July 3, 1923. 1,460,732

C. PULFRICH

PHOTOMETRIC DEVICE

Filed March 1, 1922 4 Sheets-Sheet 1

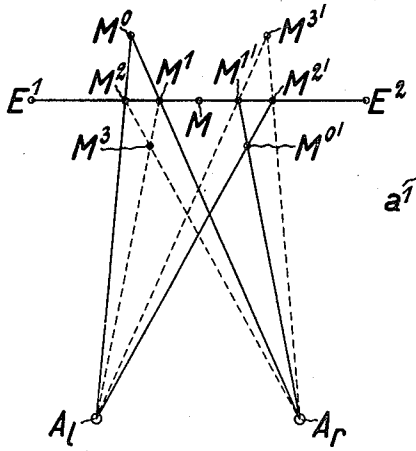


Fig. 1

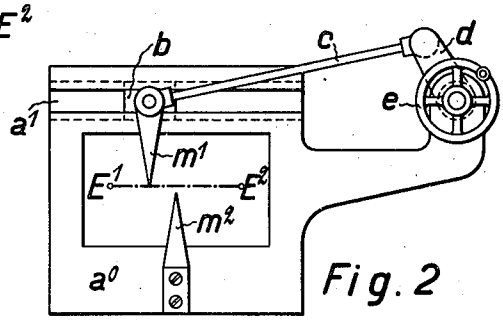


Fig. 2

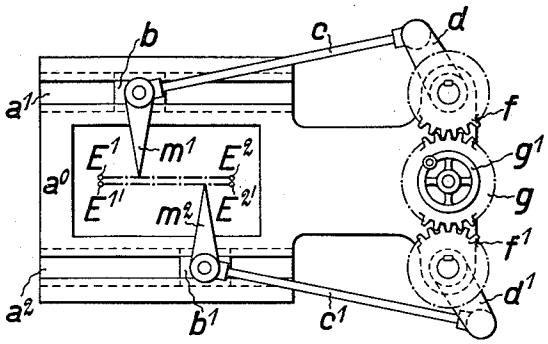


Fig. 3

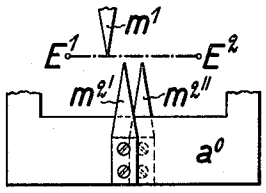


Fig. 4

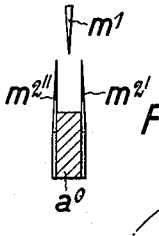


Fig. 5

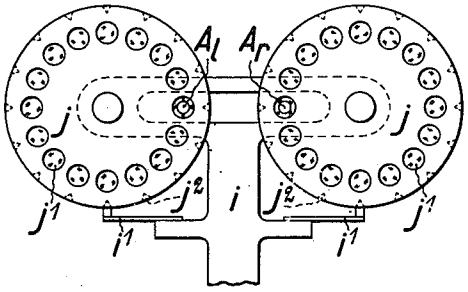


Fig. 7

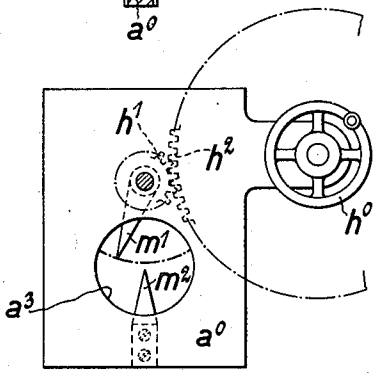


Fig. 6

Inventor:

Carl Pulfrich

July 3, 1923. 1,460,732

C. PULFRICH

PHOTOMETRIC DEVICE

Filed March 1, 1922 4 Sheets-Sheet 2

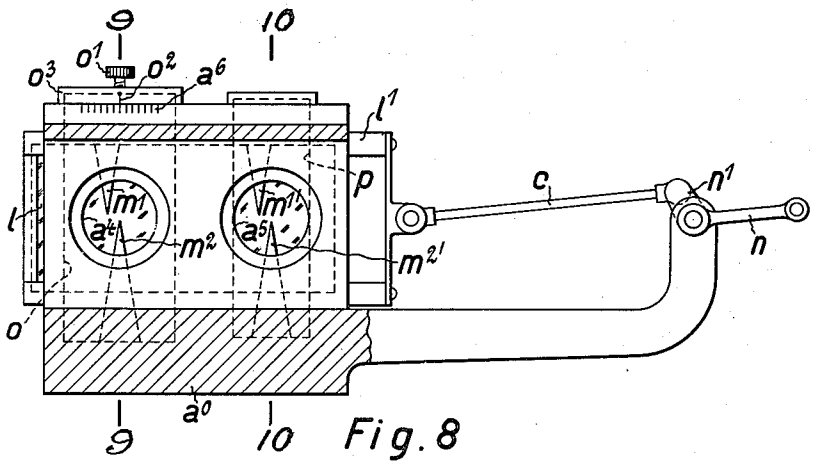


Fig. 8

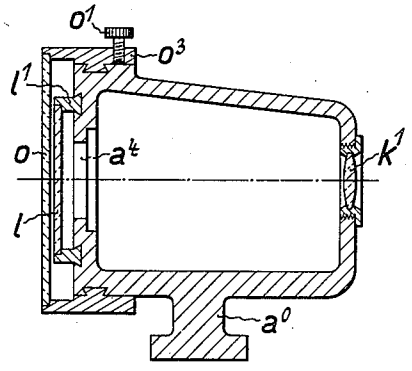


Fig. 9

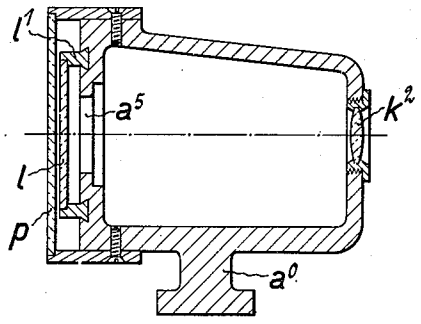


Fig. 10

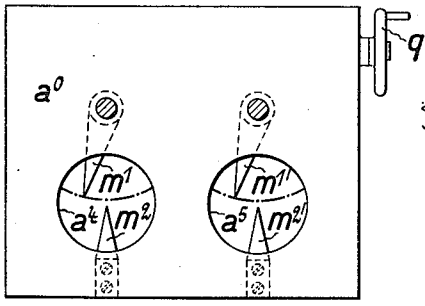


Fig. 11

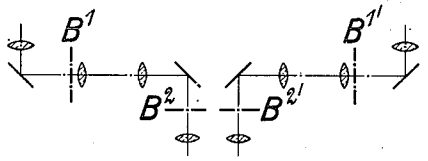


Fig. 12

Inventor:

Carl Pulfrich

July 3, 1923. 1,460,732

C. PULFRICH

PHOTOMETRIC DEVICE

Filed March 1, 1922 4 Sheets-Sheet 3

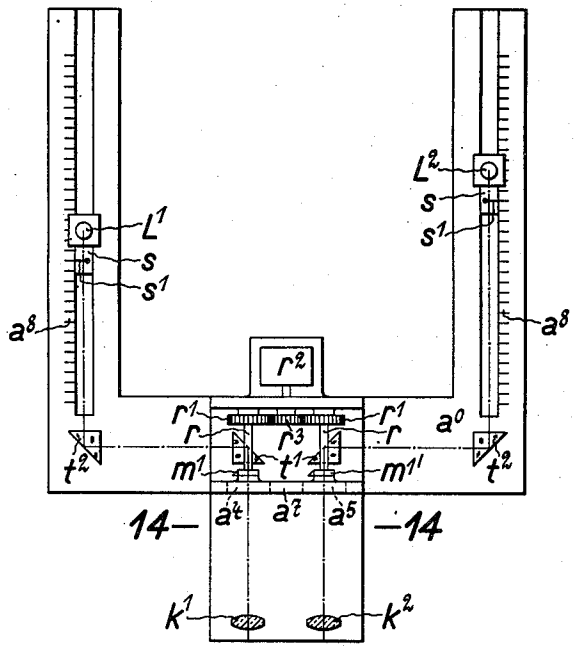


Fig. 13

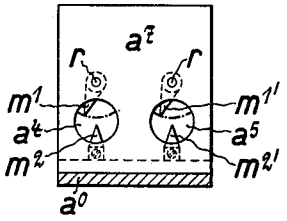


Fig. 14

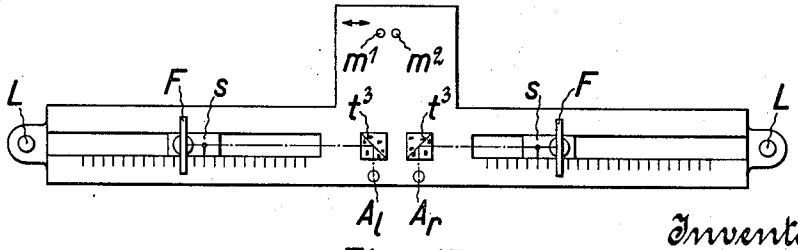


Fig. 15

Inventor:
Carl Pulfrich.

