

in Fig.9. These curves 230, 232 and 234 are substantially the reverse of those of Fig.3. By varying the voltage across the liquid crystalline layer 114, the amount of red light from the source 97 passing through the layer 114, the amount of red light from the source 97 passing through the layer 114 and through the output window 103 can be controlled. As can be seen from Fig.9, with no voltage applied the light from source 97 would be substantially scattered and only 50 percent of light would be transmitted through. As the voltage across the layer 114 is increased the layer would allow more transmission of the red light. If the light source 97 is circularly polarized then 100 percent of the light would be reflected at 6250 Å.

It is also obvious that other monochromatic light sources could be utilized such as green and blue to take advantage of the nontransmissive portions of curves 232 and 234 of the layer 114 in these regions. It is, therefore, possible to provide a multicolor projection television system in which a separate system as illustrated in Fig.8, would be provided for the red, green and blue colors. In a specific example shown in Fig.8, a red color is obtained. By providing a second system with a blue light source and a third system with a green light source, a three color projection system would be available. The three separate color images projected through the liquid crystal layers could then be combined by well known optical means to superimpose the three images. Representative video signals of the representative three colors would be provided by the separate control tubes for

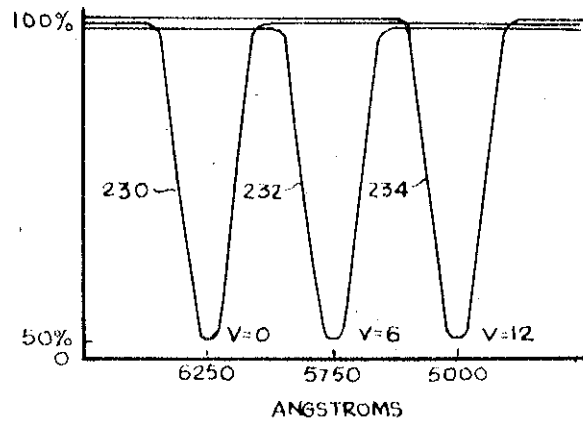


FIG. 9

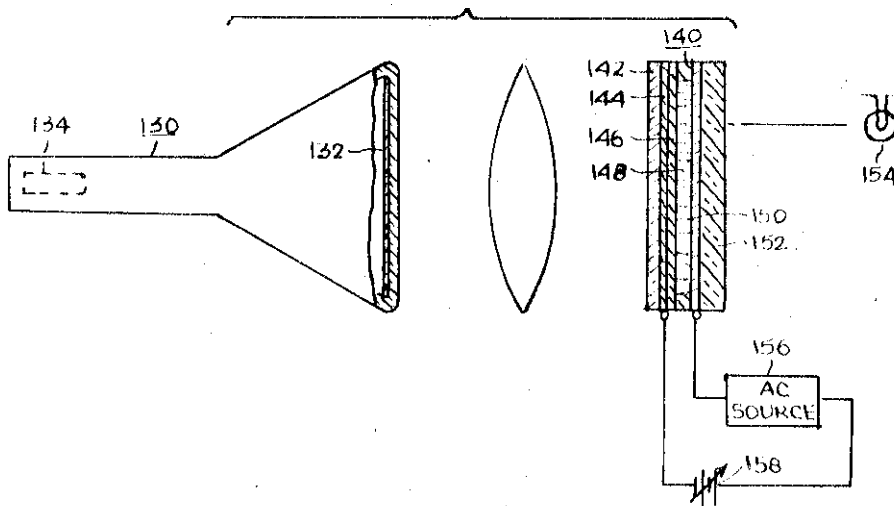


FIG. 10

each other color. The images could be projected simultaneously or sequentially onto the screen.

It is also possible to use the selective optical rotational properties of the liquid crystals. This can be accomplished simply by providing a polarizer between the source 91 and the control tube 103 and an analyzer between the control tube 103 and the screen 98.

In Fig.10, there is illustrated another arrangement for displaying a multicolor image by using the light scattering properties of the liquid crystals. This device or arrangement consists of a flying spot scanner which is comprised of a substantially conventional type cathode ray tube 130. The tube 130 includes an electron gun 134 and a phosphor screen 132 of a suitable material which in this case may be of a type which emits ultraviolet light in response to electron bombardment. Suitable deflection and scanning circuitry well known in the art may be utilized to scan a raster on the screen 132. The light generated by the cathode ray tube 130 is projected through a suitable lens system onto a liquid crystal control structure 140. The liquid crystal control structure 140 consists of a layer 142 of glass transmissive to the light from the cathode ray tube 130, a layer of electrically conductive material 144 also transmissive to radiations from the cathode ray tube 130, a layer 146 deposited on the conductive layer 144 of a suitable photoconductive material which exhibits the property

as represented by Figs.3 and 4. On the opposite side of the layer 148, a layer 150 of electrically conductive material is provided transmissive to light directed onto the layer 148 from a source 154. The layer 150 may be of a suitable material such as stannic oxide. A glass support member 152 is provided on the exposed surfaces of the conductive layer 150. The light source 154 is provided for illuminating the liquid crystal layer 148 through the transmissive layer 150 and 152. The light source 154 should be of the type that emits white light. An alternating current source 156 is connected across the two conductive layers 144 and 150. A direct current potential source 158 is also provided in series with the source 156.

In the operation of the device, the cathode ray tube 130 would project a blank raster through the layers 142 and 144 and excite the photoconductive layer 146 causing it to become conductive. This would, in turn, permit that voltage from the source 156 to be applied primarily across the liquid crystal layer 148 and by varying the amplitude of the source 156, the overall color of the screen could be varied. Thus, using liquid crystal materials that follow or respond at 90 cycles per second, three frames may be projected each lasting a thirtieth of a second with a different color set by the level of the bias provided by the direct current voltage source 158. This would provide in effect a field sequential type color display. In the operation of the device, the light from the cathode ray tube 130 would

cause the photoconductive layer 146 to become conductive. The application of a suitable d.c. potential from the voltage source 158 across the liquid crystal layer 148 would cause the layer 148 to scatter red, green or blue and the particular color selected would be modulated with video intelligence by the source 156 to modulate the intensity of the relative colors. For this particular application, it would be advisable to utilize a light source 154 in which the source provides maximum intensities in three bands namely red, green and blue, each about 200 angstroms in width or by providing filters in with a white light source to provide a black background.

The arrangement could also be operated with a video intelligence applied across the two conductive layers 144 and 150 such that the video signal would include both a d.c. component to change the selective scattering of the liquid crystal layer 148 from red, green or blue and also provide an a.c. component which includes the necessary video intelligence for the color. In this manner, the color from the screen could be changed on a line-to-line basis or element-to-element if so desired. It is also possible to apply a suitable signal to the liquid crystal layer 148 to determine the proper color and utilize or apply video information to the cathode ray tube 180 to modulate the conductivity of the photoconductor in accordance with the intensity of the particular color at that instant.

While there has been shown and described what are at present considered to be the preferred embodiments of the invention, modifications thereto will readily occur to those skilled in the art. For example, a piezoelectric layer of a suitable material such as barium titanate may be used to generate the electric field necessary to activate the liquid crystal layer. In this manner, sound or other mechanical energy may be detected and converted to a visible pattern.

Application 5

RADIATION SENSITIVE DISPLAY SYSTEM UTILIZING A CHOLESTERICLIQUID CRYSTALLINE PHASE MATERIAL

This invention relates to a radiation sensitive display device which includes a heat sensitive display screen of a liquid crystalline material of the cholesteric phase with a radiation sensitive screen incorporating heating elements in thermal contact with the heat sensitive display screen which the heating is due to current flow. The radiation sensitive screen responds to input radiations to cause a current flow which in turn provides heat for impressing a thermal image on the heat sensitive display screen.

Referring to Fig.1, a display system is illustrated. The display system consists of a cathode ray tube 10 for directing a radiation image onto a display screen 12. A suitable lens 11 may be provided for focussing the radiation image onto the screen 12. The other surface of the display screen 12 is illuminated by a viewing light source 14 and a viewer 16 may observe the visible pattern or image on the display screen 12. The cathode ray tube 10 is of any suitable design and includes an electron gun 20 and a luminescent screen 22 of suitable phosphor material which emits visible light in response to electron bombardment by the gun 20. A video signal is fed to the cathode ray tube 10 from a source 24 and may be connected to any suitable electrodes of the electron gun 20. Suitable deflection

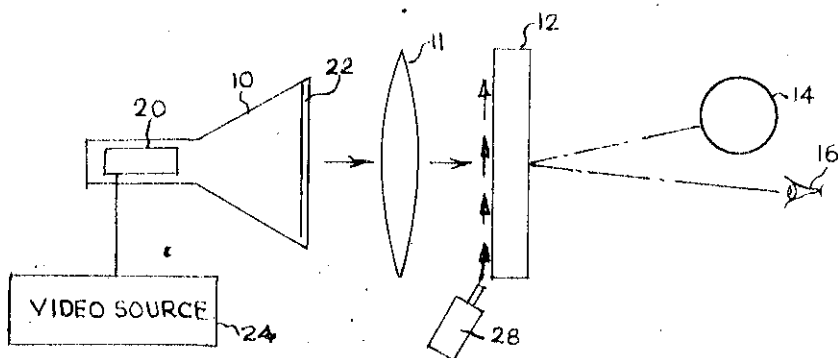


FIG. 1

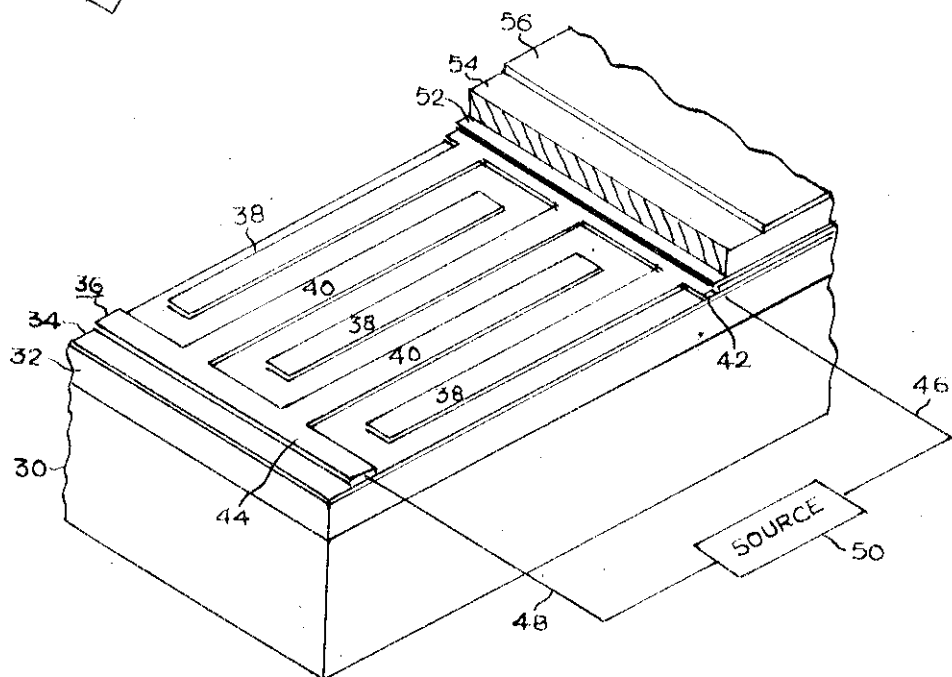


FIG. 2

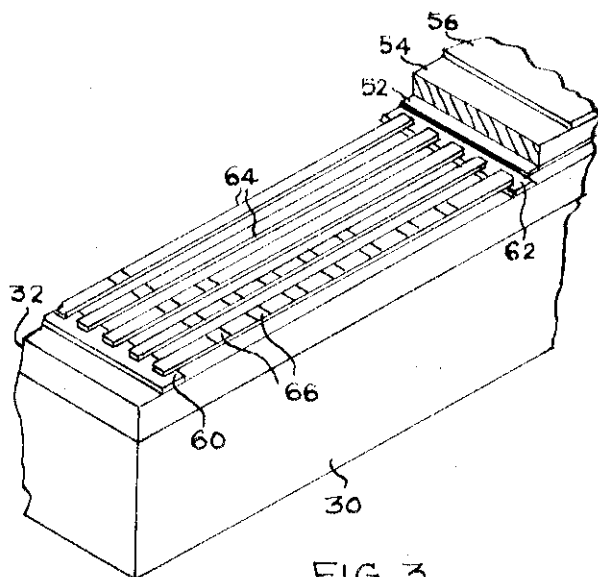


FIG. 3

means, not shown, are provided for scanning of the electron beam generated by the gun 20 over, the screen 22. The intensity of the electron beam is modulated by the video signal from the source 24. It may be desirable to utilize a long time persistent phosphor in the screen 22. A radiation image thus is generated on the face of the cathode ray tube 10 representative of the video information applied from the source 24 and this radiation image is directed onto the display screen 12.

The display screen assembly 12 is shown in detail in FIG. 2, and is comprised of the following layers. The display screen assembly 12 is supported by a substrate layer 30 which is also the heat sink for the display screen assembly. Temperature control of the display screen 12 may be obtained by any suitable means such as directing air along one surface of the layer 30 by the air source 28. The support layer 30 is transparent to the input radiation from the cathode ray tube 10 and may be of a suitable material such as glass for visible radiation, barium chloride for infrared radiation or quartz for ultraviolet radiation. In the specific embodiment illustrating a visible radiation input, the thickness of the glass support layer 30 may be of a thickness of about 1 centimeter. The device may be used to convert X-Ray pattern to visible light pattern. A thermal barrier layer 32 of a suitable thermal insulating material such as polyethylene terephthalate is provided on one surface of the glass substrate 30. The layer 32 may be

secured to the substrate by any suitable adhesive and may be of a thickness of about 25 microns. This material is suitable adhesive for both the visible and ultraviolet. In the case of infrared, a layer of polyethylene or polypropylene may be utilized. The thermal barrier layer 32 is to reduce thermal conduction from the sensitive screen portion of the heat sink layer 30. The thermal time constant of the layer 32 should provide a time constant for the sensitive screen layer adjacent thereto of about 1/30th of a second.

A layer 34 of photoconductive material is evaporated onto the layer 32 and may be of a thickness of 1 to 25 microns and of a suitable high impedance photoconductor having a resistance of about 10^{10} ohms-centimeters. Suitable materials for visible light are cadmium sulfide or arsenic triselenide. A suitable material for ultraviolet is selenium and a suitable material for infrared is lead sulfide.

A layer 36 consisting of a plurality of electrically conductive strips 38 and 40 is provided on the layer 34. The conductive strips 38 are connected to a common bus bar 42 and the strips 40 are connected to a common bus bar 44. Suitable leads 46 and 48 are connected respectively to the conductive bus bars 42 and 44 for providing a voltage between the conductive elements 38 and 40.

This potential is supplied by a potential source 50 connected across the leading 46 and 48. The potential source 50 may be an AC or DC potential and may be of the order of about 50 volts. In the specific embodiment shown, the electrode strips 38 and 40 may be evaporated on to the photoconductive layer 34 by well known techniques such as evaporating through a mask to provide strips of thickness of about 100 angstroms. The width of strips of thickness about 50 microns and with a spacing between strips of about 200 microns.

An optical isolation layer 52 is provided on the conductive layer 36. The optical isolation layer 52 prevents radiation from the light source 14 affecting the photoconductive layer 34. The optical isolation layer 52 may be provided by sparing a coating of a water soluble black aniline dye of a thickness of about 1 micron.

