

May 22, 1945.

E. H. LAND ET AL

2,376,493

APPARATUS FOR GENERATING SOUND WAVES

Filed Sept. 16, 1940

3 Sheets-Sheet 1

FIG. 1

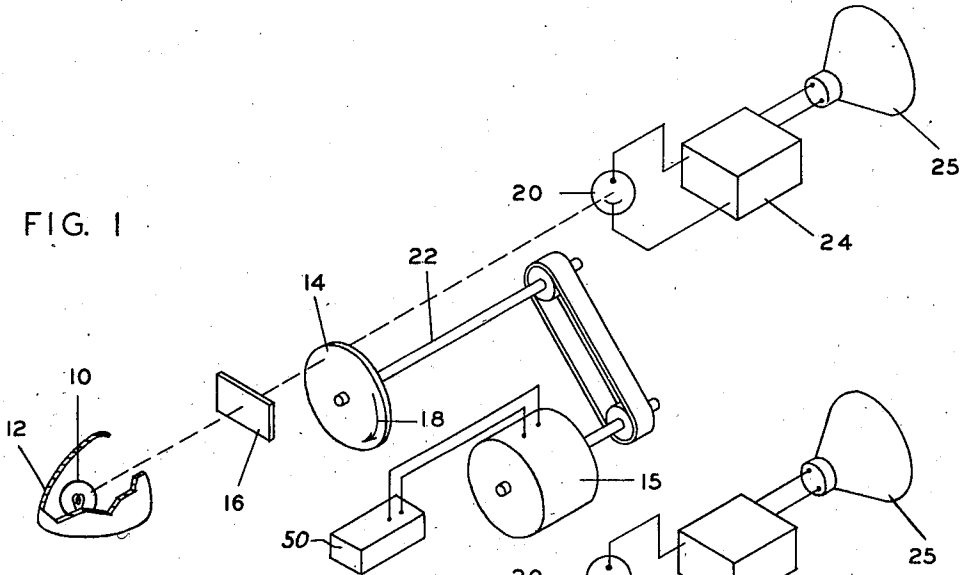


FIG. 2

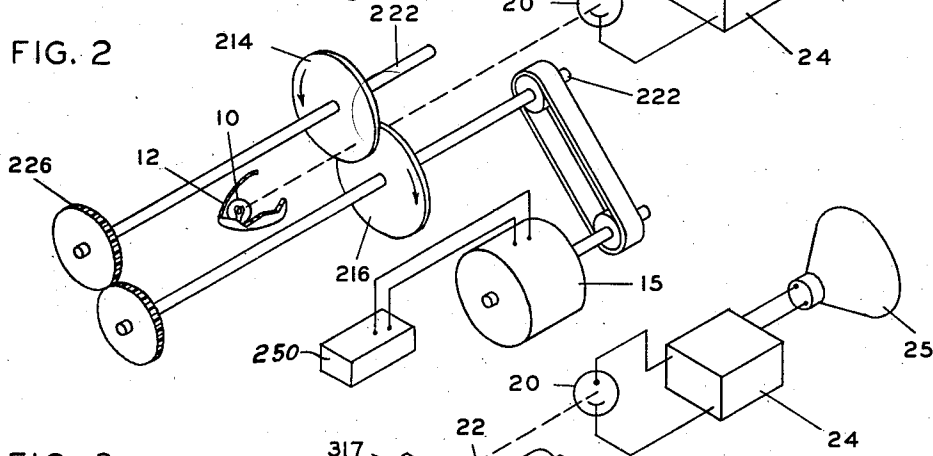
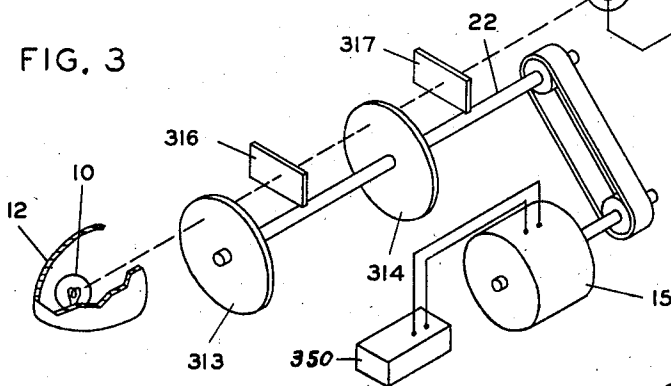


FIG. 3



INVENTOR
Edwin H. Land and
BY *Martin S. G. B. B.*
Ronald L. Brown
ATTORNEY

May 22, 1945.

E. H. LAND ET AL

2,376,493

APPARATUS FOR GENERATING SOUND WAVES

Filed Sept. 16, 1940

3 Sheets-Sheet 2

FIG. 4

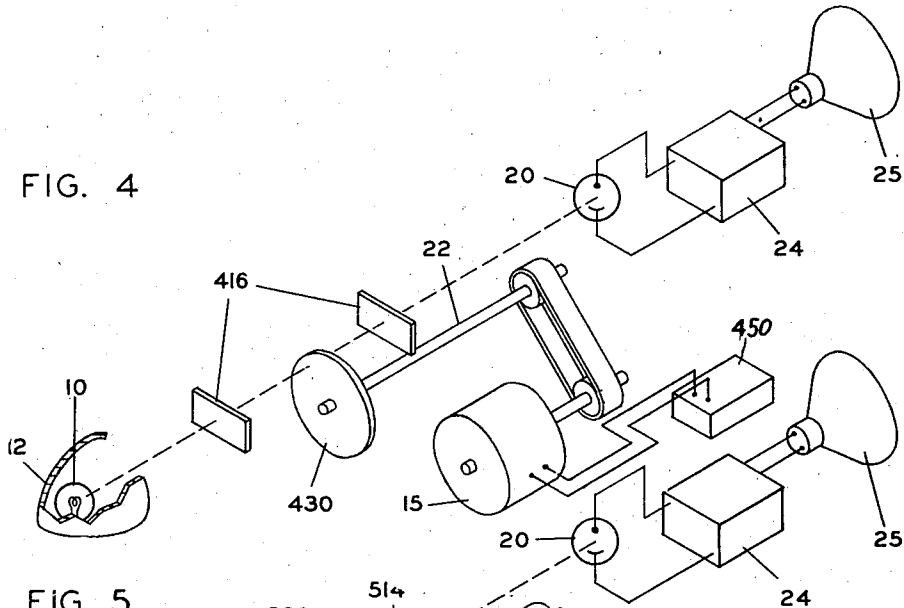


FIG. 5

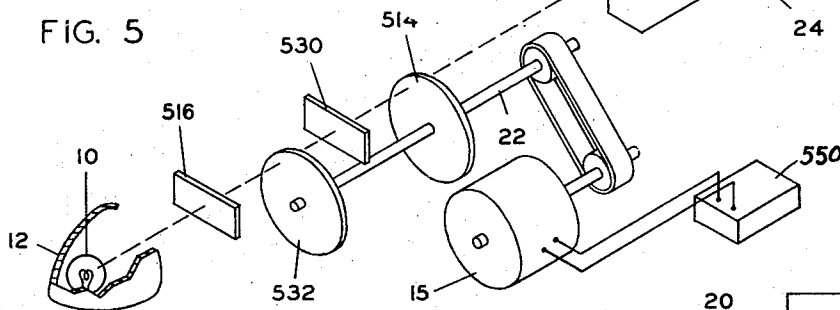
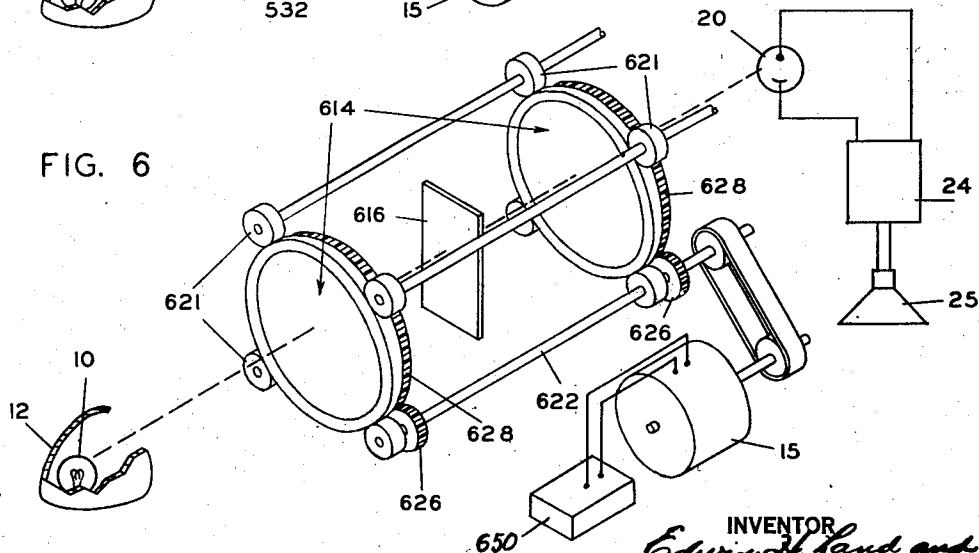


