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2,299,260

ENERGY TRANSLATION UTILIZING PYROELECTRICITY

Filed Aug. 31, 1939

2 Sheets-Sheet 1

FIG. 1

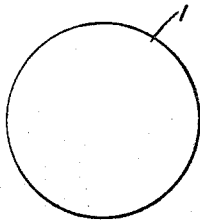


FIG. 2

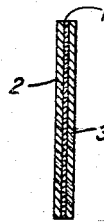


FIG. 3

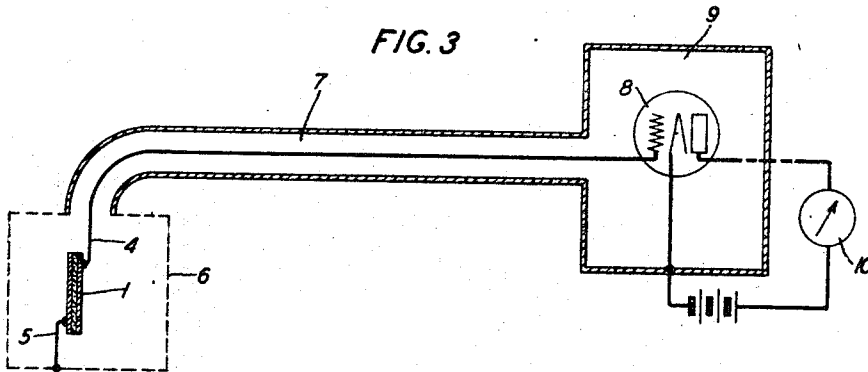


FIG. 4

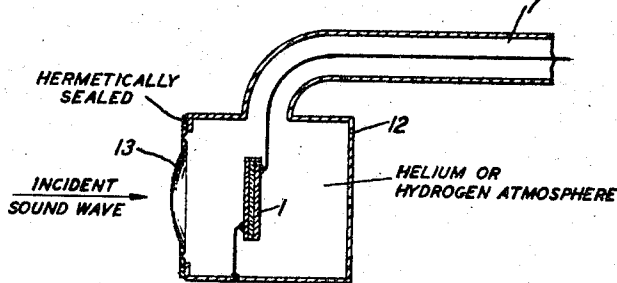


FIG. 5

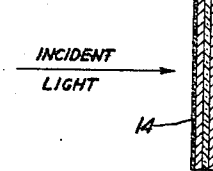
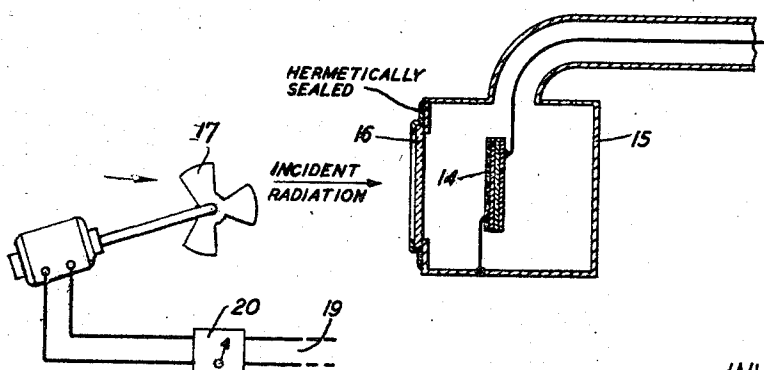