Positioned on the optical isolation layer 52 is a liquid crystalline layer 54 of cholesteric material and responds to heat by changes in the light reflective properties thereof. Several suitable materials are disclosed in U.S. Patent 3,114,836 by Ferguson et al and a specific material for this specific application may be 60 percent by weight of cholesteryl nonanoate, 30 percent by weight oleyl cholesteryl carbonate and 10 percent by weight of cholesteryl benzoate. A protective film

56 may be provided upon the surface of the layer 54 of liquid crystalline material of a suitable material such as polyethylene terephthalate and of a thickness of about 6 microns. It should be noted that the radiation assembly 12 may function as a simple detector simply by providing the photoconductive layer 34, the electrode layer 36 and the liquid crystalline layer 54.

In the operation of the device, the cholesteric liquid crystal film 54 and the photoconductive layer 34 are held at a constant operating temperature by the heat sink 30 and the associated temperature control system 28, in the absence of a projected light image from the cathode ray 10 onto the display assembly 11. The temperature of the liquid crystal layer 54 may be about 32°C. so as to provide a background color of black to the viewer 16. With the white light source directed to the liquid crystal layer 64 at the temperature of 32°C. the viewer will simply see a uniform black background due to light reflected from coating 52. When a light image is focused onto the photoconductive layer 34 by means of the cathode ray tube 10 and with the potential source 50 connected across the conductive electrodes 38 and 40, current carriers are introduced into the illuminated areas. The amount of illumination directed onto the photoconductive layer 34 determines the amount of current flowing in the illuminated areas of photoconductive material positioned between the electrode strips 38 and 40.

The video source 24 can control the intensity of the electron beam striking the phosphor 22 and accordingly the amount of current and heating by the photoconductive layer 34. Power dissipation from the resulting photocurrent is localized to only the illuminated areas by the electrode structure design, which limits the length of the current path to a fraction of the smallest resolvable image distance and the high resistance of the photoconductive layer 34 that is not illuminated. The thermal insulator 32 between the heat sink 30 and the photoconductive layer 34 and the closely coupled liquid crystal film 54. The amount of illumination determines the amount of current flow and heat generated. Due to this temperature rise, the reflection band of the liquid crystal film 54 in those areas is shifted toward a shorter wavelength part of the spectrum. This is illustrated in Fig. 5 and for example if the temperature is raised to 33.5°C. the reflected color will be red. At 34.1°C the color will be yellow, at 35.5°C the color will be green, at 37°C. the color will be blue and at 40°C. the color will be in the ultraviolet region and appear black to the observer.

The optical isolation layer 52 between the photoconductive layer 34 and the liquid crystal film 54 permits heat transfer between the two. The layer 52 blocks light from the light source 14 used for illuminating of the viewing side of the panel from affecting the photoconductive layer 34.

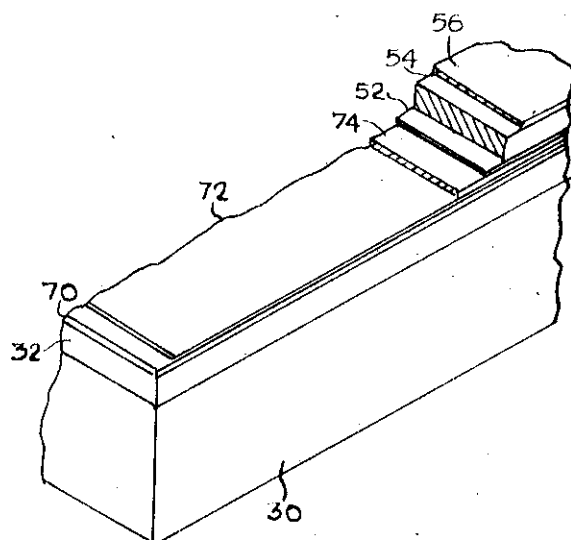


FIG. 4

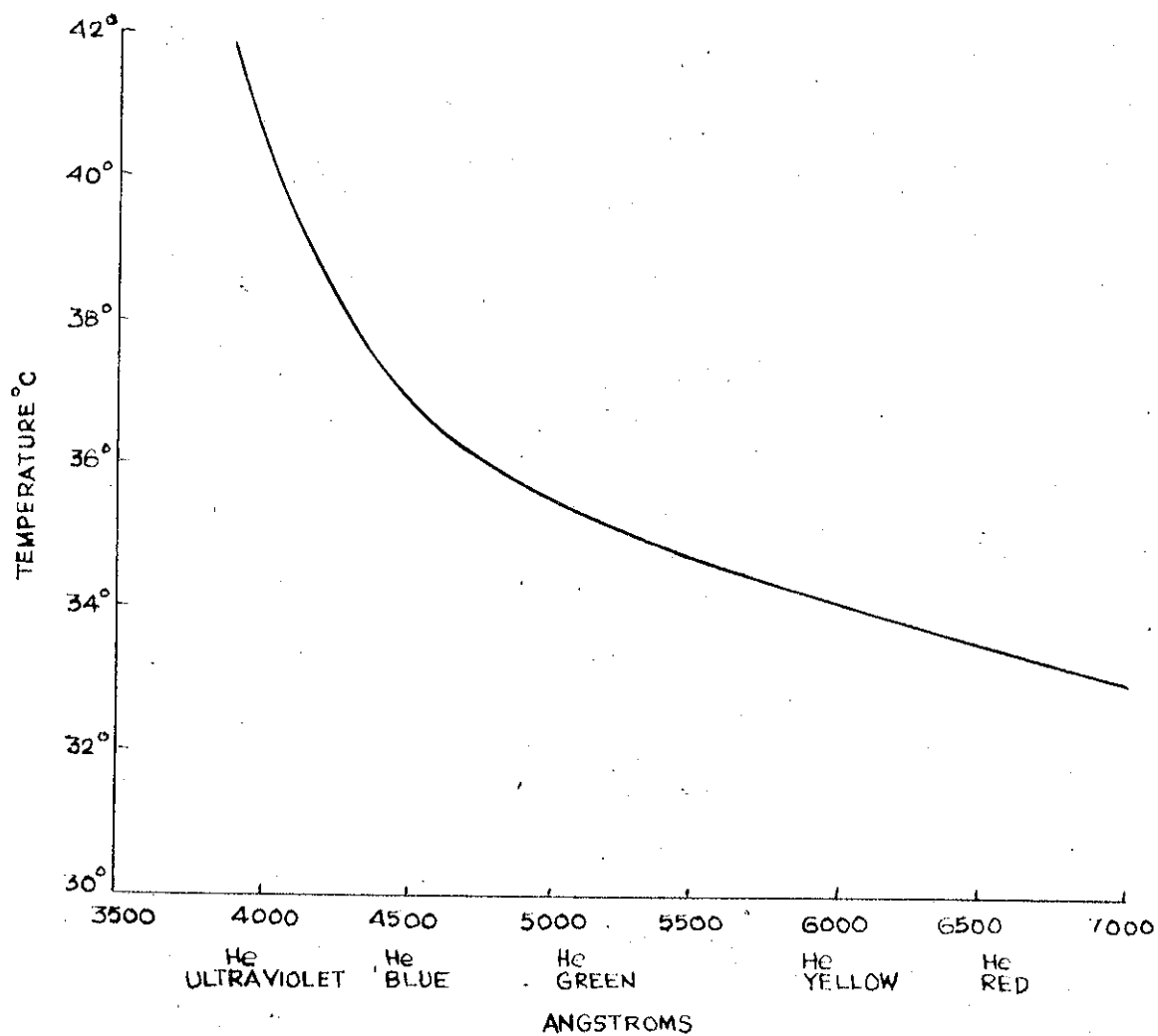


FIG. 5

This isolation layer 52 also serves as a black background for the liquid crystal film 54.

As indicated if the liquid crystal display is illuminated with white light from source 14, the liquid crystal film 54 provides a color display of the temperature pattern or image. Such a display is inherently compatible with high ambient illumination because reflective light, which is proportional to the incident light rather than internal generative light, produces the image. In this manner a large amplification of the input signal from the cathode ray tube 10 may be obtained so as to obtain an amplification greater than 100. If the display is illuminated with a monochromatic light from the source 14 rather than white light, a single color display with gray scale capabilities results.

The temperature rise required to activate the liquid crystal is created when light impinges on the photoconductive layer 34, resulting in photocurrent. The photocurrent is generated by applying a voltage from source 50 across the interlaced comb-like electrodes consisting of alternate conductors 38 and 40. The conductive electrode system 38 and 40 consists of parallel conductors whose width is a fraction of a spacing to obtain maximum active surface area and whose spacing is determined by the desired display panel resolution. The length of the photoconductive current path, which is equal to the electrode spacing, must be a fraction of the smallest resolvable distance on the display.

The liquid crystal film 54 may be of various materials and is selected for the required sensitivity and the operating temperature range. The operating temperature may be chosen arbitrarily within the limits compatible with the temperature control method. The sensitivity of the film is determined by the application of the display. A liquid crystal film with high temperature sensitivity will result in a display with high overall sensitivity, but will also require a much better temperature control system and layer uniformity to eliminate color variations in the reflected light image due to small temperature variations over the surface and to sensitivity and normal resistance variations in the various layer.

The protective film 56 is provided on the liquid crystal to reduce contamination of the liquid crystal film by dust and chemicals in the atmosphere. It also minimizes temperature variations due to air flow in front of the image intensifier panel 12. If chosen properly, the film material provides additional enhancement for the molecular alignment in the liquid crystal film and does not contribute significantly to lateral heat spread. The chemical composition of the film 56 and the optical isolation layer 52 must prevent contaminating substances from being released into the liquid crystals, whose optical properties are very sensitive to the presence of various chemical substances as well as temperature variations.

In Fig.3 a modified photoconductive and electrode system is illustrated. In this embodiment, two conductive bus bars 60 and 62 are provided and parallel strips 64 of photoconductive material are evaporated across the space so as to be in electrical contact with both of the conductive elements bus bars 60 and 62. The photoconductive strips 64 may be provided with conductive elements 66 interspersed in the photoconductive strips to limit the range of carriers to provide high resolution. In this type of configuration a lower impedance photoconductive material may be utilized, that is one having a dark resistance, of less than 10^3 ohms-centimeters and such materials as lead sulfide, lead telluride and indium antimony. Here again, the conductive bus bars 60 and 62 may be evaporated onto the thermal insulating layer 32 and the photoconductive elements 64 evaporated onto the substrate 32 by well known procedures in which evaporation is provided through a mask. The source 80 would be connected to the bus bars 60 and 62. The remainder of the device is similar to that already described and the operation is also similar and will not be described again.

Fig.4 illustrates another possible modification of the photoconductive and electrode system in which a large area of electrically conductive layer 70 is deposited on the thermal barrier 32. A layer 72 of photoconductive material 70 is deposited on the layer 70 and another electrically conductive layer 74 is provided on the photoconductive layer 72. The optical isolation layer 52

would be provided on the conductive layer 74. Here again, the operation is similar to that previously described. The layer 70 should be transmissive to the input radiations and may be of a material such as stannic oxide. The source 50 would be connected to the electrodes 70 and 74. If desired, the photosensitive element may be used to control the current through a resistive heating element in contact with the heat sensitive screen. It is also possible to convert sound energy into visible energy by detecting the sound on an element whose resistance is modified and therefore permitting control of current and associated through the detecting element per se or an associated resistive heating element in thermal contact with the heating sensitive screen.

ANALYTICAL METHODS AND DEVICES EMPLOYING CHOLESTERIC
LIQUID CRYSTALLINE MATERIALS

It has been discovered, and it is on this discovery that the present invention is in large part predicated, that gases, liquids and solids can affect the structure of cholesteric liquid crystals so that one or more optical properties thereof is at least temporarily changed. It has further been discovered that, upon providing a comparable basis, the resultant change is specific for the unknown involved which is thereby determined. By utilizing these general principles an utterly new mode of analysis is provided.

The optical property most readily utilized in the practice of this invention is that of selective scattering since it requires no polarizers, or analyzers for observation. Each cholesteric liquid crystal, at a given temperature and composition, exhibits, when exposed to white light, a scattering peak. In accordance with this invention, the shift in the scattering peak may be utilized for the analysis of unknown materials since the direction of the shift is a qualitative indication of the unknown and the extent of the shift is an indication of the quantity of the unknown. However, it is also possible to utilize changes in other optical properties of the liquid crystals.

For example, it has also been found that the circular dichroism and optical rotation of cholesteric materials are similarly affected by foreign matter. The component of circularly polarized light that is affected by the cholesteric material has a waveband of minimum transmission. This waveband shifts in the same direction and to the same extent as the scattering peak. Similarly, the waveband of peak optical rotation exhibits such a shift. Since cholesteric liquid crystalline materials have negligible optical absorption, the transmitted radiation may be utilized for the purposes of this invention as well as the scattered radiation.

In general, a material that is at least partially intersoluble with the cholesteric liquid crystalline material will affect the optical properties of the liquid crystal in a reversible manner. Also it is the case that a material that chemically reacts with the cholesteric liquid crystalline material will affect its optical properties in an irreversible manner. In instances in which the effect is reversible, the liquid crystal provides an optical indication of the nature and quantity of the foreign material present at that instant. Because of the reversible nature of the effect, the liquid crystal, may be continually reused. In instances in which the effect is irreversible, the liquid crystal provides an optical indication of the same type that is cumulative.

Hence, each type of effect has advantageous applications and the present invention is concerned with both reversible and irreversible effects.

Referring now to the drawing, numeral 10 indicates a support or substrate member upon which a cholesteric liquid crystal can be deposited and supported. Generally, the criterion for the use of any material as a substrate is only that it not interfere, as by reacting with the crystal that is to be deposited thereon or masking the optical properties of the crystal. Typical materials that have been used include halogenated hydrocarbon resins such as polytetrafluoroethylene, polyethylene terephthalate and the like, glass, methyl methacrylate resins, ceramics generally, etc. The substrate 10 may have any thickness desired. In instances where transparent substrates are used, it may be useful to limit the thickness so that the substrate does not contribute unnecessary scattering of light that may be employed. On the upper surface 12 of the substrate 10 is shown a cholesteric liquid crystal 14. As is evident from the wide number of materials that have a cholesteric liquid crystalline phase and therefore can be used in the invention, it will be evident that a wide variety of ways of applying the liquid crystal to the substrate is possible. For example, the crystal can be cast thereon, "buttered thereon," applied from a dropper, painted, sprayed or otherwise applied. A

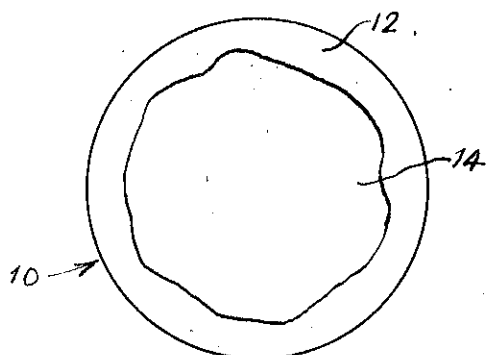


FIG. 2

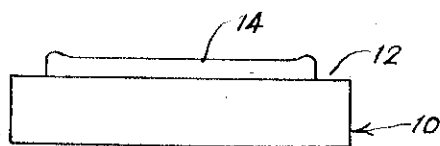


FIG. 1

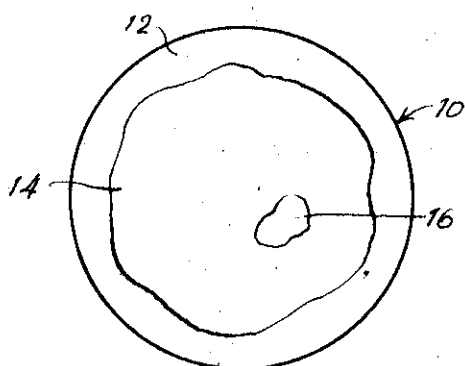


FIG. 3

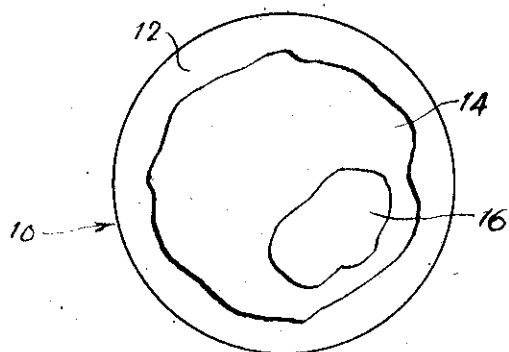


FIG. 4

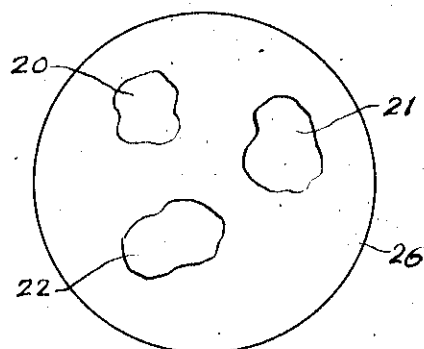


FIG. 5

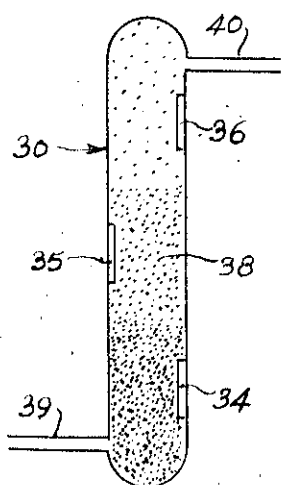


FIG. 6

A quite common method of application is to pour a solution containing the liquid crystal thereon and allow the solvent to evaporate.