FIG. 6



INVENTOR
Edwin H. Land and
BY *Martin G. Brown*
Ronald E. Brown
ATTORNEY

May 22, 1945

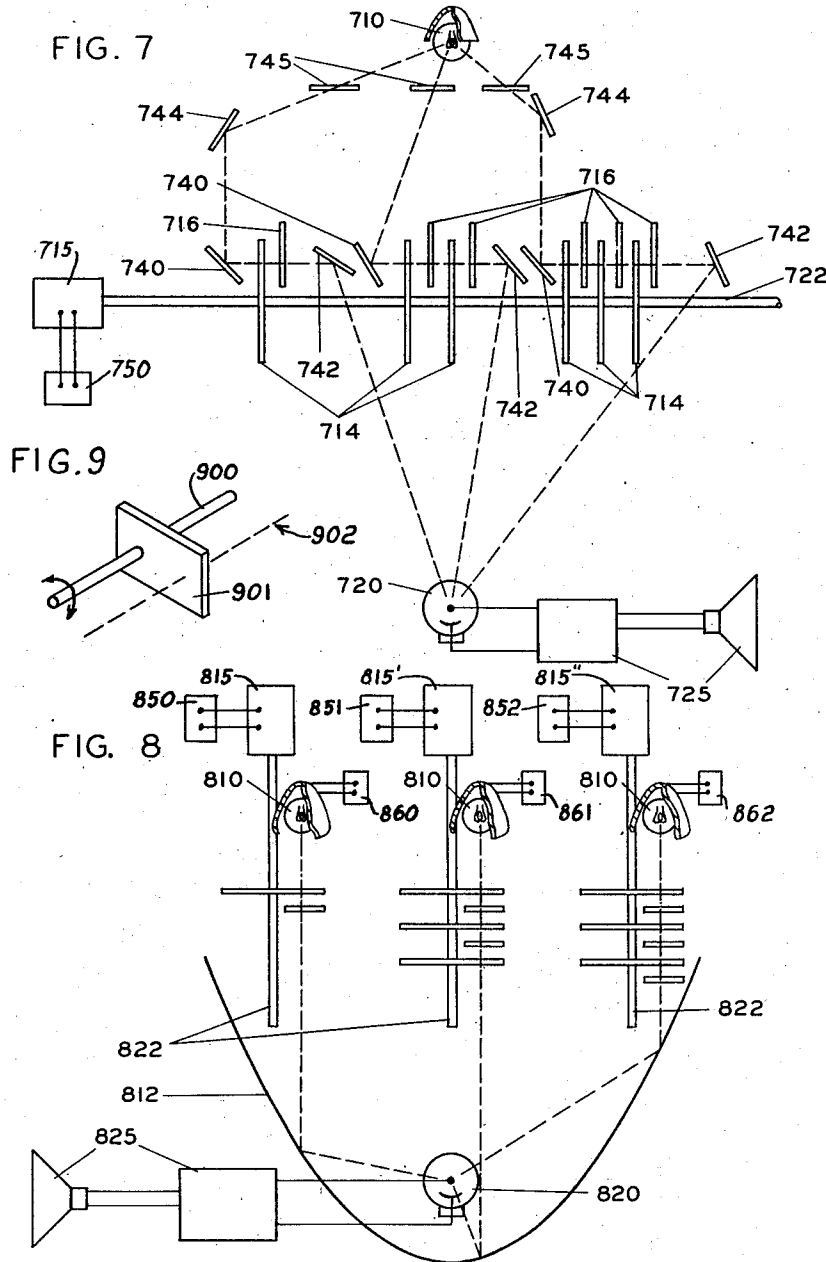
E. H. LAND ET AL

2,376,493

APPARATUS FOR GENERATING SOUND WAVES

Filed Sept. 16, 1940

3 Sheets-Sheet 3



INVENTOR
Edwin H. Land and
BY *Martin Grabau*
Ronald F. Brown
ATTORNEY

UNITED STATES PATENT OFFICE

2,376,493

APPARATUS FOR GENERATING SOUND WAVES

Edwin H. Land and Martin Grabau, Cambridge, Mass., assignors to Polaroid Corporation, Dover, Del., a corporation of Delaware

Application September 16, 1940, Serial No. 357,036

33 Claims. (Cl. 34—1.18)

This invention relates to a new and improved apparatus and to an improved process for generating sound waves.

An object of the invention is to provide a method and apparatus employing polarized light for the generation of superaudible, audible or sub-audible sound waves.

A further object of the invention is to provide a simple, efficient, inexpensive and readily manufactured mechanism for accomplishing the desired result.

Further objects of the invention are to provide a method and means for setting up fluctuations in the intensity of a beam of light, and more specifically fluctuations of a sinusoidal nature; to provide a means and method for translating these fluctuations into sound waves; to provide means in connection with apparatus of the character described for altering the fundamental frequencies of the sound waves generated; to provide means for the simultaneous production of a plurality of sound waves of different fundamental frequencies; to provide means for the production of a sound wave or sound waves of predetermined fundamental frequency or frequencies with the natural harmonics thereof; to provide means for controlling the relative strengths of the said harmonics or overtones and the fundamental frequencies; and to provide means for altering the fundamental frequency of a sound wave produced.

Still further objects of the invention are to provide a plurality of relatively rotatable elements for mechanically and periodically altering the intensity of a beam of light; to provide means associated therewith for translating said alterations into sound waves; to provide means for modifying said periodic alterations without altering the relative speed of rotation of said elements; to provide photoelectric and translating means adapted to receive and reproduce the fluctuations introduced into a plurality of light beams in separate optical systems; and to provide means associated with each such optical system for imparting to the beam associated therewith fluctuations of intensity of a character to reproduce in said photoelectric and translating means a predetermined tone with or without predetermined natural harmonics or overtones of a predetermined relative intensity.

Still further objects of the invention are to provide means for controlling the relative intensity of any tone or group of tones produced by the apparatus, and to provide means for accomplishing the said result without alteration in the

intensity of the light source or sources employed.

Still further objects of the invention are to provide, in a device of the character described, a plurality of relatively rotatable light-polarizing elements interposed in the path of a beam of light for effecting fluctuations in the intensity thereof, and to provide in connection therewith a plurality of light-transmitting elements, such for example as doubly refracting elements or light-polarizing elements, or fractional wave plates for effecting predetermined desired alterations in said fluctuations.

Other objects of the invention are to provide a musical instrument of the character described adapted to produce any desired tone or combination of tones of any desired quality and with any desired combination of natural harmonics; and to provide a device of the character described for use in connection, for example, with signaling devices, such as fog signals and the like, and adapted to produce a tone or tones of predetermined fundamental frequency and quality.