FIG. 6



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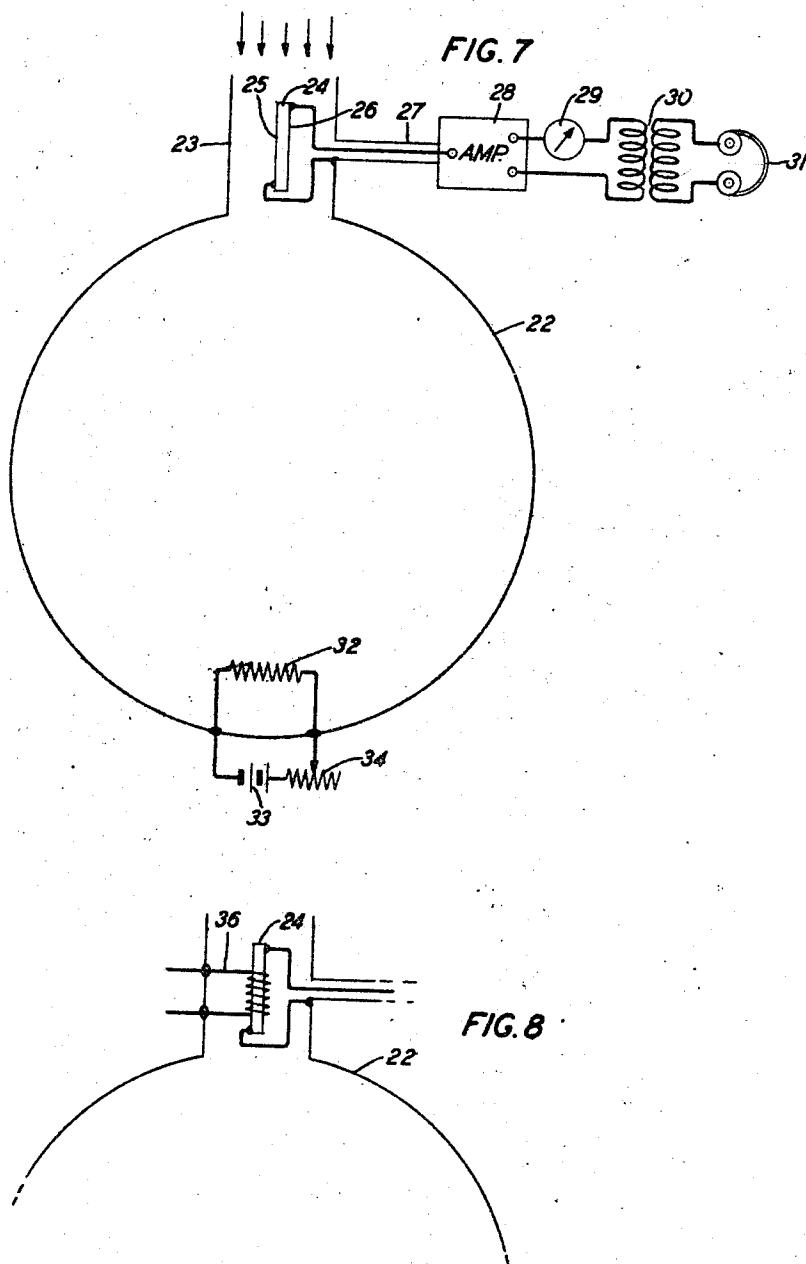
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2 Sheets-Sheet 2



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ENERGY TRANSLATION UTILIZING
PYROELECTRICITY

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8 Claims. (Cl. 171-327)

This invention relates to methods of and apparatus for utilizing pyroelectricity in energy translation systems.

It has long been known that certain substances, when warmed or cooled, exhibit an electrification which manifests itself as a change in electrical polarization of the substance or separation of its positive and negative charges. This phenomenon known as pyroelectricity has been observed in studies of a large number of crystalline substances, a list of some of which is given at Table 3, page 209, vol. 6, of the International Critical Tables, published in 1929 for the National Research Council by McGraw-Hill Company. Among these substances are tourmaline, lithium sulphate and lithium selenate.

The general nature of pyroelectricity may be readily demonstrated by subjecting a crystal of tourmaline suspended by an electrically insulating thread to a heating atmosphere. One end of the crystal will be found to be positively electrified and the other negatively electrified. When such a pyroelectric crystal is cooled its electrical polarity becomes reversed from that produced by heating; the end which was positive now has become negative and that which was negative has become positive. If the crystal be subjected to alternate heating and cooling an alternating electrical polarization will ensue.

An object of this invention is to take advantage of the pyroelectric phenomenon in order to translate into electrical energy, impulses or trains of heat waves or of any wave energy which are capable of producing temperature variations in pyroelectric material.

Another object of the invention is to translate radiant energy into electrical energy by means of pyroelectric apparatus which may at the same time be very rugged and extremely sensitive.

An additional object of the invention is to improve the effectiveness of a pyroelectric translating device for converting heat-bearing waves into corresponding electrical waves.

