United States Patent

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[73] Assignee **The United States of America as represented by the Secretary of the Navy**

[54] **ATHERMAL ACOUSTIC LENS**
12 Claims, 10 Drawing Figs.

[52] **U.S. Cl.** **181/.5, 340/8**
[51] **Int. Cl.** **G01v 1/16**
[50] **Field of Search** ..... 340/8 C, 8 LF, 5; 181/.5

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ABSTRACT: This invention is an acoustic refractor that contains a combination of individual fluid lens elements having different indices of acoustic refraction which cooperate to produce a uniform acoustic refraction over a wide range of ambient temperatures.

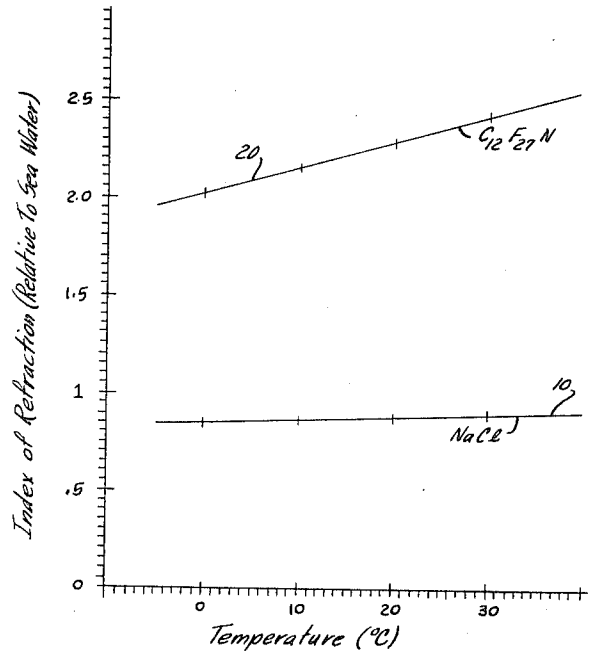


FIG. 2

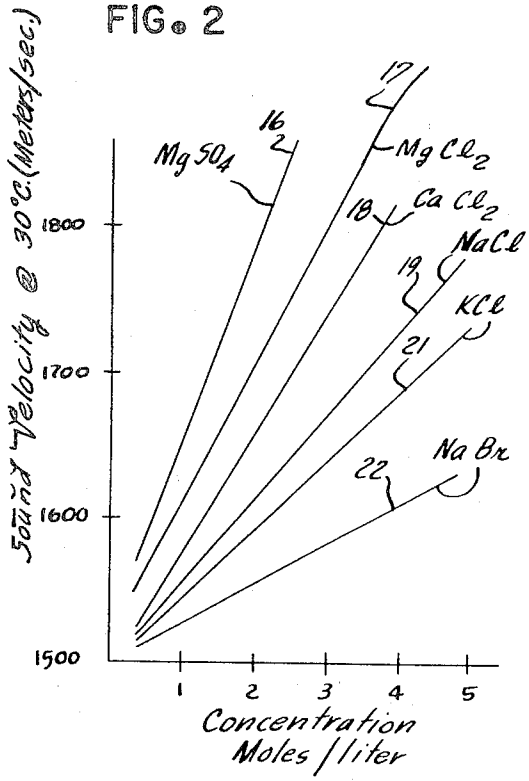


FIG. 3

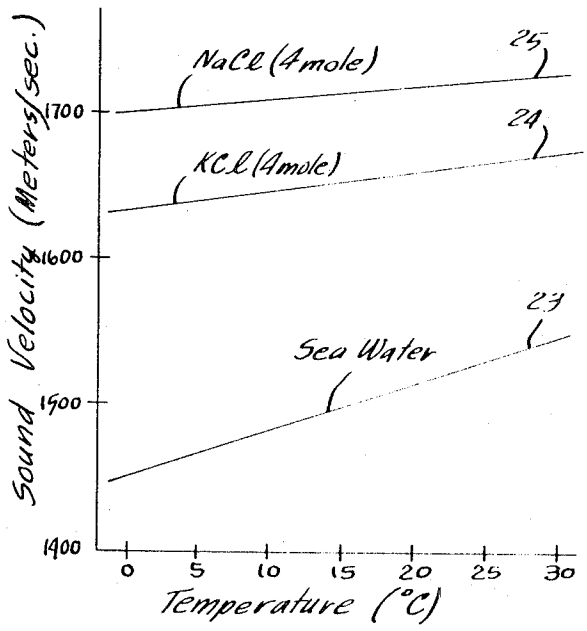
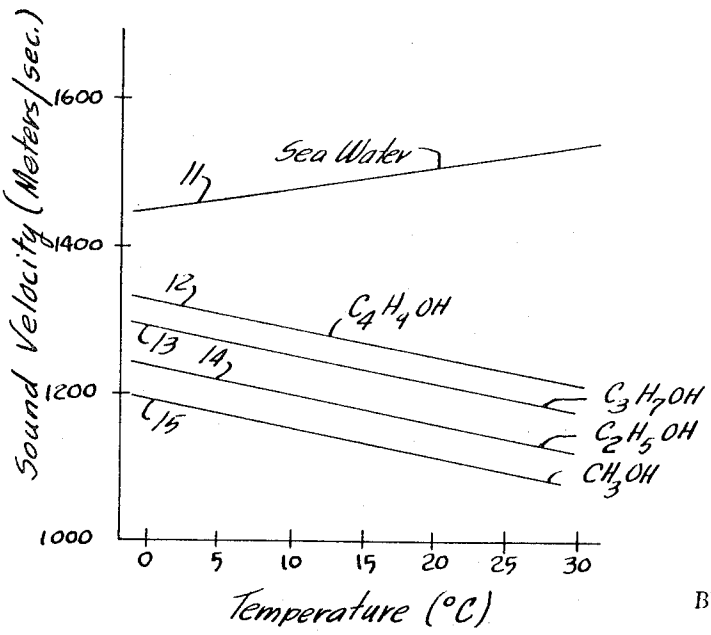


