to lie well below the large base of the conical surface **26**. The reduction of images is not regular. Actually it takes place progressively and radially inwardly of the composite image, there being no reduction in size at the extreme periphery of the image and the reduction amounting to 100% at the center of the image. Circular objects such as the objects O^1 and O^2 thus will take on the tear drop image configuration shown at I^1 and I^2. In a general way, this type of image reduction is similar to a Mercator's Projection wherein distances at the poles of the earth's sphere are magnified with respect to distances at the equator.

The optical system described in connection with the prismatic body **20** of FIG. 14 has been embodied in a practical optical instrument in the form of an endoscope **30** the details of which are disclosed in FIG. 1. In this embodiment of the invention, the optical system of FIG. 14 has been incorporated bodily and without change in the lower end region of an elongated cylindrical transilluminating rod **32**. The transparent prismatic body **20** with its cylindrical polished side face **24**, its concave conical end face **26**, and its internal effective convex optical face **28**, occupies a position at the extreme lower end region of the elongated transilluminating rod and is integral and coaxial therewith. Actually, in the manufacture of the endoscope **30**, the rod **32** and body **20** are machined from a single length of Lucite or other optical rod stock capable of being machined and thus the end face **24** of the schematically illustrated optical system of FIG. 14 exists only as an imaginary one in the transverse juncture plane between the transilluminating rod **32** and the body **20**. This juncture plane is the transverse plane which passes through the apex **27** of the internal conical face **26** normal to the axis of the cone. The transparent cylindrical body **20** and the elongated cylindrical transilluminating rod **32**, being integrally formed, provide, in effect, a single elongated optical body which has been designated in its entirety at **34**. On such a basis, the body **34** may be regarded as being comprised of a prismatic body portion **20** and a transilluminating rod portion **32**. For convenience of description and claim definition, this terminology will be adhered to hereinafter.

Still referring to FIG. 1, the outer cylindrical surface of the transilluminating rod portion **32** of the body **34** is preferably, but not necessarily, rendered translucent by a suitable etching, sanding, or other process, while the cylindrical face **22** of the prismatic body portion **20** thereof is polished and therefore clear.

The upper end region of the generally cylindrical body **34** is provided with an enlarged head portion **36** of slightly larger diameter than the diameter of the rod portion **32**, this head portion defining a downwardly and outwardly directed frusto-conical shoulder **38**. The outer cylindrical surface of the head portion **36**, as well as the frusto-conical shoulder **38**, are optically clear for the purpose that will be described presently. The lower region of the head portion **36** is formed with a relatively deep, narrow annular groove **40** therearound, the function of which likewise will appear presently. As shown in dotted lines in FIG. 1, the bottom wall **42** of the groove **40** presents a narrow cylindrical band-like surface the diameter of which is somewhat less than the diameter of the rod portion **32** of the body **34**.

Considering now the previously described optical system which is afforded by the prismatic body portion **20**, as integrally embodied in the optical body **34**, it will be apparent that the transilluminating rod portion **32** and the enlarged head portion **36** function, in effect, to displace the normal planar circular optical light-incident surface **24** (FIG. 14) an appreciable distance upwards from its normal position of FIG. 14 and thus establish an elevated light-incident surface **44** (FIG. 1) for viewing purposes by the eye of the observer. This elevated optical surface **44** is slightly larger in diameter than the normal viewing surface **24** of the optical system as portrayed in FIG. 14, but, despite this, the basic optical system remains substantially the same in optical function. The transilluminating rod portion **32** has no effect on the image which is established by the optical system, either as to regards its size or its shape characteristics, the only function of this rod portion being to collect and transmit the reflected light issuing from the internal conical face **28** directly to the eye of the viewer. This rod portion **32** also serves the incidental function of maintaining the eye of the observer at a greater distance from the image than when this rod portion is not present. The length of the transilluminating rod portion **32** may be varied within wide limits ranging from an extremely short length to the maximum length which is within the capabilities of the observer in viewing the image. Ordinarily, this length will be determined by the effective depth of the cavity to be explored by the endoscope instrument.

