ONE HUNDRED AND TWENTY-NINTH PAPER
(OF TRANSACTIONS).

FLUID WAVES.

BY

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CHAIRMAN :
MR. JAS. ADAMSON (HON. SECRETARY).

PART I.

BEFORE directly dealing with the subject of waves in fluids it is necessary to call your attention to the oft-stated laws of matter and energy, as all physical states and conditions are associated with them, they being the two fundamental agencies of nature. Matter is that which affects our senses —that which we can feel and touch. Energy we have never seen; we only know of this "something" by its effect upon matter. In other words, energy acts through matter. Both exist in many forms, and both are indestructible and uncreative by man. The scientist can merely toy with them, as a juggler with a set number of balls, making different forms and creating different actions and reactions, but the sum total of matter and energy remain the same.

I would ask you to accompany me in imagination on to a modern combination of matter and energy—I mean a modern steamship lying at anchor in the harbour. Some kind cook on a vessel close by, perhaps recognising our studious mien, has thoughtfully consigned an empty cask to the deep. The waves, as they roll in from sea to shore—telling us that at some far-distant spot matter and energy are somewhat boisterously associated—pass over this cask, giving to it a circular motion. First it is lifted up, then moved forward a little;

thirdly it is lowered, and lastly drawn back. The wave has passed, and is now performing the same cycle of motion, of elevation, forward movement, depression, and backward motion, upon a small rowing-boat close shoreward. It is reasonable to assume that the circular motion imparted by the wave to the cask is also performed by every water particle supporting it, and that the particles next to them, again, also underwent a similar cycle of movement. The marked difference between the movement of each individual particle and the motion of the wave train is therefore very apparent.

Our attention is now attracted by a sailing yacht as she skims past, leaving wave trains in her trail. Two distinct wave trains are visible—one from the bow and another from the stern. The vessel itself also seems to be resting upon two wave crests moving at the same speed as herself. Such a vessel actually creates, however, four different wave trains.

The question naturally arises, how and what are the conditions which produce these water motions? For a wave to be created there must obviously be a medium in which to produce such a motion. This medium must be elastic—i.e., must resist deformation—and, secondly, possess inertia. That is, when once a particle is set in motion it must possess that property of endeavouring to remain in motion. Water fills these conditions. This property of resistance and persistence can well be illustrated by means of a U tube of glass, containing some coloured water. By blowing down the one arm the water is elevated in the other in accordance with the pressure applied. Now suddenly remove this pressure, and the force of gravity acting upon the particles tends to cause motion. The potential, or energy of position of the elevated water, is thus converted into kinetic, or energy of motion, and, owing to the inertia of the water, or its inability to stop when at its normal level, the water is elevated in the other arm. This oscillation keeps on being repeated and repeated until the—might I say excess of?—energy is all frittered away or transformed—not lost—by friction, air resistance, and a multitude of other agencies.

Now when two fluids are in contact, one moving faster than the other, wave motion is set up. This heaping up of the water gives an oblique, and therefore more effective, surface to the action of the wind, which explains to some extent how a rough sea is gradually worked up by an air current moving over its surface. Deep sea waves are sometimes termed gravitation waves, in distinction from very small waves (known as ripples), whose creation is chiefly due to the surface tension of the water—a subject beyond the limit of the time at my disposal.

Wave motion exists in any medium when each particle along a line executes in order a continuous and repeated motion, one after the other, in regular interval of time. This motion can be illustrated in many ways. No doubt many present have seen a bargeman dexterously send a wave motion along a rope with such skill that the wave crest just reaches an obstacle in time to clear it, and then travels on to the other extremity of the line; it is reflected, and the wave motion returns back again. For those, however, who have not been so fortunate—shall I say?—as to have been brought directly into contact with this wave production and its associations I have here a model consisting of twelve heavy glass marbles slung on a rod at regular intervals by means of cords some 12 in. long. These marbles are also connected together by means of an elastic thread. We have therefore a mechanical device possessing all the properties necessary for true wave production—that of inertia due to weight, and elasticity, or resistance to deformation due to the elastic thread. Taking one marble disconnected from the others, elevating it to one side, and releasing it, gravity acting, the marble falls; but, owing to its inertia, it overshoots the mark and rises the other side, to again return, and so performs a series of regular and continuous oscillations. Now connect this marble with the others and repeat the operation. This time each particle in the train transmits its motion by means of the elastic cord to its neighbour, and we have produced a true wave motion, consisting of a series of crests and hollows reflecting from the fixed ends backwards and forwards similarly to the wave produced by the bargeman with his tow rope.