FIG. 1



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FIG. 4

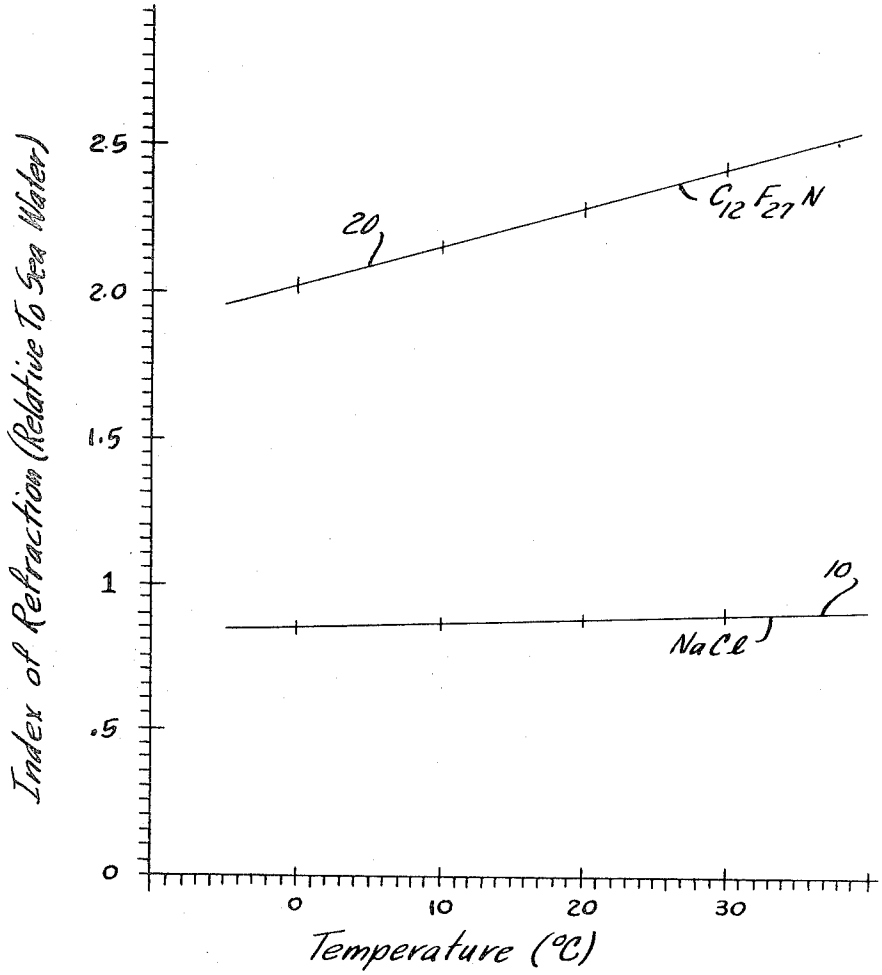
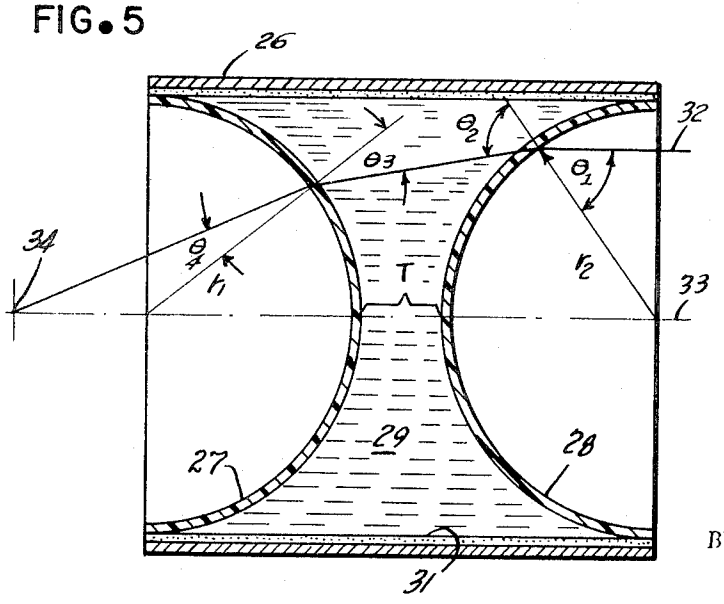


