beats for ten second periods with the magnet current flowing and with it off. The difference between these readings gave the increase due to the field. The average for all the sets was 5 cycles increase for the ten second periods, making an average increase of 0.5 cycles in 30,000. Crystals of 40, 70 and 100 K.C. natural frequency were tried, but each gave negative results.

Discussion of Results

When a quartz bar is caused to expand and contract as in a piezo-electric oscillator, electric charges of first one sign and then the other are liberated on the faces at the extremities of the electric axis. Since the charges change sign at a rate equal to the natural frequency of the crystal there must be a transfer of electricity of some kind or other. This transfer is supposedly made by a change in the internal structure of the crystal. This would involve a motion of the atoms, which being charged would constitute a minute electric current. The conductor of such a current when placed in a magnetic field would experience the usual thrust perpendicular both to the direction of the current and to the magnetic lines of force. Also according to modern theories of atomic structure the atom consists of electrons which rotate around a positive nucleus. These rotating electrons really constitute a current. The magnetic field would affect the direction of this current and thereby distort the normal orbits of the electrons. The net result of these two effects might be to change the modulus of elasticity and hence the natural frequency of the crystal.

Acknowledgments

The writer wishes to acknowledge his indebtedness to Dr. A. L. Foley, who suggested the problem, and who followed its progress with kindly interest and helpful counsel. He is also grateful to the other members of the Department of Physics at Indiana University who aided in various ways.

EFFECT OF SOUND ON SPACE CURRENTS

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The object of the following investigation was to find a desirable method of measuring sound intensity. It was thought if sound could, somehow or other, be used to modify space currents in air, it might be possible to eliminate some of the objections to previous methods of measuring sound intensity. Three different methods were tried: (1) The effect of sound on the path of the electron current given off from a hot Nernst filament; (2) the effect of sound in modifying the amount of space current given off from a fine hot platinum wire; (3) the effect of sound on electron radiation.

The Effect of Sound on the Path of the Current from the Nernst Filament Circuit and Theory. The positive and negative discharge of a Nernst filament was studied by Gweln Owen.[1] The diagram of the circuit which we used is given in figure 1. D is the heated Nernst filament which is mounted vertically, B and C are two safety razor blades insulated from each other by a mica film at a distance of 1 mm. and mounted on the table of a traveling microscope with their edges vertical.

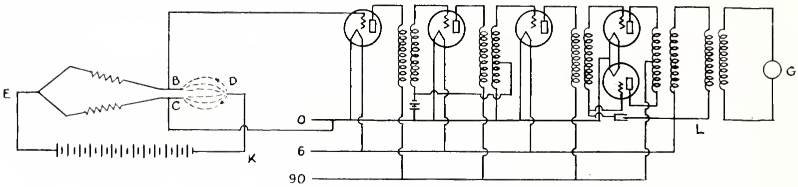

Fig. 1. EK is Nernst Filament Circuit. LM is step down transformer. G is hot wire instrument.

The theory of the circuit is as follows: B and C are the sharp edges of the razor blades. By imposing a difference of potential of 1,500 volts between D and edges of the razor blades a field of the nature of that shown in the diagram would exist between B, C, and D. It was thought that the discharge from the Nernst filament would follow these lines rather closely. The photographs taken by Dr. Foley in an unpublished investigation on electric discharges suggests that the stream of ions in air maintained quite definite lines of flow. It was therefore thought that by passing sound waves perpendicular to the Nernst filament and razor blade edges, it might be possible to find a proper potential and position of blades and filament such that the sound wave (by actual mechanical displacement or by changing the dielectric constant due to compression and rarefaction) might cause an increase in the number of ions in one path and a decrease in the other path; say, an increase in DC and a decrease in BD. There also might be slight change in surface temperature which would change the radiation of the Nernst filament. Dr. Foley has shown by his condenser microphone that such an effect as changing the dielectric constant exists. Assuming that there was sufficient directive action on the ions by the electric field to keep the two streams in well defined paths, there would be a current of different strengths in R_1 and R_2 and hence a difference in potential between B and C. When the mechanical state of affairs is reversed by the sound wave then there would be a reversed difference of potential from B to C. Suppose current in R_1 is i_1, and in R_2 is i_2, then the difference in potential between B and C would be equal to $R_1 i_1 - R_2 i_2$. This difference in potential would change with the same frequency as the sound waves causing it and would depend in magnitude on the amplitude of the sound vibration. This was tried under a variety of circumstances and no effect was observed on the milliameter.