When the crystal is deposited from a solvent as just indicated, an irregular shape normally occurs and such is shown in the top view thereof in Fig.2. In Fig.2, the irregular shape 14 is the cholesteric liquid crystal and the circular shape 12 is the surface of the substrate 10.

Optical properties, such as color, of the liquid crystal change when a vapor is allowed to permeate the crystal. In Fig.3, there is shown a small irregular shape 16 within the irregular shape 14 which constitutes the liquid crystal supported on the surface 12 of the substrate 10. The irregular shape 16 constitutes a color area brought about by permeation by a vapor into the cholesteric liquid crystal 14. As more of that vapor is added, the irregular shape 16 expands correspondingly as is shown in at 16 in Fig. 4.

Since each liquid crystal is distinct and its reaction or response to an unknown is distinct, an array of liquid crystals can be devised to give an immediate determination of the unknown. Such an array is shown in Fig.5. Thus three distinct liquid crystals 20, 21 and 22 are supported on a substrate 26. The liquid crystals being of known characteristics and known response to a given

vapor, can be simultaneously exposed to an unknown vapor. Observation of all crystals will, upon comparison with standard information, indicate through optical change the identification of the unknown. Of course, such an array need not be limited to three cholesteric liquid crystals, but any larger or smaller number of crystals can be used as well.

An indicative of the results that can be achieved in accordance with the present invention, the following demonstration was made... All percents given are by weight. Ten liquid crystalline compositions were made, each consisting of a mixture of cholesteryl chloride and cholesteryl nonanote. The amount of cholesteryl chloride in the compositions varied from 18 percent to 30 percent. Films, of substantially uniform thickness, of each composition were made by mixing the constituents in a solvent of 20 percent chloroform and 80 percent petroleum ether. The solutions were poured on polyethylene terephthalate film having a black coating on the opposite surface formed by spraying with a black acrylic lacquer available under the name 'Krylon'. The solvent was then permitted to evaporate. Each film was then exposed, at 270C, to a group of common organic solvents including acetone, butyl acetate, benzene, chloroform, trichloroethylene, n-heptane and pyridine. The solvent concentration varied from about 1 part per thousand to about 50 parts per million. The concentration was sufficient to produce color changes readily

apparent to the human eye, Where no color change was observed, the detecting element eventually became colorless due to a phase change. These solvents reversibly affected the film color(i.e., the scattered waveband with the film exposed to white light) in the manner shown to the

The data in the Table illustrates that each solvent had a unique effect on the set of ten liquid crystals. Thus if an unknown solvent of the group described were exposed to the set of liquid crystals, it could be readily identified. For example, acetone is unique in producing a red to green shift in the 19 percent crystal; butyl acetate is unique in producing no change in the green color of the 23 percent crystal; benzene is unique in causing no change in the green color of the 23 percent or 24 percent crystals; chloroform is unique in producing a green to red shift in the 20 percent crystal; trichloroethylene is unique in producing different effects in the 21 percent crystal (green to blue) and the 22 percent crystal (green to red); n-heptane is unique in turning all of the liquid crystals blue; and pyridine is unique in producing a green to red shift in the 21 percent crystal that is readily distinguished from the slightly red appearance of that crystal when exposed to acetone.

Consequently, an array of the seven compositions having from 19 percent to 25 percent cholesteryl chloride in

cholesteryl nonanoate permits the specific identification of the above mentioned seven solvents.

The foregoing demonstrates the feasibility of forming an array of cholesteric liquid crystals that have a unique pattern in response to any of the materials that alter the optical properties of the liquid crystals, thus providing a "fingerprint" of each of those materials.

Another application of this invention is in gas chromatography, to which reference can be made in conjunction with Fig. 6. There a vertically disposed transparent tube 30 can be adapted to have a plurality of liquid crystals of predetermined composition along its inside surface. In the embodiment shown three liquid crystals 34, 35 and 36 are used, though any other number could be employed. Within the tube 30 is a mass of gas absorbents 38. At its lower end, tube 30 is provided with a gas inlet 30 and a gas outlet 40 extends from the upper end of the tube. Upon passing a gas into the system, it is absorbed on the absorbent until the latter is saturated, at which time it passes onwardly. By appropriate placement of specified liquid crystals lengthwise or vertically along the tube 30, the effective absorbency, or more correctly the failure to absorb possibly due to saturation, is promptly indicated because the gas would pass by that portion of the absorbent, permeate the liquid crystal, for example liquid

crystal 34, and thereby change its optical properties which would be visible through the transparent tube, or could be measured. Similar action in due course will be evidenced by crystals 38 and 36 vertically disposed from crystal 34. Consequently, the liquid crystals can be used to indicate absorbent effectiveness, and visually show when regeneration or replacement should take place.

The cholesteric liquid crystals as such can be employed as the packing for a gas chromatograph column. This is possible for gases to permeate and diffuse through each crystal in a distinct manner. This property permits gas resolution; and the conditions at all times in the column would be directly observable because of the light scattering effects accompanying the diffusion.

In another contemplated use for the present invention, a cholesteric liquid crystal would be disposed within a controlled atom atmosphere reaction zone. If the reaction to be carried out were, for example, to be accomplished in the absence of oxygen or air, a liquid crystal particularly sensitive thereto could be used. Upon observing changes, if any, in the liquid crystal an operator would immediately know if his conditions of oxygen concentration were no longer tolerable. He could accordingly take appropriate action. Where this system is used in connection with a vacuum pump, a photocell can be focused on the crystal and be adapted to start the pump when the crystal indicated

an undesirable oxygen concentration. For example, a mixture of 30 percent by weight of cholesteryl eleostereate, 20 percent by weight of cholesteryl nonanoate and 50 percent by weight cholesteryl oleyl carbonate, which is red at 24°C., would change to a blue color upon absorption of oxygen. A typical reaction in which such a system may be particularly useful is that in which organo-metallic compounds, such as an alkyl lithium, are involved. Numerous similar applications are possible in view of the great number of controlled atmosphere reaction and processes that are presently practiced.

Another example of the invention was: A liquid crystal was made from equal parts by weight of cholesteryl acetate and cholesteryl benzoate. At room temperature in ordinary light, a 10 micron thick film of this crystal was red. Benzene vapors changed it to blue. Chloroform vapors deepened its red color. Trichloroethylene caused a change to blue. The optical property most frequently used to observe change (and therefore the presence of an unknown) in the cholesteric liquid crystal has been color. Other optical properties are similarly affected, such as optical rotation, shift of circular dichroism, birefringence, and the like, and changes in those properties can be used in the analysis system. Conventional optical instruments, recorders and the like, such as a photomultiplier, a photocell and so on can be used also to read out the detector

in addition to direct visual observation. These may be indeed be necessary for remote operations.

Mixtures of compounds also can be used. For example, one such mixture was 45 percent cholesteryl acetate and 55 percent of cholesteryl benzoate. It had a deep red color at room temperature. The composition of this mixture was varied in five percent steps in both directions. It was found that the color was shifted further toward the red for either direction of composition change.

In Fig. 7 there are plotted data obtained on a cholesteryl liquid crystal varied by the presence of a small amount of different commercial oils. The various liquid crystals were illuminated with a helium lamp. The color of maximum reflected intensity, corresponding to the strong spectral lines of helium, was observed at various temperatures and plotted for each system. The base cholesteric liquid crystal in all instances was, by weight, 80 parts of cholesteryl propionate and 20 parts of cholesteryl nonanoate. Data for the first (top) curve were obtained on that mixture free of oils. Then a crystal was formed by adding 5 parts by weight of oleic acid to the 20:80 mixture of the propionate and nonanoate, and pouring to a substrate in the usual manner. The third mixture was made by adding 5 parts of coconut (commercial oil with high percentage of free fatty acids) to the base mixture. Number 4 and 5 parts of coconut oil and 100 parts of the base. Similarly, 5 parts of corn

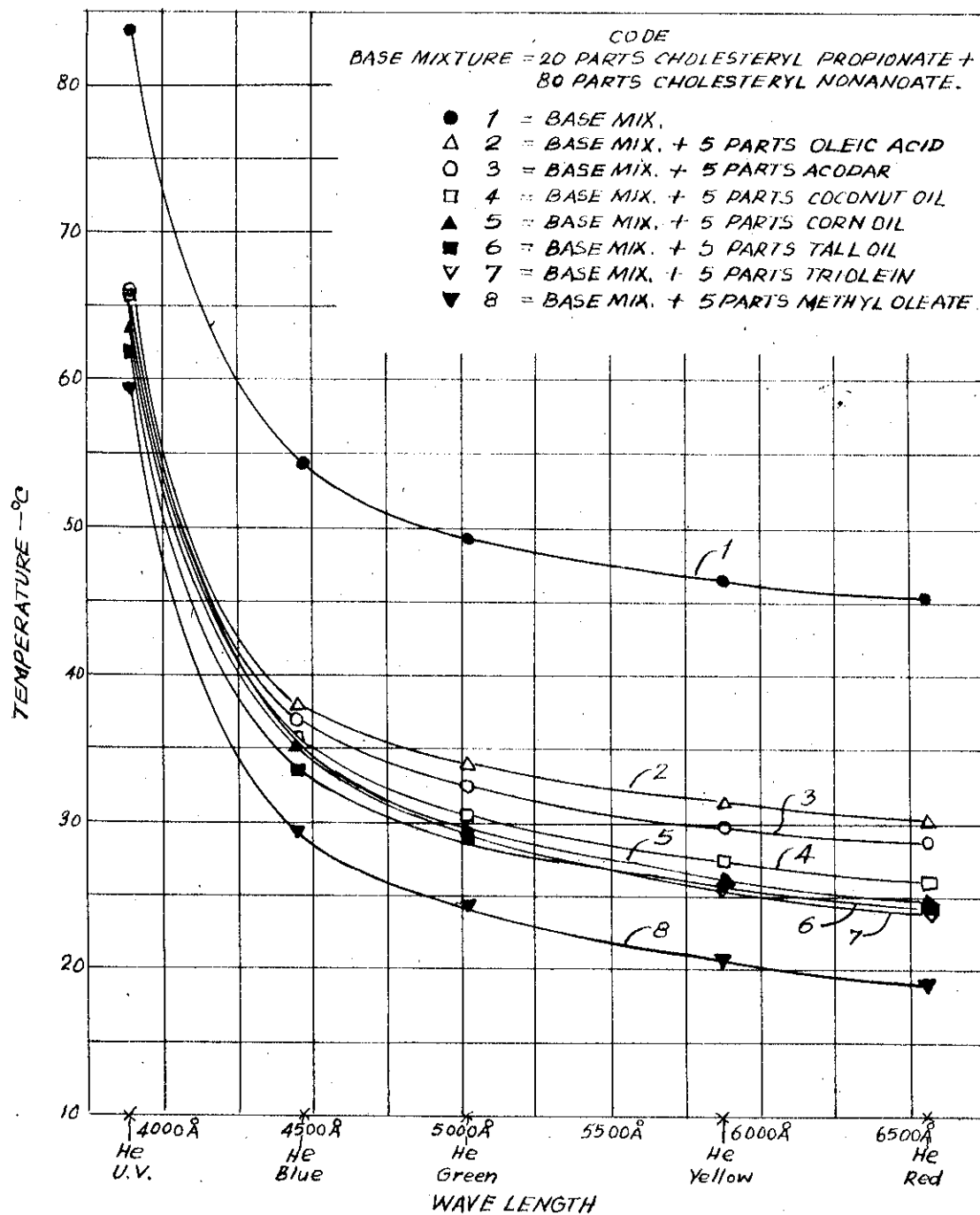


FIG. 7

oil, of tall oil, of triolen and of methyl oleate were used with base mixes to provide, respectively, the 5th through 8th liquid crystals. Temperature - wave length data were taken on each and plotted. It is to be noted that Fig. 7 is substantially to scale, and direct reading can be made from it.

The curves of Fig. 7 show many of the unique characteristics of the discovery. The substantial effect of temperature ON any of the given crystals is plain. The unique effect OF any of the additives in the same liquid crystal also is plain, and shows at ONCE that these materials, which have some chemical similarity, can be detected and distinguished. For example, if any of these materials are known to be present in the base crystal mixture, temperature scanning to give a characteristic color will immediately show which it is. Or at constant temperature, the maximum reflection of helium light can be noted, thereby showing which additive is involved. Thus if maximum reflectance of the crystal is red at 26° C., the additive is coconut oil, while if, at the same temperature, it is yellow, the curves show it to be corn oil.

Further, a constant temperature line can be projected across this graph and the sharply differing colors noted for several compositions. For example, the 26°C. line crosses the curves for mixtures 4, 5, 6, 7 and 8 and the colors indicated will range from red to blue.

The data in Fig.7 can be replotted. Thus if the ratio of the slopes of any of the curves 2 through 8 to that of curve 1 be replotted versus the wave length, a curve characteristics of the effect of the additive in the particular liquid crystal (the base mixture) is found. Any other amount of that additive in this liquid crystal will give another curve of this type having the same general characteristics as this particular curve. Identification is possible through this, and by standardisation procedures quantities can also be recognized. This same procedure of forming standard references can be accomplished with any other cholesteric liquid crystal and with any other series of chemically similar additives with similar results.

For analysis or detection system where continuous monitoring is undesirable or not possible, an irreversible detector may be more useful than those of reversible systems. In the irreversible system interaction of the cholesteric liquid crystal and the unknown occurs bringing about a permanent change in optical properties because, in effect a new cholesteric liquid crystal results from the interaction. The effect on optical properties depends on the specific materials reacted and their concentrations. In this manner, cholesteryl nonanoate, or any cholesterol derivative, can be used to detect free halogens such as chlorine or bromine. Ozone, oxygen and

the halogens can be detected and determined by cholesteryl allyl ether or cholesteryl eleostearate.