The invention accordingly comprises the several steps and the relation of one or more of such steps with respect to each of the others, and the apparatus embodying features of construction, combination of elements and arrangement of parts which are adapted to effect such steps, all as exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description, taken in connection with the accompanying drawings, in which:

Figure 1 is a diagrammatic representation of a simple apparatus embodying one form of the invention;

Fig. 2 is a similar view of a modified form of the invention;

Figs. 3-6 are similar representations of additional modifications of the invention;

Fig. 7 is a diagrammatic representation of a modified form of the invention wherein a plurality of different sets of related elements are mounted for rotation on a common shaft; and

Fig. 8 is a similar view of a still further modification of the invention wherein a plurality of separate sets of elements are mounted for rotation on separate shafts.

Fig. 9 is a diagrammatic view of a light transmitting element used with the invention together with means for movably mounting the element.

Where two light-polarizing elements are inter-

posed in the path of a beam of light and where one of said elements is rotated and one other held in fixed position, the variation of the operative relation of these elements will produce a fluctuation in intensity in the transmitted beam, the beam fluctuating from maximum to minimum intensity with twice the frequency of the speed of rotation of the rotated element, for example, if the rotated element is rotated at a speed of 220 revolutions per second, the transmitted beam will fluctuate at a frequency of 440 vibrations per second. If the fluctuations of the intensity of the beam are translated into electrical oscillations of the same frequency without distortion and these in turn are translated into mechanical vibrations of a suitable diaphragm in a loud speaker, again without distortion, a tone will be produced. This tone will be a pure tone substantially without upper harmonics or overtones of a frequency of 440 vibrations per second, i. e., it will be an audible tone and will have that pitch produced by striking A above middle C on a piano. Fig. 1 of the drawings illustrates a simple form of a device adapted to produce such a result.

In Fig. 1, element 10 represents any suitable light source, preferably adjacent a reflector 12, and elements 14 and 16 represent light-polarizing elements. Element 16 is represented as stationary and fixed in position, and element 14 is mounted to rotate as in the direction indicated by arrow 18 about shaft 22, which may be driven by any suitable source, for example the motor 15, and at any desired speed.

A photoelectric cell or similar device 20 is positioned in the path of a beam of light traversing elements 14 and 16. Said cell should be such that the range of wavelengths to which it responds should include at least a portion of the wavelength range which the polarizing elements are adapted to polarize. An amplifier 24 is represented in circuit with the photoelectric cell, and said amplifier in turn has a translator or loud speaker 25 in circuit therewith. It should be pointed out that, although a photoelectric cell or tube is preferred, they may alternatively be used any similar device which is responsive to variations in intensity or the plane of polarization of incident light, for example a thermo-couple. Moreover, it should be understood that although the invention is shown and described in connection with an amplifier and loud speaker, any translating means, such as that indicated, or any recording means, such as a moving photographic plate, may be used, if it is responsive to activation of the responsive means, and any such combination must be deemed within the scope of the invention and claims herein.

Suitable light-polarizing elements for use in apparatus embodying the present invention may comprise discs or other like elements of any suitable light-polarizing material, for example, the materials made and sold under the trade name "Polaroid." If desired, these materials, which are available in thin sheets of adequate tensile strength for the purposes of this invention, may be employed in unmounted or un laminated form, or it may be mounted upon or laminated to a plate or between plates of glass, plastic or other light-transmitting material. It is not essential that the polarizing material employed function to effect complete polarization of the transmitted beam.

Fluctuations in the intensity of the transmitted beam arise from the relative rotation of the element 14 with respect to the element 16 and give

rise to corresponding oscillations in the current delivered by the photoelectric cell 20. These oscillations, after being amplified as at 24, are translated into sound waves by the translator 25 and, if the frequency of rotation of the element 14 is such as to give rise to audible frequency sound waves at the translator device, an audible tone is produced. Alterations in the speed of rotation of the element 14, which may be accomplished by any control at the driving element 15 or in any other desired manner, give rise to corresponding alterations in the pitch of the tone produced at the translator. Conventional power control means 50 are suitably connected to the driving element 15 whereby the latter may be regulated to alter the speed of rotation of the light-polarizing element 14 as desired. With the device shown in Fig. 1, therefore, it is possible to produce a variety of different, pure tones of any desired pitch and of any desired intensity within the physical limits of the apparatus.

It appears desirable in connection with the production of tones of high pitch in the audible range and of supersonic sound to employ a device such as shown for example in Fig. 2, or obvious modifications thereof, so as to avoid excessively high speeds of rotation, as will hereafter be described. It is possible with other modifications of the device to produce overtones or harmonics of the basic pure tone without altering the speed of rotation of the elements and it is also possible to control the relative intensity of these overtones with respect to the basic tone in such manner as even to eliminate the basic tone as well as undesired overtones, each of which is a tone having a frequency which is an integral multiple of the basic rotation frequency, and to produce only the desired tone. Thus, for example, if the basic frequency of rotation is 220 revolutions per second, an isolated overtone may readily be produced having a frequency of 2640 vibrations per second or even a greater or lesser frequency if desired. It is thus apparent that even with relatively low speeds of rotations, relatively high pitched tones may be produced. This is particularly desirable in producing supersonic or superaudible tones as, for example, for use in beacons or signaling.

In Fig. 2, both of the discs of the polarizer, here designated as 214 and 216, are shown mounted to rotate on shafts 222 geared together by gears 226 and positioned in the path of the beam emanating from the light source 10 and impinging upon the photoelectric cell 20. As shown, polarizing element 214 is adapted to rotate in a counterclockwise direction and polarizer 216 in a clockwise direction. This rotation of the two elements quadruples the frequency of the fluctuation set up in the transmitted beam over the frequency of rotation of either shaft and thus permits the production, in the more complicated forms of the invention employing this arrangement, of very high pitched tones without subjecting the elements of the mechanism to excessive speeds of rotation. As in the modification shown in Fig. 1, the frequency of the fluctuations in the intensity of the transmitted beam may be varied by varying the speed of rotation of the light-polarizing means. For this purpose use is made of conventional power control means 250 which are designed to permit regulation of the driving element 15 and hence the rotative speed of the light-polarizing elements 214 and 216.

Another method of accomplishing the same result, and by the use of rotation elements mounted on a single shaft, is to add to the device

shown in Fig. 1 a second, rotatable, polarizing element positioned between fixed polarizer 16 and the light source 10 and mounted for rotation with shaft 22 or an extension thereof or, for example, mounted as shown in Fig. 6 and described hereinafter. With such an arrangement, and if the rotating polarizers are positioned each with its polarizing axis at right angles to the polarizing axis of the other, the fluctuations of intensity created in the transmitted beam have four times the frequency of rotation of the polarizers. If now the phase relation of the two rotatable polarizing elements is changed, i. e., if the relative orientation of their polarizing axes is altered from that described toward parallelism, there appears with such alteration a sub-harmonic tone, and the relative intensity of this sub-harmonic increases with the change of phase relation until the polarizing axes of the elements are parallel, at which position the intensity of the sub-harmonic is a maximum. This sub-harmonic has one-half the frequency of the tone that was produced when the two rotating polarizing elements were set with their polarizing axes perpendicular and with the fixed polarizer between them.

In Fig. 3 there is shown a modification of the device shown in Fig. 1. This device comprises two rotatable polarizing elements 313 and 314 and two fixed polarizing elements 316 and 317, all positioned in the path of a beam emanating from a light source 10 and impinging upon photoelectric cell 20 in circuit with any suitable amplifying and translating device 25. If these polarizing elements are positioned so that the polarizing axes of the fixed polarizers are parallel and the polarizing axes of the rotatable polarizers are parallel, the tone produced comprises a strong component having a frequency twice the frequency of rotation of the shaft, a somewhat weaker component having a frequency four times that of the frequency of rotation of the shaft and a still weaker component having a frequency six times the frequency of rotation of the shaft, i. e., the tone produced comprises a fundamental tone with its second and third harmonics. If the relative orientations of the polarizing elements are in any way altered, a change in the relative intensity of the fundamental and its harmonics is produced. In particular, if the orientation of the polarizing axis of the element 314 is 60° from the orientation of the polarizing axis of the element 313 in one sense, i. e., either clockwise or counter-clockwise, and if the orientation of the polarizing axis of the fixed element 317 is 60° from the orientation of the polarizing axis of the element 316 in the opposite sense, then the fundamental frequency, i. e., first harmonic, and the second harmonic are substantially suppressed and the tone produced comprises primarily the third harmonic of the original fundamental. Alteration of the speed of rotation of the shaft which carries the rotatable light-polarizing elements 313 and 314 will also alter the frequency of the fluctuations in the intensity of the light incident on the photoelectric cell 20. To this end use is again made of power control means, indicated by the reference numeral 350 in Fig. 3 for the purpose of regulating the driving element 15 and altering the rotative speed of the light-polarizing elements 313 and 314 at will.