A further object of the invention is to provide a sensitive detector for radiation energy of electromagnetic character in the frequency ranges commonly designated as heat and light.

In accordance with one embodiment of the invention, a plate of a pyroelectric material is suspended in a medium traversed by beams of wave energy which on incidence upon the material cause its temperature to change. The resulting electrification of the plate gives rise to charges upon conducting electrodes or coatings placed in close association with the plate but elec-

trically insulated from each other. A circuit leading from the electrodes of the pyroelectric plate may be connected to an amplifier with the output circuit of which an indicator is electrically associated. Consequently, incidence of the wave energy beam upon the pyroelectric plate may be made evident by the indicator.

Sound waves in air may be allowed to fall directly upon the pyroelectric plate or may pass through a diaphragm to a confined atmosphere in which the pyroelectric plate is positioned. The adiabatic compression and rarefaction of the atmosphere immediately surrounding the plate give rise to a fluctuation in its temperature which is partially communicated to the pyroelectric plate thus causing a corresponding fluctuation of its temperature and a consequent alternating electrical polarization at the electrodes associated with the plate. In fact the principle of the invention is applicable to any sort of system in which a disturbing or impelling force can set up an alternating temperature in a pyroelectric element thus giving rise to a corresponding alternating pyroelectric charge between the associated electrodes.

Inasmuch as the pyroelectric phenomenon is dependent upon heat transfer to and from the pyroelectric element it is necessary in order to make the pyroelectric element sensitive to reduce its thermal inertia as far as possible. This may be effectively accomplished by reducing the thickness of the pyroelectric element to very small dimensions as for example of the order of .005 of an inch. A tourmaline plate having a thickness of .0015 of an inch has been found quite effective. It is also advantageous in cases where the varying heat by which the temperature of the pyroelectric element is altered is conveyed by a gaseous medium to choose such a gas as will most readily conduct heat to or from the crystal. For this purpose hydrogen and helium are markedly superior to air.

If the surfaces of the pyroelectric plate be blackened to convert incident radiant energy into heat in the manner well known, the pyroelectric operation may be utilized to enable the system to serve as a photoelectric cell or radiation detector.

The invention may best be understood by reference to the following specification taken in connection with the accompanying drawings in which

Fig. 1 shows a circular disc of pyroelectric material;

Fig. 2 is another view of the disc of Fig. 1,

illustrating the electrical coatings on its major faces;

Fig. 3 illustrates schematically a system for responding to sound waves and converting their energy by pyroelectric action to corresponding electrical waves;

Fig. 4 shows a modification in which the microphone element of Fig. 3 is positioned in an enclosed atmosphere of helium or hydrogen;

Fig. 5 shows a pyroelectric element having coatings similar to the element of Figs. 1 and 2 and with an additional black absorbing coating on one of its faces for converting radiant energy into heat;

Fig. 6 discloses a system responsive to radiant light or heat employing the detecting element of Fig. 5; and

Figs. 7 and 8 disclose systems employing a pyroelectric element in conjunction with a Helmholtz resonator to respond to incoming sound waves.

Referring to Fig. 1, a disc 1 of tourmaline is cut from the virgin crystalline material in such a manner as to have its major or parallel plane faces extending perpendicular to the optical or Z axis of the crystalline material. The disc is preferably made very thin as, for example, of the order of .0015 to .005 of an inch in thickness. As shown in Fig. 2, its major faces are provided with coatings 2 and 3 of conducting material such as aluminum or platinum which may be applied according to the methods now well known in the piezoelectric technique.

If such a crystal of tourmaline as that of Figs. 1 and 2 with its electrically conducting coatings or electrodes be subjected to an increase of temperature $d\theta^\circ \text{C.}$, its major faces develop equal and opposite charges amounting to dP electrostatic units per unit area. If, on the other hand, the crystal be cooled by $d\theta^\circ \text{C.}$, the polarization or charge developed is also dP electrostatic units per unit area but with an opposite polarity to that developed by increase of temperature. The ratio

$$\frac{dP}{d\theta}$$

is known as the pyroelectric coefficient. At room temperature of about 300°K.

$$\frac{dP}{d\theta}$$

has a magnitude of the order of 1.2.