Referring now, additionally, to FIG. 2 wherein the optical instrument or endoscope **30** of FIG. 1 is illustrated for exemplary purposes as being operatively installed in a bore **50** the surface characteristics of which it is desired to explore, the entire internal surface of the bore may be explored by a progressive shifting of the instrument vertically within the bore to bring the prismatic body portion **20** into radial register with selected portions of the bore. A seating ring **52** may surround the rod portion **32** of the body **34** if desired to assimilate the downward thrust of a split supporting band or collar **54** which may be tightened upon the instrument at various selected longitudinal regions by means of a thumb screw **56**.

Assuming that a selected cylindrical region such as the region designated at **58** in FIG. 2 is to be examined for surface finish or surface defects, the body portion **20**, together with the adjacent region of the transilluminating rod portion **32** will be telescopically inserted into the bore and lowered until the body portion **20** is in radial register with the portion **58** to be examined. Thereafter the thumb screw **56** may be tightened to maintain the instrument in a fixed position.

Illumination of the selected region **58** of the bore **50** will automatically be effected by reason of ambient light conditions in the vicinity of the instrument **30** exteriorly of the bore **50**. Parallel side transilluminating rods are well known, as are the principles of light transmission and light emission associated therewith, and therefore a detailed discussion of these principles will not be set forth herein, suffice it to say that light which enters one end face of an optically clear transilluminating rod will travel, substantially undiminished in intensity to the other end face and pass outwardly of the latter with practically no distortion. Thus, an object presented to one end face of the rod will present to the eye of the viewer at the other end face a substantially undistorted erect image of such object. This ability to transmit undistorted images of undiminished light intensity is predicated upon well known phenomena relating to total internal reflection in prismatic bodies. It is well known that total reflection will occur at the boundry separating two media having different refractive indices when any ray in the medium of higher index is directed toward the other medium at an angle of incidence greater than the critical angle. Thus, in a parallel side rod, light which enters the rod through one end face thereof and is directed longitudinally along the rod is confined within the cylindrical contour of the rod substantially in its entirety since at no time does it approach the surrounding medium at an angle less than the critical angle. An extremely small amount of diffused light may escape laterally through the outer cylindrical face of the rod due to microscopic particle impurities in the optical media of the rod but the amount involved is negligible and does not detract appreciably from the quantity of light issuing from the end face of light emergence. An image existing by reason of such emerging light remains substantially undiminished in intensity.

By these tokens, ambient light which enters the viewing end face **44** of the optical body **34** will pass through the circular "opening" afforded by the bottom wall **42** (FIG. 1) of the annular groove **40** and pass longitudinally along the rod portion **32** to the internal reflective conical face **28** of the prismatic body portion **20**. Some light will enter the body **34** radially inwardly through the cylindrical side surface of the optically clear enlarged head portion **36**. An additional and appreciable amount of light will pass inwardly through the optically clear frusto-conical shoulder **38** and impinge against the lower side wall **60** (FIG. 2) of the annular groove **40**, from whence it will be totally reflected by total internal prismatic reflection and directed longitudinally along the rod portion **32** to the internal conical reflecting face **28**. Still more light will pass radially inwardly in diffused form through the translucent cylindrical side surface of the rod portion **32** of the body **34**. The net result of all of this light entering the body **34** at various locations or regions thereof will be to "flood" the interior of the body, so to speak, with light rays. These light rays, which ordinarily in connection with conventional transilluminating rods would emerge longitudinally from the lower end face of the rod, are in the present instance

prevented from thus emerging due to the total reflecting function of the internal optical conical face **28** which is presented to these light rays at an angle less than the critical angle of incidence. The light rays therefore will be reflected radially outwardly of the optical body **24** in all radial directions for illumination of the surrounding object which, in the present instance, is the selected limited portion **58** of the internal bore **50**. The thus illuminated object, i.e., the area **58** of the bore **50**, is then visible as a lemniscular distortion of the image panorama to the eye of an observer looking through the circular end face **44**, by reason of the reflection phenomena associated with total reflection of light from a conical surface as previously described in connection with the basic optical system of FIG. 14.

