

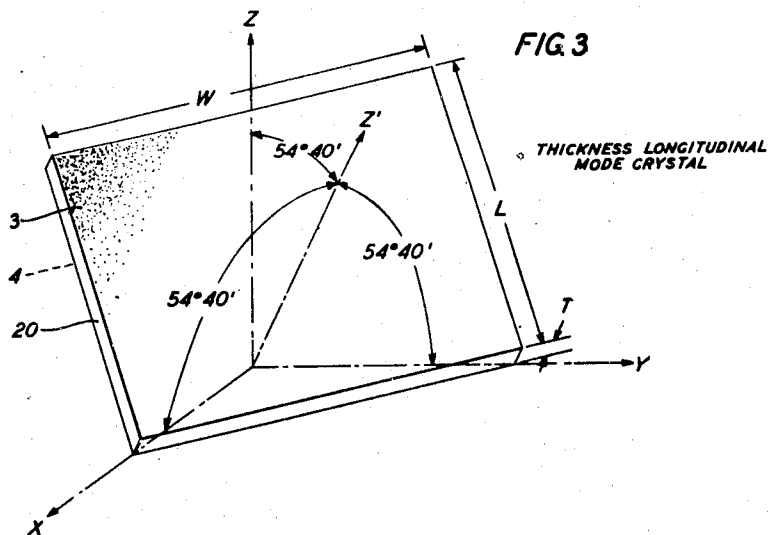
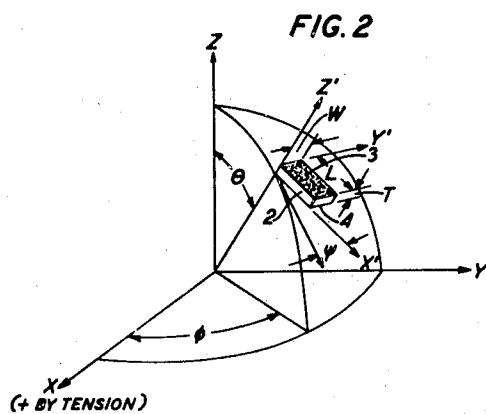
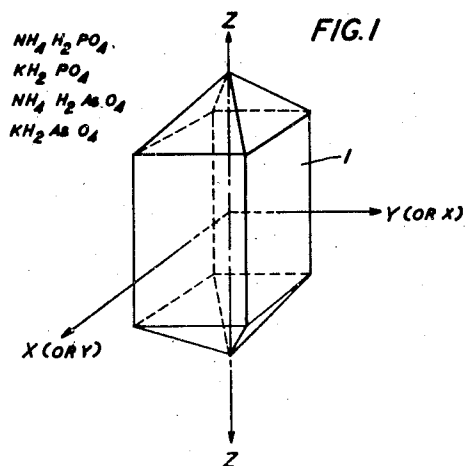
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2,450,011

PIEZOELECTRIC CRYSTAL APPARATUS

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PIEZOELECTRIC CRYSTAL APPARATUS

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18 Claims. (Cl. 171—327)

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This invention relates to piezoelectric crystal apparatus and particularly to thickness longitudinal mode piezoelectric crystal elements comprising crystalline ammonium dihydrogen phosphate ($\text{NH}_4\text{H}_2\text{PO}_4$), potassium dihydrogen phosphate (KH_2PO_4), ammonium dihydrogen arsenate ($\text{NH}_4\text{H}_2\text{AsO}_4$), potassium dihydrogen arsenate (KH_2AsO_4) and isomorphous combinations.

This application is a division of my copending application for Piezoelectric crystal apparatus, Serial No. 497,883, filed August 9, 1943, now Patent Number 2,450,010. Such crystal elements are useful as electromechanical transducers utilized, for example, in sonic or supersonic projectors, microphones, pick-up devices and detectors. Also, they may be utilized as frequency control elements in electric wave filter systems, oscillation generator systems and amplifier systems. Other applications for such crystal elements may include harmonic producers, and, in general, any application where either a resonant or non-resonant piezoelectric crystal element may be utilized. The non-linear hysteresis loop characteristics of the non-resonant crystal may be made use of to produce overtones or harmonics therefrom.