FIG. 5



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FIG. 6

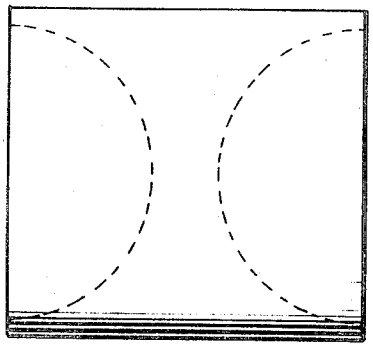


FIG. 7

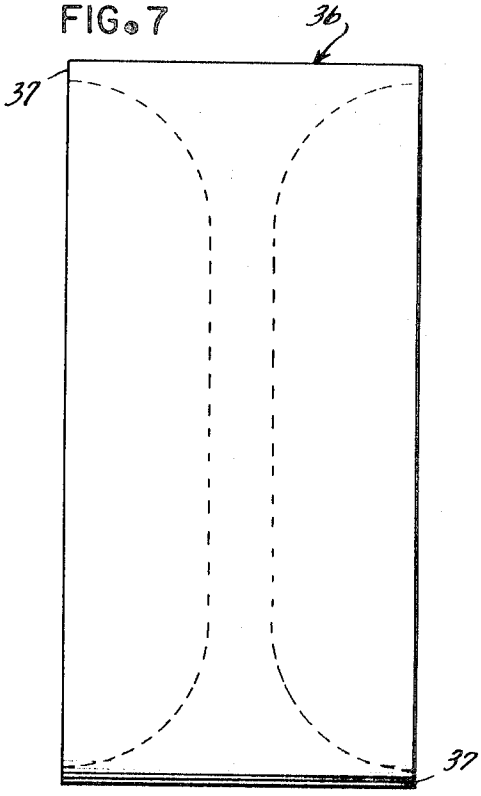
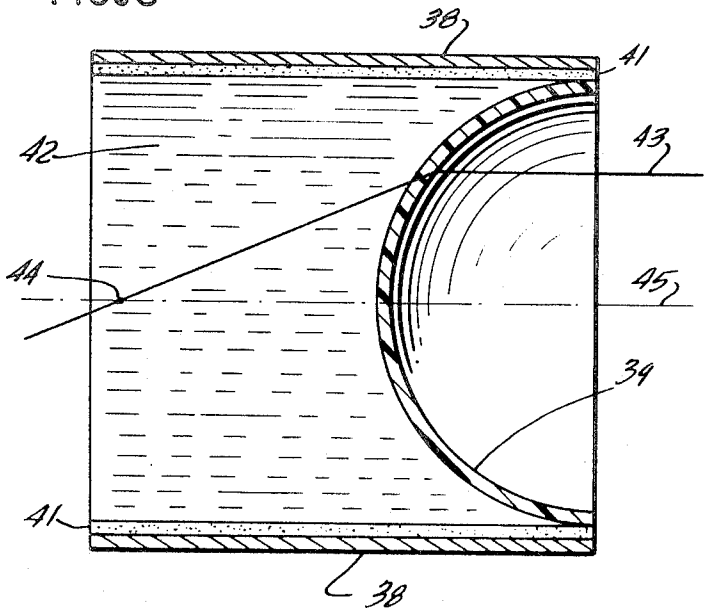


FIG. 8



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FIG. 9

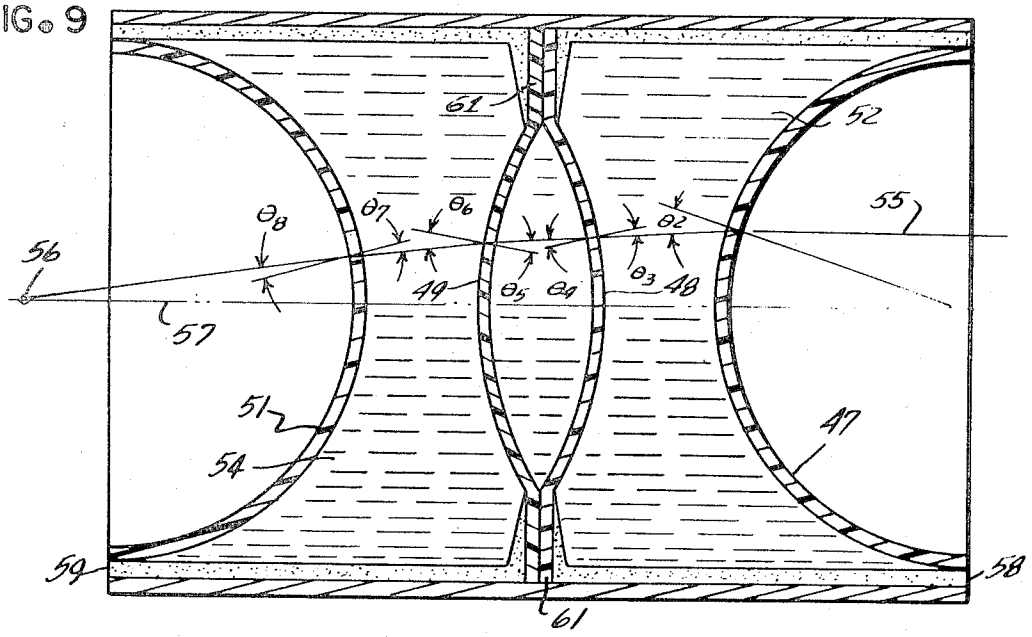
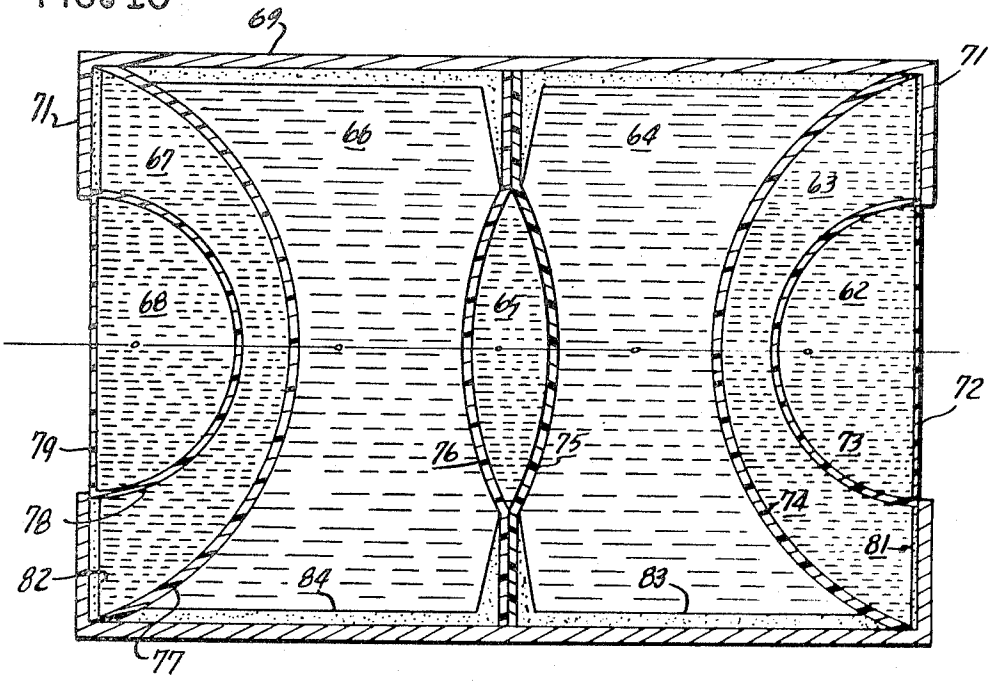


