April 30, 1957 R. H. TAPLIN ET AL 2,790,438

EARPIECES FOR OXIMETERS

Filed Jan. 13, 1956

2 Sheets-Sheet 1

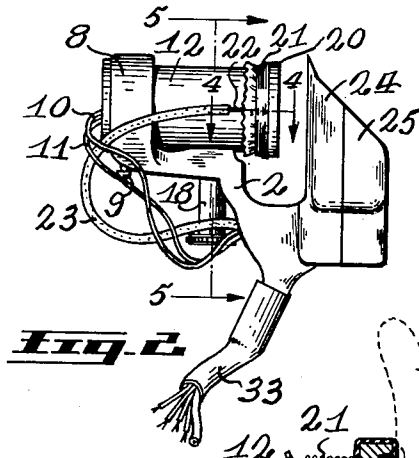


Fig. 2

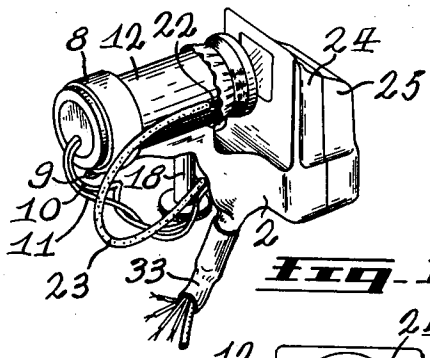


Fig. 1

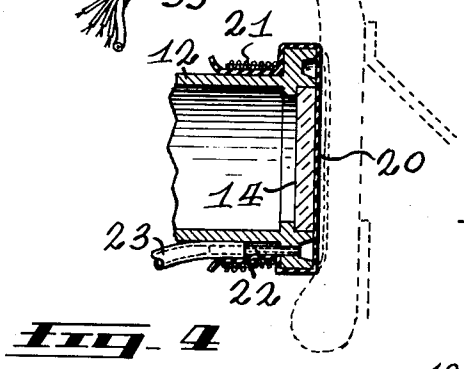


Fig. 4

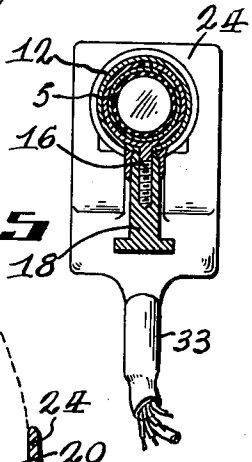


Fig. 5

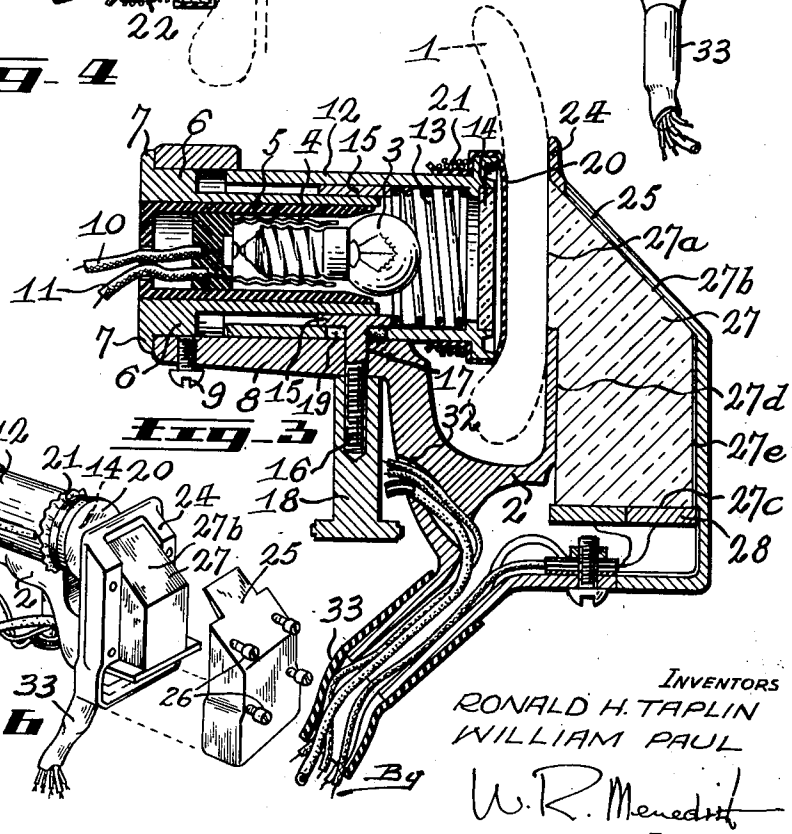


Fig. 3

Fig. 6

INVENTORS
RONALD H. TAPLIN
WILLIAM PAUL
By W. R. Meredith
ATTORNEY

April 30, 1957 R. H. TAPLIN ET AL 2,790,438

EARPIECES FOR OXIMETERS

Filed Jan. 13, 1956 2 Sheets-Sheet 2

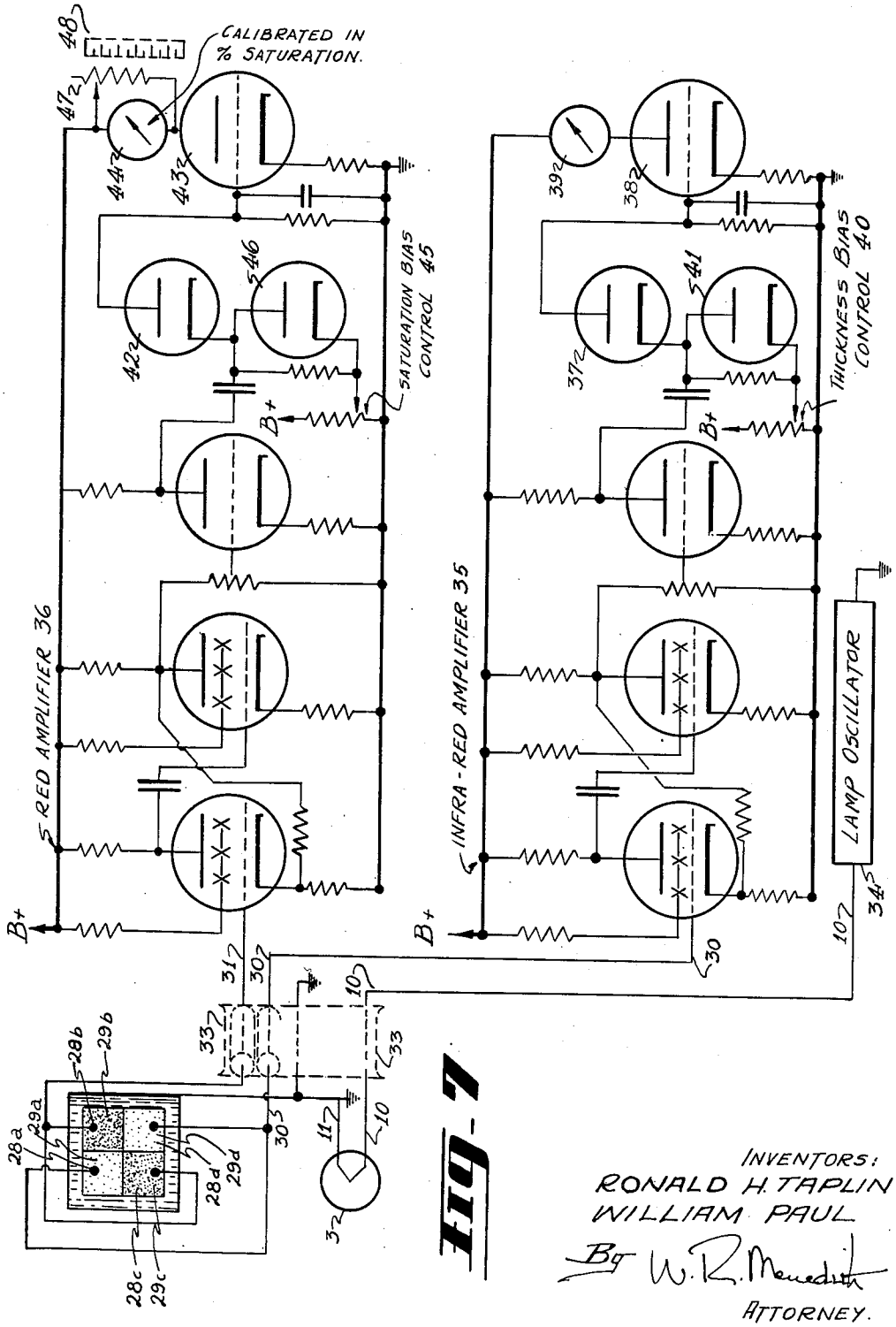


Fig. 7

INVENTORS:
RONALD H. TAPLIN
WILLIAM PAUL
By W. R. Meredith
ATTORNEY.

United States Patent Office 2,790,438
Patented Apr. 30, 1957

2,790,438

EARPIECES FOR OXIMETERS

Ronald Harold Taplin, Pointe Claire, Quebec, and William Paul, Toronto, Ontario, Canada

Application January 13, 1956, Serial No. 558,981

3 Claims. (Cl. 128—2)

This invention relates to a device for determining the degree of oxygen saturation of the blood, and is particularly directed to such a device which operates photoelectrically.

Measurement of the degree of oxygen saturation of the blood is necessary for many clinical purposes, and it is obviously most convenient to carry out such determination without actually taking a sample of blood from the patient. Various devices have ben developed whereby light is passed through a portion of the body, such as the pinna of the ear, and the transmitted light analyzed, and in such procedure the amount of light transmitted and the degree of colour attenuation determines the degree of oxygen saturation of the blood in the blood vessels through which the light passes. Such