One of the objects of this invention is to provide useful orientations and modes of motion in crystal elements made from crystalline ammonium dihydrogen phosphate, potassium dihydrogen phosphate, ammonium dihydrogen arsenate, potassium dihydrogen arsenate and isomorphous combinations.

Other objects of this invention are to provide crystal elements comprising dihydrogen phosphate and arsenate substances that may possess useful characteristics, such as large piezoelectric constants, large vibrational motion, minimum coupling of the desired mode of motion with undesired modes of motion therein, and temperature coefficients of frequency that may have the relatively lower values.

Another object of this invention is to take advantage of the high piezoelectric activity, the low cost and other advantages of crystalline ammonium dihydrogen phosphate and similar dihydrogen phosphate and arsenate crystals.

Crystal elements of suitable orientation cut from crystalline ammonium dihydrogen phosphate, potassium dihydrogen phosphate, potassium dihydrogen arsenate, ammonium dihydrogen arsenate and isomorphous combinations thereof may be excited in different modes of motion, such as longitudinal length, longitudinal width or longitudinal thickness modes of motion, shear face modes of motion controlled mainly by

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the width and length major face dimensions, or thickness shear modes of motion controlled mainly by the thickness dimension. Also, low frequency flexural modes of motion of either the width bending flexure type or the thickness bending flexure type may be utilized. The contour or face modes of motion may be either the face shear mode of motion, or the width or length face longitudinal modes of motion, as disclosed and claimed in my parent application Serial No. 497,883 heretofore referred to. The thickness modes of motion may be either the thickness longitudinal mode of motion as involved in the present application, or the thickness shear mode of motion as involved in my copending application for Piezoelectric crystal apparatus, Serial No. 637,127, filed December 24, 1945. These modes of motion are similar in the general form of their motion to those of corresponding names that are already known in connection with quartz, Rochelle salt, and other known piezoelectric crystals.

Crystal elements composed of crystalline ammonium dihydrogen phosphate, potassium dihydrogen phosphate, potassium dihydrogen arsenate, ammonium dihydrogen arsenate and isomorphous combinations may have piezoelectric and elastic constants or moduli of considerable interest for use in electromechanical transducers, filter systems and oscillator systems, for example. In accordance with this invention, a number of crystal orientations or cuts are provided that may be utilized for these purposes and others. The types of crystal cuts may be divided into several categories, such as (a) crystals cuts that have relatively large piezoelectric constants and hence may be driven strongly piezoelectrically, (b) crystal cuts that have advantageous elastic properties, such that the longitudinal face modes of motion therein are free from coupling to the face shear modes of motion therein, and face shear mode crystal elements that are free from coupling with other modes of motion therein, and (c) crystal cuts that may have the relatively lower values of temperature coefficients of frequency.

Crystal elements comprising ammonium dihydrogen phosphate, potassium dihydrogen phosphate, ammonium dihydrogen arsenate, potassium dihydrogen arsenate and isomorphous combinations also possess ferroelectric properties such as large dielectric constants, hysteresis loops and non-linearity of charge field relationships below their critical or Curie temperatures of about 115°K ., 91°K ., 155°K . and 220°K ., respectively. These crystal substances also possess high piezoelectric constants at room tempera-

tures, which, in general, are larger than those of most other piezoelectric crystals except Rochelle salt. Ammonium dihydrogen phosphate crystals have relatively the largest piezoelectric constants of any of the four isomorphous dihydrogen crystal substances mentioned, and are relatively easy to grow in shapes and sizes that are suitable for cutting useful plates or elements therefrom.