Under certain circumstances it may be found desirable to illuminate the bore or other object undergoing visual exploration with artificial light and one means for accomplishing this has been illustrated in FIGS. 4 and 5. Illumination is accomplished without modifying the basic optical system described in connection with FIG. 14, or the embodiment thereof in the endoscope instrument of FIGS. 1 and 2. Accordingly, a torus-like annular casing **70** surrounds the upper end region of the transilluminating rod portion **32** immediately below the level of the frusto-conical shoulder **38** and may either be frictionally held in position therearound or cemented to the rod portion **32**. The casing **70** is square in radial cross section and has operatively mounted therein a series of circumferentially spaced light-emitting elements **72** in the form of incandescent filaments adapted to be electrically connected to a suitable source of energizing current (not shown). The innermost upper annular peripheral edge of the casing **70** is truncated as at **74** to provide an exit window for light rays emanating from the elements **72**, the window being in coextensive register with and close proximity to the transparent frusto-conical surface **38** as shown in FIG. 4. Artificial light rays entering the body **34** through the transparent frusto-conical surface **38** will assist in flooding the interior of the body **34** with light as previously described, but, specifically, directional rays emanating from the filaments **72** will enter the body **34** through the frusto-conical surface **38** and strike the lower side wall **60** (FIG. 2) of the annular groove **40** and thus be reflected generally downwardly as indicated by the arrows in FIG. 4 and, thereafter, by total internal reflection from the cylindrical side wall of the transilluminating rod portion **32**, ultimately be directed to the internal conical reflecting surface **28**.

In order to shield the eye of the observer from light rays issuing from the filaments of the light sources **72**, a suitable filler material or strip **76** may be positioned within the annular groove **40**. This strip is of an opaque nature and its function is principally a shielding one rather than a reflecting one. However, if desired, the strip, in addition to being opaque, may be of a reflecting character to prevent any rays which may be directed toward the surface at an angle greater than the critical angle from entering the head portion **36** through the surface **60**. In such an event, the filler strip **76** may be formed from aluminum or other reflective metal foil.

In FIG. 6, a modified form of endoscope instrument **130** has been illustrated, the instrument embodying the basic optical system of FIG. 14. The optical body **134** which, in its entirety, comprises the instrument is identical in many respects to the optical body **34** of the form of instrument described in connection with FIG. 1 and therefore, in order to avoid needless repetition of description, corresponding reference numerals but of a higher order have been applied to the corresponding parts as between the disclosures of FIGS. 1 and 6 respectively.

The shape characteristics of the optical bodies **34** and **134** of FIGS. 1 and 6, respectively, are substantially identical except for a slight reduction in the diameter of the cylindrical body portion **120** as indicated at **121**.

An additional difference resides in truncation of the concave conical end face **26** of the body portion **20** and consequent truncation of the effective internal reflecting conical optical surface **128** (see FIG. 7), thus providing a corresponding frusto-conical end face **126** and an internal reflecting frusto-conical face **128** in the body **134**. A third difference resides in the elimination of the frusto-conical light-incident shoulder **38** and the substitution therefore of a radial shoulder **138**. Truncation of the internal and external faces **128** and **126**, respectively, is effected by the provision of a coaxial pilot bore **129** (see FIG. 6) in the lower end face of the body portion **120** and which intersects the cone outline of the surface **126**.

Truncation of the internal optical surface **128** has little effect on the character of the images which are produced for visualization when the instrument is in use inasmuch as the portion of the cone which is removed is merely a small fragment of the apex region of the cone. This apex region, when considered in connection with the internal conical face **128** of FIG. 1 is productive of an image fragment which is of greatly reduced size and, furthermore, it is possible, by proper manipulation of the instrument, to maintain the entire image within the confines afforded by the frusto-conical face **128** for all useful bore inspection, comparison or measurement purposes as will be made clear presently.

In addition to the above-described variations in shape characteristics of the optical body **132** over the body **32**, the transparent optical surfaces represented by the upper end face **144** of the head portion **136** and the side face **124** of the optical body portion **120** are provided with surface markings which, when imposed upon the optical system and viewed by the eye of the observer, provide convenient reference lines by means of which image dimensions, image positioning, and image shapes may conveniently be ascertained. The surface markings selected herein for illustrative purposes are purely exemplary and it will be understood that other surface markings than those shown may be employed if desired.

