CHAPTER VIII

Wave Peculiarities

WAVES are transmitted by a combination of momentum and elastic recoil; and, in order to convey them, the medium must have the two corresponding properties, viz. something corresponding to inertia or massiveness and something corresponding to elasticity. There is a displacement from the mean position, with a tendency to spring back, this displacement being either material or electric, according to circumstances; and there is a rushing past the mean position with a momentum which overshoots the mark, and carries the particles into a region of recoil, propelling them against the electric force, which in due course drives them back again. It is the elastic force which generates the momentum; and it is the momentum which piles up an opposite elastic force. It is by the interaction of these two properties that oscillations are maintained, and it is by possession of these two properties that the medium is able to pick up the oscillations and transmit waves.

In the case of mechanical waves the momentum is straightforward mechanical momentum,

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due to the inertia of matter; in electric waves the momentum is magnetic momentum, and is due to the inertia of ether; just as the elastic recoil is due to the electrical rigidity or elasticity of ether—the term "rigidity" being a technical or quantitive one, not at all implying infinite rigidity.

The reaction of the two properties is easy enough to follow in the oscillator, or source of the waves, where the two are in different phases. It is rather less easy to follow in the wave itself, where they are both in the same phase. But it may help if we consider the simplest case, viz. that of sound. As the wave advances the particles are simultaneously thrown forward and nearer together, so as to make a condensation. If at the maximum condensation they came to rest, they would rebound, and the wave would go backwards. That is exactly what happens when sound encounters a wall or other obstacle and is reflected, giving rise to what are called "stationary waves," with nodes and loops in definite places. But in a progressive wave the particles are thrown forward into the condensation, and the condensation moves on by reason of the momentum of the particles, and so continually advances into new regions, spreading the disturbance at a steady advancing pace. The particles ultimately come to

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rest, and go back again; but when they do that the rarefaction is beginning. And so this rarefaction, or pull on the medium, travels forward likewise; though it requires a little more effort to follow the details of the advancing rarefaction, as compared with the more easily grasped details of an advancing condensation; since in a rarefaction the particles of the medium are moving in a direction opposite to that of the advancing wave—which at first seems a little confusing.

To follow out the details in the electromagnetic case is less easy, because we are less familiar with the intimate nature of electricity and magnetism. We know that magnetism is the result of an electric current (or, rather, that the two are different names for the same thing), and that it simulates mechanical inertia and momentum. We also know that electric displacement is another name for electric charge, and that it simulates an elastic spring-back, which is demonstrated by an electric discharge. The term "charge" is only applied to a conductor: the more general term is electric displacement, because that applies to an insulator too. But, as the process is not a mechanical one, the only way we can safely and completely follow it is by the use of the vitally important equations of Clerk Maxwell, which contain the whole theory embedded in their intricate and illuminated recesses.

But now, to understand the phenomenon of wave transmission more thoroughly, we ought to ask whether there is any kind of wave which does not obey those laws—which has not both momentum and elastic recoil, which does not require those properties in the medium, and which does not advance at a definite pace.

The answer is that there are such waves—if they can be called waves—waves of diffusion, transmitted from an alternating source. It may be a source of alternating temperature, for instance, like the summer and winter temperatures applied to the crust of the earth. The result is that periodic waves of temperature sink into the crust, and succeed one another at regular intervals; so that by penetrating a sufficient depth you will find a trace of last summer's heat, and by penetrating deeper you will find a trace of the preceding winter's cold, and so on, though it is true that these traces tend to smooth themselves out rapidly, and become before long difficult to recognize. But if we ask at what rate these waves travel we can give no answer, at least no clear and simple answer, as we can in the case of true waves with momentum. For the peculiarity of these heat waves is that they have no momentum.

They travel according to a different law; and the time taken for any given portion of heat to reach a certain depth will depend upon how sensitive the detecting instrument can be.

We may illustrate the matter by taking a long rod of metal, packed in cotton wool or some insulating material to prevent loss of heat from the surface, and then put a thermometer at one end (which might be a sensitive thermopile), and to the other end apply heat and cold alternately; for instance, first a flame and then a douche of liquid air. The thermometer at the far end will exhibit alternations of temperature. There will be a lag, perhaps a very considerable lag, before it feels the first heat wave. The cold wave may be well on its way, and another heat wave too, before it responds; but in due time it will go up and down in response to the succession of impulses imparted to the other end. But if we ask how soon it will feel those impulses after they started, we must realize that it is merely a question of how sensitive it is. If it can only respond to a Fahrenheit degree or two, it will be very sluggish; but if it can feel the millionth of a degree, it will be fairly quick.

This is the actual problem which had to be solved in connexion with the first Atlantic cable, and Lord Kelvin solved it completely.