In any analysis procedure, standardization is practiced to insure reproducibility and that the results achieved can be appropriately interpreted. In this invention, substrates can affect the intensity of a color (dark substrates reflect better) and must be considered to that extent. Temperature in most instances has a striking effect (see Fig. 7), and can bring about a color change or change in other optical property. This can occasionally be utilized to further refine the analysis system. Generally however, this must merely be noted so that changes resulting will be attributed to the proper influences. A dipole field can affect the dipolar character of cholesterol derivatives. A shear stress applied to a cholesteric liquid crystal can change the optical characteristics. Radiation can affect the chemical constitution thereby providing a different cholesteric liquid crystal and, consequently, different optical properties. The angle of incidence and the character of light used can also be significant. For example, with polarized or unpolarized light, the scattering maximum (50 percent) is all circularly dichroic at normal incidence, but decreases as the angle of incidence increases. In any of the foregoing instances, no adverse effects will result in any analysis procedure if, for example, the test temperature is the same as that at which the standard was determined, or but a single angle of

incidence is used and so on.

From the foregoing discussion, description and data it is evident that the present invention constitutes a unique and highly effective analysis discovery. Its sensitivity can be compared to that of the human nose in scope. Data have shown that with it, changes in concentration on the order of but a few parts per million can be detected, as well as chain characteristics, isomerism and other slight variations in chemical structure. It may be noted that quantities of material used are not critical, and are generally important only for quantitative analysis. In the practice of the invention it has been the usual practice to use about one to 100 parts by weight of the unknown per 100 parts of lg liquid crystal, though other weight ratios could be used as well. When it is considered that a determination can be readily made with very minor amounts of the cholesteric liquid crystal, the economy available with this invention becomes apparent.

Application 7

DISPLAY SYSTEM UTILIZING A LIQUID CRYSTALLINE MATERIAL
OF THE CHOLESTERIC PHASE

A large area display screen is provided which includes a layer of liquid crystalline material of the cholesteric phase in which a temperature image is applied thereto according to electrical information by means of lossy elements provided in intimate contact with the liquid crystalline material. The lossy elements may be in the form of resistive elements of nonlinear characteristics. ,

Referring to Fig.1, a system is shown including a display screen assembly 10. The screen assembly 10 is provided with a heat sink 12 on one surface with an associated temperature control means 14. The temperature control means 14 consists of an enclosure on one surface of heat sink 12 with means for permitting flow of a liquid medium such as water over the surface of the heat sink 12. The temperature of the water may be controlled to the desired operating temperature. A thermoelectric temperature control system may be employed for controlling the operating temperature.

The display screen 10 is illuminated with a light source 16. The source may be of white light or monochromatic depending on the particular application. The display on the screen 10 may be observed by an observer 18.

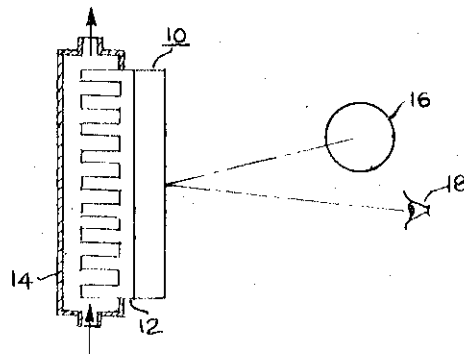


FIG. 1

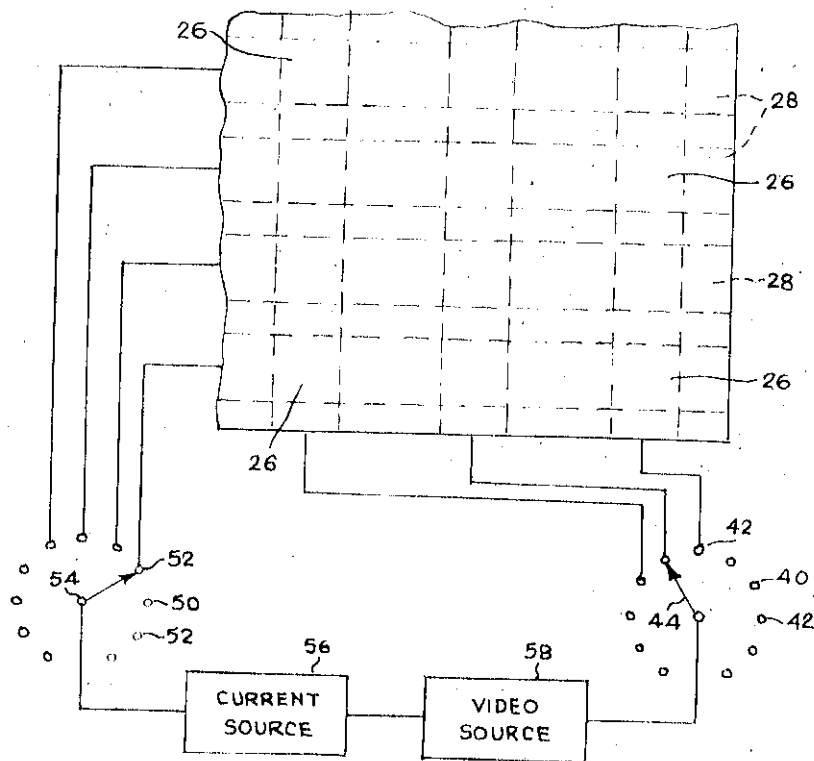


FIG. 2

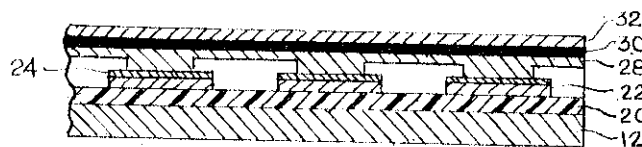


FIG. 3

The display screen structure 10 is shown in detail in Figs. 2 and 3. The screen structure 10 included a support layer which is the heat sink 12. The heat sink 12 is comprised of a suitable material such as aluminum and having a thickness of about 2 cm. A thermal barrier layer 20 is provided on the support layer 12 and may be of a suitable material such as polyethylene terephthalate and known under the trade name Mylar. This film or layer 20 may be applied and secured to the support layer 12 by a suitable adhesive. The thickness of the layer 20 is to provide a thermal barrier layer to provide a time delay in thermal conduction from the heat sensitive screen to the heat sink 12 so as to provide a Dröner time constant for the screen structure. The material and thickness of the layer 20 may be varied to obtain a desired time delay.

A plurality of electrically conductive strips 22 shown as vertical columns are provided on the layer 20 and may be of a suitable electrically conductive material such as aluminum. The conductive strips 22 should be of thickness of about 100 angstroms and the width of about 400 microns. The spacing between the conductive strips 22 should be about 130 microns. Positioned on the conductive strips 22 is heating layer 24 of a suitable lossy material. In the specific embodiment a resistive material such as selenium, magnesium oxide or aluminum oxide is provided in the layer 24 and having a thickness of about 25 microns. The coating 24 may be evaporated and provided on the entire conductive 22, as a continuous layer or simply on active

areas 26 of the screen as illustrated in Fig.2. Positioned on the exposed surface of the resistive layer 34 are electrically conductive strips 28 to provide a non-linear resistor within the active areas 26. The resulting structure consisting of the conductive electrodes 22 the resistive layer 24 and the conductive electrode 28 is to provide the matrix of non-linear resistive elements or active areas 26.

A coating 30 is provided on the conductive strips 22 as a continuous coating and may be of a suitable black paint such as India ink to provide a black surface. A layer 32 of a liquid crystalline material of cholesteric phase is provided on the black coating 30. A suitable material for the liquid crystalline layer 26 is a mixture including 60 percent by weight of cholesteryl nonanoate, 30 percent by weight of oleyl cholesteryl carbonate and 10 percent by weight of cholesteryl benzoate. There are other suitable materials and mixtures that exhibit the change in reflecting properties in response to heat such as described in the U.S. Patent 3,114,836.

The conducting strips 22 are connected to a switching member 40 and as indicated each of the conducting strips 22 would be connected to a separate terminal 42 of the switching device 40 with rotor 44 provided for making contact to selected terminals 42. A similar switching system 50 is provided in which terminals 52 thereof are connected to the conducting strips 28 with a rotor 54 provided

for connecting to any of the desired terminals 52 and associated strips 28. The rotors 44 and 54 are connected together through a suitable current source 56 and a video source 58. In this manner, the necessary current source 56 and a video source 58. In this manner, the necessary current may be applied across a selected active area 26 to provide the heating. The switching units 40 and 50 have been shown as simple mechanical switching arrangements for convenience of illustration and it is understood that any suitable scanning or selecting arrangement might be utilized. The scanning system for a display would normally require that it be capable of providing a standard television scan. It might be desirable to utilize a simple cathode ray tube with special fiber optics face plate to provide the desired control signals to actuate semiconductor devices or glow discharge switches associated with the conductive elements 22 and 28. Various other switching devices might be used to control the current flow through selected areas 28.

In the operation of the device shown in Figs. 1, 2, and 3, the active elements 26 are heated by coincident technique. The ambient temperature of the display screen 10 is controlled by the control means 14. The ambient temperature of the liquid crystal layer 32 associated with the element 26 for this specific material will be at 32°C. Light directed onto the display screen 10 from the viewing light source 16

will cause the screen 10 to look black to the observer 18 due to the fact that the light is not reflected from the liquid crystal layer 32 but from the black coating 30. In order to display an image, heat must be applied to the elements 26. The heat may be applied to a given middle resistive active elements 26 and specifically the element 26 in the bottom row. the switch 50 would be connected to the terminal 52 as shown in Fig.2 and the switch 40 would be connected to the terminal 42 as shown in Fig.2. A current corresponding to the source 56 and the video source 58 would be applied across the element 26. The current flowing in with the amount of the resistive layer 24 of the element 26 would cause heating in accordance with the amount of current. Since a resistance of the area 20 is non-linear, the ratio of power dissipated will have 119 or more. If the temperature of the elemental area 26 is raised to a temperature of 33.5°C, then a red color will be reflected by the screen 10, at a temperature of 34°C, a yellow color, at a temperature of 35.5°C, a green color, at a temperature of 37°C, a blue color and at a higher temperature the structure will again be black to the observer. By the amount of this current flow, the color may be controlled.

This property of the screen 10 is illustrated by the curve shown in Fig.5. In this manner, a color visual image can be displayed of contrasting colors or by

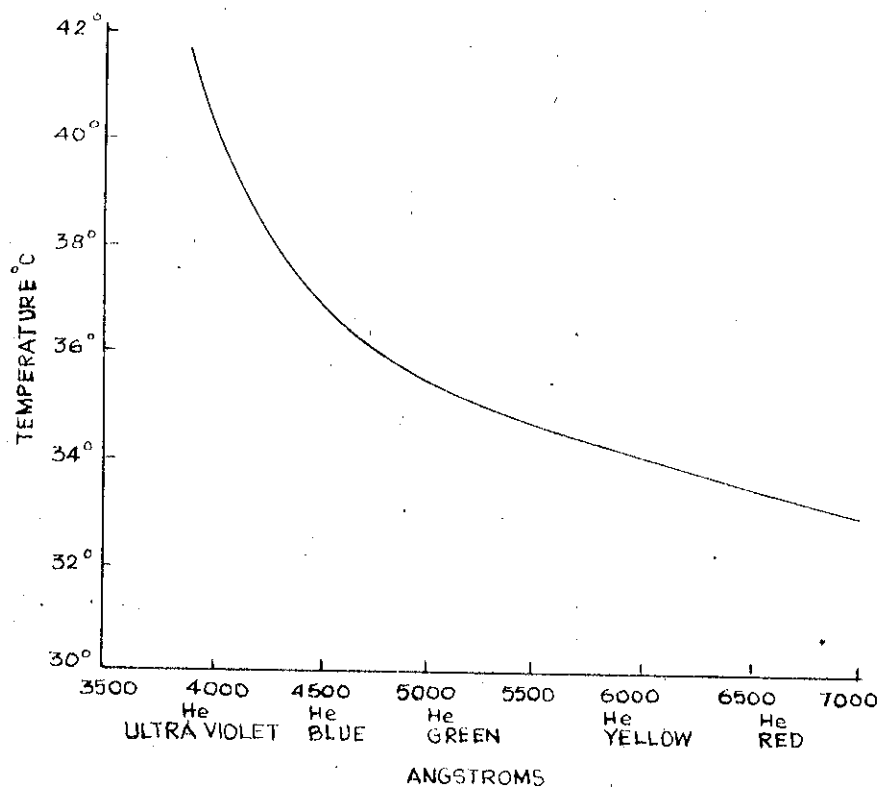


FIG. 5

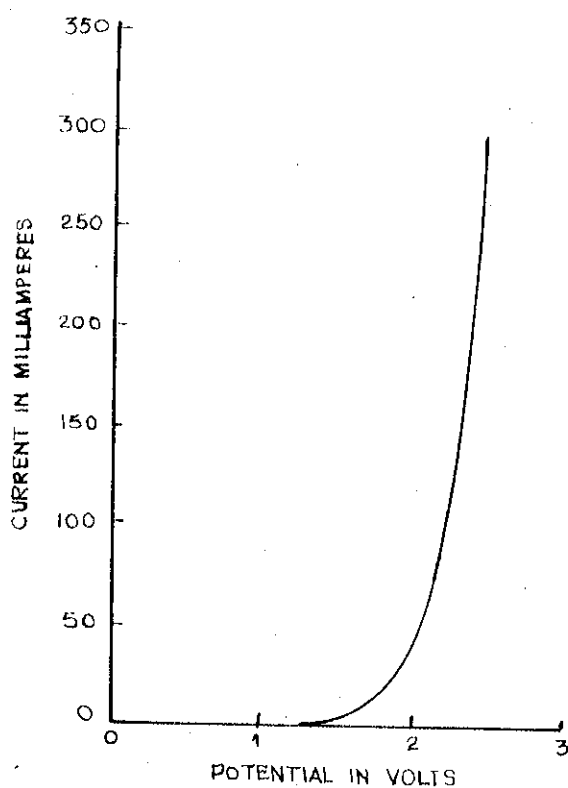


FIG. 4

controlling the temperature by current flow, the image may be made to appear in a single color on another color background. The above description is directed to the use of a light source 6 of white light. If a monochromatic light source is used then a single color can be obtained so as to obtain a brightness variation within a single color on black background.

A typical characteristic curve for the non-linear resistive element 24 is illustrated in Fig.4. By utilization of the non-linear device, one is able to insure that power will not be dissipated in adjacent elements but will be applied across the single element where substantial conduction is found due to the fact that a greater voltage is applied across the single element, rather than the other elements. By providing the temperature barrier layer 20, one is able to control the amount of time that the heat image is applied to the liquid crystalline layer 32. Although the suggested scanning method does not provide for a storage type display, it is recognized that the proposed display screen is adaptable to other scanning structures which incorporate both storage and selective erase.

Application 8

VISUAL DISPLAY DEVICE

This invention relates to temperature-sensitive visual display devices and, more specifically, relates to arrays of encapsulated liquid crystal material which irridescence whenever temperature changes occur on the arrays.

Up to this time, the utility of cholesteric mesomorphs in temperature-sensitive systems has been severely limited due to a number of reasons, the following points being some of the assigned faults:

(1) Such systems containing a mixture of one or more intermingled mesomorphic compounds as a film are subject to crystallization of large areas at the desired working temperatures. This undesirable crystallization tends to concentrate one of the active materials at each crystallization site to thereby separate it from the other components of such a mesomorphic mixture. This component separation results in (a) loss of precision and efficiency in color change at the desired temperature, and (b) anomalous color change activity at other temperatures;

(P) mesomorphic cholesterol derivatives are oily liquids at and above their melting temperatures. When they exist as a film on any surfaces, the film, being wet, is subject to injury of many types from ageing, and contact with the environment. Dust particles are easily entrapped by the liquid surface and can serve as undesirable nuclei for

crystallization. Such films are exposed to the danger of contact with any material in the vicinity, with resultant disorganization of the mesomorph and possible change in thickness in localized areas, which would alter the response of the system; and

(3) the subject wet-film mesomorphia systems are prone to anomalous color change behavior upon the event of only slight contamination of the system by various solutes. This contamination can cause iridescence by itself at a given temperature not otherwise associated with the yield of color in the film generally, or it can produce large shifts in the color producing temperature, either higher or lower.