It is extremely difficult, if not impossible, to deal with a subject such as this without using technicalities, and your forbearance is asked while explaining certain terms used in connection with the subject of wave motion. When a wave length is spoken of, the length of a crest or hollow is not meant, but the shortest distance between two crests or hollows. Waves have motion, and therefore velocity. Now, if we can imagine a vessel proceeding at such a speed that she keeps up with one particular wave crest, the velocity of the vessel will be the velocity of the wave. Again, when studying the cask floating in the harbour we noticed that it made a regular number of bobs up and down per minute or second as the waves passed by it. This number will be the wave frequency. The amplitude of a wave is the distance a particle moves from its normal position of rest, whereas the height is the measurement from crest to hollow. The period of a wave is the time taken to make one complete movement.

Now, as may be imagined, the velocity, length, frequency, and period are mathematically associated with one another.

Wave velocity, V, = wave length, L, × frequency, F.

$$(1)\ \text{Or}\ V = L \times F.$$

From this it is obvious that the wave period is proportional to wave frequency.

$$\therefore \frac{\text{Wave length}}{\text{Wave period}} = \text{Wave velocity.}$$

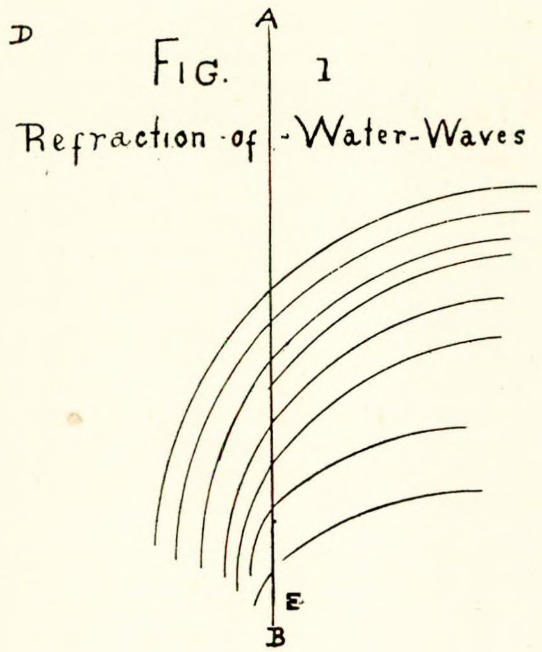
Another rule given by White and others for wave lengths and wave speed in miles per hour is

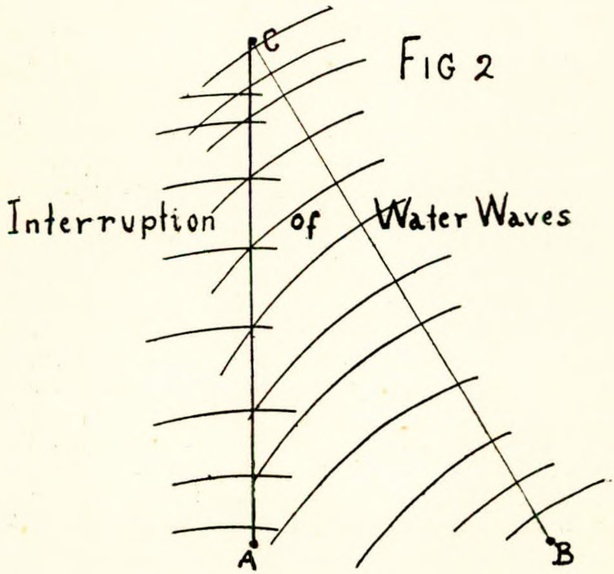
$$(2)\ \text{Speed in m.p.h.} = \sqrt{2\tfrac{1}{4} \times \text{wave length in feet.}}$$

It is a well-known fact that storm waves are surface effects only, and do not disturb the depths of the ocean.