Other combinations of rotatable and fixed elements in various relative orientations may be employed to produce a wide variety of combinations of fundamentals and their respective upper har-

monics with varying intensities of upper harmonics with respect to each other and with respect to the fundamental harmonic. Any fundamental can be produced by altering the speed of rotation of the shaft carrying the rotatable members. All such combinations fall within the scope of the invention. The addition to the combination of elements shown in Fig. 3 of additional fixed and rotating elements gives rise to the creation of tone combinations having additional upper harmonics or overtones. All such combinations are also within the scope of the invention.

It is thus obvious that, by a proper selection of the number of rotating and fixed polarizers and by a proper arrangement of the phase or orientation relationships of successive polarizers with respect to each other, it is possible to isolate the highest harmonic of the fundamental tone of a particular combination and to suppress the fundamental and all the harmonics except the highest. Similar modifications of the apparatus shown in connection with the device illustrated diagrammatically in Fig. 2 will be obvious, and are deemed to fall within the scope of the invention.

The apparatus has thus far been described as one employing fixed and rotatable light-polarizing elements as the means for causing predetermined fluctuations in the intensity of a transmitted beam. In Figs. 1, 2 and 3 the rotatable elements are shown mounted on a shaft. It will be obvious that they may be mounted in other ways. In Fig. 6, for example, the rotatable elements 614 are shown mounted at each side of fixed polarizer 616 to rotate on bearings 621, and are shown as being driven by a shaft 622 provided with gears 626 adapted to engage suitable gears 628 on the peripheries of the polarizing elements. Power control means 650, similar to those shown, are suitably connected to the driving element 15 of Fig. 6 whereby regulation of the rotative speed of the light-polarizing elements 614 is effected. With such a system the entire area of the polarizers may be employed to intercept the transmitted beam. It will be obvious that other methods of mounting and rotating the rotatable elements and of mounting the fixed elements may be employed, and that all or any desired portion of the surface area of any of the elements may be employed to intercept the transmitted beam. In this connection it might be pointed out that the intensity of the tone produced may be controlled in part by controlling the quantity of light falling upon the photosensitive element, i. e., as the intensity or cross-sectional area of the light beam is increased, the intensity of the tone produced by the system may be increased. Control means of this character are shown in Fig. 8 and will be presently explained.

If desired, birefringent elements, and more specifically and preferably half-wave retardation elements, may be inserted between the polarizing element adjacent the light source and the polarizing element adjacent the photosensitive element, and these birefringent or half-wave retardation devices may be employed as rotating or as fixed, or as fixed and rotating elements in apparatus embodying the invention. All of these elements, including the light-polarizing elements and the birefringent elements are termed herein optically anisotropic elements. In, for example, the apparatus shown diagrammatically in Fig. 4, the two polarizing elements 416 are fixed with respect to each other, and have between them a half-

wave retardation device 430 mounted for rotation with shaft 22. The rotation of the half-wave device will produce variation of the operative relation of the polarizing elements, and the resulting fluctuations in the light beam traversing the three elements give rise in the translator to a tone having a frequency four times the frequency of the speed of rotation of the half-wave device. So also, if element 616 in Fig. 6 represents a half-wave device fixedly mounted between the two rotating elements 614, the same result is obtained. Variations in the fluctuations in the intensity of the transmitted beam may also be attained in the device of Fig. 4, by power control means 450 associated with the driving element 15 for regulating the speed of rotation of the half-wave retardation means 430.

A further modification is shown in Fig. 5, and comprises a fixed polarizing element 516, a rotating polarizing element 514, a fixed half-wave plate 530 adjacent the rotating polarizer but between it and the fixed polarizer, and a rotating half-wave plate 532 mounted on shaft 22 for rotating with the rotating polarizer and positioned between the fixed half-wave plate and the fixed polarizer. With this arrangement a pure tone will be produced in translator 25 having a frequency six times the frequency of the shaft speed, and other modifications of added half-wave devices fixed and rotating to give tones of higher pitch may also be used and will be understood to fall within the scope of the invention. Power control means 550 are also employed in the device of Fig. 5 to the end of regulating the frequency of the fluctuations in the intensity of the transmitted light by regulating the rotative speed of the rotatable members 514 and 532.

Another arrangement involving the use of half-wave retardation devices may be produced by modifying the device shown, for example, in Fig. 2, where two polarizing elements are employed, one adjacent the light source, the other adjacent the photocell, each mounted for rotation on a separate shaft in a direction opposite the direction of rotation of the other. If this apparatus is modified by mounting with each rotatable polarizer a half-wave plate, so that the structure comprises, successively, and in addition to the light source, the photocell and the translator, a polarizing element mounted for clockwise rotation, a half-wave element mounted for counter-clockwise rotation, a second half-wave plate mounted for clockwise rotation, and a second polarizer mounted for counter-clockwise rotation, and if the beam impinging upon the photoelectric cell traverses all of said rotating elements in the order mentioned, the tone produced will be a pure tone having a frequency twelve times the frequency of the speed of rotation of the shafts, and the characteristics of the tone will remain unchanged irrespective of changes in the relative phase relations, i. e., in the orientations of the polarizers and the half-wave plates.

If the device shown in Fig. 2 is modified in such a way that two polarizing elements are mounted on the same shaft, and if a half-wave plate is mounted on the other shaft for relative rotation between the two polarizing elements, so that the two polarizing elements, while rotatable as a unit, are fixedly positioned with respect to each other, the resulting tone produced will have a frequency eight times the frequency of the shaft rotation. As the number of relatively rotatable half-wave devices between the polarizers in structures such as are shown in Fig. 2, i. e., where two shafts are

employed, is increased, the pitch of the tone produced increases in the manner indicated in connection with the discussion of the two preceding modifications. Wherever rotating half-wave retardation devices are employed positioned between relatively rotating polarizing elements (alternate elements in the ensemble being rotated in opposite directions), the quality of the tone produced is independent of the initial orientations of the polarizing axes of the polarizing units, or the principal axes of the half-wave plate elements.

In this connection it should be pointed out that, strictly speaking, a retardation plate can be a so-called half-wave plate only for one wavelength of light. For neighboring wavelengths of light, it will not be a perfect half-wave plate. If white light (comprising the usual distribution of light energy in the spectral range from 4000 to 7000 Å.) is used, and if the half-wave plate is designed for the wavelength, say 5500 Å., where the sensitivity of the eye is greatest, then its retardation is 0.69 wavelength at 4000 Å. and 0.39 wavelength at 7000 Å. Hence, in any system in which a combination of fixed and rotating polarizing sheets and "half-wave plates" is designed to produce a pure tone, the tone will still involve traces of harmonics whose relative intensity can be calculated from the spectral distribution of intensity of the source, the spectral distribution of retardation of the half-wave plate or plates, and the spectral distribution of response of the photoelectric cell.

This deficiency can easily be corrected by the use of monochromatic light, such as an electric sodium lamp, whose light energy is concentrated in two intense yellow lines in the spectrum which are very close together (5890 and 5896 Å.) and designing the half-wave plates for this narrow region of the spectrum. Another method involves the use of a common mercury vapor lamp, or a neon lamp whose spectral distribution of intensity lies almost entirely in the region between 6000 and 7000 Å. and designing the half-wave plate accordingly.