devices are commonly known as oximeters, which generally include as part thereof an earpiece whereby an incandescent lamp is adapted to be held on one side of the pinna of the ear and photoelectric cell means is held on the opposite side of the pinna making it possible to determine the degree of transmission and the characteristics of the light passing therethrough. It is particularly to the earpiece portion of oximeters that the present invention relates.

It has been the practice to provide a pressure capsule consisting of a hollow, inflatable, translucent member, which when inflated presses the pinna of the ear to remove most of the blood therefrom during the test, and a suitable space is provided between the translucent capsule and the means for receiving the transmitted light which is appropriate for the size of the pinna.

Filters are normally used in such a device on the side of the pinna opposite the source of light, and it is common to use two of such filters, one chosen so that there will be a maximum sensitivity at the photoelectric cell to a band of light at or near 650 mμ and the other filter is commonly chosen so that there will be a maximum sensitivity in the region of 800 mμ. The reason for the choice of such filters is that light of 650 mμ is strongly attenuated by reduced haemoglobin and attenuated only slightly by oxygenated haemoglobin. A wave length of 800 mμ is absorbed substantially equally by reduced and oxygenated haemoglobin, and accordingly provides a standard of comparison.

With the use of such filters it will be seen that the transmitted light in the region of 800 mμ is unchanged by the degree of oxygen content of the blood, whereas the transmitted light at 650 mμ is attenuated a varying degree depending on the amount of oxygen in the blood, and both are changed by changes in the amount of haemoglobin. This provides a convenient manner of determining the oxygen content.

Prior art devices have failed to function with a great degree of accuracy because the light falling upon adjacent photoelectric cells has been transmitted through different sections of the pinna and this introduces an error known as "vessel error" which exists because adjacent sections of the pinna may not have the same degree of light transmission characteristics quite apart from the amount

of oxygen in the blood. It has been found that there are often marked inhomogeneities between adjacent parts of the pinna and this results in an unpredictable "vessel error."

Certain prior art devices have been designed with a photoelectric cell means in the form of a block consisting of three parallel photoelectric cell elements, the two outer elements of which are connected together. The prime necessity for such an arrangement is to provide sufficient current for the 800 mμ cell, which is between five and ten times less sensitive than the 650 mμ cell, to satisfactorily operate its indicating galvanometer.

This prior art may appear to overcome "vessel error" by reducing by a small degree the possibility of a particularly dense or bright area being opposite one cell only, but it has been shown by experiment that this is not the case, since there is substantially a 2:1 possibility that any inhomogeneity will be opposite the 800 mμ section and not the 650 mμ section, depending upon the position and spatial orientation of the obstructing vessel.