The present invention provides for the isolation and protection of these thermotropic liquids as droplets as the cores of minute transparent-walled capsules, and the distribution of these capsules in a film-layer onto a suitable substrate for use as a temperature sensing device.

Thus, according to the invention, there is provided a visual display device comprising a substrate coated with a mass of minute capsules each having a liquid nucleus including one or more materials capable of assuming a cholesteric mesophase in a predetermined temperature range, said nucleus being retained by a capsule wall material which transmits light incident on or reflected from the capsule contents.

By the term "Minute" it is meant that the capsules range from 1 micron to 5000 microns in average dimension, being of such small size as to make the individual manufacture thereof impossible or impracticable.

It should be understood that the capsule product of this invention can be attained by any suitable encapsulation technique which is capable of producing capsules of the required small dimensions. The final form of the capsular material to be coated is preferably ten-to-fifty-micron capsules, but it has been found that any size of capsules can be successfully utilized, the larger capsules only showing a decreased degree of visual resolution when used in a data display system. Encapsulated mesomorphic-compound film layers appear to be free of the, heretofore, limiting disadvantages associated with exposed continuous wet films of the materials. Layers cast from an aqueous slurry of the encapsulated material and dried are dry to the touch, are relatively unaffected by brushing contact with foreign bodies, are substantially immune to solute contamination, and are not subject to rapid deterioration by selective crystallization on contaminating foreign bodies; and, in cases where crystallization does begin, it is stopped from further areawise development by the boundary of a capsule wall.

The Invention also provides for the distribution in such a film-layer of mixed capsules distinguished by their

different content and performance which system of mixed capsules can serve the purpose of sensing temperature or displaying data at several temperature levels. Such a system, in one case, may consist of layers, each layer comprising one, two, or more types of capsules having different characteristics. These characteristics may involve:

- a) temperature response range;
- b) size of liquid core;
- c) type and thickness of capsule wall material;
- d) kind of mesomorphic materials,

and the like, all to the purpose of choosing an exact response suitable for the proposed use.

The wall of the mesomorph-containing capsules may be of colored material and such capsule walls serve also as color filters for light traveling to and from the mesomorphic materials. Capsule walls are easily tinted by the use of stains. Such a controlled system would find use in devices where the broad iridescent effect is objectionable.

The substrate 1 can be any suitable material, thick or thin, transparent or opaque, colored or not. Figs. 1a and 1b show a film-thickness of material as a substrate, but the use of a film material is optional. If it is more convenient or to the intended use, any firm body can be utilized to provide a surface for material. As an alternative

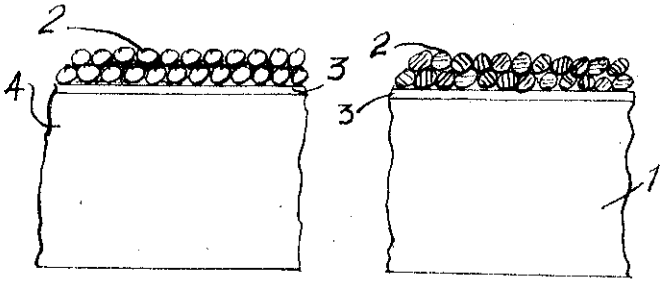


FIG. 1a

FIG. 1b

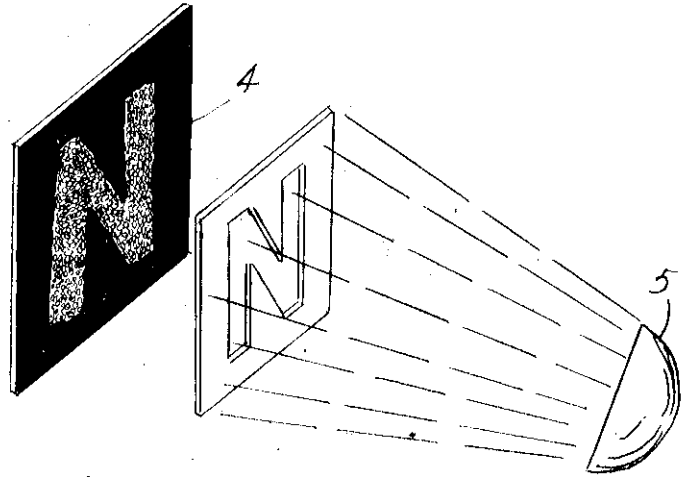


FIG. 2

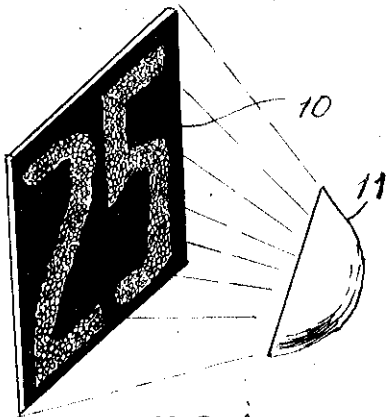


FIG. 4a

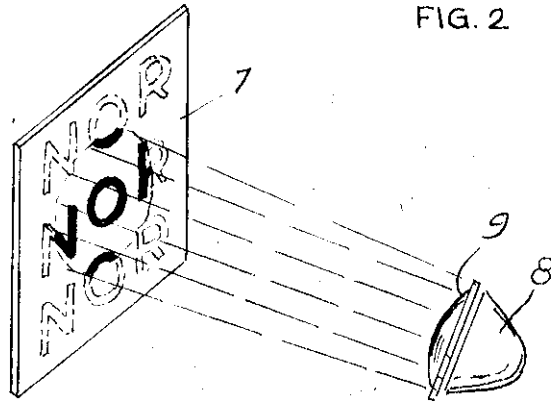


FIG. 3

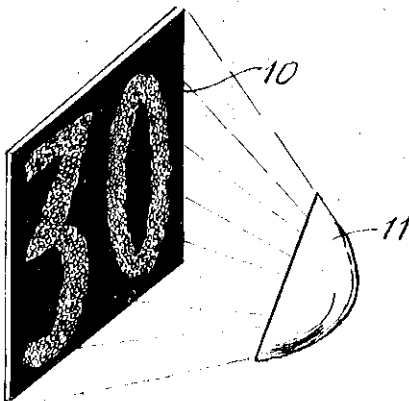


FIG. 4b

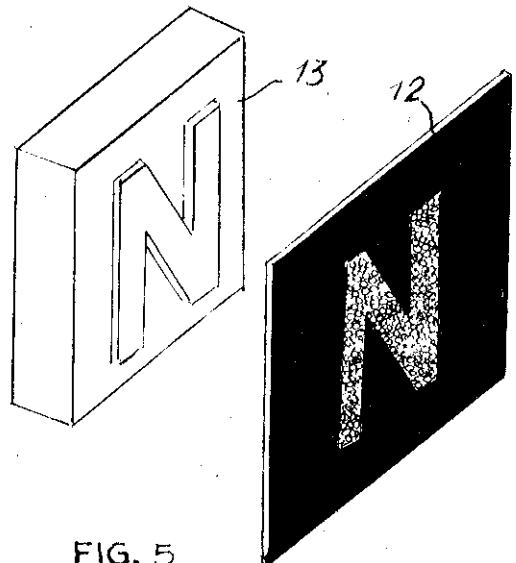


FIG. 5

method, the encapsulated, temperature-responsive materials can be utilized as a liquid slurry, the color change phenomenon remaining the same as with the dried film material. Fig. 1a is intended to represent the capsule coating at a temperature above or below that which is required for the color change effect of the mesomorphic material, while Fig. 1b is intended to represent the same capsule coating within the temperature range of the color change effect. The cross-hatching of the capsules in Fig. 1b is used only to depict a color change and not to suggest particular colors. Capsules having an average diameter of 5 to 1,000 microns or perhaps slightly larger can be used for the coating; and one capsule layer or a number of superimposed layers can be used, depending upon conditions and requirements of the intended coating application. Different areas of the same surface may contain different kinds of capsules. Figs. 1a and 1b show a colored layer 3 on the base 1, the use of which is optional.

Figures 2 and 3 illustrate the use of a display screen 4 comprising a coating of capsules containing but one system of cholesteric material, which has been coated onto a substrate of self-supporting material. An infrared energy source 5 is directed at the display sheet and is controlled by a stencil 6. Infrared rays which pass the stencil 6 are absorbed on the display screen 4 and thereby raise the screen surface temperature in such a manner as to cause a

color change having an outline similar in shape to the stencil cut-out. In Fig.3, the encapsulated material has been coated onto a display screen substrate 7 which has the same color and texture as the unheated, encapsulated material. As infrared rays are directed from an energy source 8 in a beam, through the focusing lens system 9 provided, the capsules in the beam-image area are warmed, causing the characteristic iridescence and visual appearance of the image. Of course, it is understood that any appropriate source of energy can be used in the practice of this invention, heat lamps being shown in the figures only as a convenient means of depicting an energy source.

Figures 4a and 4b illustrate the practice of this invention as a direct reading temperature display device 10 employing more than one responsive system. The device has, coated on its front surface, individually responsive layers of encapsulated mesomorphic materials, each layer being applied in the outline of the numerals which represent the temperature at which the layer undergoes a color change. In Figs. 4a, the surface has absorbed infrared radiation emitted from source 11 of an amount required to bring the temperature of the capsules up to about 25 degrees, the temperature at which color change occurs in the (first) outline layer of the numerals "2" and "5". The result of this heat absorption is a visual indication of the surface temperature.

In Fig.4b, more radiation has been absorbed, and the temperature of the first kind has been raised above the coloration temperature of the first kind of encapsulated material and up to the coloration temperature of a second kind of material in another layer represented by '13' and '10'-. The result, as shown, is disappearance of the numerals '25' and subsequent appearance of the numerals '30' a direct temperature indication created by the adaption and preparation of different areas with appropriate encapsulated mesomorphic materials.

Figure 5 illustrates a further aspect of this invention in the use of encapsulated mesomorphic materials for data display. Capsules are coated onto a display sheet 12 and display characters are caused to appear by contact with or proximity to a warmed character, such as an embossed type 13. There can be prepared, by proper selection of mesomorphic systems, sensing devices and display devices which yield their visual color advent at temperature levels considerably above or below room temperature.

Example I.

1.25 grams of acid-extracted pigskin gelatin, having a Bloom strength of 285 to 305 grams and an isoelectric point of pH 8-9, and 1.25 grams of gum arabic, were stirred with 125 grams of distilled water at 55 degrees Centigrade in a Waring Blendor to yield a solution, which was about pH 4.5.

When the solution was formed, the pH was adjusted to 6.0 by the drop-by-drop addition of 20 percent by weight, aqueous sodium hydroxide solution. To the above system was added a solution of 2 grams of cholesteryl propionate in 8 grams of cholesteryl oleate. The cholesterol derivative materials were emulsified in the Waring Blendor vessel to an average droplet size of 10 to 50 microns, and the pH of the system was slowly reduced by the dropwise addition of 14 percent, by weight, aqueous acetic acid solution. Addition of acid was continued until the single, liquid welled, capsules clustered to form aggregates having diameters of about 25 to 300 microns. At this final state, the system pH was about 5.

The entire liquid was then chilled with an ice bath to below 10 degrees Centigrade, while the agitation was continued. At 10 degrees Centigrade, 0.6 milliliter of a 25 percent, by weight, aqueous solution of ~~an~~ pentanediol, a chemical hardening agent for the gelatine, was added to the Blendor vessel, and the system was stirred for about 12 hours while slowly returning to room temperature. At the end of that time, the capsule walls were firm and hardened, and the capsular system was poured through a wire mesh sieve having openings of 74 microns. That which passed the screen was suitable for coating the intended substrate. Capsules, along with the equilibrium liquid which passed through the sieve were coated, using a drawdown

applicator, to a wet thickness of more than 2 but less than 10 mils onto a blackened, 5 mil-thick, polyethylene terephthalate film and then were dried in air at about 25 degrees Centigrade. If temperature was raised at a point on the a-atad layer, concentric rings representing a temperature gradient pattern appeared outwardly from a central ring of blur, thence spectrally in order through red, as the temperature gradient decreased. As the temperature of the point was increased or decreased, the effect was evidenced by expansion or contraction of the rings. The system of Example I. first exhibited the mesophase coloration transition at about 25 degrees Centigrade and continued to about 25 to 30 degrees Centigrade. Systems of adjacent expanding and contracting rings intersected, and the resultant color was a function of the temperature of a given area.

Example II.

The encapsulation process of this example is identical with that of Example I. except that a different mixture of cholesterol derivatives was employed. In this example, the cholesteric mesomorphic materials were 5 grams of cholesteryl propionate and 5 grams of cholesteryl nonanoate to be substituted for the cholesteryl propionate and cholesteryl oleate used in Example I. With regard to color change and transition temperatures, this system behaved much like the system of Example I., the proportions being

selected with the end in view of making the behavior of the system aligned with ordinary living environment temperatures, as was also the objective of Example I.

Example PIX.

In this example, two different cholesterol derivative mixtures were separately encapsulated by the method described in Example I., and the capsules were coated, as a mixture, onto a blackened substrate film. The cholesteric mesomorphic mixtures were (a) oleyl cholesteryl carbonate and cholesteryl nonanoate in a one-to-one ratio, and (b) Oleyl cholesteryl carbonate and cholesteryl nonanoate in a one-to-three ratio, respectively. Maximum response to incident light (strong in 5500 A. components) was at 34.5 degrees Centigrade in one system (a) and at 48.8 degrees Centigrade in the other system (b).

The visual effect of such a coated mixture of capsules was much the same as that of the previous examples, except that the iridescence occurred in two sequences beginning at two different temperatures. In warming a test point on the coated layer, the first sequence of concentric rings of color appeared circling the point of heat application. When the spot on the coated layer was further heated above the first color producing temperature but below the color producing temperature of the second encapsulated material, the test point again appeared black with only a ring

of color remaining, at the time, a fixed distance from the center of heat source, due to the static temperature gradient. Upon further heating of the test point on the canted layer, a second set of color rings began to appear and move outwardly, but never reached the first rings, giving rise to a visual indication of the temperature at two different locations on the coated substrate. So much for point application of heat. When Chr coated substrate film, as a whole, was heated, the film reflected changing colors, not in rings, but all over colors first appearing due to one encapsulated material, the film appearing black for a time at temperatures intermediate to the different color producing temperatures. The color changes appeared in reverse order on cooling the film. If capsules of different cholesteric mesomorphic materials which have overlapping color-change temperature ranges are combined, then the reflected colors will be combined to alter the visual appearance, depending on the relation of the different responses and the resolution of the capsular system. As discussed previously, smaller capsules yield systems with higher resolution.