The surface markings on the upper end face **144** are in the form of a series of concentric circles **181** these circles being three in number. While three such circles have been illustrated herein, a greater or lesser number may be employed. The three circles are concentric with the circular end face **144**. The surface markings on the cylindrical side face of the optical body portion **120** are in the form of a first series of three vertically spaced parallel band-like lines **183**, a second series of three spaced vertical and longitudinally extending lines **185**, and a single vertical longitudinally extending reference line **187**. All of these reference lines are visible in sharp focus when viewed by the eye of the observer and a superimposed pattern of lines such as has been illustrated in FIG. 10 constitutes the composite pattern image which is seen by the eye.

The circular reference lines of the series **181** are not used as a pattern chart in connection with image measurements although their pattern lines are superimposed over the image which is viewed by the eye. These reference lines are close to the viewing eye and therefore their apparent thickness will prevent them from useful register with small portions of the image and they should not be used for measuring. The purpose of the reference lines is solely to facilitate eye alignment with the axis of the instrument for the most effective viewing of the image.

The vertical reference lines of the series **185** have been labelled *w***1**, *w***2** and *w***3** respectively, as have their pattern representations in the charts of FIGS. 10, 12 and 13. These lines, when imposed over a given image, may be employed to facilitate a determination of the width of an object such as a flaw or other small defect.

The vertical line **187** has been labelled *r*, as has its pattern representation in the various charts, and this line, in combination with the vertical lines *w***1**, *w***2** and *w***3**, may be employed for facilitating a determination of the circumferential distances around the area of the bore which is undergoing inspection. Such distances may be spacings between circumferentially arranged objects, or they may be relatively large flaw width dimensions. When considered in connection with the reference lines *w***1**, *w***2** and *w***3**, distance measurements such as have been indicated at *d***1**, *d***2** and *d***3** in FIG. 9 are available for use in ascertaining circumferential distances.

The vertically spaced band-like lines of the series **183** have been labelled *h***1**, *h***2** and *h***3** respectively. These lines serve to facilitate a determination of vertical spacings or small vertical heights or distances associated with an object such as a flaw within the bore undergoing inspection.

The functions of the various reference lines described above and the relationship which they bear to another in establishing a reference pattern for superimposition over a given image or series of images may best be understood by graphically illustrating the distortion pattern which result from the optical viewing of specific shapes, utilizing the endoscope instrument of FIG. 6. FIG. 9 is a chart which represents a panoramic view of the cylindrical optical face of the body portions **20** and **120**, the cylinder being unfolded to a planar condition. The chart shows the various reference lines with no image superimposition thereon. FIG. 10 is a diagram representing the image of the various reference lines as viewed by the eye when there is no object present to be viewed. FIG. 11 is a chart showing a limited portion of the field of view when viewing five differently shaped objects with the adjacent reference lines superimposed thereover. FIG. 12 is a diagram of the actual field of view as seen through the endoscope instrument when viewing the five objects of FIG. 11 and the positional relationship of the various reference lines with respect to these objects.

It is a demonstrable fact that if an object and a reflective cone are positioned on a horizontal planar surface in side-by-side relationship, the reflected image of the object will be distorted in cochleate fashion, the upper regions of the image being progressively reduced in size. Thus a cube will yield the image of a pyramid, while a cylinder will yield the image of a cone. The reduction in size is effective through the entire height of the image except for its base which remains equal in size to the size of the base of the object. This reduction in size is effective only insofar as the width of the image is concerned. The height of the image at all times remains the same as the height of the object. If the reflective cone is elevated slightly above the level of the object, the lower portion of the image will run off the lower circular edge of the cone, so to speak, while the upper region of the image will increase in width. If the cone is lowered with respect to the object, a portion of the diminished upper region of the image will shrink to a point and run off the apex of the cone. This phenomenon of reflective conical surfaces is carried into the optical system of the present invention in such a manner that radial directions of the viewed panoramic image represent object height and do not diminish in size regardless of relative vertical displacement between the conical reflective surface **128** (FIG. 6) and the object, while circumferential direction of the circular panoramic image represents object width.