FIG. 10



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ATHERMAL ACOUSTIC LENS

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention pertains to the field of acoustics. More particularly, the invention pertains to the acoustic refractor aspects of the acoustic arts, and in greater particularity, but not by the way of limitation, the present invention pertains to an acoustic lens which focuses acoustic energy impinging thereon. In greater particularity the invention as herein disclosed provides an acoustic lens which focuses acoustic energy impinging thereon to the same focal plane over a wide range of temperatures. This lens is properly described as being athermal because of this unique property.

A great many acoustic devices of the prior art employ a focused acoustic transducer to generate acoustic energy or to receive acoustic energy. In many such devices, a lens which is spatially separated from the transducer is the focusing agent.

The lenses of the prior art which are most effective for underwater applications use a fluid refraction material which, because the sound velocity therein is slower than in the ambient sea water, is formed to follow the design practices of their optical counterparts. This results in a double convex lens which focuses impinging acoustic energy at a predetermined point on a focal plane determined by the geometric considerations of the location and bearing to the source of the acoustic radiations and the focal length of the lens. Such lenses may be made to be fixed focus and mounted together with the transducer in a unitary assembly. However, difficulty is encountered when the units incorporating these lenses are operated in waters of temperatures other than that for which the lens was designed.

This temperature instability of the lenses of the prior art is due, in some part, to the fact that the propagation of the acoustic energy through the medium and through the fluid lenses themselves is a function of the temperature. Further, the gradient of temperature change is of an opposite sense so that of sea water, the most common operational medium. In such devices, the lens and transducer must be mounted in such a fashion as to permit relative movement therebetween to correct the focus changes brought about by the temperature variations when the operating device is moved into different temperature waters. While the focus may be corrected in this fashion, there are other faults introduced by the temperature changes which cannot be so easily corrected.

SUMMARY OF THE INVENTION

This invention overcomes the deficiencies of the prior art by providing a lens which is uneffected by changes of temperature over the normal temperature range encountered in the earth's oceans. This highly desirable result is obtained by employing a lens comprised of a plurality of lens components made of solutions of inorganic salts separated by acoustically transparent septa made of rubber or the like. Because the propagation velocities in the component lens elements are greater than velocities in the surrounding medium, the lens components of a positive lens combine to form shorter transmission paths on its axis than along its marginal positions. The lenses may use aspherical elements, as well as the more common spherical and cylindrical elements. The lens may, if desired, employ a metallic mounting with relatively good thermal conduction and an anechoic layer on the interior thereof. As will be explained herein, these individual features cooperate in a new and improved fashion to produce a lens of exceptional performance not heretofore obtainable with the prior art constructions.

It is therefore an object of this invention to provide an acoustic refractor which is substantially uneffected acoustically by changes in the temperature thereof.

A further object of this invention is to provide an improved acoustic lens with uniform thermal response characteristics.

A further object of this invention is to provide an acoustic lens with fluid components, including at least one component comprised of an aqueous solution of inorganic salts.

Another object of this invention is to provide a compound acoustic lens having components with a faster sound propagation velocity than that of the ambient medium.

A still further object of this invention is the provision of an improved construction for an acoustic lens comprised of a plurality of individual contiguous fluid components.

Yet another object of this invention is the provision of an acoustic lens which exhibits a very small change of focus over a wide temperature range.