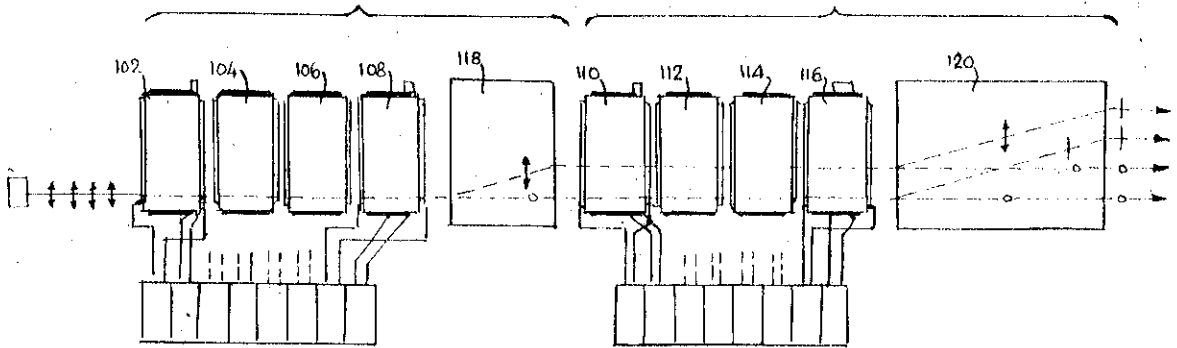
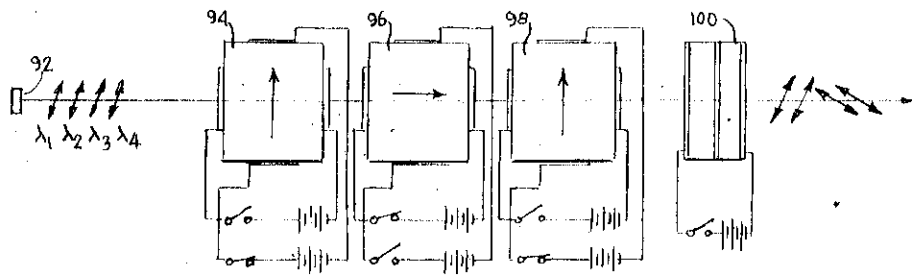
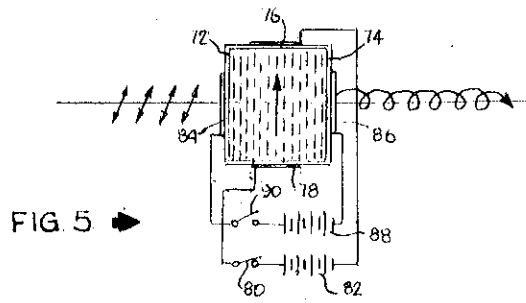
Application 9

MULTI-FREQUENCY LIGHT DEFLECTORS

The present invention relates to a method for separating a polychromatic light beam into two or more spaced output beams, each comprising one or more of the component light frequencies of the original polychromatic light beam. In accordance with the invention a multifrequency light deflector comprises beam forming means adapted to produce a beam of plane polarized light including a plurality of wavelengths, polarization control means for orienting the polarization plane of at least one of the wavelengths perpendicular to the polarization plane of the other wavelengths perpendicular to the polarization plane of the other wavelengths, and beam splitting means adapted to separate wavelengths having mutually perpendicular polarization planes into spatially separated light outputs...

A polarization control apparatus which may be used is comprised of a series of electric field controlled liquid crystal cells.

...The device shown in Figure 5 enables a single light frequency to be changed in its polarization direction such that it will be perpendicular to the remaining light frequencies in a polychromatic light beam. The device consists of a transparent vial or cell 72 filled with a liquid crystal material 74. A first electrode pair 76 and 78 is secured to the cell and is connected to a source of



high potential 88 by means of the switch 90. If a voltage is applied to a first electrode pair 76 and 78 by closure of the switch 80, as shown in Fig. 5, the molecules of that liquid crystal material will align in the direction of the electric field, as shown in by the arrow, which is perpendicular to the light direction. Giant molecules of elongated structure often exhibit birefringence if they form a microscopic structure known as liquid crystals. The optic axis of such liquid crystals coincides with the elongated axis of the molecules. Many kinds of such molecules have a considerable dipole moment which makes them align in an external electrical field. This property is made use of in the cell of Fig. 5.

Therefore, the light that passes the liquid crystal of said orientation gets split in two components, the ordinary and the extraordinary ray which has polarization rotated 90° with respect to the ordinary ray. Both have the same direction, but different speed thus getting out of phase. Upon recombination, this phase shift causes, in general, an elliptic polarization state. Due to the dispersion of the indices of refraction, the total phase differences in a cell of given length, depends on the light wavelengths. There can always be found a length of the cell whereby at least one wavelength is polarized perpendicular to all other wavelengths upon leaving the cell. If in Fig. 5 the voltage is applied to the second

pair of electrodes 84 and 86, instead of to the electrodes 78 and 78, the liquid crystal molecules will align parallel to the light beam. This is now the direction of the optical axis and therefore, no birefringence occurs. All light of whatever wavelength now passes without change of its polarization state.

The effect of putting several such cells in series leads to a binary selection rule for the polarization direction of the wavelength passing the device. To describe the result of the combined cells, the birefringent state of a cell, that is when the molecular orientation in the cell (the arrow in the diagram) is in a direction perpendicular to the light beam, will be designated as '1' and the state at which it is nonbirefringent will be designated as '0'. That any we can list the possible polarization combinations according to the cell states. This is done in the Table.

As one sees from the Table the number of combinations of polarization directions which can be achieved by three of the described liquid crystal cells is eight. This is true for four light wavelengths, switched to two mutual perpendicular polarization directions. However, sixteen different combinations may be obtained by the addition to the system of three cells of an electrooptical switch 100 which is achromatic, to switch any polarization state to its perpendicular direction. Such a system is shown in Fig. 6.

TABLE

The light wavelength enter Cell-
1 all with the same linear polarization direction.

Cell - 1	Cell-2	Cell - 3	Result
0	0	0	
1	0	0	
0	1	0	
0	0	1	
1	1	0	
0	1	1	
1	1	1	
1	0	1	

In case where six light frequencies are to be controlled in the same way, one would need five cells similar to the cell shown in Fig.5, the functions of the cells being analogous to the former example. The number of combinations of wavelengths achieved by five cells is $2^5=32$. The use of an additional achromatic electro-optical switch increases the number of combinations to 64. In general n wavelengths require $n-1$ cells to perform the maximum number of 2^{n-1} different wavelength combinations in the two mutually perpendicular polarization direction.

The device shown in Fig.7 consists of electric field controlled liquid crystal cells in combination with beam splitting means which separate light beams according to their polarization direction. In the example shown by Fig.7 four light frequencies are used and the two stages of the device give four output beams.

The cells used for the polarization control 102, 104, 106, 108, 110, 112, 114 and 116 are each a cell as has been described above with reference to Fig.5. The combination of four cells is similar to the arrangement shown in Fig.6 but with the electro-optical switch 100 of Fig.6 being replaced by a fourth cell which would give to all wavelengths a phase shift of 90° if switched to state '1'. Thus, if switched to '1' cell 102 makes the polarization direction of the

light wavelength perpendicular to all others, the cell 104 makes the polarization direction of the light wave perpendicular to all others, cell 106 makes the polarization direction of the light wave perpendicular to all others and cell 108 makes all wavelengths to change their polarization direction by 90^a .

NONDESTRUCTIVE TESTING METHOD USING
CRYSTALS

This invention involves a method of applying liquid crystal materials to a surface to be tested for discontinuities. Test areas ON the surface are defined through utilization of a hollow, loop-forming tubular member through which a vacuum is applied, and which produces a thermally responsive contact between the crystal holding medium and the surface within the test area.

A flexible application device has been devised and is shown in Fig.1 in an elliptical view wherein a hose 14 is joined at point 17 and permanently bonded (connected) to form a hollow tubular shaped member 14 capable of being shaped in different configurations. Typical materials used for this have been polyvinyls, rubber and Tygon. A multiplicity of holes 15 are made on the inside circumference of the hollow member (ring). At least one pitot opening 16 capable of being adapted to fit into vacuum systems is inserted into the member 14. The hose is assembled so as to include sufficient area within its circumference to enable adequate testing to be done within this defined area.

In Fig.2, the member 14 is placed ON the object 10 to be tested and connected with vacuum drawing means (not shown) at the pitot opening 16 so that air is evacuated

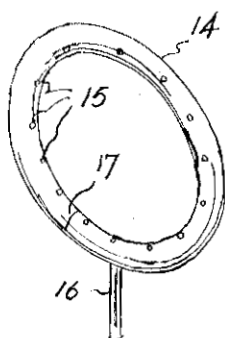


FIG. 1

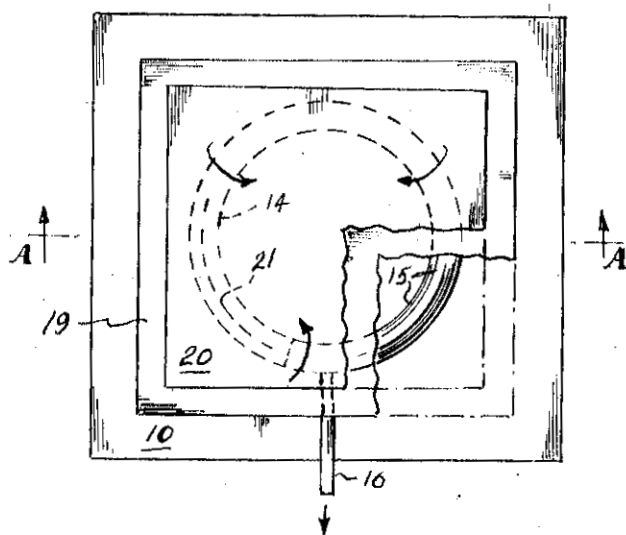


FIG. 2

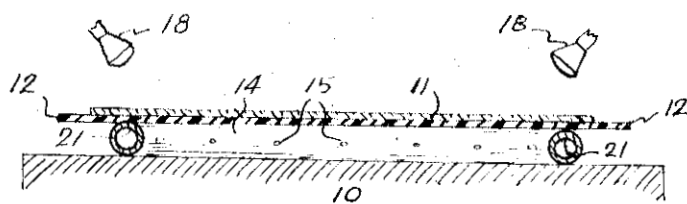


FIG. 3

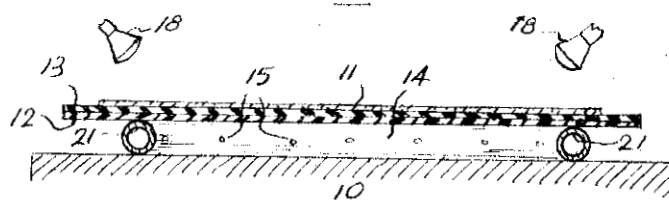


FIG. 4

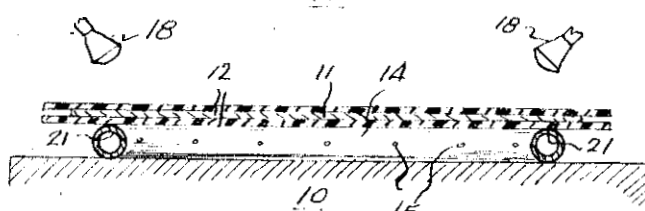


FIG. 5

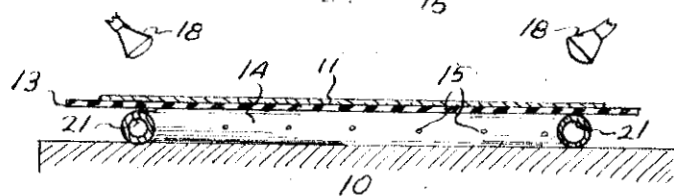


FIG. 6

through the openings 15 inside the inner circumference of the member 14. Thereafter at least one solid film layer 19 suitably coated with a selected cholesteric medium 20 is placed upon the member 14, the top of which has thereon a bonding agent 21 such as an adhesive tape. It is also possible to have a retaining hoop placed over the film layer. In Fig. 2, as a vacuum is drawn, film 19 is drawn inward in the middle region of the area defined by the circumference of the member 14. Eventually as more vacuum is drawn, film 19 and medium 20 make a thermally responsive contact with the article 10 in the area defined by the inner circumference of the member 14. The vacuum is maintained during testing and released when the testing is completed.

Fig. 3 (cut along line A d of Fig. 2) shows a film 23 being placed upon member 14 held in place by adhesive 21 which member 14 rests on a substrate 10 to be tested. The film 12 is coated with a filled cholesteric compound layer 11. Typical embodiments of film 12 are saran, Teflon, Polyethylene, polyvinyl alcohol and clear plastics. Another arrangement possible for Fig. 3 is an unfilled cholesteric material layer 11 when the substrate 10 is a dark article which of its own accord will bring out the color patterns of the unfilled cholesteric material 11.

Fig. 4 sets forth a combination of film 12 with the member 14, the film 12 being held in place by adhesive 21

upon which film 12 is a dark opaque film 13 followed by a topmost coating layer of an unfilled cholesteric medium 11. A typical embodiment of film 13 would be a black carbon filled polymeric film.

A further embodiment is shown in Fig.5 in which substrate 10 has a member 14 resting thereon with a film 12 being held in place by adhesive 21 upon which film 12 is filled liquid crystal layer 11 followed by a topmost film 12. Typical embodiments of such a film 12 would be saran, Teflon, etc. Another arrangement possible for Fig.5 is using an unfilled cholesteric material 11 when the substrate 10 is a dark article which of its own accord will bring out the color pattern of the cholesteric material 11. Again layer 12 is the topmost film with a second layer being the bottommost film thus surrounding layer 11 and layer 12 is constituted as set forth above. It is also possible to have the layer 12 which comes in contact with the substrate 10 when vacuum is applied comprised of a dark opaque layer when using an unfilled cholesteric medium on a light colored substrate 10. (Typical embodiment as per Fig.4)

Fig.6 shows a dark opaque film 13 resting on the hollow-member 14 with an unfilled cholesteric layer 11. The dark opaque layer 13 can be of the same materials as listed for layer 13 in Fig.4.

After a thermally responsive contact has been achieved between the cholesteric medium and the article to be tested, application of heat is commenced by a number of means such as heat lamps, circulating fluids, enclosed heating ovens, electrical resistance setups and any device for impinging hot air currents so that the temperature of the article 10 and the cholesteric medium 11 are heated to a temperature producing at least a first color transition for areas of the cholesteric medium. At this point it should be noted that any discontinuities in the substrate 10 will have different thermally responsive characteristics being shown in the cholesteric layer 11 so that discontinuities will be defined by a color discontinuity within the cholesteric layer 11. Heating can further be conducted until a multiplicity of color transitions takes place within the cholesteric layer at the point of the discontinuity in the substrate (that is, depending on the composition of the liquid crystal mixture being employed, the color changes will normally be from clear to red to yellow to green to blue on heating and vice versa on cooling).

It is also possible to record the thermal patterns which develop by means of motion pictures, sketches, etc. Such recordings can be used to very accurately form overlays on the part and precisely locate the exact configuration of the discontinuity detected.

WS have also studied the feasibility of preparing (by encapsulation) sandwiches of liquid crystals using very thin (in the order of 0.001 inch) film (typically saran wrap, Teflon or polyethylene films) to permit inspection of surfaces without the necessity of painting them each time they are tested. The objective of this preparation is to obtain an encapsulated cholesteric film which can be easily manipulated without coming off on the person's hands who is handling the film or being left on the part being tested. To produce such thin films, we use the vacuum member 14 described above to draw the thin film, for example, saran wrap, tight and then paint the film with liquid crystals. The first film is then cut to the inner dimensions of the vacuum frame (member 14) and a second film is placed on the frame. The frame is next placed over the first film so as to have the edges of the film within the circumference defined by the vacuum frame. When the frame is re-evacuated, the second film is pressed against the liquid crystal layer and forms an air-free sandwich. The sandwich can then be placed on the surface of an article for testing and reused repeatedly. Such sandwiches have very high, efficient thermal responsiveness when molded to said substrate. It is readily apparent that such permanent sandwiches are easily handled and add an efficiency factor to any nondestructive testing applications.

Application 11

THERMOMETER

It is a prime object of the present invention to provide an improved clinical thermometer which is relatively inexpensive, fast-acting, simple to read, unbreakable, as well as otherwise harmless, and thereby particularly suited for throw-away use.