July 3, 1923.

1,460,732

C. PULFRICH

PHOTOMETRIC DEVICE

Filed March 1, 1922

4 Sheets-Sheet 4

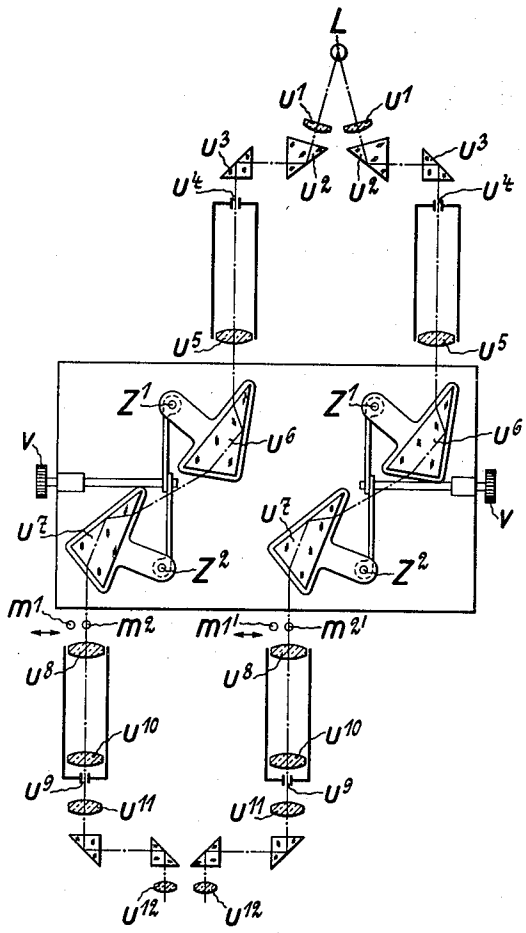


Fig. 16

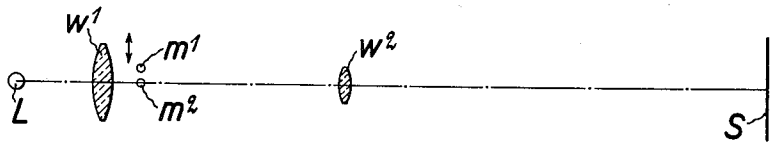


Fig. 17

Inventor:

Carl Pulfrich.

Patented July 3, 1923. 1,460,732

UNITED STATES PATENT OFFICE.

CARL PULFRICH, OF JENA, GERMANY, ASSIGNOR TO THE FIRM CARL ZEISS, OF JENA, GERMANY.

PHOTOMETRIC DEVICE.

Application filed March 1, 1922. Serial No. 540,300.

To all whom it may concern:

Be it known that I, CARL PULFRICH, a citizen of Germany, residing at Jena, Germany, have invented a new and useful Photometric Device (for which I have filed an application in Germany, February 17, 1921), of which the following is a specification.

If an observer, well capable of stereoscopic viewing, moves in a plane a mark to and fro in a straight line and looks at it with both eyes in such a way that this plane is parallel with the connecting line of the points of rotation of the eyes and stands perpendicularly on the plane determined by the two principal lines of vision, he will only have the impression of this real motion of the mark if the luminosities presented to both his eyes be uniform. In every other case the mark appears to move on a close path, of which only two points lie in the plane of the real motion of the mark, whilst the other points lie at different distances partly in front, partly behind this plane. The larger is the difference in luminosity and the greater is the speed at which the mark is moved, the larger are the differences in depth noticed. According to the right or the left eye receiving the greater luminosity, the apparent motion, as seen from above, takes place clockwise or counterclockwise. For the experiment it is of no importance whether there is presented a bright mark on a dark ground or a dark mark on a bright ground. The appearances remain alike.