Other objects and many of the attendant advantages will be readily appreciated as the subject invention becomes better understood by reference to the following detailed description, when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graphic representation of the temperature variations and the effect on the velocity of acoustic propagation for fluid lens substances of the prior art;

FIG. 2 is a graphic representation of the effect on acoustic propagation velocity of increasing the molarity of an inorganic salt solution transmitting acoustic energy;

FIG. 3 is a graphic representation of the effect of temperature on the acoustic propagation velocity in solutions of potassium and sodium chloride, as compared with sea water;

FIG. 4 is a graphic showing of the effect of temperature on the refractive index of a sodium chloride solution and a common organic lens substance used in acoustic lens construction;

FIG. 5 is a cross section of a concave lens structure according to the invention;

FIG. 6 is an exterior view of a simple converging lens of spherical surfaces;

FIG. 7 is an exterior view of a simple converging lens of cylindrical surfaces;

FIG. 8 illustrates, in longitudinal section, an alternative arrangement of the invention with a single refracting surface and an internal focal point;

FIG. 9 is a longitudinal section of a three element acoustic lens according to the invention; and

FIG. 10 is a longitudinal section of a five element acoustic lens according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the present invention and the profound improvements made possible thereby may be more readily understood by reference to the graph of FIG. 1. As shown, the velocity of sound in sea water, as represented by plot 11, and in the common component substances of acoustic lenses, as represented by plots 12, 13, 14, and 15, is a linear function of temperature. However, it should be noted that the slope of plot 11 is of a different sign or direction than that of plots 12–15 representing methanol, athanol, n-propanol, and n-butanol, respectively.

The amount that an acoustic energy wave is refracted, i.e., the angle that the direction of propagation is bent from the direction of travel, when passing from one medium into another, is determined by the index of refraction between the two mediums. This relates to the relative acoustic propagation velocities of the two mediums according to the following equation:

$$\sin \theta_1/\sin \theta_2 = C_1/C_2, \quad (1)$$

where

Θ_1 is the angle made by the impinging energy wave in said first medium with respect to a normal to the interface between the two mediums at the point of interception by the energy;

Θ_2 is the angle made by the radiation in said second medium with respect to a normal to the interface between the two mediums at the point of interception by the energy;

C_1 is the velocity of propagation in the first medium; and

C_2 is the velocity of propogation in the second medium.

From the above equation, it may be seen that the temperature characteristics of the organic compounds permit a lens made therefrom to function only over a relatively narrow range of temperatures. Further, since the lens is made from a relatively pure chemical, the index of refraction between adjacent mediums at a given temperature is dependent upon the particular materials involved.

Referring now to FIG. 2, there is shown a graphic representation of the effect on the propagation velocities brought about by changing the concentration of inorganic salts in solution. Curve 16 represents the aqueous solution of magnesium sulfate. Similarly, curve 17 corresponds to aqueous solutions of magnesium chloride and curves 18, 19, 21, and 22 correspond to aqueous solutions of calcium chloride, sodium chloride, potassium chloride, and sodium bromide respectively. As shown by the illustrated curves, the sound propagation velocities in the aqueous solutions of inorganic salts may be controlled by adjusting the concentration of the inorganic salt. This permits the index of refraction of a lens made therefrom to be adjusted over usefully wide ranges to produce the desired refraction from a particular configuration as might, for example, be dictated by an adjacent element. This ability to tailor the index of refraction to the particular curve is an immensely useful design attribute of the structure of the invention.

The practicable limit on the amount of salt to be used in the aqueous solution is imposed by the lower temperature limits at which the device is to be operated. That is, a molarity must be chosen such that the solution is unsaturated at the lowest anticipated temperature to prevent solid granules of the salt from precipitating out of solution within the lens element. For sodium chloride, four molar solutions have worked well in developmental studies. This concentration provides an optimum compromise between a high index of refraction and freedom from becoming saturated at lower temperatures.

Referring to FIG. 3, curve 23 represents the velocity of sound in sea water as a function of temperature, while curves 24 and 25 show similar characteristics of 4-molar solutions of potassium chloride and sodium chloride. As indicated by curves 23–25, the velocities of propagation in the two illustrated saline solutions are greater than the corresponding velocity of sound in sea water of the same temperature. Likewise, it may be noted that the rate of change and direction of change are approximately the same as for sea water. This stands in marked contrast to the organic refractive materials of the prior art, as illustrated in FIG. 1 and discussed above.

The marked difference in the thermal effect on the propagation velocities is shown in the index of refraction variations illustrated in FIG. 4. Curve 10 shows the variation of the index of refraction of a four molar solution of sodium chloride with respect to sea water. Curve 20 shows a much greater change for Heptacosafluortributylamin ($C_{12}F_{27}N$), another common organic material used in prior art acoustic lenses. Most other organic substances show an even greater variation of index of refraction.

It should be noted that mixtures of inorganic salts may be used to good effect in the practice of applicant's invention. Such mixtures may be used to produce a desired index of refraction or other desirable properties. The exact proportions at which the various saline solutions are combined to produce the desired effects may be arrived at by suitable experimentation, since the developmental studies indicate that the exact properties of a solution of a mixture of salts are difficult, at the present time, to accurately predict. In this regard the mixing of salts in aqueous solution is similar to the metallurgical arts in being somewhat empirical. The results obtained by the various saline mixtures are reproducible with similarly constituted mixtures so a uniformity of product may be assured. It would be appear that the acoustic properties of saline solutions follow, in a complex fashion, the thermodynamic properties. For purposes of illustration, only solutions of a single salt will be considered.