The ammonium dihydrogen phosphate crystals, for example, may have properties somewhat similar to 45-degree Y-cut type Rochelle salt crystals but will stand a much higher operating type which may be of the order of about 180° C. or much higher, and also have no water of crystallization and hence will not dehydrate when operated in air or in vacuum. The temperature coefficients of frequency for certain of the principal cuts are roughly of the order of 100 to 300 parts per million per degree centigrade. The dielectric constants decrease slightly with an increase in temperature while the piezoelectric constants relating charge and stress are nearly independent of temperature. Since the ammonium dihydrogen phosphate crystals have the relatively higher values of electromechanical coupling, and are free from water of crystallization which eliminates dehydration in the crystal, and will stand relatively high operating temperatures of the order of 180° C., or more, they are useful as driving elements for all transducer applications, such as projectors and microphones in under-water sound work, for example. Also, this type of crystal may be used as a substitute for quartz frequency control elements in filter and oscillator applications, especially when used with temperature control. For the lower frequency filter applications, the crystal cuts having the relatively lower temperature coefficients of frequency may be used at ordinary temperatures without temperature control.

Although all four of the crystalline dihydrogen substances particularly mentioned herein have relatively large piezoelectric constants and other useful characteristics, the ammonium dihydrogen phosphate crystal elements may be constructed to have the largest values of piezoelectric constants of the four crystalline dihydrogen phosphate and arsenate salts mentioned, and also generally, are relatively more easy to grow in the sizes and shapes that are useful for cutting crystal elements therefrom.

The crystal elements disclosed in this specification may have conductive electrode coatings on their major surfaces of any suitable composition, shape, and arrangement, such as those already known in connection with quartz, Rochelle salt and other piezoelectric crystals; and they may be mounted and electrically connected by any suitable means, such as for example, by pressure type clamping pins or by conductive supporting wires cemented by conductive cement to the crystal coatings at or near the nodal regions, as already known in connection with quartz, Rochelle salt and other crystals having similar or corresponding modes of motion.

Spurious modes of motion may be avoided in these crystal elements by a suitable dimensioning of the crystal element, such as by adjusting the thickness dimension thereof relative to the length and width dimensions thereof, in the case of face shear mode or face longitudinal mode crystals, and by adjusting the length and width dimensions relative to the thickness dimension in the case of thickness mode crystals, such as thickness shear mode crystals or thickness longitudinal

mode crystals. Also the effect of spurious modes in these face mode and thickness mode dihydrogen crystals may be reduced by the use of centrally disposed electrodes partially covering the major faces of the crystals, in the manner of such partial electrodes as are now used in connection with quartz crystals, for example.

For a clearer understanding of the nature of this invention and the additional advantages, features and objects thereof, reference is made to the following description taken in connection with the accompanying drawings, in which like reference characters represent like or similar parts and in which:

Fig. 1 is a perspective view illustrating the prismatic tetragonal-scalenohedral form in which ammonium dihydrogen phosphate, potassium dihydrogen phosphate, potassium dihydrogen arsenate, ammonium dihydrogen arsenate and isomorphous combinations thereof crystallizes, and also illustrating the relation of the prism faces and cap faces of such crystalline substances with respect to the mutually perpendicular electric axis X, mechanical axis Y, and optic axis Z thereof;

Fig. 2 is a perspective view illustrating the orientation, in terms of the angles ϕ , θ and ψ , of a crystal element cut from any of the dihydrogen crystalline substances illustrated in Fig. 1, and may be taken to illustrate the orientation of any dihydrogen salt crystal element disclosed in this specification; and

Fig. 3 is a perspective view illustrating the orientation of a thickness longitudinal mode crystal element cut from any of the crystalline substances ammonium dihydrogen phosphate, potassium dihydrogen phosphate and corresponding arsenate crystal substances, as illustrated in Fig. 1.

This specification follows the conventional terminology as applied to piezoelectric crystalline substances, which employs three mutually perpendicular X, Y and Z axes, as shown in the drawings, to designate an electric axis, a mechanical axis and an optic axis, respectively, of piezoelectric crystalline substances, and which employs three orthogonal axes X', Y' and Z' to designate the directions of the axes of a crystalline piezoelectric body or element that is angularly oriented with respect to such X, Y and Z axes thereof.