Bearing these considerations in mind, and assuming for purposes of discussion that the circle appearing in the chart fo FIG. 11 represents the intersection of a small bore such as the bore **100** of FIGS. 7 and 8 with a larger bore **102** within which the endoscope instrument **134** is inserted for the purpose of inspecting the bore **100**, the image which the bore **100** will present to the eye is the teardrop configuration in FIG. 12. No radial diminution has taken place but appreciable width diminution has occurred. To test the bore for concentricity, the teardrop shape will be brought into centered relationship within the intersecting confines of the reference lines *w***1**, *w***3**, *h***1** and *h***3** insofar as is possible by manipulation of the instrument bodily as a whole within the bore **102**. Rotation of the instrument about its longitudinal axis will sweep the radial reference image lines *w*1, *w*2, *w*3 and *r* around the field of view for image centering purposes, while raising or lowering of the instrument bodily will draw the image radially inwardly or radially outwardly to decrease its width and bring the same into the desired position of register with the various reference lines. With the teardrop image thus in tangential relationship to the four reference lines *w*1, *w*3, *h*1 and *h*3, and with the line *w*2 bisecting the teardrop image, it may be assumed that the object is truly circular. The presence of a protruding burr or other imperfection such as has been indicated at **104** in FIG. 7, even though the flaw be remote from the region of bore intersection, will be revealed in the image by a projection such as has been shown at **106** within the confines of the circles of FIG. 11.

Experimentation has shown that a square object pattern, an inverted triangular object pattern, and upright triangular object pattern and an elongated vertically disposed narrow rectangular object pattern such as have been illustrated in FIG. 11, will assume the shield shape image pattern, the distorted triangle image pattern, the trapezoidal image pattern, and the knife blade image pattern respectively of FIG. 12.

In FIG. 13, the image pattern illustrated shows the effect which is produced on the various images of FIG. 12 when the square object pattern of FIG. 11 is brought into register with the intersecting reference lines *w*2 and *h*2 and is centered between the lines *w*, *w*3, *h*1 and *h*3. The trapezoidal image pattern of FIG. 12 has increased in width but remains the same in length; the narrow rectangular image pattern has become wider; the relatively sharp pointed end of the teardrop image pattern of FIG. 12 has become blunt and appreciably enlarged in width with a portion of the image pattern having moved from the field of view, while the two triangular image patterns have moved from the field of view. Such image displacements are caused by raising the endoscope instrument bodily in the bore **102** and rotating the same through a small angle to effect the necessary image and reference line register.

From the above description it will be understood that an operator, after a short period of study and experimentation with the conversion of various object shapes or markings will become skilled in image determination so that by viewing a given image shape, he may readily visualize the particular shape of the object from which the image is derived. By thus acquiring skill in image determination, an operator such as a surgeon or an engineer may become proficient in bore or passage examination utilizing the endoscope instrument of the present invention.

In FIG. 7, the endoscope instrument of FIG. 6 is shown as being equipped with an articulate protective sheath **200** for the optical body portion **120** and a portion of the transilluminating rod portion **132**. An end cap or plug **202** also is provided for protecting the polished concave frusto-conical surface **126**. The sheath **200** is of open-ended cylindrical design and it is telescopically received over the rod portion **132**. The end cap or plug **202** is in the form of a circular closure disk which extends across and closes the cavity afforded by the provision of the frusto-conical surface **126** in the prismatic body portion **120** of the elongated body portion **134**. A pilot plug or stem **204** is formed centrally of the end cap and projects into the pilot hole **129** and is cemented in position therein. The peripheral region of the end cap **202** overhangs the cylindrical confines of the rod portion **132** and is recessed as at **206** to provide a seat for the lower open rim of the tubular sheath **200**. The sheath **200** is normally maintained in its seated relationship on the end cap **202** by means of a spring **208** which surrounds the rod portion **132** and bears at its lower end against an annular outwardly turned flange **210** provided at the upper rim of the sheath, and at its upper

end against the downwardly facing shoulder **138** at the juncture region between the head portion **136** and rod portion **132**. When seated on the end cap **102**, the prismatic body portion **120** is completely withdrawn into the sheath and consequently the polished optical side face **124** thereof is protected from contact with external objects, as well as being shielded from contamination by dirt or moisture.

The prismatic body portion **120** is adapted to be projected outwardly beyond the lower open rim of the sheath **200** in order to expose the same for operative bore inspection purposes in a manner that will be made clear presently, the exposed position of the body portion being illustrated in FIG. 8.