The form and formula for waves in confined areas differ somewhat from those in the open sea, the velocity of canal waves being that which a body would acquire when falling freely from a height equal to the half depth of the canal. It is characteristic of all wave motions that they can be reflected or thrown back (refracted or bent), and that interference can be effected—that is, two wave trains so meet that the crest of one intercepts the hollow of the other, and so destroy one another. When interference can be effected it is taken as convincing proof that wave motion exists. Water wave reflection can be produced and studied in a large tank, or even the household bath. To refract or bend water waves we have to take advantage of the fact already stated, that the wave velocity is slowed down in shallow water. Therefore, assuming that the depth of a pond suddenly decreases, on the area A, B, C, D (Fig. 1, Plate I.), the wave train emanating from E will be bent down or refracted as illustrated, due to the drop in velocity, when passing line A, B. To produce interference we will assume that waves of equal velocity, length, and frequency start from A and B (Fig. 2, Plate I.), meeting at C. It is necessary that the crest of A should meet the hollow of B at about C; therefore it is obvious that the length of the lines A, C and B, C must be such that their difference is an odd number of wave lengths.

Before a Marine Institute it would be almost a criminal offence to leave the subject of water waves without paying


D
A
Fig. 1
Refraction of Water-Waves
E
B


C
Fig 2
Interruption of Water Waves
A
B

tribute to such names as Froud and Clark Russel, who by their exhaustive researches and untiring energy have done so much to solve the intricate problem of ships' resistance. It is my regret that time will not permit of investigating this very interesting and instructive side of our subject other than in a most desultory manner.

Solid bodies moving in liquids set up eddy currents. These eddy currents always involve an expenditure of energy.

In early days it was generally accepted that the resistance a vessel had to overcome was due to pushing aside the water. Take the parallel case of a fish swimming. A somewhat perplexing question here arises, namely: How does the fish get through the water? For the fish must first move forward to displace the water, and, water being an unyielding substance, the fish cannot move forward until the water is removed. It is obvious, therefore, that the resistance theory as thus set forth was, to say the least, faulty. Recent investigation has established the fact that the resistance offered to a ship is threefold:

(*a*) Skin friction; (*b*) eddy resistance; (*c*) wave resistance.

The waves formed by sailing craft are four in number, of which the oblique bow waves and the stern wave are most easily determined. The experimental tank has played a part in solving this problem, and the establishing of the two laws of Froud can be ranked as master points of modern naval architectural research.

The breaking of the waves on the sea-shore is due to a combined effect. Firstly, the retardation due to friction of the bottom; and, secondly, the velocity of the forward, shallower part of the wave drops, and so the particles further out mount up, forming, as it were, a wall of water, which ultimately breaks upon the shore. When we stop in our walk by the sea and watch the waves tossing large vessels to and fro, we view the effects of a previous storm, and are apt to comment upon the energy of the waves; and rightly conclude that they are not merely a form of motion, but a means of transmitting energy.

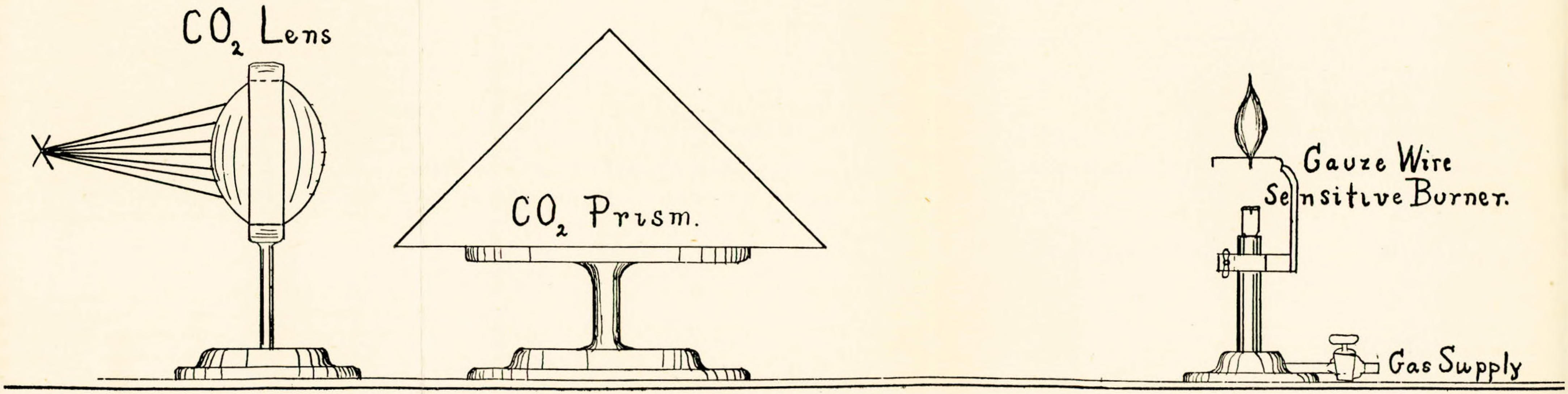
PART II.