[1] Phil. Mag. 8, 236, 1904.

Conclusion. Failure to observe any effect is probably due to the collisions between ions and molecules, keeping the boundaries of the two different paths of such an irregular nature that a small shift would have too small an effect on the strength of the current in either path to cause a detectable difference in potential between B and C. There would also be a question of phase relations among the three possible effects mentioned at the beginning; namely, change in the path due to mechanical displacement, change in path due to change in dielectric, and change in temperature. The change in temperature would undoubtedly be extremely small in a filament as large as the Nernst filament used and could at best be a surface effect only.

Effect of Sound on Ionization Current from Incandescent Platinum. It is a well known fact that heated solids give both positive and negative ionization currents. Elster and Geitel[2] investigated this phenomenon very thoroughly. Rutherford[3] measured the discharge, both positive and negative, from platinum under various conditions; namely, variation of current with potential, variation of current with distance between discharging and receiving plates, variation of current with temperature of discharging plate.

There are a number of factors which influence the discharge; namely, pressure, long continued heating, absorbed gases, dust, and gas in which the plates are placed. The phenomenon is apparently very complicated. J. J. Thompson says, "The initial rapid decrease with time is presumably due to the removal of the potassium or sodium, which forms the ions from the surface layer of the metal."

D in cm.	Current	iD
2	18,800	150,000
3	2,690	72,600
4	835	53,400
5	296	37,000
6	156	33,700

The current falls more rapidly than the equation indicates. No allowance was made for temperature between the plates. When the equation was derived, this would account for the difference in data and experiment.

H. A. Wilson[4] has shown the relation between positive and negative currents. He used two concentric platinum cylinders of diameters .75 cm. and .3 cm., respectively, in air at atmospheric pressure. The outer tube was the hot electrode as in the diagram shown below, Fig. 2.

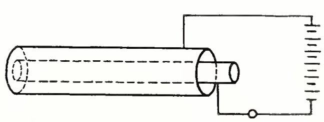

Fig. 2.

[2] Wied. Ann. 16, 193, 1882; 19, 588, 1883; 22, 123, 1884.

[3] Phys. Rev. Vol. 8, 1901, p. 321.

[4] J. J. Thompson cond. of Elect. Through Gases 397.

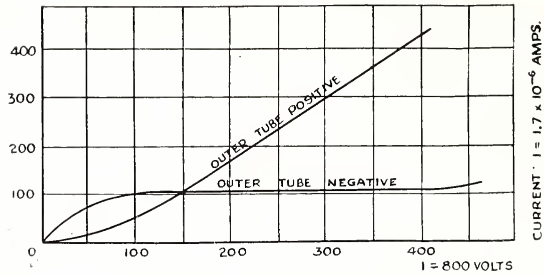

Fig. 3.

We are especially interested in Fig. 3 which calls attention to the curves of H. A. Wilson. We should especially notice that the positive current at these temperatures is much larger than the negative. We had these factors in mind when we designed the apparatus for the present experiment.

KL, Fig. 4, is a battery for heating a fine platinum wire (.0003′ in diameter) and 3 cm. long. MN represents a tin plate .2 cm. from the wire. The remaining part of the diagram is the conventional method of representation and is self-explanatory.