In order to cut out far red and infra-red light, for which Polaroid film is less perfect as a polarizer than elsewhere in the visible spectrum and where the sensitivity of a photocell is large, a suitable filter may be interposed in the system, such as a Zeiss BG-18. It should be pointed out, however, that this is not as important a problem as it seems, for the reason that it is only the variation in the polarized radiation which causes the system to operate. In other words, it is the light fluctuations caused by the polarizers which give rise to the tones produced, and light reaching the photocell without interception by two or more polarizers will be constant and will have no effect thereon except to establish its minimum illumination.

Other modifications of shaft and element arrangements than those previously discussed are shown in Figs. 7 and 8. In Fig. 7, for example, three tone-producing units, comprising a plurality of overlapping polarizing elements 714 and 716, are shown mounted on the same shaft 722 in combination with a single light source 710 and a single photoelectric tube 720 and translator 725. Light from source 710 is caused to traverse the rotating elements 714 and fixed elements 716 of each of the three units by means of mirrors 740 and 742, which act respectively to direct a portion of the beam through the predetermined elements which comprise each unit, and then to

direct each of said portions so that it impinges upon the photo cell. Supplementary directional mirrors 744 may be employed, if desired, and shutter means, indicated at 745, may be employed to block any of the beams emanating from light source 710. With such a device a plurality of separate tones including, if desired, their overtones, may be produced with the use of a single light source and a single rotating shaft. As in the other modifications of the invention, power control means 750 are employed in Fig. 7 to regulate a driving means or element 715 which drives the shaft 722 whereby to vary at will the rotative speed of the shaft and the light-polarizing elements 714 carried thereby to the end of predeterminedly altering the fluctuations in the intensity of the light transmitted to the photoelectric cell 720.

In Fig. 8 a modified structure is shown wherein a plurality of light sources 810 are provided, each with its own rotating shaft unit 822. This unit may comprise in any case a predetermined arrangement of fixed and rotatable elements, including polarizing elements and half-wave devices. The shafts may, if desired, be separately driven by separate power means or driving elements 815, 815' and 815''; or they may be so mounted as to be driven from a single power source by means of separate gear trains, not shown, whereby different shaft speed may be secured. Variation in the rotative speeds of the different shafts 822 may be obtained through individual power control means 850, 851 and 852 suitably connected to the driving elements 815, 815' and 815'' respectively. The beams traversing the elements associated with each shaft may be brought to focus on a photoelectric cell 820 mounted at the focal point of a parabolic reflector 812, and the tone may be produced in the translator and amplifier 825. Here, again, control of the tone production may be secured by controlling the energization of the light sources separately. For this purpose, use is made of separate control means 860, 861 and 862 of conventional design, each connected to an individual light source 810 whereby the intensity of the source may be regulated as desired. As previously intimated, if desired intensity control means of this character may be employed with the light source of the other embodiments of the invention for controlling the intensity of the light emitted by them. It will be obvious that the structure shown in Fig. 8 may readily be modified by arranging the light sources and their associated shaft units radially about the photoelectric cell, and that the number of such light sources and shaft units may vary to any desired degree.

Other modifications of the invention, other shaft arrangements and assemblies, will be obvious. In any of the modifications of the invention it will be understood that means may be provided to bring predetermined elements into engagement with other elements or similarly to remove them from such operative engagement. For example, the half-wave retardation devices mounted between the polarizing elements in certain of the modifications of the invention described, or certain of the polarizing elements in other modifications of the invention described, may be mounted to be swung into and out of operative relation to the rest of the polarizing or birefringent elements, whereby the tone produced may be altered in pitch or in quality, or in both ways. This may be accomplished by mounting separate elements independently on pivoted arms, so that

they may be swung out of operative relationship with respect to the other elements. For example, as shown in Fig. 9, an element 901 may be fixed to a rotatable shaft 900 for rotation therewith. Element 901 may be a light-polarizing device or fractional wave retardation means. It is shown in operating position in the path 902 of a light beam adapted to be transmitted onto a photoelectric cell of any of the embodiments of the invention. By rotating shaft 900 in the counterclockwise direction of the arrow at the left end of the shaft, element 901 may be swung out of the path 902 of the beam. Counterclockwise rotation of the shaft will then return element 901 to its operating position shown in Fig. 9. All such methods of controlling the pitch or tone qualities of the sound produced by devices embodying the present invention are to be deemed within the scope thereof. It may also be pointed out that by the use of a number of the above described units, suitably mounted and arranged and provided with appropriate controls, a musical instrument may be produced which will have the general characteristics of an organ. Similarly, it is possible by suitable control of overtones and harmonics to reproduce the tones of virtually any conventional musical instrument.

It should be understood that it is also practicable to arrange the various polarizing and half-wave elements so that certain thereof intercept only a portion of the light beam. Thus, a portion of the beam may be intercepted at one frequency and the remainder at another frequency, which will give rise to a still more complex combination of overtones. In a still further modification, elements rotating in the same direction may be caused, as by suitable gearing, to rotate at different relative speeds, thus making it possible, for example, to secure extremely low frequencies with a minimum of gearing and at any desired shaft speed.

TRIGONOMETRIC EXPLANATION OF THE INVENTION

It is believed that the present invention will be understood more easily if it be explained also with respect to certain mathematical formulae involved. If it is assumed that the emergent beam from a sheet of polarizing material is completely polarized and if k is the coefficient of transmissivity of a sheet of unit thickness, then for the light which is transmitted from an incident, nonpolarized beam of intensity I , a unit sheet has an emergent beam of intensity kI . If the incident beam is polarized and impinges on the sheet with its direction of vibration parallel to the polarizing axis of the sheet, then the emergent beam intensity is $2kI$. In the following, it will be assumed either that the light used is monochromatic or that k is the same for all wave-lengths and that the polarizer completely polarizes the transmitted beam.

Combinations including fixed and rotating polarizers

If a beam of non-polarized light of intensity I_0 passes successively through two sheets of polarizing material, the polarizing axes of which are at an angle θ , the emergent intensity I is

$$I = kI_0 (2k \cos^2 \theta) \quad (1)$$

or the relative intensity J , i. e., the ratio I/I_0 , is

$$J = 2k^2 \cos^2 \theta \quad (2)$$

or, since

$$\frac{1}{2} + \frac{1}{2} \cos 2\theta = \cos^2 \theta \quad (3)$$

$$J = 2k^2 (\frac{1}{2} + \frac{1}{2} \cos 2\theta) \quad (4)$$

If the sheet which the light beam first strikes is fixed, and the second rotates so that its polarizing axis rotates about the beam, then the direction of the electric force in the emergent beam is always parallel to the rotating polarizing axis. The intensity of the emergent light is proportional to the square of the electric force, and the intensity varies, in accordance with (4), with the cosine of twice the angle θ . When θ is 90° , the polarizers are crossed and the transmitted intensity is of course equal to zero. For each complete revolution of the second sheet, the intensity fluctuates through two complete cycles, each from maximum to minimum. It is to be noted, in accordance with (4), that the fluctuation is of a sinusoidal nature.

If a fixed, third polarizing sheet is positioned to intercept the beam after it has passed through the second rotating sheet and is positioned with its polarizing axis parallel to that of the fixed, first sheet, the beam incident on the third sheet is plane-polarized, the plane of polarization rotating with and parallel to the polarizing axis of the rotating, second sheet. As just mentioned, its relative intensity J varies. When the plane of polarization of the beam incident on the third sheet is parallel with the polarizing axis of the third sheet, a maximum of the beam passes through the third sheet but, as that plane rotates, the amount of light transmitted is further diminished by the third sheet until said plane is perpendicular to the polarizing axis of the third sheet. The intensity of light leaving the third sheet is

$$K = J 2k \cos^2 \theta \quad (5)$$

or substituting (2),

$$K = 2k^2 \cos^2 \theta 2k \cos^2 \theta \quad (6)$$

$$= 4k^3 \cos^4 \theta \quad (7)$$

or substituting (3),

$$K = 4k^3 \left(\frac{3}{8} + \frac{1}{2} \cos 2\theta + \frac{1}{8} \cos 4\theta \right) \quad (8)$$

Thus, the final intensity may be considered as comprising two vibrations, each fluctuating as a simple trigonometric function, one with a frequency equal to twice the frequency of rotation of the shaft of the second sheet, the other with a frequency equal to four times said shaft frequency.