If we place an electric bell under the receiver of an air pump and gradually exhaust the air the sound dies away, despite the hammer of the bell working vigorously. It is therefore obvious that sound is in some way associated with air; in fact, sound is due to the rapid vibrations set up in the air. I have here a pith ball suspended by a silk thread, and when a sounding gong or tuning fork is brought so as to touch this ball it is immediately agitated, intimating that the gong and tuning fork are in rapid vibration. These vibrations are transmitted to the atmosphere, creating a series of compressions and rarefactions of a spherical form. In fact, the tuning fork now vibrating is actually the centre of a vibrating sound sphere, the air particles swinging backwards and forwards along the line of propagation of the sound waves. The movement of each individual particle is, however, small. The length of the sound waves of ordinary speech varies between 2 ft. to 8 ft., whereas in the case of a whistle the wave length is only a few inches, while an organ produces sound waves some 30 ft. to 40 ft. long.

Waves in air differ from those in water, inasmuch as in water the velocity is determined by their frequency and length. In air the velocity for all wave lengths is the same. Thus the long, deep tones of the organ and the shrill notes of the flute reach the ear at the same time. The wave length determines the tone, the amplitude, and the intensity of the notes; wave form determines the quality. The speed of sound in the air is estimated at 1,087 ft. per second at 32° F., and for every degree rise in temperature this speed is increased by 1 ft. per second. This enables an explanation of the peculiar fact that sound will sometimes leap an area, owing to the sound waves first being bent upwards, due to their velocity being greater in the lower layers, in consequence of these layers being at a higher temperature. Now on their journey onwards these waves, already bent upward, come in contact, owing to varying causes, with the reverse conditions; the lower air strata are cooler than the upper, the sound waves for the same reason are accordingly bent to earth again, the intervening area having thus been unaffected by the sound waves. The fact that a siren is sometimes inaudible at a short distance, while at a greater distance the sound is loud and distinct, is well known. Numerous theories have been advanced, but so far no satisfactory explanation has been found. The speed of sound through a gas varies inversely as the square root of its density. The following table gives the velocity of sound in different gases:

Hydrogen	4,160	ft.	per second	(about)
CO	1,100	,,	,,	,,
Air	1,090	,,	,,	,,
Oxygen	1,040	,,	,,	,,
Carbonic acid gas...	850	,,	,,	,,

Fig. 3



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Now by constructing a lens and prism (Fig. 3) of thin india-rubber and filling them with CO_2 we have what might be called a sound lens and sound prism, and, armed with these instruments, we are enabled to deal with sound as with light. We can direct the waves, and by using the prism bend the waves down—in other words, refract them. These waves being invisible, and therefore not lending themselves to direct observation, as do water waves, we must provide some suitable sound detector. In this case we take advantage of the sensitiveness of a spear-like gas flame to sound waves of short lengths. You will observe that the flame is agitated above the wire gauze, owing to the small particles of gas between this gauze and the burner being set in violent motion by short air waves, while long waves, such as from an organ or the voice, do not affect it. This gives us a verifiable sound detector, and, armed with this sound lens, prism, reflector, and detector, we are enabled to detect, reflect, refract, and intercept sound, and convincingly prove it to be due to wave motion.

The subject of musical sounds is beyond this evening's scope. I will content myself with pointing out that with the voice the wave form is irregular, whereas with music the motion of the air is rhythmical, and it is to this regular, repeated motion that we owe the pleasurable sensation due to music.

PART III.

ELECTRICITY.—In considering the production of waves in both air and water it was obvious that, first, a medium existed in which the wave was formed, and, secondly, there was a periodic movement of the particles of that medium. It is simple and sound reasoning to conclude that the existence of wave motion indicates the existence of some medium in which the wave is formed. In the case of water our task was easy, for we are all more or less familiar with waves in some shape or form, water lending itself to direct ocular investigation. With air, by the aid of a few instruments and a little experimenting, the existence of wave motion is conclusively proved, but electrical oscillation—the existence of ether, and the waves set up therein—present a much more difficult task.