The system of Fig. 3 makes use of the pyroelectric disc of Figs. 1 and 2 in a system for detection of sound waves. The element 1 is preferably supported by lead wires 4 and 5 soldered to its opposite electrodes within an electrically shielded or screened casing 6, the apertures of which are sufficiently large to enable sound waves to freely pass through the casing. The adiabatic compression and rarefaction of the atmosphere within the casing 6 in consequence of translation of sound waves produces a variation in its temperature and, also, therefore, in the temperature in the element 1 exposed to the atmosphere. The corresponding fluctuating electrical polarization developed upon the conducting electrodes 2 and 3 of the element 1 enables the device to act as a microphone or a detector of sound waves. The leads 4 and 5 are connected respectively to the inner and outer conductors of a coaxial conductor system 7 leading to the input terminals of an electron discharge device 8 within a shielded container 9. Various mechanical and elec-

trical details of the apparatus are omitted to simplify the drawings. It will be readily understood, however, that the fluctuating potentials developed between the opposite electrodes of the element 1 will be amplified by the device 8 and indicated by the responsive device 10 in its output circuit. The electroresponsive device 10 may be a sensitive meter of any type or it may be an electroacoustic device such as a telephone receiver or loud-speaker.

Fig. 4 illustrates a system for translation of sound waves into electrical wave energy in which the pyroelectric element 1 is mounted in a hermetically sealed container 12 provided with a flexible diaphragm member 13 capable of transferring sound wave pressures from the outer atmosphere to the atmosphere within the chamber. The pyroelectric element 1 is electrically associated with a coaxial system 7 in the same manner as in the disclosure of Fig. 3. The hermetically sealed chamber 12 not only protects the pyroelectric element from moisture and the accumulation of dust particles but, also, enables the atmosphere immediately surrounding the element 1 to be made such that its density, specific heat and heat conductivity result in a greater temperature variation in the pyroelectric crystal for a given pressure amplitude in the atmosphere. The chamber preferably contains an atmosphere of hydrogen or helium to improve the heat transfer to the pyroelectric element.

Fig. 5 discloses a modification of the pyroelectric device shown in Figs. 1 and 2 to adapt the device for reception of heat-bearing electromagnetic beams. For that purpose, a device similar to that of Fig. 2 is coated with a black absorbing coating 14 of a type effective to convert incident beams of short electromagnetic waves into heat. It is to be understood that any radiation which can be converted into heat by absorption such as electromagnetic waves of radiant heat or infra-red rays may be employed.

Fig. 6 illustrates a system utilizing the device of Fig. 5 in which the pyroelectric element is enclosed in a sealed chamber 15 which may be exhausted to a very low pressure. The chamber 15 is provided with a window 16 of a material transparent to the light or heat wave or other radiant energy beams. Accordingly, beams of radiant energy passing through the window and falling upon the coating 14 of the pyroelectric element are converted into heat energy to vary the temperature of the pyroelectric element. Preferably, the exhaustion of the chamber is carried to a high degree for the reason that the presence of air or other gas would, to an extent, absorb heat from the incoming radiant energy and would also serve to conduct heat away from the pyroelectric element thus causing the amplitude of alternating temperature of the element to be lower than it would otherwise be. At a point in the path of the incoming beam which may be close to the window 16, if desired, or may be at a remote transmitting station, a rotary interrupting device 17 is provided with vanes which traverse the path of the light beam thus momentarily intercepting the beam. The interrupter 17 is preferably driven by an electric motor 18 supplied with energy from alternating current mains 19. A variable controlling element 20 connected in the current supply circuit enables the speed of the motor 18 to be varied as desired or even to be changed in accordance with code impulses. It follows that the beam of incident radiation may at times undergo inter-

ruptions of one frequency as, for example, 20 cycles, and at other times of 25 or 30 cycles. Accordingly, the beam of radiant energy incident upon pyroelectric element 1 is modulated at the interruption frequency. In the manner already explained in connection with the system of Fig. 3, the pyroelectric element will serve to supply alternating electric potentials of the modulation frequency to its outgoing circuit.