It has also been proposed to separate the pinna and the photoelectric cell to allow the light to mix before reaching the cell thus minimizing the error, but experiment shows that sufficient mixing does not occur in the distance conveniently tolerable in a practical earpiece.

In summary, the prior art devices have failed to overcome the inaccuracies resulting from the presence of miscellaneous blood vessels in the pinna which affect the light reaching one of the sensitive cells but not the other. Since the differences in light transmission being measured are very small, the presence of even a small error gives very misleading results and accordingly none of the prior art devices have been satisfactory.

It is an object of the present invention to overcome the disadvantages of the prior art and provide a device which measures the amount and quality of the light transmitted through the pinna with a lower degree of error than has been heretofore possible.

It is a further object of the present invention to provide such a device which is easy to manufacture and to service and repair.

It is also an object of the present invention to provide a device of the character described which is economical to manufacture, light in weight and neat in appearance.

It is also an object of the present invention to provide such a device which is highly accurate.

An additional object is to provide a device of the kind described which is of such a shape as to fit on the ear with convenience and without pain to the subject.

Other objects will be apparent to one skilled in the art from an examination of the present specification.

To accomplish the foregoing objects the present invention in its preferred embodiment consists of a bifurcated frame member adapted to be placed around the pinna of the ear having a source of light in one area of the frame and a light mixing and analysing means in the other. The light mixing means consists of a transparent block of material which receives the light transmitted by the pinna, further scatters it and passes it to the light analysing means. The light analysing means consists of a particular form of photoelectric cell block which preferably consists of four photoelectric elements appropriately connected to form a mosaic of alternate 650 mμ and 850 mμ elements. There are preferably two of each, and the two 650 mμ elements are connected together and likewise the 850 mμ elements. Common outputs from the 650 mμ elements and the 850 mμ elements are connected to appropriate indicating means.

As in prior art, the present device provides an inflatable capsule for compressing the pinna, but the capsule contemplated herein is superior in that it is preferably constructed from a sheet of polyvinyl acetate plastic film

which, unlike the rubber capsules previously used does not change its colour with age.

The invention will now be described with the assistance of the accompanying drawings, wherein a preferred embodiment is shown. It will be realized that various changes could be made in the embodiment shown and described and other apparently different embodiments of the invention could be constructed without departing from the scope thereof. Accordingly it is intended that all matter shown in the accompanying drawings or described herein shall be interpreted as illustrative and not in a limiting sense.

In the drawings wherein like parts are denoted by identical reference numerals,

Figure 1 shows an oblique three-quarters view of a preferred embodiment of the invention;

Figure 2 shows a side elevation view of the device illustrated in Figure 1;

Figure 3 shows a cross-sectional view of the device illustrated in Figures 1 and 2 as it would be used in association with the pinna of the ear;

Figure 4 shows a fragmentary cross-sectional view indicating the structure of the inflatable capsule;

Figure 5 shows a cross-sectional view taken as at 5—5 in Figure 2;

Figure 6 shows an oblique three-quarters partly "exploded" view of the device; and

Figure 7 shows a circuit diagram illustrating the function of the device described herein.

Referring to the accompanying drawings wherein the same reference numerals denote like parts in all figures, the earpiece device will be seen to have a bifurcated or clamp-shaped structure adapted to surround the pinna of the ear. For convenient reference the earpiece may be described as consisting of a light-emitting portion, which is cylindrical in shape and a light-receiving portion of box-like appearance connected by a bracket denoted by 2. The pinna of the ear is denoted by 1.

The light adapted to be transmitted through the pinna 1 is supplied by any convenient source, such as a small incandescent lamp shown at 3. Lamp 3 preferably consumes approximately one watt, which, in addition to supplying the necessary light, will provide sufficient heat to dilate the blood vessels of the pinna 1. It is contemplated that alternating current of a frequency of, for example 30 cycles per second will be supplied to lamp 3, the reason for which will be apparent below. Lamp 3 is mounted in a conventional socket, shown at 4, and socket 4 is suitably held in a tubular lamp holder denoted by 5.