First let us consider the subject of ether. The idea of absolute emptiness is one which the human mind finds it difficult, if not impossible, to conceive. Above the earth's mantle of air is all absolute emptiness? The question was answered when it was discovered that light took time to travel.

This scientific fact was established by observing the eclipses of the moons of Jupiter. It being noticed that the eclipses of one of Jupiter's many moons occurred at irregular intervals, some sixteen minutes later at one time of the year than at another, Roemar, an astronomer living in the year 1675, from these facts concluded that light took time to travel. From these observations the speed of light was estimated at 186,500 miles per second. Light must therefore be either an actual object projected into space or a form of wave motion created in some medium. Dr. Thomas Young, by his experiment on light interference, established the fact that light is a form of wave motion. This wave motion must exist in some substance or medium more universal than air, occupying all space ; to this we give the name of ether. Young allowed a beam of one colour light, say red, to fall upon a screen with two holes punctured in it close together. From these two holes he obtained two rays of light, which he interrupted with a white screen. The screen was found to be marked with alternate coloured and black lines when both rays fell upon it, but when one hole was obstructed the black lines disappeared.

Young by this means established the fact that light is a form of wave motion; the black lines being due to the light waves killing one another, owing to the crest of the one meeting the hollow of the other.

Before we can proceed further it is necessary that we should investigate certain electrical facts and conditions. First let us take an electrical current. We marine engineers are somewhat familiar with electricity under certain conditions, the term electrical current being one of daily use. I must confess myself unable to give a satisfactory explanation, and content myself by saying that electricity is a physical condition which can exist only in a closed circuit, and that an electrical current, having directive properties, must be classified with force and motion. If a conductor such as a wire through which an electrical current is passing be held over a magnetic needle, the needle is at once deflected, owing to its tendency to place itself at right angles to the flowing current. This can be remembered by the word "SNOW," which gives us the assumed direction (from South to North), the position of the conductor (Over), and the direction of the deflected needle (West).

Again, when an electrical current is allowed to flow through a conductor the conductor possesses all the properties of a magnet, and if wound into a solenoid these properties are intensified. Such a solenoid will attract iron filings ; and the pole repels and attracts a magnetic needle. Again, take two closed circuits lying in close proximity, one having an electrical current passing and the other not, but being connected to sensitive galvanometer. Now, when this electrical circuit is broken an electrical current is induced in the closed circuit of the other in the same direction as the first flowing current, and upon making the circuit we again see the galvanometer needle deflect, this time in the opposite direction, indicating that another electrical current has been induced in the closed circuit, but flowing in the opposite direction. These induced currents are the source of constant trouble to the telegraphists, and have to be grappled with and guarded against in lines many yards apart.

The induction coil—an instrument for transforming low tension electricity into electricity of many thousand volts—is based upon this principle. Such an instrument you have before you. The details of its construction and operations are, however, beyond the province of this evening. Any substance which allows electricity to flow is termed an electrical conductor, while those which do not allow of its flowing—or, to be more correct, feebly so—are termed insulators. Now, when substances which are good insulators under low E.M.F. are subjected to high electrical strain their insulating properties break down, and they become electrical conductors, allowing a number of oscillating discharges, and so the electrical strain is removed. Such a condition of affairs exists when discharging through a Leyden jar—an electrical apparatus no doubt many are familiar with. A Leyden jar is really an electrical condenser. Electricity, collecting on the tin-foil surfaces, subjects the glass to an electrical strain, which ultimately breaks down, as explained. To discharge such an apparatus it is only necessary to almost connect the two surfaces, leaving a spark gap between the two balls of the jar and the discharger. The electrical strain then breaks down the insulating properties of the air, and we see a spark pass. This discharge is made up of some twenty or thirty electrical oscillations, lasting in all one one-thousandth part of a second. The oscillatory nature can best be detected by a vacuum tube. When such a tube is lit from the terminals of an ordinary induction coil one bulb is dark, indicating the negative terminal of the tube, the secondary current from an induction coil being more the nature of a direct current than alternating. Now discharge the coil through a battery of Leyden jars, and again light the tube from their terminals. Both bulbs glow with equal brilliancy, indicating the alternating or oscillatory nature of the discharge. This oscillating backwards and forwards of the electrical discharge lasts until the electrical strain is removed, and is analogous to the oscillating of the water in the U tube, which, as explained, was due to its inertia.