Should the fixed, third sheet have a polarizing axis at an angle of $\pi/2$ or 90° with the polarizing axis of the fixed, first sheet, then Equation 6 becomes

$$K = 2k^2 \cos^2 \theta 2k \cos^2 (\theta + \pi/2) \quad (9)$$

$$= 4k^3 \left(\frac{1}{8} - \frac{1}{8} \cos 4\theta \right) \quad (10)$$

The fluctuating component is made up entirely of a component which fluctuates with a frequency which is four times that of the rotating shaft.

Similarly, when there are four polarizing sheets, the first and third fixed and the second and fourth having the same angular velocity about the light beam as an axis and all at certain identical times having their polarizing axes parallel, the ratio L of the intensity of the final emergent beam to the original incident beam is given by

$$L = 8k^4 \cos^4 \theta \quad (11)$$

which by similar trigonometric substitution becomes

$$L = 8k^4 \left(\frac{3}{8} + \frac{1}{2} \cos 2\theta + \frac{1}{8} \cos 4\theta + \frac{1}{8} \cos 6\theta \right) \quad (12)$$

Considering the fixed third sheet to have a direction of polarization at an angle of $-2\pi/3$ radians,

or -120° , to the direction of polarization of the fixed first sheet, and considering the rotating second sheet to start from a position such that its direction of polarization is then parallel to the first sheet and considering the rotating fourth sheet to start from a position such that its direction of polarization then makes an angle of $-2\pi/3$ radians or -120° , with the direction of polarization of the first sheet, the value of L after the rotating sheets have gone through an angle θ is

$$L = 8k^4 \cos^2 \theta \cos^2 (\theta + 2\pi/3) \cos^2 (\theta - 2\pi/3) \quad (13)$$

which becomes

$$L = 8k^4 \left(\frac{1}{2} + \frac{1}{2} \cos 6\theta \right) \quad (14)$$

The general rule, which includes Equations 4, 10 and 14, for determining the relative orientation of the various sheets whereby all partial tones, except a certain predetermined highest partial tone, are suppressed, is as follows:

Given a system of n Polaroid discs in which alternate elements are respectively stationary and rotating, the relative intensity of light transmitted by this system is

$$J = \frac{1}{2} (2k)^n \cos^2 (\theta + e_1) \cos^2 (\theta + e_2) \dots \cos^2 (\theta + e_{n-1}) \quad (15)$$

where the quantities e_1, e_2, e_{n-1} are representative of the initial orientations of the polarizing axes of the successive Polaroid discs in the ensemble in a way that will presently be made clear.

This function J will, in general, be a composite of vibrations of a sinusoidal character whose frequencies are given by the harmonic series $2f, 4f, 6f \dots 2(n-1)f$ where f is the frequency of rotation of the shaft. The relative intensities of the several components in this series will depend upon the values of the quantities e_1, e_2, e_3 , etc.

In particular, however, all the harmonic components of this series, except the one of highest frequency, may be made to vanish by a suitable choice of the values of e_1, e_2, e_3 , etc., in which

$$\begin{aligned} e_1 &= 0 & e_4 &= 3\alpha \\ e_2 &= \alpha & 3e_{n-1} &= (n-2)\alpha \\ e_3 &= 2\alpha \end{aligned}$$

and in which

$$\begin{aligned} &= 2\pi/n-1 \text{ in radian measure} \\ &= 360/n-1 \text{ in degrees} \end{aligned}$$

The expression for the relative intensity of the light is then

$$J = \frac{1}{2} (2k)^n \cos^2 \theta \cos^2 \left(\theta + \frac{2\pi}{n-1} \right) \cos^2 \left(\theta + \frac{4\pi}{n-1} \right) \dots \cos^2 \left(\theta + \frac{2\pi(n-2)}{n-1} \right) \quad (16)$$

and this by a suitable sequence of trigonometric substitutions reduces to one in which a term in $\cos^2(n-1)\theta$ is the only fluctuating component.

In order to determine the initial orientations of the polarizing axes of successive Polaroid discs in the assembly, insert the condition $\theta=0$ in the above equation for J . Assume that the odd-numbered elements in the assembly are stationary and that the even-numbered elements are mounted so as to be capable of a rotation in an arbitrarily chosen positive sense. It follows that the first two Polaroid discs must be so set that their polarizing axes are initially parallel. Since the second Polaroid disc is rotating positively,

the polarizing axis of the third Polaroid disc must be set at an angle

$$\frac{-2\pi}{n-1}$$

from the initial orientation of the polarizing axis of the second Polaroid disc. The third Polaroid disc is stationary. The polarizing axis of the fourth Polaroid disc must then be set initially at an angle

$$\frac{4\pi}{n-1}$$

to the orientation of the polarizing axis of the third Polaroid disc, and this procedure may be continued for any given number of discs.

Equation 4 defines the intensity of a beam which has traversed a fixed and rotating sheet when, after a given time, the direction of polarization of the latter has reached an angle θ with the direction of polarization of the former. If both had been rotating at the same rate but in opposite directions, the angles between the directions of polarization would have increased twice as fast and, after the same time, the last-mentioned angle would have been equal to 2θ . In which case

$$J = 2k^2 \cos^2 2\theta \quad (17)$$

$$= 2k^2 \left(\frac{1}{2} + \frac{1}{2} \cos 4\theta \right) \quad (18)$$

Similarly, if certain intensity components are present with respective frequencies of fluctuation in a beam which has passed through fixed polarizing sheets and sheets rotating in one direction, then if the fixed sheets are given an equal speed of rotation but in the opposite direction, those intensity components have twice as great frequencies of fluctuation.

Combinations including retardation plates

In the case of two polarizing sheets, with parallel polarizing axes and rotating with the same angular velocity, with an interposed retardation plate having an equal angular speed and opposite angular velocity, the polarized light received from the first sheet by the plate is resolved in the plate into two components which emerge from the plate differing in phase by an angle d and each having its direction of vibration at right angles to that of the other. The geometric reference systems have to be taken with axes along these directions. If a is the amplitude of the intensity of the light leaving the first sheet, then, at any instant at which the direction of polarization of the light incident on the retardation plate is inclined at the angle α to the x axis in the retardation plate, the amplitudes of the two components, x and y , leaving the plate would be

$$x = a \cos mt \cos \alpha \quad (19)$$

$$y = a \cos(mt+d) \sin \alpha \quad (20)$$

where m is equal to 2π times the frequency of the light.

If the first sheet and the plate rotate in opposite directions, when each has turned through an angle θ , then α will be equal to 2θ in the previous equation, and

$$x = a \cos 2\theta \cos mt \quad (21)$$

$$y = a \sin 2\theta \cos (mt+d) \quad (22)$$

The above values of the amplitude x and y must now be resolved along the polarizing axis of the second rotating sheet. The resultant amplitude is the sum of their contributions. If A is the resultant amplitude, then

$$A \cong x \cos 2\theta + y \sin 2\theta \quad (23)$$

The symbol $\cong$ is here used to signify "is proportional to." The intensity J is, of course, proportional to the square of the amplitude A . On making the appropriate substitutions and simplifications, there is obtained:

$$J \cong \frac{1}{4} (1 - \cos d) \cos 8\theta + \frac{3}{4} - \frac{1}{4} \cos d \quad (24)$$

or, for a half-wave plate, where $\cos d = -1$,

$$J \cong \frac{1}{2} \cos 8\theta + 1 \quad (25)$$

If the polarizing sheets, instead of having parallel polarizing axes as in the preceding case, have axes which are at an angle of 90° , a similar mathematical treatment gives

$$J = \frac{1}{2} \sin^2 \frac{1}{2} d (1 - \cos 8\theta) \quad (26)$$

Again the resulting frequency of fluctuation of the intensity of the light emerging from the device is eight times the frequency of rotation of either the shaft which carries the plate or of the shaft which carries the polarizers.