In actual use for bore inspecting purposes, the cylindrical sheath **200** is inserted endwise into a bore such as the bore **102** and is lowered to the desired depth within the bore. In the exemplary use of the endoscope instrument **134** shown in FIG. 7 wherein it is desired to ascertain the character of an intersecting bore such as the small bore **100**, the sheath will be lowered to such an extent that the open lower rim thereof just meets the bore intersection. Thereafter the previously mentioned seating ring **52** and split locking collar **54** are applied to the sheath **200** to prevent further downward movement thereof. With the sheath **200** thus in position, downward pressure is applied to the optical body **134** against the yielding action of the spring **208**, thus lowering the prismatic body portion into register with the intersecting bore **100** as shown in FIG. 8 and establishing the previously described object outline represented by the circle of FIG. 11. Light entering the optically clear body of the instrument as previously described is transmitted to the interior of the bore **100** so as to illuminate the same and produce the image schematically represented by the teardrop image pattern of FIG. 12 as likewise previously described. The bore imperfection **104** will then be visible as the image representation **106** within the teardrop outline. After the necessary bore inspection has been completed, pressure on the instrument may be released and the spring **208** will restore the prismatic body portion **120** to its retracted position within the sheath **200** and with the end cap **202** closing the lower open rim of the latter. It is to be noted at this point that the reduced diameter of the body portion **120** affords a clearance region or annulus between the side surface **124** and the tubular sheath **200** to prevent abrasion of the polished side surface during relative sliding movement between the sheath **200** and body **134**.

The invention is not to be limited to the exact arrangement of parts or to the specific shape characteristics of the optical bodies **34** and **134** shown in the accompanying drawings and described in this specification as various changes in the details of construction may be reorted to without departing from the spirit of the invention. For example, the various graduation lines which have been illustrated herein as being applied to the optical faces **124** and **144** in the form of the invention shown in FIG. 6 may be applied to the optical faces **24** and **44** in the form of the invention shown in FIG. 1. Furthermore, these reference lines are purely exemplary of one system of reference marking. Other systems involving a greater or lesser number of such lines, or lines which extend in directions other than vertically and circumferentially are contemplated. The diameters of the various body sections may be varied to accommodate different size bores or passages to be inspected, while the length of the transilluminating rod sections **32** and **132** may be varied for different depth explorations. Although the bodies **34** and **134** are shown and described herein as being of one-piece integral construction, it is within the purview of the invention to construct the same in plural sections operatively cemented together by a transparent bonding agent. In such an instance it is preferable that all of the sections, as well as the bonding agent, be formed of materials having identical indices of refraction. It is not essential however, that such be the case because the phenomenon of refraction establishes an optical offset which merely displaces the image slightly but does not distort the image. Finally, although the transilluminating rod portions **32** and **132** of the two forms of optical bodies **34** and **134** respectively illustrated herein have been described as being formed of effectively rigid cylindrical rod stock incapable when cut in relatively short lengths of being flexed, it is within the purview of the invention to form the optical bodies of optically clear plastic or other materials which will yield when flexing stresses are applied thereto. Certain of the phenol formaldehyde resinous condensation products are extremely flexible at room temperatures when formed into rod stock at diameters on the order of one-quarter inch and less and when such rods are employed as the basis for forming the optical bodies **34** and **134** they may be caused to follow the tortuous contours of irregular bores the interiors of which are to be inspected. In such instances the panoramic images produced will present no distortion other than the herein described lemniscular distortion which is inherent in the optical system of the body **20** of FIG. 1.

Having thus described the invention and several embodiments thereof and the results and advantages attained thereby, it will be apparent to those skilled in the art how the stated objects are accomplished and how various and further modifications can be made therein without departing from the spirit of the invention the scope of which is commensurate with the appended claims.