The explanation of these appearances is due to the fact that in order to perceive the irritation of the retina of the eye a certain amount of time is required, which is all the larger, the smaller the luminosity presented to the eye, and that, if the luminosities presented to both eyes be different, owing to the motion of the mark the latter is seen by each eye at a different place, the distance of which from the real place of the mark is all the greater, the smaller the luminosity presented to the respective eye.

Considering the facts just explained, Fig. 1 of the annexed drawing shows the path of rays with the observation of a mark, moving to and fro in a straight line. Fig. 2 shows a constructional example of the invention with a stationary and a rectilinearly movable mark. Fig. 3 illustrates an example with two marks which are movable relatively to each other in a straight line. Figs. 4 and 5 show in a front view and in a section respectively an example with two stationary and one rectilinearly movable mark. Fig. 6 illustrates an example with a stationary and a circularly movable mark. Fig. 7 shows a device for graduating the luminosity for both eyes of the observer. Figs. 8 to 10 show in a cross section and in two longitudinal sections respectively an example with two stationary and two rectilinearly movable semi-images of the marks. Fig. 11 illustrates an example with two stationary and two circularly movable semi-images of the marks. Fig. 12 shows an example in which for the observation there serves a binocular telescope. Figs. 13 and 14 show in a front view and a cross section respectively a photometer according to the invention. Fig. 15 shows another form of a photometer according to the invention. Fig. 16 illustrates a photometer for the comparison of two spectral ranges. Fig. 17 shows an arrangement for the projection of a stationary and a movable mark.

In Fig. 1 it is assumed that a mark moves to and fro in a straight line between two terminal points E^1 and E^2. The two observing eyes A_l and A_r are in such a position that the connecting line of their points of rotation is parallel to the path E^1 E^2 of the mark. Supposing the mark, on moving from the left to the right, has reached the place M. Owing to a certain irritation of light received by the right eye A_r, the latter then sees the mark in M^1, whilst the left eye A_l, which may receive a weaker irritation of light than the right one, sees it at the place M^2 lying behind the place M^1. Hence in the stereoscopic view of the mark there appears a spatial image at the place M^0, lying behind the path E^1 E^2. When the mark, on moving from the right to the left, reaches the place M, it is seen by the right eye A_r in $M^{1'}$ and by the left one A_l in $M^{2'}$, and a spatial image appears at the place $M^{0'}$, which lies in front of the path E^1 E^2. If for all points of the path E^1 E^2 of the mark the appertaining spatial images would be constructed, the apparent path of the mark would be obtained in the shape of a close curve and it would result, as seen from

above, an apparent, clockwise motion of the mark. By exchanging the luminosities transmitted to both eyes, i. e. if the right eye receives the weaker and the left eye the stronger irritation of light, the mark, on reaching in its movement from the left to the right the place M, is seen by the right eye in M^2 and by the left eye in M^1, whilst, on reaching in its movement from the right to the left the place M, it is seen by the right eye in $M^{2'}$ and by the left eye in $M^{1'}$. Hence the appertaining spatial images (vide the path of rays shown by dotted lines) appear in M^3 and $M^{3'}$. In that case there results, as seen from above, an apparent, counter-clockwise motion of the mark.

The figure shows, that by reducing the difference in luminosity, viz, by a reduction of the distance apart of the places M^1 and M^2 and $M^{1'}$ and $M^{2'}$ respectively, it is possible to reduce the difference in the distances of the spatial images from the connecting line of the points of rotation of the eyes. By the transmission of uniform luminosities to both eyes, the difference in distance of the spatial images becomes nil, i. e. the observer notices a motion of the mark as it really exists.

It may be easily seen that the above described appearances may be used for supplying a device which serves for comparing the luminosities presented to both eyes of an observer. The importance of the comparison depends in that case, on the one hand, upon the stereoscopic power of vision of the observer and, on the other hand, upon the amount of the difference in the irritation of light which is still perceivable at all by the eyes.

Basing upon the fact that to the eyes it will be easier to perceive the differences in depth of two marks, simultaneously seen, than to perceive differences in depth which are observed with motions of one and the same mark, according to the invention such a device is fitted with two systems of marks, which admit of binocular observation and of being moved relatively to each other in parallel planes.