Combinations including half-wave retardation plates

A half-wave plate rotates the plane of polarization of incident plane-polarized light. If such a plate is interposed between, and has an angular velocity equal in magnitude and opposite in direction to two polarizing sheets, and if the polarizing axis of the first sheet makes an angle u to the positive side of either of the principal axes of the half-wave plate, then the plane of polarization of the light emerging from the half-wave plate makes an angle u with the same principal axis of the half-wave plate toward the negative side. Hence, the angular disparity between the polarizing axis of the first polarizing sheet and of the plane of polarization of the light emerging from the half-wave plate is $2u$. When the first polarizing sheet has rotated positively through an angle θ and (in the meantime) the half-wave plate has rotated negatively through an angle θ , the angle between their axes is 2θ . Consequently, the plane of polarization of the light emerging from the half-wave plate must have turned through an angle 4θ from where it was originally. This rotation is negative, but both the first and second polarizing sheets have turned through the positive angle θ in the same time. Hence, the angle between the plane of polarization of the light emerging from the half-wave plate and the polarizing axis of the second polarizing sheet is 4θ . Neglecting any absorption of light by the half-wave plate,

$$J = 2k^2 \cos^2 4\theta \quad (27)$$

$$= 2k^2 \left(\frac{1}{2} + \frac{1}{2} \cos 8\theta \right) \quad (28)$$

Hence, the frequency of the fluctuation of the intensity of the light emerging from the second polarizing sheet is eight times the frequency of rotation of either shaft.

If a light beam passes through a polarizing sheet, two half-wave plates and a second polarizing sheet, all rotating at the same rate but with alternate elements rotating in opposite directions, the intensity of the finally emergent beam is

$$J = 2k^2 \cos^2 6\theta \quad (29)$$

$$= 2k^2 \left(\frac{1}{2} + \frac{1}{2} \cos 12\theta \right) \quad (30)$$

For each additional half-wave plate inserted, the argument of the cosine term is increased by 4θ (compare Equations 26 and 28).

The foregoing formulae represent the results obtained in an ideal system. They may be close-

ly approximated in actual practice in many ways. For example, where Polaroid film is employed as the polarizing elements, it is necessary only to restrict the wavelengths of light emanating from the source to those values or regions in the spectrum for which the degree of polarization of light produced by Polaroid film is substantially unity. Standard Polaroid film gives a degree of polarization equal to or greater than .999 for light in the middle third of the visible spectrum, with, at the same time, relatively high transmission properties.

Where the light source employed is either a sodium vapor arc, or a mercury vapor arc in combination with a suitable filter to isolate the green line in the spectrum, or an incandescent source with a suitable filter to restrict the light employed to a wavelength band approximately in the middle of the visible spectrum, and where Polaroid film is employed as the polarizing elements, the results achieved are approximately those expressed mathematically in the above formulae. In such systems the use of half-wave devices comprising sheets, for example, of half-wave Cellophane will impart no distortion to, or appreciable departure from, the results expressed by said formulae.

In the event that it may be desired to employ circularly polarized light in the practice of the present invention, it is necessary to employ, in addition to the circular polarizer and the analyzer, a partial wave retardation device, mounted between the two polarizing elements for relative rotation with respect to the one adjacent the light source.

It should be borne in mind that in devices employing the invention, the polarizing and wave retardation elements employed are preferably mounted in such a way that alternate elements are adapted for rotation, one with respect to another.

It should also be understood that the foregoing formulae and the descriptions of various modifications of the invention are intended merely as generally illustrative of devices embodying the invention, and are given in the belief that from them a wide variety of devices and other modifications will be readily apparent to those skilled in the art to which the invention appertains.

Since certain changes in carrying out the above process and in the constructions set forth which embody the invention may be made without departing from its scope, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described our invention, what we claim as new and desire to secure by Letters Patent is:

1. In combination with a light source, means sensitive to variations in incident light and translating means associated with said sensitive means and responsive to activation thereof, a plurality of optically anisotropic elements including at least two light-polarizing elements positioned between said source and said sensitive means to intercept light emanating from said source and incident on said sensitive means, means to alter the intensity of light incident on said sensitive means and traversing said anisotropic elements,

said means including means for altering predeterminedly and periodically the position of the axis of at least one of said anisotropic elements with respect to the others of said elements.

2. In combination with a source of light, means sensitive to variations in incident light positioned in the path of light emanating from said source and translating means associated with said sensitive means and responsive to activation thereof, a light-polarizing element positioned between said source and said sensitive means, a second light-polarizing element positioned in the path of light traversing said first-named polarizing element, means comprising birefringent material positioned between said polarizing elements, and means for varying the relation between the polarizing axis of at least one of said polarizing elements and the principal axes of said birefringent material.

3. In combination with a source of light, means sensitive to variations in incident light positioned in the path of light emanating from said source and translating means associated with said sensitive means and responsive to activation thereof, a plurality of light-polarizing elements positioned between said source and said sensitive means, at least one element comprising birefringent material positioned between said polarizing elements, and means for rotating at least one of said polarizing and birefringent elements with respect to at least one other thereof.

4. In combination with a source of light, means sensitive to variations in incident light positioned in the path of light emanating from said source and translating means associated with said sensitive means and responsive to activation thereof, a plurality of light-polarizing elements positioned between said source and said sensitive means, and means comprising a plurality of elements of birefringent material positioned between said polarizing elements, alternate elements in said assembly being mounted for rotation relatively to the remainder of said elements.

5. In combination, a source of light, a plurality of groups of light-polarizing elements positioned in the path of light emanating from said source in predetermined directions, alternate elements in said groups being mounted for rotation relatively to the remainder of said elements, and means sensitive to variations in incident light positioned in the path of light traversing said polarizing elements.

6. In combination with a source of light, means sensitive to variations in incident light and translating means associated with said sensitive means and responsive to activation thereof, a plurality of light-polarizing elements arranged in overlapping relation, alternate elements in said plurality being mounted for rotation relatively to the remainder of said elements, and means for directing beams of light emanating from said source through predetermined groups of said polarizing elements and for causing the resulting polarized beams to impinge upon said sensitive means.

7. In combination with a source of light, means sensitive to variations in incident light and translating means associated with said sensitive means and responsive to activation thereof, a plurality of light-polarizing elements arranged in overlapping relation, alternate polarizing elements in said plurality being mounted for rotation relatively to the remainder of said elements, and mirror means positioned to direct beams of light emanating from said source through predeter-

mined groups of said polarizing elements and to cause the resulting polarized beams to impinge upon said sensitive means.

8. In a tone producing device having a source of light, photo-sensitive means positioned in the path of light emanating from said source and speaker means associated with said photo-sensitive means and responsive to activation thereof, in combination, a plurality of light-polarizing elements positioned in the path of the light emanating from said source and located between said source and said photo-sensitive means, alternate elements in said plurality being mounted for rotation relatively to the remainder of said elements, and means for causing said rotatably mounted elements to rotate.

9. In a tone producing device having a source of light, photo-sensitive means positioned in the path of light emanating from said source and speaker means associated with said photo-sensitive means and responsive to activation thereof, in combination, a plurality of light-polarizing elements positioned in said light path between said source and said photo-sensitive means, alternate elements in said plurality being mounted for rotation relatively to the remainder of said elements, means for causing said rotatably mounted elements to rotate, and means for regulating the frequency of rotation of said elements such that a superaudible sound is produced in said speaker means.

10. In a tone producing device having a source of light, photo-sensitive means positioned in the path of light emanating from said source and speaker means associated with said photo-sensitive means and responsive to activation thereof, in combination, a plurality of light-polarizing elements positioned in said light path between said source and said photo-sensitive means, alternate elements in said plurality being mounted for rotation relative to the remainder of said elements, means for causing said rotatably mounted elements to rotate, and means for regulating the frequency of rotation of said elements such that a sub-audible sound is produced in said speaker means.