Referring to Fig.1, the embodiment of the invention shown therein comprises a plurality of hollow, substantially-cylindrical sensor cells, ten such cells being illustrated and numbered 12a to 12j, containing temperature responsive liquid compositions 14a to 14j, such as hysteretic cholesteric liquid crystalline compositions of the type such as set forth, for example, in copending U.S. patent application Ser. No. 557,060, Filed June 13, 1966 and assigned to the assignee of the patent application. These compositions exhibit a certain color, green for example, when initially in a cholesteric phase below a precise threshold temperature, turn colorless upon reaching such temperature and increasing thereabove, and retain such colorless condition for a significant interval of time following return to and below such threshold temperature. By controlling the formulation of such compositions 14a to 14j, precise different threshold temperatures can be obtained for the several sensor cells 12a to 12j. For example, cells 12a to 12j can be made responsive to body temperatures ranging from 98°F to 102°F in steps of 1/2°. This spans a

FIG. 4

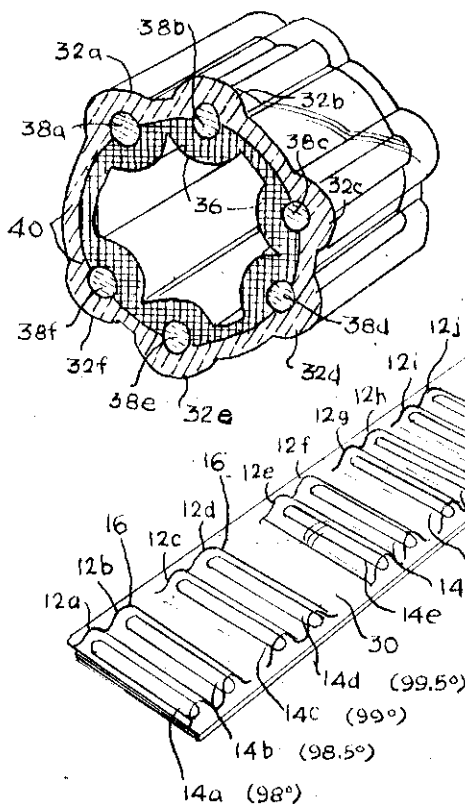


FIG. 1

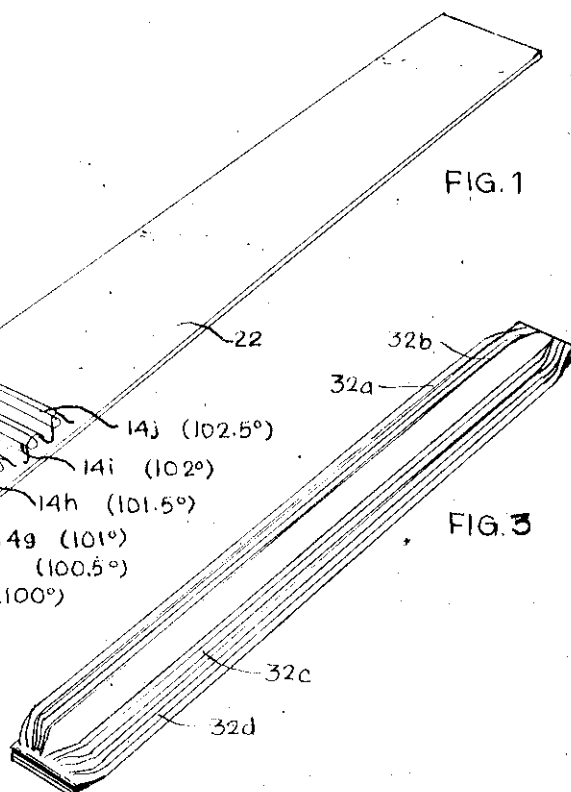


FIG. 3

FIG. 2

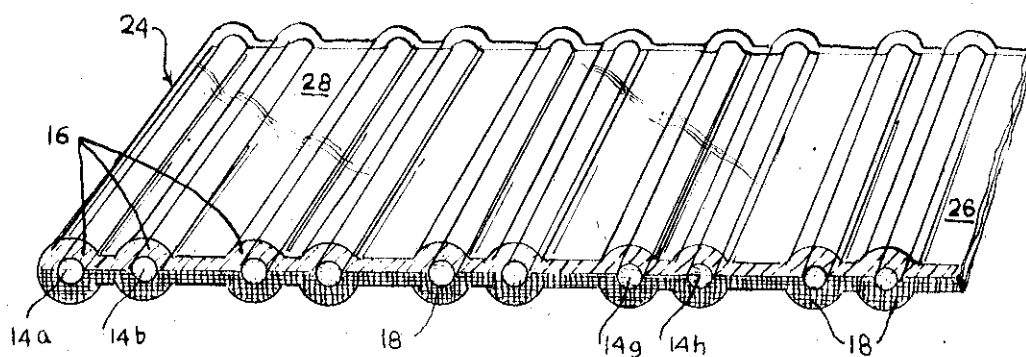
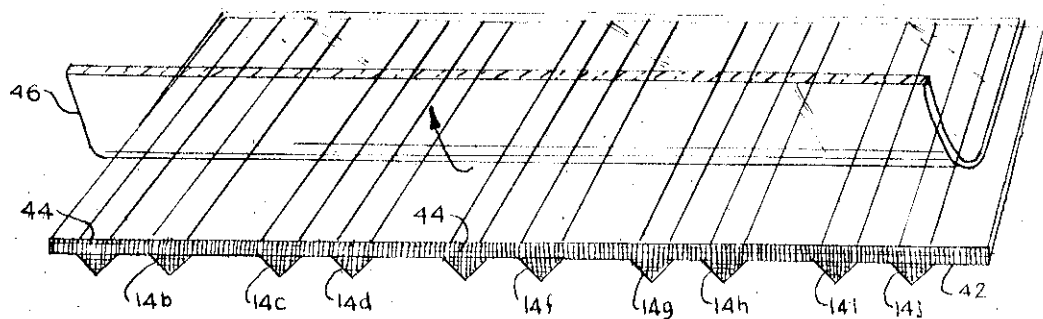


FIG. 5



range from subnormal body temperature to fever temperatures. The sensor cells 12a to 12j when containing such liquid crystal compositions and disposed within a patient's mouth are fast acting and susceptible to threshold-temperature-response within ten seconds.

As is apparent from the showing in Fig.1, the several different prime-temperature responsive cells 12a, 12c, 12e, 12g, and 12j are arranged in groups of two with their $1/2^{\circ}$ complements and are spaced apart in such groups to afford ready identification and differentiation of those temperature sensor cells which have responded to their threshold temperatures from those cells which have not so responded.

In the chosen example, those sensor cells 12a to 12j which have not been subjected to their threshold temperatures will retain their initial color, green, for example, while those sensor cells which have been subjected to their threshold temperatures will have changed to the colorless state.

In the case of use of such liquid crystal compositions, the initial color is enhanced by a dark background, such as black, for example, so that in their non-responsive condition the sensor cells 12a to 12j will exhibit their initial color condition, while in their threshold-temperature-responsive condition in which the liquid crystal composition turns clear, such sensor cells will appear black, in accord with the black background as is observed through the then clear liquid crystal composition filling such cells.

In accord with the Fig.1 construction and as is apparent also from Fig.2, the sensor cells 12a La 12f each comprises an elongated transparent rounded upper wall 16 through which the color state of the liquid crystalline composition within such cells may be observed; such rounded walls serving to magnify the appearance of such compositions, as well as to provide separating indentations on the surface of the thermometer which can be recognized visibly in assist to distinguishing the several cells, one from the other, and thus facilitate counting of the number of cells from one end to of the thermometer which have experienced threshold-temperature-response.

Also in accord with use of such liquid crystal compositions, each of the sensor cells 12a to 12j will have a dark or black pigmented layer or background therebeneath. In behalf of economy in manufacture of fabrication such dark background may be furnished by dispersal of pigmentation throughout the thickness of the bottom wall 18 of each cylindrical sensor cell as shown, or sprayed on as a coating on such wall.

The thermometer configuration in the embodiment of Fig.1 is tab-like, with the array of sensors 12a to 12j arranged at one end of an elongated support means in the form of a thin rectangular tab 22. The overall dimensions of such tab-like thermometer may be, for example, a quarter of an inch wide and about two inches long; with the array of ten sensors extending about three quarters of an inch along one end of

the tab 22, which is relatively small, relatively conservative in material, and readily insertably in the patient's mouth.

In behalf of economy of fabrication, the walls of the sensor cells 12a to 12j can be formed integrally with the tab 22 of a suitable thermoplastic material, such as an ionomer resin, by extrusion. Referring to Fig.2, the tab 22 and the walls 16 and 18 of the cells 12a to 12j can be formed integrally by extrusion and filled with the liquid crystal compositions to form a continuous sheet 24 having a needle part 26 and a sensor cell part 28. Subsequent to such formation of the sheet 24, such sheets may be subjected to indentations (not shown) by a heated roller, or other suitable joining means, transversely of the Direction of extension of the continuous liquid-crystalline-composition-containing convolutions or cylinder parts to obtain sealing of the ends of such cylinders to form the discrete sensor cells, simultaneously with or following which the sheet 24 separated along such indentations to obtain individual thermometers. In the use of liquid crystalline compositions according to the present state of the art and formulation of such compositions where the cell sealing is obtained by application of heat, a thermoplastic material needs to be chosen which will soften sufficiently to obtain such heat sealing and fusion between layers at temperatures which will not alter or destroy the temperature responsive properties of such compositions.

In accord with the preferred feature of the invention, the material of which the thermometer is composed should be somewhat nonrigid, or flexible, in order to enjoy the advantage of such thermometer being unbreakable.

The number of sensor cells 12 which the thermometer may employ is somewhat arbitrary. For example, perhaps only two or three response temperatures may be desired to merely give indication of above, normal, and/or below normal body temperatures, or even a single response temperature to indicate an above normal condition, following which more precise information as to the specific body temperature could be obtained by use of an auxiliary thermometer of the conventional type. In this latter case, use and interpretation of such a thermometer is simplified, and will satisfy the majority of hospital needs. Further investigation of the patient's temperature need be made only when abnormal.

In the configuration shown in Figs. 3 and 4, six temperature cells, 32a to 32f respond to respective body temperatures of 98°F, for example. Circumferential spacing between cells can be employed to readily identify and distinguish between such cells and between groups of such cells.

Referring to Fig. 4, the cylindrical configuration also can be fabricated by extrusion to provide a black inner layer 36 to 38f between inner layer 36 and outer clear layer 40

which 1a rounded in the region of the sensor cells for magnification of appearance of the liquid crystalline compositions thereunder as well as for distinguishment of the sensor cells from each other. The Fig.3 configuration is one which would accommodate oral as well as rectal use, but would tend to be somewhat more difficult to read than the tab-like configuration of Fig.1.

Referring to Fig.5, a third concept of fabrication of tab-like thermometers somewhat similar to that of Fig.1 can be arrived at by provision of a dark-pigmented bottom sheet 42 having a plurality of parallel-arranged troughs 44 formed in an upper surface thereof which could be filled with the liquid crystalline materials 14a to 14j MA covered for containment by a transparent upper sheet 46 of clear plastic material bonded to such bottom sheet. Following this, the sandwich assemblage of sheets could be indented and sealed along lines transverse to the direction of extension of the troughs to form discrete sensor cells similar to those of the Fig.1 thermometer and severance of the thermometers along the lines of seal indentations.

Where the temperature responsive liquid composition employed for the sensor cells of the thermometer of the present invention are hysteretic cholesteric liquid crystalline compositions, the desired threshold temperatures can be obtained by those versed in the art of formulating such compositions with a relatively high degree of accuracy,

such, for example, as within a tenth of a degree Fahrenheit. By way of example, a threshold temperature of 98°F. can be obtained by a composition including 26 percent cholesterol chloride, 73 percent cholesterol oleyl carbonate and 1 percent triolein, and a threshold temperature such as 101°F might be obtained by a composition including 26 percent cholesterol chloride and 74 percent cholesterol erucyl carbonate. The rate of response of these materials to increase in temperature to their threshold values can be a matter of several seconds, as compared to three minutes for the usual prior art clinical thermometers. Once having experienced a color change upon temperature increase, these materials retain their color-altered state for a sufficient period of time, for at least a matter of minutes, upon return to subbody temperature, thus affording ample time for reading the thermometer without erasure by the room temperature conditions to which the thermometer becomes exposed after removal from the patient.

Application 12

LIQUID CRYSTAL COMPOSITIONS

This invention relates to a series of compositions of cholesteric materials of two or more components which have increased sensitivity in temperature responsive color patterns.

Testing of adhesively bonded structures is conveniently carried out with filled cholesteric liquid crystals. A filled cholesteric liquid is a composition of cholesterol which has incorporated and dispersed therein various other substances. The test surface is initially warmed to facilitate spreading of the cholesteric film. The filled material is then brushed or sprayed (with approximately 10 percent benzene added) onto the surface and brushed until a uniform color pattern is observed when the surface is slowly heated to a temperature to which the cholesteric material responds. The bonded structure is then rapidly cycled through the range of temperature to which the cholesteric materials respond. Heating is generally accomplished with a bank of 1000 watt photoflood lamps positioned to provide even heating of the test surface. The intensity of the lamps is controlled by variable autotransformers. Convective cooling is used to lower the temperature of the panel following application of heat from the flood lamps. As the bonded panel is quickly heated and cooled, voids, lack of adhesive and other flaws are

revealed as temperature anomalies which produce a color contrast over the flaw. These local temperature differences arise due to variations in the thermal diffusivity of the bonded structure in the vicinity of the bonding irregularity as compared with the more uniform thermal properties of well-bonded regions. Bonding flaws may then be outlined on the surface with a marking device and/or the cholesteric temperature pattern photographed to obtain a permanent record. Following testing, the cholesteric materials and filler are removed by cleaning the surface with a flexible rubber scraper. The last traces of the cholesteric materials are removed by wiping with a rag containing benzene.