Supposing in the first place the simplest case that the two systems of marks consist of a single mark each and that the device be destined for the determination of the difference in luminosity zero. In that case it is suitably to be claimed that with the difference in luminosity zero both marks are observed at one and the same distance. In addition, for the one mark the case, on which Fig. 1 is based, may be supposed that it moves to and fro in a straight line between two points E^1 and E^2, whereby the path E^1 E^2 is parallel to the connecting line of the points of rotation of the eyes. The said demand can then be satisfied by disposing the second mark in a plane containing the path E^1 E^2, which plane is at the same distance from the connecting line of the points of rotation of the eyes as the path E^1 E^2. In that case there result two particularly suitable forms of construction. The one is characterized by the feature that the said second mark is rigidly disposed in such a manner as to be adjacent to the centre of the path E^1 E^2. With the other form of construction the second mark is movably disposed between two points, the connecting line of which is parallel and adjacent to the path E^1 E^2 and which are equidistant each from the centre of this path, in such a manner that their motion is always opposed to that of the first mark. With this form of construction spatial images of both marks, corresponding to each other, in the event of differences in luminosity, always assume positions on different sides of the plane containing the two marks. Hence greater differences in depth are perceived than if the second mark is rigidly disposed, so that greater accuracies of adjustment are also to be expected.

An example corresponding to the aforesaid first form of construction is shown in Fig. 2. In a dove-tailed groove a^1 of a frame a^0 there is rectilinearly guided a slide b, carrying a pointed mark m^1. By means of a crank d, movably coupled to the slide b by a connecting rod c, which crank is rotatably supported on the frame a^0 and movable by a hand wheel e, it is possible to impart to the mark m^1 a forward and backward motion during which the point of the mark is moving to and fro in a straight line between the points E^1 and E^2. A second pointed mark m^2 is rigidly disposed on the frame a^0 in such a manner that its point is adjacent to the centre of E^1 E^2.

Fig. 3 illustrates an example corresponding to the above second form of construction. It differs from the example just described by the feature that the second mark m^2 is movably disposed in the same way as the mark m^1. For this purpose the frame a^0 contains a second dove-tailed groove a^2 which is parallel to the groove a^1 and in which there can move a slide b^1, carrying the mark m^2. The slide b^1 is actuated from a crank d^1 by means of a connecting rod c^1. To each of the two cranks d and d^1 there is fitted a toothed wheel f and f^1 respectively. Both toothed wheels are alike and both mesh with a toothed wheel g, capable of being actuated by a hand wheel g^1. The arrangement is made in such a way that the points of the marks m^1 and m^2 always move in opposite direction in two parallel paths, adjacent to each other, the terminal points of which E^1, E^2, $E^{1'}$ and $E^{2'}$ determine a rectangle.

The adjustment for the difference in depth zero is rendered less difficult by so con-

structing the one of the two mark-systems that it consists of several marks which are disposed in succession like the prongs of a fork, and by so disposing the other mark-systems that, in the event of the difference in luminosity being zero, it will be seen passing through the centre of two adjacent prongs. Such an arrangement is shown in Figs. 4 and 5 in which m^1 denotes the mark movable to and fro by its point along the straight lines E^1 E^2 (the drive should be assumed to be supplemented as per Fig. 2). By $m^{2'}$ and $m^{2''}$ there are denoted two marks which are fixed on different sides of the frame a^0 in such a way that their points are also displaced in the breadth-direction. The latter displacement serves for affording the perception of the difference in depth of the two points during the observation perpendicular to the plane of the marks.

With a view to be able to adjust for a prescribed difference in luminosity deviating from zero, a fixed and a movable mark-system is suitably used. In that case the fixed mark-system must be so disposed that its distance between the connecting line of the points of rotation of the eyes and that of the movable mark-system is different. The difference of the two distances depends on the desired difference in luminosity. By rendering adjustable the aforesaid distance of the fixed mark-system, any desired differences in luminosity can be measured.