Electricity possesses a somewhat similar property called inductance, by virtue of which even under higher E.M.F. an electrical current cannot be started instantaneously. Now an electrical circuit in a way is similar to a moving body. In electricity the current energy is measured by the product of two factors, the half square of current strength and the inductance of the circuit; whereas with a moving body the energy of motion is the product of the mass and half square of velocity. The inductance of a circuit can be increased by coiling it into many turns, or reduced by straightening it out.

Let us now turn our attention to the discoveries of Professor Hertz. Here are two zinc plates (Fig. 4) some 16 in. square, to which are fitted two metal discharging balls. When the two plates are placed in line with each other they form an electrical condenser, but in this case there is one metallic plate with an insulating coating of air on either side. Adjusting the discharging balls some ¼ in. apart, and connecting the plates to an induction coil, we obtain a discharge of an oscillating nature, owing to the electrical strain in the air—set up by the electrified plates—breaking down between the two nobs, as in the Leyden jars. So we have the air around these two plates subjected to a series of alternating electrical strains, those strains setting up what are termed electric waves, which waves, travelling into space, are capable of carrying alternating electrical strains originated in some point of an oscillating discharge from an electrical condenser. Hertz used as a detector a ring of wire, similar to the one before you, terminating in discharging balls. As this detector is held in position small sparks are passing between these balls, and when a small vacuum tube is connected the electrical current is sufficient to illuminate the tube.

Another and more delicate form of ether wave detector is the coherer (Fig. 6). This instrument you have before you in two forms; the main principle of each is, however, the same, and is due to the peculiar property discovered as far back as 1860 by Mr. S. A. Varley, and further investigated by Bramley in 1889. It was found that loose metal, carbon, and other conductors offered a high resistance to the passage of the electric currents. These substances, however, cohere or collect together

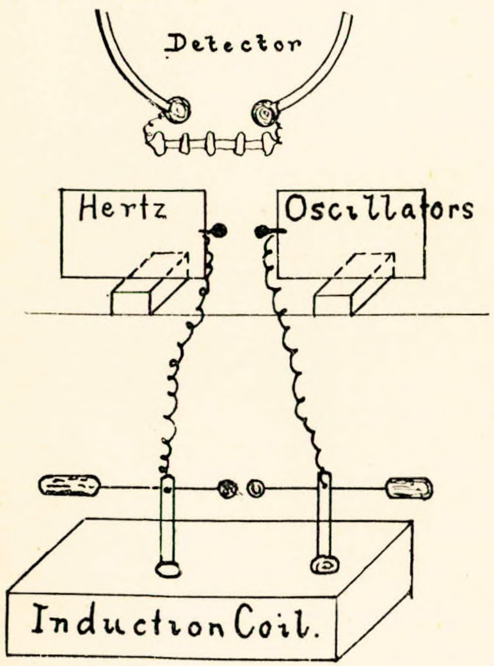


FIG. 4.