Lamp holder 5 is preferably provided with a pair of flanges denoted by 6 and 7, flange 7 being at the end of tubular member 5 and of slightly larger diameter than flange 6. The purpose of flanges 6 and 7 is to effect suitable mounting on bracket 2 and to this end bracket 2 is provided with a ring denoted by 8 of such internal diameter that flange 6 slides easily wihtin ring 8 but flange 7 is unable to enter the said ring. A set-screw denoted by 9 is threadably mounted in a suitable opening in the part of bracket 2 where the latter is formed into ring 8. The power supply wires for lamp 3, denoted by 10 and 11, pass out of lamp holder 5 through one or more suitable openings.

Extending from lamp holder 5 is a telescopic tubular member denoted by 12 having an internal diameter such that it is able to receive lamp holder 5 therewithin, and is able to slide freely over the said lamp holder. It is contemplated that the ends of tubular member 12 opposite lamp holder 5 will be pressed toward the pinna 1 in a manner to be described below.

A helical spring denoted by 13 is provided inside tubular member 12, and it is preferable if spring 13 is of such size that it touches the internal walls of tubular member 12 without sticking or binding. At the end of tubular member 12 opposite lamp holder 5 is a transparent window denoted by 14. A slidable collar shown at 15 is also provided of such size that it moves easily along the inner wall of tubular member 12, and it is contemplated that spring 13 will urge window 14 and collar 15 apart thereby tending to telescopically extend tubular member 12 away from lamp holder 5.

Attached to collar 15 is a threaded shaft denoted by 16 and shaft 16 passes loosely through an unthreaded opening in bracket 2, denoted by 17. A clamping nut denoted by 18, suitably threaded to engage shaft 16 is provided, and it will be apparent that when clamping nut 18 is tightened, tubular member 12 is locked between collar 15 and bracket 2. A slot, denoted by 19 is provided in tubular member 12 so that when clamping nut 18 is loose, tubular member 12 may be telescopically slid on lamp holder 5, and will be urged away from the said lamp holder; and alternatively, the tightening of clamping nut 18 will lock tubular member 12 in whatever position it then happens to be in relation to lamp holder 5.

The window 14 at the end of tubular member 12 has already been referred to. For reasons which will be apparent below, window 14 should be so mounted in tubular member 12 that an air-tight seal is produced. In order to provide appropriate pressure on pinna 1, it is contemplated that an inflatable capsule will be provided by stretching a resilient membrane over window 14 and incorporating means for supplying air under pressure to the space between the window 14 and such membrane. The membrane, denoted by 20 is preferably made of polyvinyl acetate plastic film which does not change its colour with age. Membrane 20 is stretched over the end of tubular member 15 and secured by a fastening ring denoted by 21, which may be, for example, several strands of thread wound therearound. An air tube denoted by 22 communicates with the space between window 14 and membrane 20, and a flexible tube, denoted by 23 is used to apply air under pressure to tube 22.

It will be apparent that the device disclosed above is convenient for applying the proper pressure to the pinna 1. The telescopic relationship of tubular member 12 and lamp holder 5, and the action of spring 13 provides a simple manner of engaging pinnae of a wide range of sizes. When such engagement is made, clamping nut 18 may be tightened to hold tubular member 12 in place, and appropriate air pressure can then be applied to tube 23 to compress the pinna to the required degree and to release such pressure when desired.

Referring now to the light-receiving portion of the device, in contact with which inflation of membrane 20 compresses pinna 1, the said light-receiving portion consists of two housing members denoted by 24 and 25 and various components contained therein, to be described below. Housing member 24 is integral with bracket 2 and housing member 25 is attached to housing member 24 by means of capscrews denoted by 26.

Held within housing members 24 and 25 is a block of transparent material denoted by 27, preferably of the particular shape shown. Block 27 is preferably of an acrylic resin with suitable optical properties such as "Lucite" which provides a significant "light-pipe" effect common to such materials. The "light-pipe" effect is produced by the combination of transparency and a highly reflective surface and accordingly various other materials having similar characteristics could of course be used.

It is intended that the light transmitted through the pinna will be gathered by block 27 and transmitted through a length at least three times that of the aperture diameter where the light enters block 27, with little light loss and absence of image formation.