The disclosure of Fig. 6 serves also to illustrate a fundamental distinction between the operation of a pyroelectric element and that of the well-known piezoelectric element. Since piezoelectric electromotive forces are generated only as a result of pressures or pressure variations, the pyroelectric element 1 which is enclosed in the highly exhausted chamber 15 of Fig. 6 and is therefore free from pressure is not subject to forces which will cause it to generate piezoelectric electromotive forces. It will therefore generate pyroelectric electromotive forces wholly free from piezoelectric electromotive forces.

The extreme case just considered is particularly easy to grasp. In reality the distinction enters into every aspect of the present disclosure. Consider, for example, the case of Fig. 3 where pyroelectric element 1 is subjected to the action of an incident sound wave, say in air. At every point in the wave there is an alternating pneumatic pressure. If all linear dimensions of the pyroelectric crystal element are very small compared with the sound wave-length in air, all portions of the crystal surface will be subjected to the same alternating pneumatic pressure. In consequence of its peculiar piezoelectric system a substance such as Rochelle salt (sodium potassium tartrate tetrahydrate) immersed in an atmosphere and subjected over its entire surface to the same pressure from the surrounding medium generates no piezoelectric charge. If, therefore, the element 1 of Fig. 3 consists of Rochelle salt no piezoelectric electromotive force results from the variation in pneumatic pressure. However, an alternating pyroelectric charge is generated in Rochelle salt as a result of the adiabatic temperature alternations accompanying a sound wave in air. It is otherwise in the case of tourmaline, the quite different piezoelectric system of which permits a varying pneumatic air pressure to generate a piezoelectric charge. It will be apparent, however, that the mere fact that under certain conditions some substances may generate both piezoelectric and pyroelectric electromotive forces is no genuine indication of the general inseparability of the two effects. It will be appreciated that in the aspects just discussed the performance of the structure of Fig. 4 is similar to that of Fig. 3.

Another instance of a purely pyroelectric apparatus is disclosed in Figs. 7 and 8 in which a Helmholtz resonator 22, the natural resonance frequency of which corresponds to the frequency of an incoming sound wave to be indicated or detected, is provided at its throat portion 23 with an element 24 of pyroelectric substance having electrodes 25 and 26 which are connected by the coaxial line 27 to the input of an amplifying or detecting device 28, the output circuit of which includes a current indicator 29 and the primary winding of a transformer 30 connected to a loudspeaker or other sound reproducer 31. Within the Helmholtz resonator 22 is a heating coil 32 in circuit with an external source 33 of heat electromotive force and a rheostat 34. Although the precise theory of operation of such "hot wire"

type instruments is not known with certainty, it is believed to be substantially as follows: The heat generated in the wire 32 sets up an air circulation with a central hot current upward and a cool peripheral downward current in the neck 23. The central hot current raises the temperature of the element 25, and the larger that current the higher the temperature of element 25. The oncoming sound wave imparts an alternating velocity to the air in the neck 23 as a whole, and, in particular, it accelerates and decelerates the velocity of the unidirectional central air current. The result is an alternating component in the temperature of the crystal, and an alternating electric polarization with it. Consequently it is possible to utilize the energy of the incoming sound waves to initiate varying pyroelectric electromotive forces of the same frequency in the circuit of the amplifier 28.

Fig. 8 discloses a modification of the apparatus of Fig. 7 in which the pyroelectric crystal is surrounded by a heating coil 36. The transfer of heat from the coil 36 to the pyroelectric element 24 will accordingly be modulated by the alternating current air flow in the throat portion of the resonator.

What is claimed is:

1. An apparatus for responding to electromagnetic wave energy of such wave-length as to convey heating energy comprising an evacuated container having a window pervious to radiant heat bearing waves, a thin element of pyroelectric material having electrodes upon which pyroelectric charges developed in the element may be impressed, means for supporting the element in front of the window and with its thinnest dimension extending in the direction of travel of the radiant waves, means for setting up intermittent variations in incoming radiant wave energy whereby the pyroelectric device is caused to yield a periodic electric response and means for varying the temperature of the pyroelectric element in consequence of the incidence of electromagnetic waves.