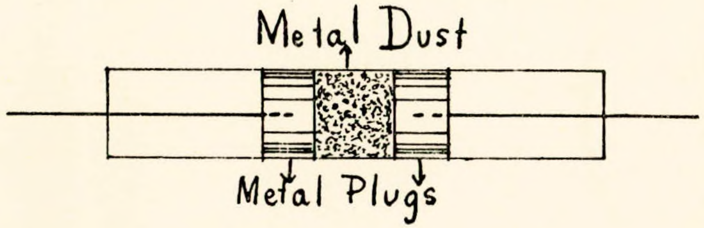


FIG. 6

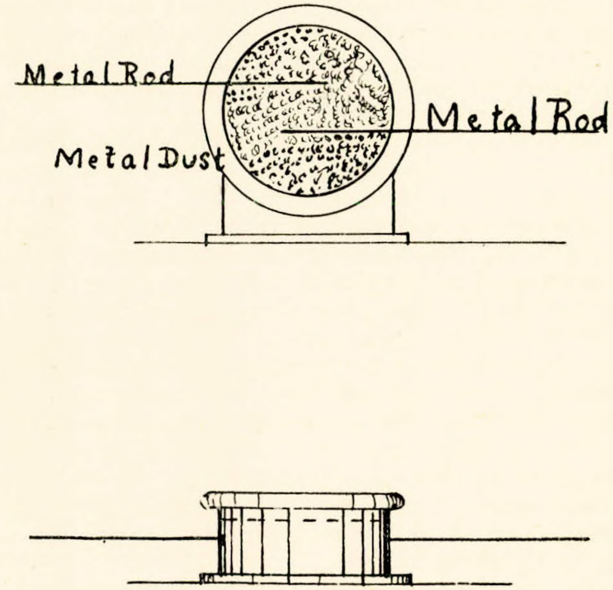


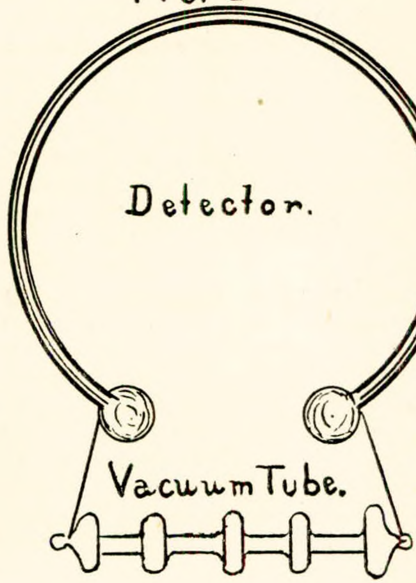
FIG. 6.

under the influence of a distant spark, and then offer much less resistance to an electrical current. Modern researches tend to point to the phenomena of electricity and magnetism as conditions dependent upon actions taking place in the electro-magnetic medium, and it seems as if we are likely to revert to a modification of the ideas of the early electrical investigators. This electro-magnetic medium indicates all properties previously found necessary for enabling wave motion to be formed, which motion can be set up by electrical discharger as explained. All good electrical insulators are transparent to these waves, while conductors are more or less opaque. By suitable directing and receiving metal boxes, lenses, and prisms of paraffin wax as shown in Fig. 8, these waves can be subjected to direction, reflection and refraction, and, in fact, can be dealt with in a manner analogous to light waves, and travel at the same velocity as light—namely, 186,500 miles per second. It is therefore reasonable to imagine that electro-magnetic radiation, light, etc., are affections of the same medium, "ether."

The perfection of wireless telegraphy having of late been brought into prominence, I offer this as an excuse for introducing and demonstrating its principles. The apparatus consists of a sending apparatus and a receiving. For sending, a long rod or similar arrangement is connected to one spark ball of the induction coil, the other ball (advisably) earthed (Fig. 9).

The receiving station consists of a similar upright collector connected to one terminal of the coherer, the other being earthed. Connected to these terminals is also a battery and relay to bring into action another more powerful battery for working the signalling apparatus—in this case a bell. Now, as the metal dust offering a high resistance to the local current, the relay is kept out of action. When, however, a spark passes the balls of the sending apparatus, electro-magnetic radiation is set up from the sending station rod, and is interrupted by that of the receiving, resulting in the cohering or collecting together of the metal particles, and consequently the breaking down of the electrical resistance, thus bringing the relay into action, and ringing the bell. It is necessary to decohere or separate the particles by mechanically tapping the containing vessel. This is provided for in the telegraphic apparatus. Each station must therefore be fitted with a set of both sending and receiving apparatus. The fact that signalling can be conducted better across water than land may be due to the water being more opaque to the radiations than the land; the energy is thus not reduced.