He perceived that the electric capacity of the cable would make the laws of electric propagation correspond exactly with the laws of the flow of heat—which had been worked out by Fourier. So he gave the theory of the cable, treating it as a long conductor to one end of which positive and negative electrification was alternately supplied, a detecting instrument being at the other end. And he realized that if signalling was to be at all rapid, this detecting instrument must be of surpassing sensitiveness. He knew that there was no true velocity of propagation in a cable possessing only resistance and capacity; he knew that the waves were waves of diffusion, having no definite speed, and that the rapidity of their detection must depend on the sensitiveness of the receiving instrument. Hence his mirror-galvanometer, and then his siphon recorder. He knew further that violent applications of electricity to a cable were unnecessary and troublesome, as well as dangerous; that they put into the conductor disturbances which would have to leak out; and that within limits the feebler the signals were, the better. Sharp momentary curbed signals ought to be sent, and though at the far end they arrive washed out by diffusion, yet a sufficiently sensitive instrument can detect them without more than a fraction of a second delay, and with a reasonable amount of sharpness.

But this theory after all was not complete, was not quite complete. It left out of account self-induction ; that is to say, it treated the electric waves as if they were really like heat waves, without momentum. As a matter of fact, the heat wave theory is only an approximation or an analogy. Electric waves must have momentum, since every electric current has a magnetic field round it. The magnetic-inertia effect was omitted in Kelvin's theory. If thought of at all, it was thought to be insignificant, wiped out as it were by the capacity and the resistance ; just as sound waves trying to pass through a haystack would have their momentum wiped out by friction, and would be stopped. Or, a better analogy, as light waves are stopped when they encounter any black material. The propagation of heat waves through a good conductor, the propagation of light waves through a bad conductor, and the propagation of electric oscillations through a long submarine cable, all follow the same law —the law of diffusion—the law according to which a coloured solution like sulphate of copper is conveyed along a tube of water ; the law on which a particle of salt dropped into a bucket of water is ultimately found to permeate every part, even if the water is not stirred but continues stagnant.

But whereas in the chemical case and the heat case the absence of momentum is complete, in the electro-magnetic cases it is only approximate. And when electro-magnetic momentum is taken into account, the law is somewhat modified ; an element of true wave makes its appearance, and there is a true velocity of propagation, though it may be only for an insignificant part of the wave. The head of the wave, however, does advance with the velocity of light, though it may be a head so small as to be undetectable.

But it may be strengthened, and the way to strengthen it is to increase the magnetic momentum, that is to say, to increase the self-induction, as might be done by coiling the wire upon itself, or by surrounding the wire with a sheath of iron. In that way the diffusion effect can be minimized and the wave effect strengthened, with immense gain in rapidity and clearness of signalling. The complete Theory of the Cable exhibits all this, and enables quantitive calculations to be made. And that complete theory the world owes to Mr. Oliver Heaviside, whose brilliant investigations were not recognized at the time by those in high telegraphic authority. He seemed to be merely complicating matters, and not introducing anything practical. So no practical improvements resulted, until ultimately Lord Kelvin himself perceived the merit of Heaviside's extended theory: and Silvanus Thompson in England, and Dr. Pupin in America, advocated the introduction of special self-inductance coils into a cable, especially one that was to be used for telephonic purposes.

Undoubtedly the construction of such electrically improved cables was a real difficulty; and the men who had to lay them naturally shied at additional complications to a problem which in its early form was difficult enough. Moreover, the Kelvin instruments had enabled so much speed and certainty to be obtained in ordinary Morse signalling through a cable, that there was no great stimulus to a revolutionary improvement.

But when it came to telephony, the case was different. Telephonic speech was impossible if all the consonants and vowels were diffused and run together in a vague indistinguishable mass, with no genuine velocity of propagation; so that as it were the stronger waves arrived first, and the feebler ones never arrived at all, and the peculiarities and harmonics of a tone (on which speech depends) were blotted out in transit. Speech through a submarine cable a hundred miles long is impossible, unless extra self-induction is introduced. Even forty miles long is difficult, and the difficulty increases with the square of the length. But if sufficient self-inductance is introduced, so as once more to gain magnetic momentum, true wave propagation is restored; the signals travel with a definite speed, independent of intensity and of pitch, and arrive with their features fairly intact, weakened no doubt, but not disfigured. The deleterious effect of capacity combined with resistance remains, and there is some diffusion as well. Speech through a cable is never so easy as through a land line, or through the unconfined ether of space. But it becomes possible; and in the light of Heaviside's theory, the possibility is clearly intelligible.

The great advantage of radio-transmission is that these diffusion difficulties do not occur, true waves are propagated at one definite speed, every feature is retained; and so speech through free ether has no limit of distance.