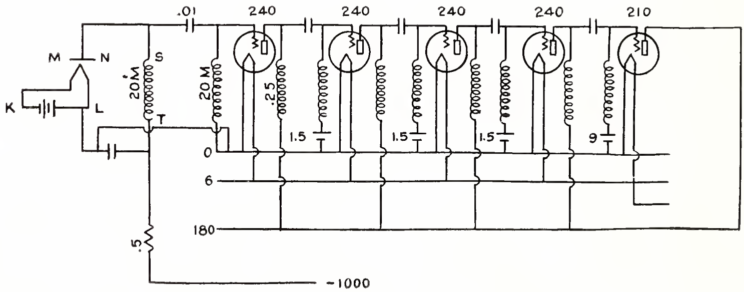

Fig. 4.

Sound waves passing the heated platinum wire should cause variations in the temperature of the wire, which, according to the theory, should cause variations of the space current from the platinum filament to the plate which was maintained by B batteries at a negative potential of 1,000 volts. This current passing through ST would impose a varying potential between the grid and the filament of the first two-hundred-forty tube in the amplifying circuit. In short, this is practically a two electrode tube operating at atmospheric pressure instead of in a vacuum. The output of the amplifier was connected to a sensitive head-set with sufficiently long heads so that one could make observations across the hall. Organ pipes of various pitch were sounded but no effect could be detected. The sensitivity was ascertained by several different methods.

We think that we have arranged the apparatus in all details to give the maximum effect consistent with practical construction; namely, a wire .0003′ in diameter to increase the amount of heating and cooling, a foot of wire to supply a relatively large surface, 1,000 volts from plate to filament to cause a large current to flow, .2 cm. distance between wire and plates which increased strength of field at surface of the wire (one would expect a steep curve and hence a large change in current with small change in temperature), small tin plates and quartz insulation to keep the capacity as small as possible, negative potential on the plates as the positive ion current is much larger at lower temperatures, a high voltage amplifier, and sensitive head set.

We therefore conclude that whatever effect may exist as a result of sound passing a hot platinum wire used in this manner is, being considerably smaller than the effect, due to the unavoidable capacity of the circuit, therefore too small to be of any practical value.

Effect of Sound on Electron Radiation from Active Wires.

Theory. Richardson[5] has derived a formula for electron radiation which checks very well with experimental measurements; $i = aT^{\frac{1}{2}} \varepsilon^{\frac{-b}{T^6}}$ in which i is electron current; a is a constant; T, absolute temperature; ε, base of the Naperian logarithms and b is another constant. Accurate experiment, however, shows that the formula is more nearly correct with T^2 instead of $T^{\frac{1}{2}}$. The factor $\varepsilon^{\frac{-b}{T}}$ increases so rapidly with the temperature that either $T^{\frac{1}{2}}$ or T^2 has very little effect on the value of i.

Since the value of i varies rapidly with the temperature the idea occurred to Dr. Foley that we might heat a fine wire and then modify the electron current by sending sound waves past it. If this modification was sufficiently great, we might be able to detect it by means of an amplifier. A business concern had presented a fine wire of secret composition to Dr. Foley. Their representative recommended it as having the properties which we desired, namely, a small diameter (.0008′) would give a profuse electron current, and would stand red heat in air at atmospheric pressure for about six hours.

Twelve of these wires about one inch long were mounted in a plane parallel to each other. A similar set of platinum wires were mounted in the same manner. The two sets of wires were mounted with their planes parallel and with means for adjusting the distance between the planes, Fig. 5.

Let A B represent the active wires; C D the platinum wires. E and F were connected to grid and filament of the first tube in Fig. 4. The active wires were raised to red heat by the battery K L, a positive potential of 1,000 volts was placed on the platinum wires. Sound from an organ pipe was then passed by the wires. No effect could be de-

[5] Wilson Modern Physics, p. 49.