This specification also follows the conventional terminology used to designate the elastic constants s and c , the piezoelectric constants d and other constants of piezoelectric crystalline substances. As an illustrative example, the d_{36} piezoelectric constant means that a Z axis field represented by the numeral 3 may produce XY shear motion represented by the numeral 6. If the d_{36} piezoelectric constant of the substance has a large value, as it does in the case of the several dihydrogen salt crystals here considered, then a Z axis field applied thereto may produce a strong shear motion in the XY plane of the crystal body.

The value of the elastic compliance and sheer stiffness for rotated crystal elements may be calculated from the fundamental elastic matrix given in Equation 1 in my parent application hereinbefore referred to. One method of doing this is by the shorthand matrix method discussed in a paper "The mathematics of crystal properties," by W. L. Bond, Bell System Technical Journal, January 1943, page 1, using the matrix where the axes X', Y' and Z' of the rotated crystals are related to the crystallographic axes X, Y and Z by the direction cosines l_1 to n_3 , l_1 being the direction cosine between X' and X, n_3 the direction cosine

between Z' and Z , etc. As shown by Bond, the elastic compliances of rotated crystals are given in terms of the elastic compliances of unrotated crystals by the product of the matrices.

The direction cosines that cause the length dimension L of the crystal element to point in the desired direction are used. For this purpose, the system of angles illustrated in Fig. 2 is used where the length L of the crystal is taken along the X' axis, the width W is taken along the Y' axis and the thickness T is taken along the Z' axis. The angle θ measures angle between the Z crystallographic axis and the Z' thickness T axis. The angle φ measures the angle between the XZ plane and the ZZ' plane, and ψ the skew angle, is the angle between the length dimension L of the crystal and the tangent to the great circle through the Z and Z' axes.

The elastic, dielectric and piezoelectric equations for crystalline ammonium dihydrogen phosphate, potassium dihydrogen phosphate, potassium dihydrogen arsenate, ammonium dihydrogen arsenate and isomorphous combinations are given in my parent application hereinbefore referred to. These substances crystallize in the prismatic tetragonal-scalenohedral form shown in Fig. 1 and as a consequence have six elastic compliances, namely, S_{11} , S_{12} , S_{13} , S_{33} , S_{44} , and S_{66} , and two types of piezoelectric constants, namely, $d_{14} = d_{25}$, and d_{36} .

Referring to the drawing, Fig. 1 is a perspective view illustrating the form in which ammonium dihydrogen phosphate, potassium dihydrogen phosphate, ammonium dihydrogen arsenate, and potassium dihydrogen arsenate crystallizes. As illustrated in Fig. 1, such isomorphous dihydrogen crystal substances crystallize in the prismatic tetragonal-scalenohedral form and are formed with four major prism faces and with four cap faces at each end. The optic axis Z extends between each apex of the cap faces, and the mutually perpendicular X and Y axes, extend perpendicular to the four major prism faces. The several cuts or orientations of dihydrogen phosphate and arsenate crystal elements hereinafter disclosed may be cut from the mother crystal 1 of the substances and form illustrated in Fig. 1.

The mother crystal 1 illustrated in Fig. 1 may be grown from any suitable substances, and in any suitable manner such as, for example, by either the circulation method or the rocking method. As an illustrative example, the potassium salts, used in growing the mother crystal 1 illustrated in Fig. 1, may be obtained from potassium hydroxide and phosphoric or arsenic acid, and the ammonium salts may be obtained from ammonium carbonate and the corresponding acids. Saturated solutions may be prepared from these salts and the crystal 1 grown from watery solutions at a gradually decreasing temperature in any suitable manner. The crystal shape illustrated in Fig. 1 may be varied somewhat to obtain either needle-shaped crystals, or the more compact or short prism form as illustrated in Fig. 1. Ammonium dihydrogen phosphate produces short and thick prismatic crystals at room temperature. If liquor is added in excess, all of these salts may be crystallized in short prisms at room temperature. The short thick form of crystal 1, as illustrated in Fig. 1, is generally the more convenient form for cutting the various orientations of crystal plates therefrom.