11. In a tone producing device having a source of light, photo-sensitive means positioned in the path of light emanating from said source and speaker means associated with said photo-sensitive means and responsive to activation thereof, in combination, a plurality of light-polarizing elements positioned in the path of light emanating from said source, and located between the source and said photo-sensitive means, at least one half-wave retardation device positioned between said polarizing elements, at least one of the elements in the assembly being mounted for rotation relatively to the remainder of said elements, and means for rotating said rotatably mounted element.

12. In a musical instrument having at least one light source, photo-sensitive means receiving light emanating from said light source and loud speaker means associated with said photo-sensitive means and responsive to activation thereof, in combination, a plurality of groups of optically anisotropic elements, each said group comprising at least two light-polarizing elements, each said group being positioned in the path of light emanating from said source and incident on said photo-sensitive means, predetermined elements in each said group being mounted for rotation relatively to the remaining elements therein, and

means for rotating said rotatably mounted elements at predetermined speeds.

13. In a musical instrument having at least one light source, photo-sensitive means receiving light emanating from said source and loud speaker means associated with said photo-sensitive means and responsive to activation thereof, in combination, a plurality of groups of light-polarizing elements traversed by light emanating from said source and incident on said loud speaker means, predetermined pairs of polarizing elements in predetermined ones of said groups having half-wave retardation means positioned therebetween, alternate elements in each of said groups being mounted for rotation relatively to the remainder of the elements therein, and means for rotating said rotatably mounted elements at predetermined speeds.

14. In a musical instrument having at least one source of light, photo-sensitive means positioned in the path of light emanating from said source and speaker means associated with said photo-sensitive means and responsive to variations in the output thereof, in combination, means for causing the light from said source incident on said photo-sensitive means to fluctuate at a predetermined frequency, said means comprising a plurality of light-polarizing elements positioned between said light source and said photo-sensitive means, means for causing predetermined elements of said light-fluctuating means to rotate relatively to the remainder of said elements and means for predeterminedly altering the frequency of such variations.

15. In a musical instrument having at least one source of light, photo-sensitive means positioned in the path of light emanating from said source and speaker means associated with said photo-sensitive means and responsive to variations in the output thereof, in combination, means for causing the light from said source incident on said photo-sensitive means to fluctuate at a predetermined frequency, said means comprising a plurality of light-polarizing elements positioned between said light source and said photo-sensitive means, means for causing predetermined elements of said light-fluctuating means to rotate relatively to the remainder of said elements, and means for predeterminedly altering the frequency of such variations, said means comprising means for moving predetermined elements in said light-fluctuating means into and out of the path of light from said source incident on said photo-sensitive means.

16. In a musical instrument having at least one source of light, photo-sensitive means positioned in the path of light emanating from said source and speaker means associated with said photo-sensitive means and responsive to variations in the output thereof, in combination, means for causing the light from said source incident on said photo-sensitive means to fluctuate at a predetermined frequency, said means comprising a plurality of optical anisotropic elements and including at least two light-polarizing elements positioned between said light source and said photo-sensitive means, means for causing predetermined elements of said light-fluctuating means to rotate relatively to the remainder of said elements, and means for predeterminedly altering the frequency of such variations.

17. In a musical instrument having photo-electric means sensitive to variations in incident light, speaker means associated with said sensitive means and responsive to activation thereof and

means for projecting a plurality of beams of light onto the said sensitive means, in combination means for selectively interrupting one or more of said beams at a predetermined frequency, said means comprising a plurality of optically anisotropic elements and including at least two light-polarizing elements positioned in the path of each of said beams, and means for causing predetermined elements in any of said pluralities to rotate relatively to the other said elements therein.

18. In a musical instrument having photo-electric means sensitive to variation in the intensity of incident light, means for projecting a plurality of beams of light onto said sensitive means and speaker means associated with said sensitive means and responsive to activation thereof, in combination, a plurality of optical systems each comprising a plurality of optically anisotropic elements including at least two light-polarizing elements positioned in the path of each of said beams, predetermined elements in each of said systems being mounted for rotation relatively to the other said elements therein, and means for selectively causing the rotatable elements in any of said systems to rotate at predetermined frequencies.

19. Means for creating a sinusoidal fluctuation in the intensity of a beam of light comprising a plurality of light-polarizing elements positioned to intercept said beam, and means for causing relative rotation of the transmission axes of said polarizing elements with respect to each other.

20. In combination, a light source, means for effecting a sinusoidal fluctuation in the intensity of light emanating from said source and comprising a plurality of light-polarizing elements, means to position said elements so that a portion at least of each of said elements intercepts the same predetermined portion of the light emanating from said source, and means to cause relative rotation of the transmission axes of said polarizing elements with respect to each other.

21. In combination, a light source, means for effecting a sinusoidal fluctuation in the intensity of light emanating from said source and comprising a plurality of light-polarizing elements, means to position said elements so that a portion at least of each of said elements intercepts the same predetermined portion of the light emanating from said source, means to cause relative rotation of the transmission axes of said polarizing elements with respect to each other, and means for altering the frequency of the said fluctuation in intensity of said beam.

22. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, a plurality of light-polarizing elements positioned to intercept said collimated beam, and means for rotating at least one of said elements with respect to another of said elements to effect a sinusoidal fluctuation in the intensity of light transmitted by said elements.

23. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, a plurality of light-polarizing elements positioned to intercept said collimated beam, means for rotating at least one of said elements with respect to another of said elements to effect a sinusoidal fluctuation in the intensity of light transmitted by said elements, and means for altering the speed of rotation of said rotating element to effect a change in frequency in said fluctuation.

24. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, a plurality of light-polarizing elements positioned to intercept said collimated beam, means for rotating at least one of said elements with respect to another of said elements to effect a sinusoidal fluctuation in the intensity of light transmitted by said elements, and means for effecting a change in the frequency of said fluctuation.

25. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, and means for effecting a sinusoidal fluctuation in the intensity of said light beam, said last named means comprising, in combination, a multiplicity of light-polarizing elements positioned to intercept said beam, alternate elements in said multiplicity being mounted for rotation relatively to the remainder thereof, and means for rotating said rotatably mounted elements.

26. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, and means for effecting a sinusoidal fluctuation in the intensity of said light beam, said last named means comprising, in combination, a multiplicity of light-polarizing elements positioned to intercept said beam, alternate elements in said multiplicity being stationary and the remainder of said elements being mounted for rotation relatively to said stationary elements, and means for rotating said rotatably mounted elements.

27. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, and means for effecting a sinusoidal fluctuation in the intensity of said light beam, said last named means comprising, in combination, a multiplicity of light-polarizing elements positioned to intercept said beam, alternate elements in said multiplicity being mounted for rotation in one direction and the remainder of said elements being mounted for rotation in the opposite direction, and means for rotating said rotatably mounted elements.

28. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, and means for effecting a sinusoidal fluctuation in the intensity of said light beam, said last named means comprising, in combination, a plurality of light-polarizing elements positioned to intercept said beam, a fractional wave retardation device positioned between said polarizing elements, at least one of said elements being mounted for rotation with respect to the remainder thereof, and means for rotating said rotatably mounted elements.

29. In combination, a light source, means associated therewith for substantially collimating a beam of light emanating from said source, and means for effecting a sinusoidal fluctuation in the intensity of said light beam, said last named means comprising, in combination, a plurality of light-polarizing elements positioned to intercept said beam, at least one half wave retardation device positioned between said polarizing elements, at least one of said elements being mounted for rotation relatively to the remainder thereof, and means for rotating said rotatably mounted elements.

30. Apparatus for generating varying electrical waves comprising a source of light of substantially constant intensity, photoelectric means, a

plurality of light polarizing means positioned adjacent each to the other adapted to change the polarization of light passing therethrough in accordance with the continuous rotation of said polarizing means, and means for rotating at least one of said polarizing means.

31. Apparatus in accordance with claim 30 and wherein said polarizing means are rotated in the same direction and at differing speeds.

32. Apparatus in accordance with claim 30 wherein at least a pair of said polarizing means are rotated in opposite directions.

33. Apparatus in accordance with claim 30 wherein means are provided to modulate the light source.

EDWIN H. LAND.
MARTIN GRABAU.