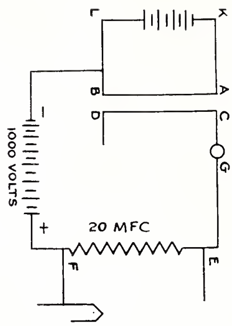

Fig. 5.

tected in the output of the amplifying circuit nor was there any change in the space current indicated by G.

SUMMARY

We have thus tried three different methods for using space currents in air at atmospheric pressure to detect sound waves.

The first method was an attempt to direct the discharge from a Nernst filament into two close, nearly parallel paths. It was thought that by mechanical impact due to sound waves passing through these paths some of the ions would be driven from one path into the other and vice versa, and that these variations in the current caused variations in the potential across a high resistance through which the current was flowing. Any variable electromotive force thus generated was imposed on the input of an amplifying circuit. The output was connected to a telephone receiver.

The second method was an attempt to vary the ionization current from incandescent platinum wires by changing the temperature of the wires by the fanning effect of the sound waves.

The third method was an attempt to modify the electron radiation from an activated wire by changing the temperature due to the passage of sound waves. The same method for detecting the effect was used in the last two cases as in the first.

No sound was heard in any of the three cases. The telephone receiver had a current sensitivity of .0000027 amp. or .00352 volt. The amplifier used in the case of the active wire and also for the Nernst filament had a voltage amplification of about 6,000. Let E stand for the minimum voltage which if impressed on the input of the amplifier can be heard in the telephone. Then 6,000 E — .00352 or E — .00000058. In the case of the Nernst filament if we let i equal the varying part of the current, the voltage impressed on the amplifier would equal 30,000,000i. 30,000,000i × 6,000 would then equal the voltage impressed on the telephone receivers. Then the equation 30,000,000i × 6,000 = .00352 or $i = 2 + 10^{-14}$ amps defines the maximum current which could flow through the 30,000,000 ohms and still not be heard in the telephone receivers.

That is, any variation caused by the sound on the discharge from the Nernst filament must have been less than ⅔ of 2×10^{-14} or $\frac{4}{3}$ of 10^{-14} amps, since the current was passing through ⅔ as much resistance.

The resistance coupled amplifier used in the case of the ionization current from incandescent platinum was considerably more sensitive than the other two cases mentioned. It was so sensitive that unavoidable capacity changes due to the circuit itself caused an audible tone in the telephone receivers.

We conclude that whatever effect there may be in any of the three cases, it is too small to be of any practical importance when used with materials and apparatus now available.

The writer of this paper wishes to thank Dr. Foley, who directed the research, for his interest and helpful suggestions during the progress of this work, and also the other members of the staff, who from time to time have shown interest in the problem and have given many valuable suggestions. I wish also to thank the Messrs. Price, Buell, and Foreman for help in making observations with the telephone.

METHODS OF MEASURING SURFACE POTENTIALS

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In the study of frictional electricity we observe the existence of large potential differences only when two surfaces have been separated to a relatively large extent. If we can observe the existence of a small potential difference with the surfaces at a small distance apart, we can understand the large potential due to their separation. Based upon this principle, a method of measuring surface potentials was devised by Volta and later used by Pellat.[1] This method, known as the condenser method, consists of two parallel surfaces, one of which is fixed, and the other is caused to move so as to vary the distance between them. In this way, an existing small potential difference between the surfaces is magnified and the effect can be measured with an electrometer. By inserting a counter source of potential in the circuit, the two surfaces may be adjusted to the same potential whereby no effect is produced by their relative motion. The condenser method, though simple in theory, has proved very delicate in operation. If one of the surfaces is a solution and the other a metal plate, it was found that the adsorption of moisture on the surface of the metal affects its potential to a considerable extent.

A second method has been used where a solution is concerned[2] and consists in measuring the potential difference between two flowing solutions. One of the solutions flows down the inside wall of a glass tube,

[1] H. Pellat: Ann. de Ch. et Phys., 24:5, 1881.

[2] Kenrick: Z. Physik Chem., 19:625, 1896.