Fig. 2 is a diagram illustrating the system, recently defined by the Institute of Radio Engineers, for specifying the orientation for a piezo-

electric crystal element or body 2 in relation to its mutually perpendicular X , Y and Z axes. As shown in Fig. 2, the X' axis is taken along the length dimension L of the crystal element 2, the Y' axis is taken along the width dimension W of the crystal element 2, and the Z' axis is taken along the thickness or thin dimension T of the crystal element 2. The angle θ is, as shown in Fig. 2, the angle between the optic axis Z and the plate normal or Z' axis, and the angle φ is the angle between the $+X$ axis ($+$ by tension) and the intersection of the plan containing the Z and Z' axes with the XY plane, while ψ is the angle between the length L axis X' and the tangent of the great circle containing the Z and Z' axes as measured in a plane perpendicular to the Z' axis. All angles are positive when measured in a counter-clockwise direction. Fig. 2 is applicable to a right-hand crystal, such as quartz, following the crystallographer's definition and the earlier Biot convention. The positive $(+)$ X axis is the X axis for which a positive charge develops on a tensional stress being applied thereto.

The crystal element 2 of Fig. 2 may be cut from any of the crystalline phosphate and arsenate substances illustrated in Fig. 1, and, by specifying the values for the three angles θ , φ and ψ of Fig. 2 may generally designate the orientation of any of the several crystal elements disclosed in this specification and illustrated in Fig. 3 of the drawing.

Suitable conductive electrodes such as the crystal electrodes 3 and 4 of Fig. 2 may be placed on or adjacent to or formed integral with the opposite major faces of any of the crystal plates disclosed herein in order to apply electric field excitation thereto. The crystal electrodes 3 and 4 when formed integral with the surfaces of any of the crystal elements 2 may consist of gold, platinum, aluminum, silver or other suitable conductive material deposited upon the crystal surfaces by evaporation in vacuum, painting, spraying, or by other suitable process. If desired, the crystal element 2 may be electroplated to the desired frequency by nickel plating or otherwise.

Fig. 3 is a perspective view of a longitudinal thickness mode piezoelectric crystal element 20 cut from crystallized ammonium dihydrogen phosphate, potassium dihydrogen phosphate or from the corresponding arsenates. The longitudinal thickness mode of motion of the crystal element 20 of Fig. 3 is controlled mainly by the value of the thinness or thickness dimension T thereof, and may be used, for example, to generate high frequency longitudinal waves in liquids as in high frequency supersonic projectors for submarine detection, and for other purposes where a relatively high frequency crystal element may be desired.

The longitudinal mode of motion which is utilized in the thickness mode crystal element 20 of Fig. 3 is controlled by the piezoelectric constant d_{33}' . The value of the piezoelectric constant d_{33}' is given by the relation:

$$d_{33}' = (2d_{14} + d_{36}) \frac{l_3 m_3 n_3}{\sin^2 \theta \cos \theta} = (2d_{14} + d_{36}) \sin \varphi \cos \varphi$$

The value of the piezoelectric constant d_{33}' of the last equation is a maximum when all of the direction cosines thereof are equal which occurs when $\theta = 45$ degrees and $\varphi = 54^\circ 40'$ giving a longitudinal thickness mode crystal element 20 of Fig. 3, the normal Z' of which makes equal angles with all three of the crystallographic axes X , Y and Z , as illustrated in Fig. 3. The major faces

of the longitudinal thickness mode crystal element 20 of Fig. 3 may be of square, rectangular, circular or other desired shape, and the length L and width W dimensions thereof may be proportioned with respect to the frequency determining thickness dimension T thereof to reduce the effect of spurious face modes of motion on the desired thickness motion thereof.

In the equation last given, the piezoelectric constant d_{14} is opposite in sign to the piezoelectric constant d_{36} , and the piezoelectric drive of the crystal element 20 of Fig. 3, represented by the resultant difference of these values, may be strongly driven since the value of the piezoelectric constant d_{36} is some ten times that of the piezoelectric constant d_{14} for ammonium dihydrogen phosphate, and is more than two times that of the piezoelectric constant d_{14} for potassium dihydrogen phosphate, and also has useful values in the corresponding arsenates.