Instead of disposing the one of the two mark-systems in such a way that it is movable to and fro along a straight line, it may also be so disposed that it carries out a rotary motion in a plane. In that case the observation suitably takes place in such a manner that the plane determined by the principal lines of vision is perpendicular to this plane. Also in this case there corresponds to the actual path of the mark-system in the event of differences in luminosity an apparent path of the shape of a close curve, the points of which lie partly behind, partly in front of the plane of the actual path, assuming the simple case that the mark-system consists of a single mark. The second mark-system, also assumed as a single mark, is in that case suitably disposed in the plane of the actual path of the first mark-system. Fig. 6 shows a constructional example corresponding to this arrangement. In that case the special case has been based upon, that there are two single marks, the one of which is stationary, and that the field of view is limited in such a way that the movable mark only admits of being observed during part of its motion. The movable mark m^1 is rotatably disposed on a frame a^0 and can be rotated by means of a pair of toothed wheels h^1, h^2 and a hand wheel h^0. The frame h^0 also carries the fixed mark m^2 which is so fitted to the frame that its point lies vertically below the axis of rotation of the mark m^1 and, whilst lying in the plane containing the path of this point, is adjacent to this path. A round opening a^3 in the frame a^0 of such a position that the point of the mark m^2 approximately lies in its centre, has such a diameter that the mark m^1 is only visible during about one fifth of its motion. This limitation of the field of view entails that an observer, if different luminosities be presented to his eyes, only sees instead of a close, apparent path of the rotatable mark m^1 a fragment of this path which, according to the direction of rotation of the mark m^1 and according to the circumstance which of both eyes receives the larger luminosity, lies in front of, or behind the plane determined by the points of the marks m^1 and m^2.

Of the various means of altering the difference in the luminosities presented to both eyes of the observer, a simple one consists in the insertion of a diaphragm device between the observer and the mark-systems, which diaphragm admits of altering at least the luminosity presented to the one eye. A constructional example of such a device is represented in Fig. 7. On a carrier i there are rotatably supported two discs j, containing each sixteen smoked glasses of different brightness j^1. By a suitable adjustment of the discs each smoked glass of the one disc can be placed in front of both eyes A_l and A_r of an observer conjointly with each smoked glass of the other disc. Two springs i^1 fastened on the carrier i and meshing with rests j^2 of the discs j, secure the desired position of the discs during the observation.

Suitable forms of construction of the invention are also obtained by devising the two mark-systems in such a manner that each of them consists of two halves which are disposed after the style of stereoscopic semi-images. When observing the latter with the lenses of a stereoscope there result the same appearances as explained by Fig. 1.

An example of this form of construction is illustrated in Figs. 8 to 10. In a box-shaped carrier a^0, into which are fitted two collecting lenses k^1 and k^2, there are disposed in the wall facing these lenses two round openings a^4 and a^5 in such a way that their centres are lying each on the axis of one of the two lenses. On the carrier a glass plate l is displaceably disposed by means of its mount l^1, parallelly to the connecting line of the centres of both lenses, in such a way that its principal boundary surface turned away from the two lenses (in the direction of the path of light) lies immediately behind the common focal plane of the two lenses and is at the same time parallel to this focal plane. By rotating a windlass n, a forward and a backward motion can be imparted to the glass plate l by means of a

crank n^1 and a connecting rod c. On the side of the glass plate l turned away from the lenses k^1 and k^2 two pointed marks m^1 and $m^{1'}$, representing the stereoscopic semi-images of a spatial mark, are cut in such a way that the connecting line of their points is parallel and adjacent to the plane determined by the axes of the two lenses and that the distance apart of their points is equal to the distance of the centres of the two collective lenses. Adjacent to the glass plate l and in front of the opening a^4 on the carrier a^0 there is adjustably disposed a glass plate o in such a manner that its direction of displacement coincides with that of the glass plate l. The glass plate o contains on its side, facing the glass plate l, a pointed mark m^2, the point of which is in the central position of the glass plate near the centre of the path of the point of the mark m^1 and which represents a stereoscopic semi-image of a second spatial mark. A set screw o^1 serves for fixing the glass plate o on the carrier. A pointer o^2 of the mount o^3 of the glass plate o indicates on a scale a^6 of the carrier a^0 the position of the glass plate o at any one time and thereby that of the mark m^2. Besides, on the carrier a^0 in front of the opening a^5 there is fastened a glass plate p in such a way as to be adjacent to the glass plate l. The glass plate p carries on its side facing the glass plate l a pointed mark $m^{2'}$, which represents the other stereoscopic semi-image of the above second spatial mark and the point of which lies with that of the mark m^2 in a straight line, parallel to the connecting line of the points of the marks m^1 and $m^{1'}$. By adjusting the glass plate o the distance apart of the marks m^2 and $m^{2'}$ is changed and thereby the observer is enabled to perceive in the depth-direction the travelling of the spatial mark corresponding to these marks.