2. A hermetically sealed chamber of electrically conducting material having a window transparent to heat-bearing rays, a pyroelectric element within the chamber having electrically separated conducting electrodes, means for supporting the pyroelectric element comprising two conducting leads integrally connected electrically to the respective electrodes, one lead being electrically connected to the chamber and the other insulated therefrom to enable pyroelectric E. M. F.'s. developed by the element to be applied to an external circuit connected between the insulated lead and the chamber, the supporting leads being so positioned as to cause the element to present a major surface to a beam of rays entering the window and incident upon the surface and a coating of heat-absorbing material on a portion of the surface of the element exposed to the rays whereby upon incidence of the rays a pyroelectric charge is impressed upon the electrodes.

3. A hermetically sealed chamber, a window in one wall of said chamber to permit heat-bearing rays to pass into the chamber and a pyroelectric element having conducting electrodes mounted within the chamber in position to intercept the heat-bearing rays, the pyroelectric element comprising a plate of tourmaline of the order of .0015 inch in thickness and the mounting supporting it in such position that a beam of heat bearing rays incident through the window strikes

the element in the direction of its thickness to permit rapid heating and cooling of the entire mass, and a heat absorbing coating superposed on the electrode on the face of the element presented to the window to facilitate heat energy transfer whereby upon incidence of the rays a pyroelectric charge is impressed upon the electrodes and upon diminution or withdrawal of the rays heat energy is rapidly radiated from the element to the space beyond the window.

4. A pyroelectric element comprising a flat plate of tourmaline having its parallel flat faces perpendicular to the optical axis of the crystalline material, said plate having a thickness of the order of .0015 to .005 inch in order to increase its sensitivity to rapid variations of incident radiant energy, a source of radiant heat waves and means for supporting the tourmaline plate in a position to cause the incident radiant heat waves to fall upon one of the parallel flat faces at substantially 90-degree angle of incidence.

5. A system for receiving, detecting and indicating a beam of heat bearing rays comprising an extremely thin plate of tourmaline the thickness of which is parallel to the optical axis of the tourmaline material, means for supporting the tourmaline plate in a space substantially devoid of atmosphere whereby pyroelectric charges may develop upon incidence of heat rays upon the tourmaline free from piezoelectric E. M. F.'s occasioned by change in pneumatic pressure, the supporting means comprising a chamber impervious to heat bearing rays except for a window whereby a beam may be intercepted and the tourmaline screened from random radiant energy from other directions, and means external to the window and in position in line with the window and the tourmaline plate to interrupt a beam of heat energy in a periodic manner to cause periodic pyroelectric charges to be produced at the faces of the tourmaline plate and means for indicating the condition of electrical charge on the faces of the plate.

6. In combination, an evacuated container pervious to radiant energy, an element within said container consisting of a crystalline sub-

stance having the property of developing electrical charges in response to changes in temperature and pneumatic pressure of the ambient atmosphere, conducting electrodes physically connected to the element and means adjacent the surface of the element and exposed to incoming radiant energy for causing at least a portion of the energy of a beam of heat-producing waves incident upon the element to be converted into heat whereby the temperature of the element is affected and the pneumatic pressure condition is varied to a negligible degree irrespective of temperature variations whereby the charges developed by the crystalline substance are substantially determined by radiant energy alone.

7. A system for converting radiant energy into electrical energy comprising an evacuated container having a window pervious to radiant energy, an element of pyroelectric material within said container and comprising a tourmaline disc supported in position in front of the window to receive radiant energy and conducting electrodes physically connected thereto to receive charges induced by change in the thermal condition of the material whereby the possible changes in pneumatic pressure to which the tourmaline is subject having been reduced to negligible degree the charges generated and impressed upon the electrodes are occasioned substantially exclusively by radiant energy reaching the pyroelectric element through the pervious window.

8. An evacuated housing having a window transparent to heat-bearing rays, a pyroelectric element within the housing, said pyroelectric element comprising a plate of crystalline material .0015 to .005 inch thick, two electrodes respectively adjacent to portions of the element between which pyroelectric charges are developed and a coating of energy absorbing material overlying the outer surface of one of the electrodes and means for supporting the element to present the face of the coated electrode to the transparent window whereby heat-bearing rays are enabled to rapidly heat the element and the element may rapidly radiate heat energy to maintain its sensitivity as a pyroelectric element.

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