Because the velocity of propagation of sound is greater in the inorganic salt solutions, a concave lens surface concentrates or focuses, impinging acoustic energy. Lenses made according to the invention are distinguished by being concave rather than the familiar convex structural arrangements of the prior art organic elements. An example of this construction is shown in FIG. 5.

Referring to FIG. 5, the housing 26 has concave acoustically transparent membranes 27 and 28, which may be made of synthetic rubber, for example, at opposite ends thereof. The interior space between membranes 27 and 28 is filled with a suitable saline solution 29. In the example illustrated, saline solution 29 is of a sodium chloride solution of four molar concentration. The interior of the housing 26 enclosing saline solution 29 may be provided with an anechoic layer 31, if desired. Anechoic layer 31 minimizes lens distortions and aberrations caused by acoustic energy being reflected from the inner surface of housing 26. The length of housing 26 is determined by the radii of membranes 27 and 28, the axial spacing illustrated as the dimension T thereof, and the aperture desired. In the example of FIG. 4, membranes 27 and 28 are hemispherical, providing the maximum aperture for a given radius of curvature, and the length of housing 26 is r_1+r_2+T+ *the thickness of membranes 27 and 28. It should be understood that membranes 27 and 28 may comprise smaller portions of spherical surfaces, if desired. The combined thickness of membranes 27 and 28 is normally so small that it may be disregarded. However, in some constructions, for example, where the ability to withstand great pressures and shock waves is required, the thickness of the membranes may become significant. Even in the instances where the membrane thickness is considerable, the lens of the invention retains its improved thermal properties. Of course, the individual parameters of constructions may be varied to produce a lens having the desired focal length and energy gathering ability in accordance with the practices of good acoustic lens design. In this respect, the radii of membranes 27 and 28 may include valves between* 2.5 cm. and 1.0 m. and the separation T therebetween may include appropriate values between 0.5 mm. and 10 cm. Likewise, the lens may be made with different radii for membranes 27 and 28 to produce an asymetric lens rather than the symmetrical arrangement with equal radii illustrated for purposes of explanation at FIG. 4. Such modifications of the illustrated invention are considered obvious expedients to a person skilled in the art.

The operation of the lens of FIG. 5 may be better understood by considering the path of a marginal ray 32 of acoustic energy impinging parallel to the acoustic axis 33. Ray 32 is refracted toward the central acoustic axis 33 of the lens. Ray 32 impinges membrane 28 at an angle θ_1 and is refracted in saline solution 29 to exit membrane 28 at an angle θ_2 given by the equation:

$$\sin \theta_2 = \sin \zeta_1 C_2/C_1 \qquad (2)$$

where

C_1 is the propagation velocity in the ambient medium; and

C_2 is the propagation velocity in the saline solution.

Ray 32 impinges on membrance 27 at an angle θ_3 which may be determined by geometric considerations including the thickness or membrane spacing T. Ray 32 is again refracted through angle θ_4 in passing through membrane 27 to cross the acoustical axis 33 at focal point 34. The angles θ_4 may be determined in a similar manner to that used to determine θ_2, paying special attention to the fact that the index of refraction changes as the ray passes from the region of high propagation velocity to a relatively slower one, assuming that the lens is immersed in a uniform medium. In one embodiment solution 29 is a 20 percent aqueous solution of sodium chloride, r_1 and r_2 are each 3 cm., axial thickness T is 2 cm. and, in 15° C. sea water, the lens so constructed has a focal length of 6.625 cm.

The lens of the invention may be comprised of surfaces of revolution, if desired, as shown in FIG. 6. In such an instance, the membranes 27 and 28 are spherical surfaces and the lens housing 26 is cylindrically shaped. Such a lens is desirable when the desired beamwidth is narrow and the transducer

with which the lens may be used is of small physical dimensions.

Referring to FIG. 7, a lens 36 is shown to be constructed in a final configuration that is useful when employed in combination with elongated transducers. In this embodiment the membranes 27 and 28 lie along surfaces which may be considered as having been generated by moving the generating curve along a line or plane at right angles to the acoustical axis to produce a lens 36 comprised by cylindrical refracting surfaces and having a generally elongated housing. The ends or lateral marginal portions 37 of lens 36 may be rounded and the refractive surface in the these areas spherical, as in lens 35, if desired. Alternatively, the ends 37 may be left squared, if desired.

Both lenses 35 and 36 are designed to be immersed in an ambient medium, such as sea water or the like, and positioned in cooperative relationship to a suitable acoustic energy transducer, now shown. To this end, they may be made as part of an acoustically opaque housing containing the transducer, in a manner similar to the manner in which an optical lens is mounted on the lens board of a camera body.

FIG. 8 illustrates an alternative arrangement of the invention. A housing 38 provides an outer cover for the lens and supports, at one end thereof, a membrane 39. An anechoic layer 41 serves the same function as layer 31 of the lens of FIG. 4 and is supported on the interior of housing 38. The interior of the lens is filled with a saline solution 42 of a predetermined composition which, for purposes of explanation and completeness, may be a 43 percent solution of calcium chloride.

Membrane 39 is curved such that a marginal ray 43 impinging thereon is refracted to a focal point 44 on acoustical axis 45. Focal point 44 is within the confines of housing 38. This permits the appropriate transducer to be mounted within the protective confines of housing 38 and results in a compact, economical construction but with a single refracting surface. Like the lens of FIG. 4, the lens shown in section of FIG. 8 may be made with the refracting surface either of a spherical or of a cylindrical configuration.