Fig. 11 shows a second constructional example, representing the two mark-systems by their stereoscopic semi-images. Behind two openings a^4 and a^5 of a carrier a^0 there are rotatably disposed two semi-images m^1 and $m^{1'}$ of a spatial mark, which are coupled for uniform rotation by means of two worm wheels (not shown in the drawing) and two worms (also not visible in the drawing). The drive is effected from a hand wheel q, supported on the common shaft of both worms. The distance of the points of the semi-images m^1 and $m^{1'}$ is equal to that of the centres of the two collective lenses (disposed according to Figs. 9 and 10). The same distance have the points of the stereoscopic semi-images m^2 and $m^{2'}$ of a second spatial mark fitted to the carrier a^0. All semi-images are to be assumed to lie in the common focal plane of the two collective lenses.

If instead of a simplified stereoscope there be used a binocular observing system, both halves of which contain a terrestrial telescope system each (vide Fig. 12), there is no obstacle of using both image planes B^1, B^2 and $B^{1'}$, $B^{2'}$ respectively of each half for the arrangement of the semi-images of the marks. If, as shown in Fig. 12, the path of rays be refracted by reflectors, it is not the semi-images of the marks themselves but their images which move relatively to each other in parallel planes.

The above described constructional examples afford devices for various physiological experiments and for medical purposes. Another important sphere of using the invention is formed by photometry. By providing a device, having two mark-systems suited for binocular observation, which are movably disposed relatively to each other in parallel planes, with an arrangement adapted to render visible of two sources of light only one to each eye of the observer, and by rendering variable the distance of at least one of these sources of light from the eye observing it, a suitable photometer will be attained.

Figs. 13 and 14 illustrate a photometer of the above kind. Fig. 13 is a plan elevation, Fig. 14 a partial section. On a base-plate a^0 there is fixed a pedestal body a^7 having a U-shaped cross section which is provided with two round openings a^4 and a^5 in its wall facing the observer. In this pedestal body two pointed marks m^1 and $m^{1'}$, representing the two stereoscopic semi-images of a spatial mark, are rotatably supported by means of two parallel shafts r which are wedged each with a toothed wheel r^1. The two toothed wheels r^1 are alike and conjointly mesh with a toothed wheel r^3 disposed on the shaft of a clockwork r^2 so that, when the clockwork runs down, there is imparted to the marks m^1 and $m^{1'}$ a uniform rotation in the same direction. To the pedestal body there are further fixed two pointed marks m^2 and $m^{2'}$, representing the two semi-images of a second spatial mark, in such a manner that their points lie in a common plane with those of the marks m^1 and $m^{1'}$. Hence the arrangement corresponds in principle to that in Fig. 11. On the base-plate a^0 there are displaceably disposed by means of two slides s two sources of light L^1 and L^2, the displacements of which are indicated by a pointer s^1 each of the slides s on a scale a^8 of the base-plate a^0. Two uniform collective lenses k^1 and k^2, the focal plane of which is the common plane of the points of the marks and which are so disposed that their axes contain the centres of the round openings a^4 and a^5, serve for the stereoscopic observation of the marks, in which case one of the two sources of light is simultaneously presented to each eye by means of two prisms t^1 and t^2. The two

sources of light may be isochromatic or heterochromous.

A device of similar construction may also be used for the comparison of differently coloured objects with regard to their brightness. Such a comparison device is diagrammatically shown in Fig. 15. In front of each of both eyes A_l and A_r of an observer there is disposed a double prism t^3. Each of these double prisms affords to the appertaining eye the observation of a thin, coloured plate F, the distance of which from the eye can be varied by displacing a slide s. Each plate is uniformly illuminated by a source of light L rigidly disposed behind it so that an observation by transmitted light takes place. A displaceable mark m^1 and a fixed mark m^2, assumed to be disposed in a similar way as in Fig. 2, are simultaneously seen by both eyes. Assuming the two plates F of a different tint, the device affords a means for comparing the brightness of the two colours by means of the observation of the marks.

Also in other types of the photometers known (e. g. in polarization photometers) the invention can be applied in which case the well-known auxiliary means of photometry may be suitably used.