Block 27 has a forward polished face denoted by 27*a* forming the light-receiving aperture adapted to touch the pinna 1. Housing member 24 is so constructed that forward portion 27*a* lies flush with the surface of housing member 24 facing tubular member 12. Block 27 also has a diagonal face denoted by 27*b*, the surface of

which is also polished. The remainder of block 27 defined by surfaces denoted by 27*d* and 27*e* is a simple rectangular prism highly polished so as to reflect any light falling upon its inner surface. The end of block 27 opposite face 27*a* is denoted by 27*c*, and attached to face 27*c* is a filter block, denoted by 28 to be described below. Obviously, all the surfaces of block 27 have to be flat as opposed to rounded, otherwise there would be a tendency to focussing, with bright and dull gradations of light intensity.

The manner in which the light is transmitted from lamp 3 will be apparent from the foregoing description, but for greater certainty will now be reiterated. Light from lamp 3 passes through window 14, membrane 20 and thence through pinna 1 where it falls upon the surface 27*a* of block 27. It will be apparent that the pinna 1 being translucent but not transparent will transmit light therethrough in such a manner that the light passes out of the pinna 1 through a solid angle of 180°. Accordingly the light reaching surface 27*a* is passing in every direction and is necessarily scattered. A large portion of the light so transmitted falls upon surface 27*b*, and as a result of the characteristics of the surface 27*b* previously referred to, such light is further scattered. The light not falling on surface 27*b* strikes the surface 27*d* over that portion of its surface which is adjacent surface 27*a* and by virtue of the light scattering characteristics of the block 27 is reflected downward to surface 27*e* and thence to filter block 28. In the result, the light reaching filter block 28 is almost completely scattered and entirely homogeneous and forms no image.

The filter block 28 attached to block 27 will now be described. As seen in Figure 7 the filter block consists of four filter components denoted by reference numerals 28*a*, 28*b*, 28*c* and 28*d*. Integral with the said filter components are photoelectric cells denoted by 29*a*, 29*b*, 29*c* and 29*d*, respectively.

The filter components 28*a* and 28*d* are so arranged as to provide maximum sensitivity of photoelectric cells 29*a* and 29*d* at 650 mμ and filter components 28*b* and 28*c* will provide maximum sensitivity of photoelectric cells 29*b* and 29*c* at 800 mμ. It will be appreciated that it is not necessary that the sensitivity characteristics be in the exact arrangement described, and there are several obvious juxtapositions. Photoelectric cells 29*a* and 29*d* are connected to outlet lead 30 and photoelectric cells 29*b* and 29*c* are connected to outlet lead 31. Leads 30 and 31 are connected to amplifier means to be described below where the light transmission characteristics are interpreted in terms of degree of blood oxygenation.

Leads 30 and 31 pass through a cable denoted by 33 which connects the earpiece to the amplifiers. Since the leads 30 and 31 carry very weak currents, it is preferable that they be shielded. Lines 10 and 11 already referred to also pass through cable 33. Line 10 passes through an opening in housing 24, denoted by 32 and thence to lamp 3. Line 11 also passes through opening 32 and to the other side of lamp 3, and line 11 is connected to the body of housing 24 near where it enters cable 33. At the end of cable 33 opposite the earpiece, line 11 is suitably grounded. The current supply for lamp 3 is shown at 34 and furnishes an oscillating current of the order of 30 cycles per second.

Lead 30 is connected to an amplifier denoted by 35 and lead 31 is connected to a second amplifier denoted by 36. These two amplifiers are quite conventional and are similar except for one feature to be described below.

The output of amplifier 35 is applied to a rectifier shown at 37 which is in turn connected to a vacuum-tube voltmeter the principal components of which are triode 38 and meter 39. A bias control shown at 40, and an associated rectifier shown at 41 are also provided.

Amplifier 36 is similarly connected to a rectifier shown at 42, which is in turn connected to vacum-tube voltmeter elements consisting of triode 43 and meter 44. A bias control denoted by 45 is similarly provided, together with a rectifier tube denoted by 46 associated therewith.

The feature of amplifier 36 not found in amplifier 35, referred to above, is an adjustable shunt denoted by 47 connected across meter 44. Shunt 44 has a graduated dial or the like denoted by 48, which is intended to be calibrated in terms of the reading of meter 39. Meter 44 is calibrated in terms of percentage saturation.