Referring to FIG. 9, a longitudinal section of a triple lens according to the invention is illustrated. Lens housing 46 supports acoustically transparent membranes 47, 48, 49, and 51 to effectively produce three refracting elements 52, 53, and 54 in the volume enclosed therebetween. The elements 52, 53, and 54 cooperate to bring an impinging acoustic energy beam 55 to a focus at focal point 56 on acoustic axis 57. As in the lenses of FIGS. 4 and 7, anechoic layers 58 and 59 may be provided on the periphery of elements 52 and 54, if desired.

As shown, membranes 48 and 49 may have a combined axial thickness and radii of curvature such that refractive element 53 enclosed thereby does not extend completely across the full aperture of housing 46. As is understood by those familiar with lens design, refracting element 53 need extend only to the extent necessary to intercept the marginal rays accepted by refractive element 52. Beyond the critical size where this total interception occurs, the desired thickness of element 53 is the controlling parameter for the lateral extend of elements of this type.

Membranes 48 and 49 are acoustically transparent and must be opaqued in their noncurved, or plane, portions 61 to prevent transmission of energy directly between elements 52 and 54 without intermediate refraction by lens element 53. This opaque septum may be provided by extending the anechoic layer of each of refracting elements 52 and 54 over the plane portions 61 of to produce a stop surrounding refractive element 53.

As illustrated in FIG. 8, there are four refractions, or bendings, of the acoustic beam 55 as it traverses the lens. The angles of refraction are designated as θ_2, θ_4, θ_6, and θ_8 in the illustration while the corresponding angles of incidence are designated as θ_1, θ_3, θ_5, and θ_7. The relationship between the respective angles is as given by equations (1) and (2) above. The refracting elements 52 and 54 may contain the same saline solution, if symmetrical construction is desired. Alternately the composition of the solutions, or the concentration thereof, may be different for elements 52 and 54, if an asymmetric construction is desired. Refracting element 53 is made of a material selected to have a slower acoustic propagation velocity than elements 52 and 54.

Like the previous examples of lens construction described above, the radii of curvature for membranes 47, 48, 49, 51, identified as r_1, r_2, r_3, and r_4 respectively, are chose to produce a lens having the desired focal length and energy gathering properties. Although a wide variation in values for these parameters is possible, the respective radii lie within the ranges indicated below.

-25 mm. $<r_1<-1$ m.
60 mm. $<r_2<1.6$ m.
-60 mm. $<r_3<-1.6$ m.
25 mm. $<r_4<1$ m.

The negative sign is indicative of the direction of curvature being concave in the direction of energy transmission.

By way of more specific example of the preferred construction, a lens of the configuration illustrated in FIG. 8 having a focal length of 273.82 mm. in fresh water at 22.5° C. has front and rear elements 52 and 54 made of 26 percent aqueous solution of NaCl which has a sound propagation velocity of 1784.6 m./sec. Central element 53 is made of fresh water having a sound propagation velocity of 1483.6 m./sec. The radii of curvature of membranes 47, 48, 49, and 51, identified as in the foregoing example by r_1, r_2, r_3, and r_4, respectively, are as follows:

$r_1=-88.90$ mm.,
$r_2=127.00$ mm.,
$r_3=-127.00$ mm.,
$r_4=88.90$ mm.

Where the radii of curvature of the membranes become small, such that the angles of incidence become large, undesirable reflections from the membrane surfaces may occur. These reflections, analogous to the phenomenon of flare in the optical lens, degrades the image quality produced by the lens. These reflections, and the acoustic image degradation produced thereby, may be minimized by providing further refracting elements of intermediate refracting power. Such a construction is illustrated at FIG. 10.

FIG. 9 illustrates a seven-element athermal acoustic lens comprised by saline solution fluid elements 62, 63, 64, 65, 66, 67, and 68 housed within a common lens housing 69. The end portions 71 of housing 69 extend partially over the aperture to provide stops to include energy from the planomarginal portions of refracting element 63. Acoustically transparent membranes 72, 73, 74, 75, 76, 77, 78, and 79 comprise the containing structure to separate the solutions of refracting elements 62, 63, 64, 65, 66, 67, and 68 for mixing with each other and the surrounding fluid, as well as defining the shape of the respective elements. Anechoic layers 81 and 82 on the interior walls of housing end portions 71 prevent acoustic reflections from these surfaces. Anechoic layers 83 and 84 line the interior surface of that portion of housing 69 occupied by elements 64 and 65. Anehoic layers 83 and 84 also cooperate with plane portions 85 and 86 of membranes 75 and 76 to provide an internal stop in the same fashion as anehoic layers 58 and 59 in the embodiment of FIG. 9.

The lens of FIG. 10 may, like the previously described exemplary constructions, be constructed to provide the desired focal length by altering the composition of the elements and their dimensions. The greater number of elements present in the construction of FIG. 10 permit a more precise compensation of thermal and refractive properties. For example, elements 62, 65 and 68 may be of the same acoustic propagation velocity as the intended surrounding medium, e.g., fresh or salt water. Refracting elements 63 and 67 would be made of a fluid with an intermediate propagation velocity such as a 20 percent solution of sodium chloride. Elements 64 and 66 are made of a fluid with a high velocity of propagation such as a saturated solution of sodium chloride.