By providing a device, containing two mark-systems movable relatively to each other in parallel planes, these mark-systems consisting of two halves each, disposed after the manner of stereoscopic semi-images, with an optical system which, on the one hand, serves for sharply presenting to each of both eyes of an observer one of the two semi-images of each mark-system, and, on the other hand, for rendering visible to both eyes two optional spectral ranges in such a way that by each eye only one of these ranges can be seen at any one time, a device will be obtained which, whilst eliminating the subjective perception, affords the comparison of different spectral colours with respect to their brightness.

A spectral photometer of the aforesaid kind is diagrammatically shown in Fig. 16. Luminous rays emanating from a source of light L traverse in equal parts two condensers u^1 and two prism systems, consisting of two prisms each u^2 and u^3. Hereupon each half of the rays enters a slit u^4 lying in the focal plane of a collimator, traverses the objective u^5 of this collimator, after that two prisms u^6 and u^7, disposed in the same way as in a spectral apparatus having a firm deflection and furthermore the objective u^8 of a second collimator. In the focal plane of the latter there is again a slit u^9 and in front of the same a lens u^{10}, the focal plane of which lies between the objective u^8 of the collimator and the adjacent prism u^7, whereby the focal planes of both lenses u^{10} coincide. The prisms u^6 are rotatable each about an axis Z^1, the prisms u^7 each about an axis Z^2. The joint rotation of each set of prisms u^6, u^7 is effected by a micrometer appliance v. In the joint focal plane of the lenses u^{10} there is disposed in front of each objective u^8 one of the two stereoscopic semi-images m^1 and $m^{1'}$, displaceable in the arrow-direction, of a spatial mark and one of the two fixed, stereoscopic semi-images m^2 and $m^{2'}$ of a second spatial mark. This arrangement is assumed to be carried out in a similar way as in Fig. 8. The rays emerging from the slits u^9 and coming from the source of light and the marks are transmitted to the objectives u^{11} of a binocular telescope having an enlarged base-line and enter the eyes of the observer through the oculars u^{12} of this telescope. By actuating the micrometer appliances v it is possible to present to both eyes two ranges of colour of the spectrum of the source of light L in any desired combination and to compare them with respect to their brightness. By rendering the width of the slit u^9 adjustable, it is possible to compare ranges of colour of different size. By rendering the width of the slit u^4 adjustable it is possible to change the intensities of light. By eventually presenting to each slit u^4 a special source of light, it is possible to compare optional ranges of colour of different spectra with each other.

In conclusion it may be mentioned that the apparent motions which are perceptible when moving two marks relatively to each other, in the event of differences in the luminosities transmitted to the eyes, can also be rendered visible by means of projection. The requisite arrangement is shown in Fig. 17. Near a condenser w^1 placed behind a source of light L there is disposed a mark m^1, movable in the arrow-direction, and a fixed mark m^2. The marks are imaged on a screen S by a projection lens w^2, in the focal plane of which they lie. Observers in front of the screen, when consecutively applying smoked glasses of different brightness to their eyes, will notice different apparent motions.

I claim:

1. In a device for comparing the luminosities presented to both eyes of an observer two mark-systems, admitting of binocular observation and being movable relatively to each other in parallel planes, and a darkening device, admitting of changing the luminosity presented at least to the one eye of the observer.

2. In a device for comparing the luminosities presented to both eyes of an observer two mark-systems, consisting of two halves each disposed after the manner of stereoscopic semi-images, the said mark-systems admitting of binocular observation and being movable relatively to each other in parallel planes.

3. In a device for comparing the luminosities presented to both eyes of an observer two mark-systems, admitting of binocular observation and being movable relatively to each other in parallel planes, two sources of light, a device for rendering visible only the one of these two sources of light to each eye of the observer, and means for varying at least the distance of one of the said sources of light from the eye observing it.

4. In a device for comparing the luminosities presented to both eyes of an observer two mark systems, admitting of binocular observation and being movable relatively to each other in parallel planes, a device for rendering visible only the one of two heterochromous, uniformly illuminated objects to each eye of the observer, and means for varying at least the distance of one of the said objects from the eye observing it.

5. In a device for comparing the luminosities presented to both eyes of an observer two mark-systems, admitting of binocular observation and being movable relatively to each other in parallel planes, an optical system adapted to sharply present to each eye of the observer one of the two semi-images of each mark-system, and optical means for rendering visible to both eyes two optional spectral ranges in such a way that each eye can only see one of the said ranges at any one time.

CARL PULFRICH.

Witnesses:
PAUL KRÜGER,
FRITZ SANDER.