Cholesteric liquid crystal mixtures suitable for temperature visualization over a given range are prepared by initially purifying the constituents by recrystallization from hot ethanol or by washing with ethanol at room temperature if the raw materials are relatively pure. The necessary percentages of the various constituents are selected from graphs similar to Figs.1 through 4 to achieve light scattering at the desired temperatures. The solid compounds combined in these mixtures are weighed to 0.1 percent and mixed in a suitable container which is then heated to approximately 80°C. The mixture is stirred continuously for at least 10 minutes. Filler material is

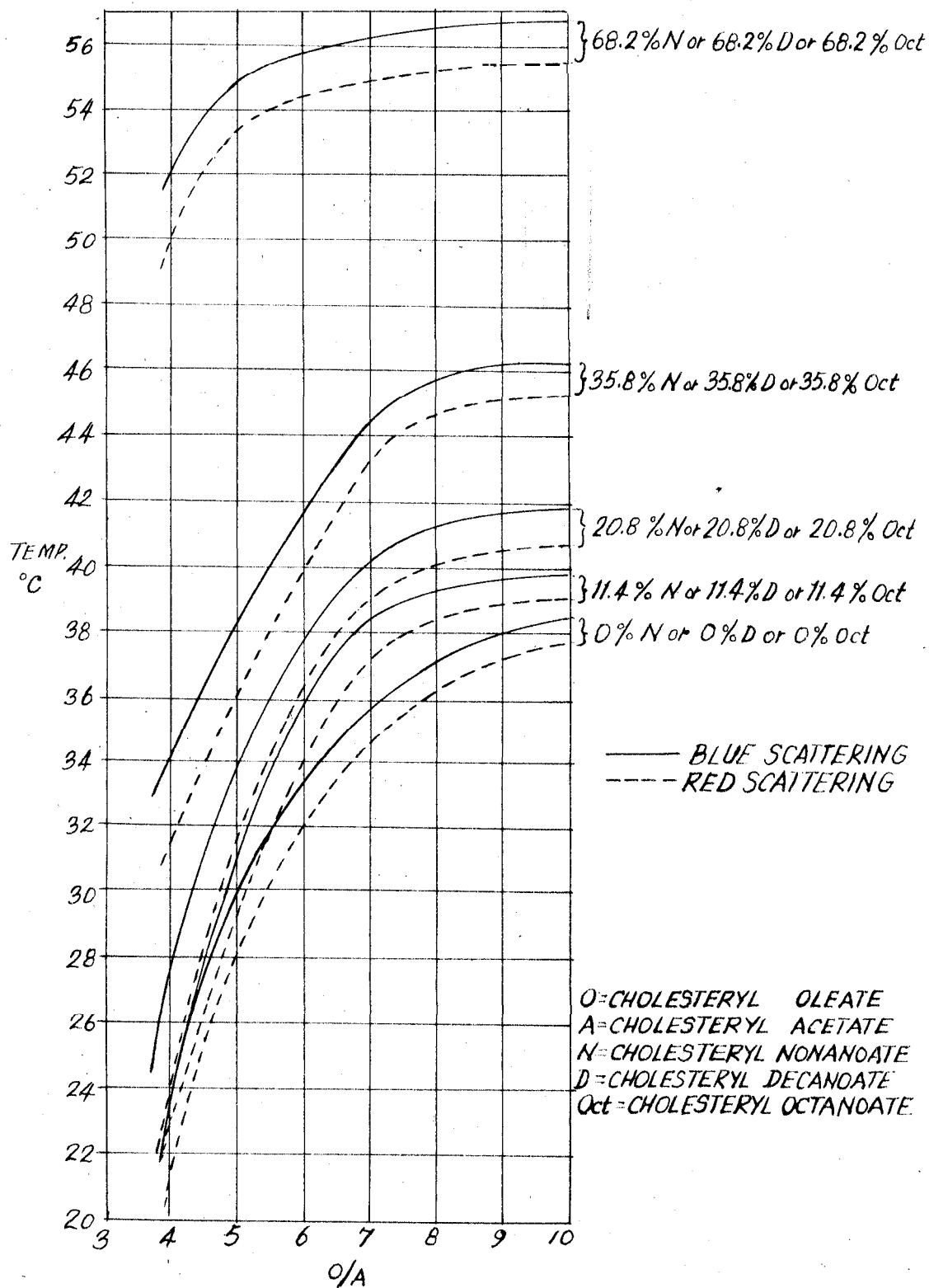
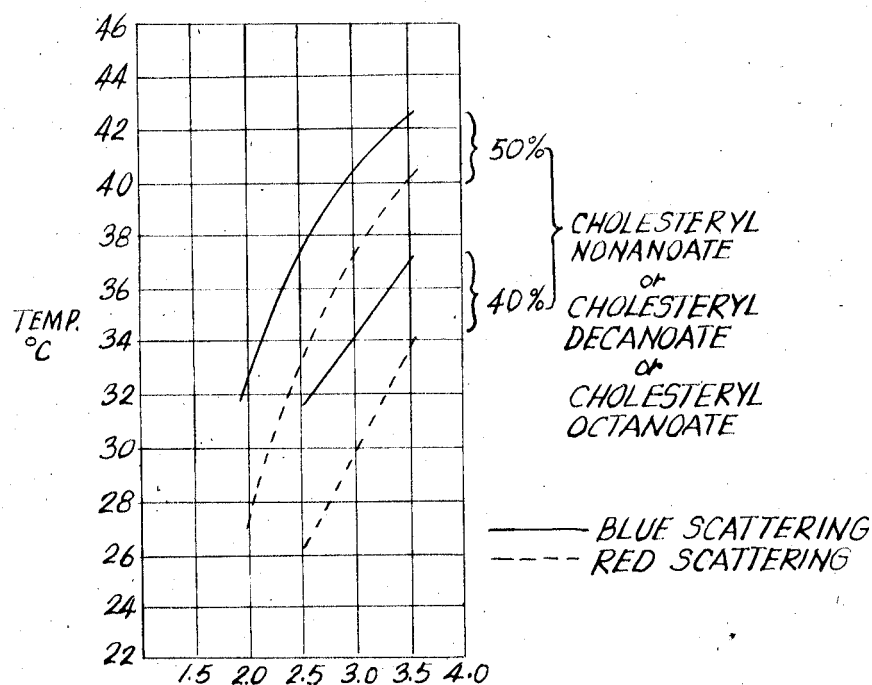
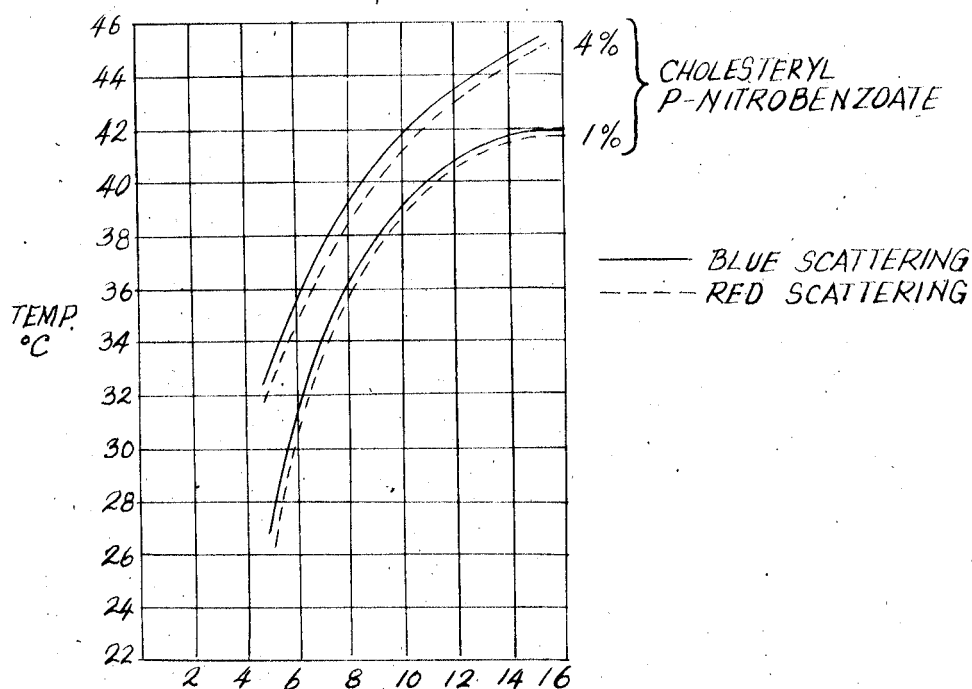


FIG 1



% CHOLESTERYL OLEATE 1% CHOLESTERYL PROPIONATE
or % CHOLESTERYL OLEATE 1% CHOLESTERYL ACETATE

FIG. 2



% CHOLESTERYL OLEATE 1% CHOLESTERYL ACETATE
or % CHOLESTERYL OLEATE 1% CHOLESTERYL PROPIONATE

FIG. 3

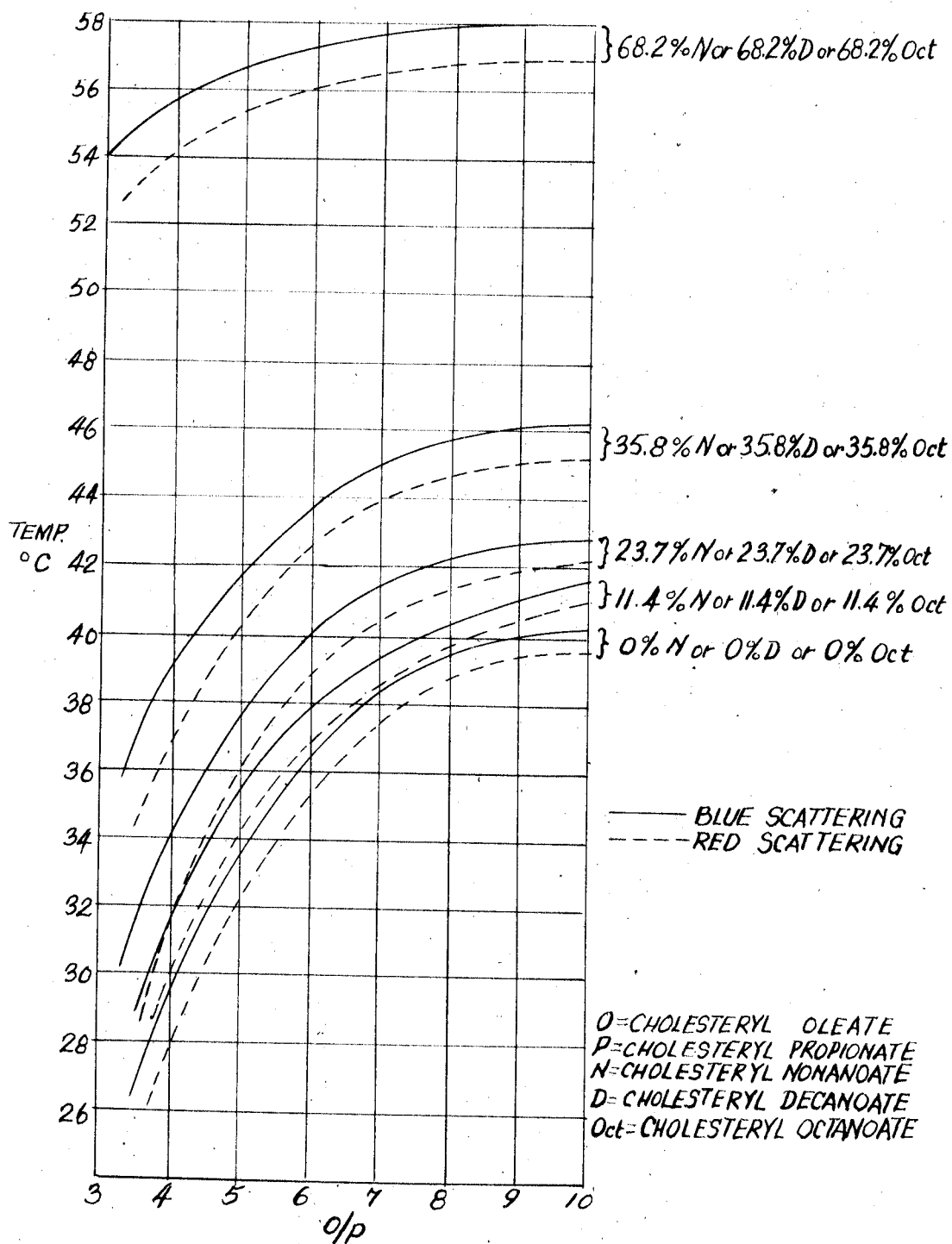


FIG. 4

then added to the liquid crystals and stirring continued for an additional 10 minutes to insure intimate mixing of the filler and cholesteric materials. Upon cooling, the filled cholesteric materials are stored at approximately 0°C. or in an evacuated container at room temperature. These storage procedures are effective in stabilizing the color temperature behavior of the mixtures for several weeks.

Experimentation with the properties of cholesteric materials led to a number of combinations of chemicals which show desirable properties of viscosity, speed of response, temperature sensitivity, and reversible color-temperature behavior.

~~It is suggested that~~ A three component composition of selected constituents will offer the sensitivity needed in cholesteric materials. The cholesteryl compositions ~~Y~~ ~~are suggested~~ a basic component providing sensitivity by color change at low relative temperature (approximately 0° C to 60°C-- a normal testing temperature range for employing cholesteryl materials) in the presence of a second component which has the function of narrowing temperature response to a small range of temperature for the occurrence of the color phenomena (red to blue transition in 1°C.) with a third component being added to adjust the actual temperature at which the color phenomena will occur.

~~From the group consisting of~~ the basic component can be selected from the group consisting of cholesteryl oleate, the second component can be selected from the group consisting of cholesteryl nonanoate, cholesteryl decanoate, cholesteryl octanoate and cholesteryl paranitrobenzoate, and the third component can be selected from the group consisting of cholesteryl acetate and cholesteryl propionate.

The amounts of the various constituents found to produce light scattering over useful temperature increments are :

Percentage by wt.

Cholesteryl nonanoate, or decanoate, or octanoate	0 to 70
Cholesteryl oleate	24 to 91
Cholesteryl acetate, or propionate.....	2 to 21

And also

Cholesteryl p-nitrobenzoate.....	1 to 4
Cholesteryl oleate	80 to 91
Cholesteryl acetate, or propionate	5 to 16

The color-temperature behavior of a series of mixtures utilizing the above mentioned components are shown in Figs. 1 to 4. Dashed lines represent the temperatures at which red scattering commences. As the temperature is increased light is scattered successively in the orange, yellow, green,

blue and violet regions of the visible spectrum. The solid lines in the figures refer to temperatures at which blue scattering is observed.

In addition to the above compositions, ^{They} ~~They~~ further improved their response and distinctive color patterns by making an addition of a filler material selected from the group consisting of carbon, carbon black, black pepper powder, finely divided metals, finely divided non-metals and combinations thereof. Examples of finely divided metals and non-metals which have been successfully embodied are nickel, molybdenum and silicon. Typical but not limiting particle sizes have been used from a range of 100 mesh to 500 mesh by the Tyler Screen Classification System. It has been found that an addition of an opaque filler material selected from the above group, when incorporated into a liquid cholesteric material according to the above compositions in the range of 3.0 percent to 30 percent by weight brings an improvement in their application for temperature visualization on reflective and nonreflective surfaces (e.g., metal surface and human skin respectively) and transparent materials (e.g., glass, Plexiglass and plastic). The incorporation of the filler eliminates using a black paint background, thus eliminating the problems associated with this black paint background.

Liquid crystals, particularly with filler added, provide a rapid and very sensitive means of mapping human skin temperatures. The darkened cholesteric materials are especially useful in applications where movement of the skin, as around joints, normally causes cracking of underlying black background paints. Several studies have been conducted in a variety of medical fields. Pediatricians are evaluating these materials as remote temperature indicators on infants in incubators. In a normal infant, the feet should be about 1°C . below the abdomen temperature. In a normal infant, the feet should be about 1°C . below the abdomen temperature. By placing liquid crystal layers on both of these areas of the infant, the respective temperatures of each area are quickly indicated. If the relative temperature difference increases beyond this, it may be an indication of an infectious disease causing vasoconstriction. If the relative temperatures are less than a degree apart, the incubator may be too warm.

The temperature indications provided by the materials set forth above reflect when vein grafts have successfully restored circulation to the extremities. The success of removal of arterial blockage is also reflected by the increase in temperature over arteries lying close to the skin. If the temperature raise does not occur, it is likely that the blood vessel has not been completely opened. The efficiency of vascular activity at sutures, skin flaps,

and wounds after surgery may also be indicated by skin temperature patterns. A plastic surgeon is studying this as a means of reducing the waiting time before commencing second-stage constructive surgery.

The damage to blood vessels in areas of second and third degree burns may produce localized temperature anomalies visible by liquid crystals. To prevent infection in areas of severe burns, a common practice is to apply silver nitrate to the area. This darkens the skin and makes visual examination of the burned tissue difficult. With layers of cholesteric materials applied to small controlled areas of third degree burns in laboratory animals, we have accurately outlined the extent of severe burning due to an appreciably lower temperature indication over these areas. This would enable early removal of the tissue in the third degree areas and allow grafting to commence shortly afterwards. As above noted, these applications are not currently possible with cholesteric materials which require an ~~xxx~~ opaque background.

Many applications and utilizations of the composition set forth in this invention have been found. A liquid crystal composition can be employed effectively to test adhesive bonding honeycomb structures for various faults and flaws in the fabrication of the structure.