As a further example of the flexibility of manipulation of the acoustic parameters afforded by the construction of FIG. 10, it should be noted that the elements 63 and 67 may be designed to eliminate reflections at the interfaces between elements 62 and 64, and 66 and 68. This is possible if the composition and solution concentration of the two intermediate elements 63 and 67 is chosen such that the acoustic impedance thereof is equal to the square root of the product of the acoustic of the two adjacent elements 62 and 64 and 66 and 68. In such an antireflection construction the thickness of elements 63 and 67 is chosen to be an odd number of quarter wavelengths in the material from which the elements 63 and 67 are made. In this particular, elements 63 and 67 are somewhat analogous to the antireflection coatings so well known in the optical lens art.

The foregoing exemplary embodiments of applicant's invention are capable of modification to produce the particular focal lengths and acoustic imaging properties desired. It should be understood that the membranes used to separate the fluid lens components are very thin and are shown, herein, with their thickness exaggerated for purposes of explanation. Likewise, the lenses are illustrated as being symmetrical, but, if desired, they may be made asymmetrical.

The foregoing description taken together with the appended claims constitute a disclosure such as to enable a person skilled in the acoustic arts and having the benefit of the teachings contained therein to make and use the invention. Further the structure herein described meets the objects of invention, and generally constitutes a meritorious advance in the acoustic art unobvious to such a skilled worker not having the benefit of the teachings contained herein.

Obviously, other embodiments and modifications of the subject invention will readily come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing description and the drawings. It is, therefore, to be understood that this invention is not to be limited thereto and that said modifications and embodiments are intended to be included within the scope of the appended claims.

What is claimed is:

1. An athermal acoustic lens comprising in combination:
housing means having an aperture extending therethrough and acoustically opaque wall portions surrounding said aperture;
membrane means attached to said housing means and extending across said aperture to provide a fluidtight volume within said housing means, said membrane being acoustically transparent and having predetermined geometrical configurations; and
a solution of inorganic salts filling said fluidtight volume in such manner as to effect an acoustic refractor means thereat.

2. An athermal acoustic lens according to claim 1 in which said solution of inorganic salts has an acoustic propagation velocity which is higher than that of sea water.

3. An athermal acoustic lens according to claim 1 wherein said solution of inorganic salt is an aqueous solution of sodium chloride.

4. An athermal acoustic lens according to claim 1 further comprising a layer of anechoic material lining the inner surface of said housing means within the confines of said fluidtight volume.

5. An athermal lens according to claim 1 wherein said membrane means has a spherical geometric configuration.

6. An athermal acoustic lens according to claim 1 wherein said membrane means comprises a plurality of acoustic septa separating said housing means into a plurality of contiguous fluidtight volumes.

7. An athermal acoustic lens according to claim 6 wherein at least one of said fluidtight volumes is filled with a fluid so constituted as to cooperate with the shape thereof to eliminate surface reflections between volumes adjacent thereto.

8. An athermal acoustic lens according to claim 6 wherein adjacent ones of said fluidtight volumes are filled with different aqueous solutions of inorganic salts.

9. An athermal acoustic lens according to claim 7 wherein the plurality of septa are four in number, so as to enclose three reflective elements therebetween, wherein said refractive elements and said septa are numbered consecutively from front to rear of said athermal acoustic lens, and wherein said septa have radii of curvatures identified consecutively from front to rear of the lens as r_1, r_2, r_3, and r_4, with said radii having values within the ranges indicated in the table:

-22 mm. $< r_1 < -1$ m.,
60 mm. $< r_2 < 1.6$ m.,
-60 mm. $< r_3 < -1.6$ m.,
25 mm. $< r_4 < 1$ m.,

wherein the minus sign indicates that the center of curvature of the radius of curvature identified thereby lies on the entrant side of said septum.

10. An athermal lens according to claim 8 wherein the entrant and exit refracting elements, between the first and second septa and between the third and fourth septa, respectively, are comprised of an aqueous solution of sodium chloride and the central refracting element, between the second and third septa, is comprised of distilled water.

11. An athermal acoustic lens according to claim 9 wherein said central refracting element is marginally surrounded by an acoustically opaque stop.

12. An improved acoustic lens for use within fluid mediums to refract acoustic energy comprising in combination:
housing means having opaque wall portions;
aperture means extending through said housing means for the passage of acoustic energy therethrough along an acoustic axis;
membrane means attached at the outer periphery thereof to said housing means to extend across said aperture means, said membrane means being made of acoustically transparent, fluidtight material and of predetermined geometrical configuration, so as to provide at least one fluidtight volume within said housing means; and
an aqueous solution of an inorganic salt filling said fluidtight volume so as to provide an acoustic refractive element thereat, said inorganic salt being selected to have a thermal change of acoustic propagation velocity such that the effective focal length of the lens remains substantially unaltered over the range of temperature normally encountered in the oceans and seas of the earth.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,620,326 Dated November 16, 1971

Inventor(s) Ernest A. Hogge

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 58, the word "athanol" should read --ethanol--.

Column 2, line 67, equation (1) should read --sin θ_1/sin θ_2 = C_1/C_2--.

Column 4, line 53, equation (2) should read --sin θ_2 = sin θ (C_2/C_1)--.

Column 5, line 18, the word "now" should read --not--.

Column 6, line 9, the word "chose" should read --chosen--.

Column 7, line 9, between the words "acoustic" and "of", the word --impedances-- should be inserted.

Signed and sealed this 20th day of June 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

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