It will be apparent that there are two principal variables here involved, namely the thickness of the pinna through which light is transmitted, and the attenuation of the light because of the degree of oxygen saturation. It is contemplated that the amplifier 36 will provide the means of measurement of the degree of oxygen saturation, and amplifier 35 will provide a correction for the thickness of the pinna observed. Accordingly, amplifier 36 will sense the amplitude of waves resulting from light transmitted of the order of 60 mμ (red) and amplifier 35 will sense the amplitude of waves resulting from light transmitted of the order of 800 mμ (infra red). Since the latter are not significantly affected by the degree of oxygen saturation, it is convenient to use amplifier 35 to provide the correction for the pinna thickness.

A description of the operation of the device will illustrate the method of calibration as well as the other operational features. The pinna is first placed in the proper position as shown in Figure 3 and the membrane 20 is inflated so as to press most of the blood out of the pinna. Lamp 3 will then be emitting light as well as heat, and this heat will assist in dilating the blood vessels of the pinna, so as to assist in providing light transmission therethrough. The light passes through the pinna 1 relatively easily. Since the light is produced by an oscillating current of the order of 30 cycles per second, there will be produced at the photoelectric cells modulated waves of the same frequency, and these waves will be passed to amplifiers 35 and 36. Both meters 39 and 44 will normally show initial readings and bias controls 40 and 45 are then adjusted so that both meters 39 and 44 read zero.

The pressure on membrane 20 is then released and a definite reading will then be shown on meters 39 and 44. There is a relationship between the readings of meters 39 and 44, such that a plot of

$$\frac{R_{47}}{R_{47} \pm R_{44}} \text{ against } \frac{1}{I_{39}}$$

(where R_{47} is the resistance of shunt 47, R_{44} is the resistance of meter 44 and I_{39} is the current read at meter 39) is a straight line. That is to say, the amplifier 36 may be corrected by adjustment of shunt 47 in accordance with the reading of meter 39 to allow meter 44 to give an indication which is independent of the thickness of pinna 1. Meter 44, by suitable calibration with the assistance of known samples of arterial blood, the oxygen saturation of which is determined gasometrically, can indicate percentage saturation directly.

After shunt 47 has been adjusted as above, meter 44 will show a changed reading, and this new reading by virtue of the calibration referred to will indicate percent oxygen saturation. It may be mentioned that the device may be continued in use for a considerable period after it has once been put in operation as described, and it is only necessary to change the setting of shunt 47 in accordance with the reading of meter 39, if necessary, to restore correct conditions, and the condition of the blood of the subject wearing the device described will be continuously indicated on meter 44.

It will be seen that the device described herein has numerous advantages; it is simple and rugged in construction, simple to apply and can be used without extensive training on the part of the operator.

What is claimed is:

1. An oximeter earpiece capable of being used in association with the human ear, comprising a source of light adapted to be placed on one side of a portion of the ear,

a light scattering means adapted to be placed on the opposite side of the said portion of the ear, said light scattering means consisting of a polished transparent block having a flat surface facing said source of light, an angular face making an acute angle with said flat surface and a rectangular prismatic section one end of which is formed by said angular face, a bifurcated frame member attached to said source of light and to said light scattering means and photoelectric light-receiving means attached to said frame member on the same side thereof as said light scattering means.

2. A device according to claim 1, wherein said photoelectric light receiving means consists of a plurality of photoelectric cells adjacent the end of said light-scattering means opposite said angular face, and having filter means interposed between said photoelectric cells and said light scattering means.

3. A device according to claim 1, wherein said photoelectric light receiving means consists of a plurality of photoelectric cells one half of which have maximum sensitivity at the region of 650 mμ and the other half of which have maximum sensitivity at the region of 850 mμ, said cells which have maximum sensitivity at the region of 650 mμ being interspaced with said cells having maximum sensitivity at the region of 850 mμ, and having in addition, filter means interposed between said photoelectric cells and said light scattering means.

References Cited in the file of this patent

UNITED STATES PATENTS

2,754,819 Kirschbaum ---------- July 17, 1956