The fundamental thickness longitudinal mode frequency of the crystal element 20 of Fig. 3 when composed of ammonium dihydrogen phosphate has a frequency constant of about 2670 kilocycles per second per millimeter of thickness dimension T and a temperature coefficient of frequency of about -400 parts per million per degree centigrade for its thickness T longitudinal mode of motion.

While in Fig. 3, a single orientation is illustrated, it will be understood that other longitudinal thickness mode crystal elements may be cut in the general region of the orientation illustrated by the crystal element 20 of Fig. 3.

Although this invention has been described and illustrated in relation to specific arrangements, it is to be understood that it is capable of application in other organizations and is, therefore, not to be limited to the particular embodiments disclosed, but only by the scope of the appended claims and the state of the prior art.

What is claimed is:

1. A piezoelectric crystal element adapted for longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof.

2. A piezoelectric crystal element adapted for longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof, said major faces of said crystal element being substantially rectangular.

3. A piezoelectric crystal element adapted for longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof, and means comprising electrodes cooperating with said major faces for operating said crystal element in said thickness longitudinal mode of motion.

4. A piezoelectric crystal element adapted for

longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof, said major faces of said crystal element being substantially rectangular, and means comprising electrodes cooperating with said major faces for operating said crystal element in said thickness longitudinal mode of motion.

5. A piezoelectric crystal element adapted for longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof, said thickness dimension being a value corresponding to the value of the frequency for said thickness longitudinal mode of motion.

6. A piezoelectric crystal element adapted for longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof, said thickness dimension being a value corresponding to the value of the frequency for said thickness longitudinal mode of motion, and said major faces of said crystal element being substantially rectangular.

7. A piezoelectric crystal element adapted for longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof, said thickness dimension being a value corresponding to the value of the frequency for said thickness longitudinal mode of motion, and means comprising electrodes cooperating with said major faces for operating said crystal element in said thickness longitudinal mode of motion.

8. A piezoelectric crystal element adapted for longitudinal motion along its thickness dimension which is normal to its major faces, and comprising one of the substances ammonium dihydrogen phosphate and potassium dihydrogen phosphate, said crystal element having said normal to said major faces inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof, said thickness dimension being a value corresponding to the value of the frequency for said thickness longitudinal mode of motion, said major faces of said crystal element being substantially rectangular, and means comprising electrodes cooperating with said major faces for operating said crystal element in said thickness longitudinal mode of motion.

9. Piezoelectric crystal apparatus in accordance with claim 1 wherein said one of said substances is ammonium dihydrogen phosphate.

10. Piezoelectric crystal apparatus in accord-

ance with claim 2 wherein said one of said substances is ammonium dihydrogen phosphate.

11. Piezoelectric crystal apparatus in accordance with claim 3 wherein said one of said substances is ammonium dihydrogen phosphate.

12. Piezoelectric crystal apparatus in accordance with claim 5 wherein said one of said substances is ammonium dihydrogen phosphate.

13. Piezoelectric crystal apparatus in accordance with claim 7 wherein said one of said substances is ammonium dihydrogen phosphate.

14. Piezoelectric crystal apparatus in accordance with claim 1 wherein said one of said substances is potassium dihydrogen phosphate.

15. Piezoelectric crystal apparatus in accordance with claim 3 wherein said one of said substances is potassium dihydrogen phosphate.

16. Piezoelectric crystal apparatus in accordance with claim 5 wherein said one of said substances is potassium dihydrogen phosphate.

17. A piezoelectric crystal element adapted for longitudinal motion along and at a frequency controlled by its thickness axis dimension disposed normal to its major faces, said thickness axis dimension being made of a value corresponding to the value of said frequency for said thickness longitudinal mode of motion, said element being a plate cut from a synthetic salt type water-soluble phosphate crystal and having said thickness axis dimension inclined at substantially equal angles with respect to all three of the mutually perpendicular X, Y and Z axes thereof.

18. A piezoelectric crystal element in accordance with claim 17 wherein said phosphate crystal is an ammonium dihydrogen phosphate crystal.

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No references cited.