What is claimed is:

1. An endoscopic instrument for making examinations within a body cavity, said instrument comprising an elongated solid cylindrical rod of optically clear material and having a proximate viewing end with an enlarged cylindrical head portion coaxial with the rod, and a distal exploratory end region adapted for insertion into the cavity, the end face of said rod at the proximate viewing end thereof being planar and extending transversely of the rod, said head portion being formed with an external annular groove therearound having a band-like bottom wall and opposed planar side walls, the end face of said rod in the distal end region being provided with a concave conical socket-like depression therein establishing within the rod at the extreme distal end thereof an internal effective convex conical reflecting surface which is coaxial with the rod, the juncture region between said enlarged head portion and the remainder of the rod establishing an annular frusto-conical light transmitting surface for entry of ambient light into said enlarged head portion, the side wall of said annular groove remote from said planar end face establishing an internal reflecting face for total reflection of light entering the enlarged head portion through said frusto-conical light transmitting surface and direction of such light longitudinally of the rod toward the distal end thereof, the portion of the cylindrical side face of the rod which is in radial register with said effective convex conical reflecting surface constituting a surface of light transmission whereby light reflected from the wall of the body cavity and entering the body through said portion of the side face of the cylindrical rod will be totally reflected from said effective convex conical reflecting surface towards the proximate end of the rod and emerge from said planar end face.

2. An endoscopic instrument as set forth in claim 1 and including, additionally, a torus-like annular casing surrounding said rod immediately below said frusto-conical light-transmitting surface, and a series of light-emitting elements operatively disposed within said casing in circumferentially spaced relationship therearound, said casing being formed with an annular light transmitting opening therein in register with said frusto-conical surface.

3. An endoscopic instrument as set forth in claim 2 and including, additionally, an opaque filler material disposed within said annular groove for shielding said transverse planar end face from extraneous light emanating from the vicinity of said groove.

4. An endoscopic instrument for making examinations within a body cavity, said instrument comprising an elongated generally cylindrical rod having an enlarged cylindrical head portion at its proximate viewing end, a cylindrical prismatic body portion at its exploratory end, and an intermediate transilluminating cylindrical rod portion, said head portion prismatic body portion and intermediate transilluminating rod portion being disposed in coaxial end-to-end relationship, said head portion presenting a planar transverse end face for viewing purposes, said prismatic body portion presenting a cylindrical side face and a concave conical end face establishing within the prismatic body portion an effective internal convex reflecting conical face in radial register with said side face, said apex region of said concave conical end face is truncated by the provision of a cylindrical pilot socket centrally of said end face whereby the effective internal convex reflecting conical face likewise is similarly truncated, a circular end cap extending across the open base of said concave conical end face, said end cap being formed with a central pilot stem projecting into said pilot socket and secured therein, said side face of the prismatic body constituting a surface of light incidence whereby light reflected from the wall of the body cavity and entering the prismatic body through said side face will be totally reflected from said effective convex conical reflecting surface and directed through the intermediate transilluminating rod portion to the planar end face of the enlarged head portion for emergence therefrom.

5. An endoscopic instrument as set forth in claim **4** wherein the juncture region between said enlarged head portion and the transilluminating rod portion establishes a frusto-conical light transmitting surface for entry of ambient light into the enlarged head portion, and means internally of said head portion for reflecting light entering the head portion through said frusto-conical light incident surface toward said internal convex reflecting surface.

6. An endoscopic instrument for making examinations within a body cavity, said instrument comprising an elongated generally cylindrical rod having an enlarged cylindrical head portion at its proximate viewing end, a cylindrical prismatic body portion at its exploratory end, and an intermediate transilluminating cylindrical rod portion, said head portion prismatic body portion and intermediate transilluminating rod portion being disposed in coaxial end-to-end relationship, said head portion presenting a planar transverse end face for viewing purposes, said prismatic body portion presenting a recessed cylindrical side face and a concave conical end face establishing within the prismatic body portion an effective internal convex reflecting conical face in radial register with said side face, said apex region of said concave conical end face is truncated by the provision of a cylindrical pilot socket centrally of said end face whereby the effective internal convex reflecting conical face likewise is similarly truncated, said side face of the prismatic body constituting a surface of light incidence whereby light reflected from the wall of the body cavity and entering the prismatic body through said side face will be totally reflected from said effective convex conical reflecting surface and directed through the intermediate transilluminating rod portion to the planar end face of the enlarged head portion for emergence therefrom.

References Cited

UNITED STATES PATENTS

1,791,794	2/1931	Chensney	128—398
2,724,766	11/1955	Hawley et al.	350—96 XR
2,843,112	7/1958	Miller.	
3,224,320	12/1965	Knudsen.	

JEWELL H. PEDERSEN, *Primary Examiner.*

O. B. CHEW, *Assistant Examiner.*