FIG. 5



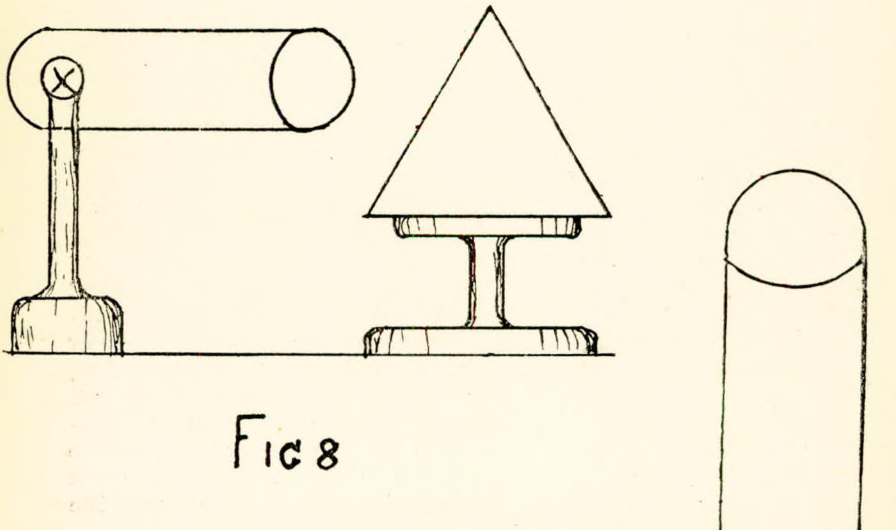


FIG 8

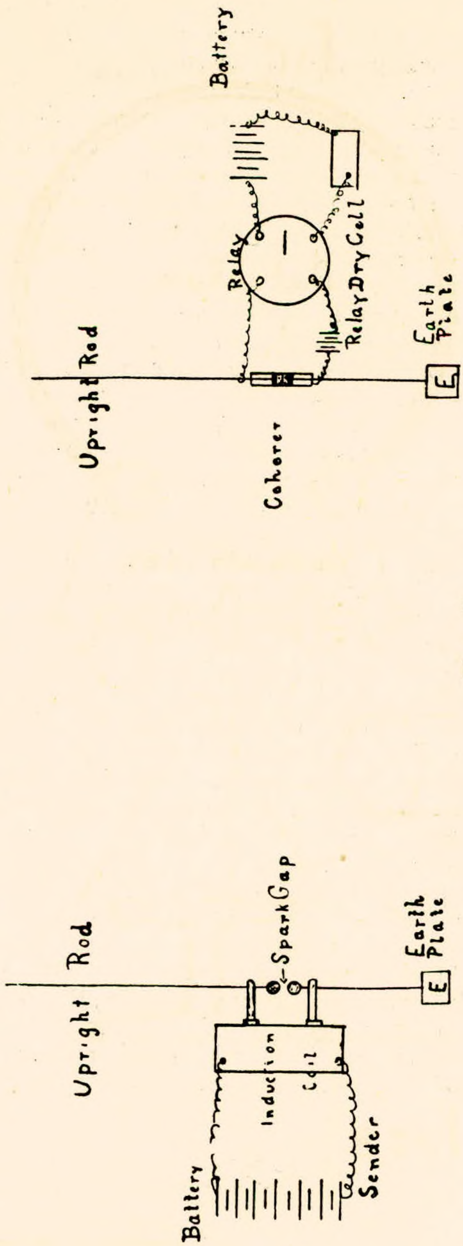

Battery
Relay
Relay Dry Cell
Upright Rod
Coherer
Earth Plate
E
Upright Rod
Spark Gap
Earth Plate
E
Induction Coil
Battery
Sender

FIG. 9.

In conclusion, I would venture to introduce a number of somewhat interesting and pretty displays of vacuum tubes, illustrating the Tesla coil and electric lighting without wires; also the condensation of smoke by electrical discharges. And while the table is being prepared we will turn our attention to another new form of vibration—the X rays. These invisible rays seem to be the exception which proves the rule. They defy, so far, all attempts to reflect or refract them. All good conductors are more or less opaque to their rays, while insulators are transparent. These rays affect a photographic plate, and possess the property of rendering various salts fluorescent. I have here a screen coated with such a salt, which, when placed in front of the Crooks tube generating the rays, becomes luminous. Now, by introducing behind the screen this small leather case containing a metal measuring instrument, some of the X rays are obstructed. The fluorescency of the screen is reduced accordingly, and we see a decided shadow picture of the instrument, while the leather case, being transparent, is barely visible.

When we look around us and realise that on all sides wave motion is in action, that beautiful music and lovely colours exist only in ourselves, each and all the effects of countless vibrations in air and ether, each one of us the centre of a sphere of wave vibration, a veritable transmitting station, and, at the same time, a perfected and ideally complete coherer or wave detector, sensitive to varying wave vibrations—when we review modern scientific researches, and what has been achieved in recent years—the researches of Crooks and Lodge relating to the electrones, or atom of the atom—we can only be convinced that the human mind has but penetrated the threshold of nature systems, and that it behoves all engineers—as members of a profession which should be broad-minded and keen on research in a direction other than those bounded by stereotyped lines—to follow up the researches of the modern scientific world. We have on board ships of the present day instruments depending on, or influenced by, the action of waves in air, waves in ether, and waves in water. This is my excuse for thus occupying the time and attention of the members of the Institute of Marine Engineers.