is “ longitudinal.” There is no “ transverse ” disturbance, that is, there is in air no motion across the line of propagation, for such motion could only be propagated from one layer to the next by the “ viscous ” resistance to relative motion, and would die away at a very short distance from the source. But trans­verse disturbances may be propagated as waves in solids. For instance, if a rope is fixed at one end and held in the hand at the other end, a transverse jerk by the hand will travel as a trans­verse wave along the rope. In liquids sound waves are longi­tudinal as they are in air. But the waves on the surface of a liquid, which are not of the sound kind, are both longitudinal and transverse, the compound nature being easily seen in watching the motion of a floating particle.

*Displacement Diagram.—*We can represent waves of longitudinal displacement by a curve, and this enables us to draw very important conclusions in a very simple way. Let a train of waves be passing from left to right in the direction ABCD (fig. 3). At every point let a line be drawn perpendicular to AD and proportional to the displacement of the particle which was at the point before the disturbance began. Thus let the particle which was at L be at *l*, to the right or forwards, at a given instant. Draw LP upward and some convenient multiple of LZ. Let the particle which was at M originally be at *m* at the given instant, being displaced to the left or backwards. Draw MQ downwards, the same multiple of M*m*. Let N be displaced forward to *n.* Draw NR the same multiple of Nn and upwards. If this is done for every point we obtain a continuous curve APBQCRD, which represents the dis­placement at every point at the given instant, though by a length at right angles to the actual displacement and on an arbitrary scale. At the points ABCD there is no displacement, and the line AD through these points is called the *axis.* Forward dis­placement is represented by height above the axis, backward displacement by depth below it. In ordinary sound waves the dis­placement is very minute, perhaps of the order 10-5 cm., so that we multiply it perhaps by 100,000 in forming the displacement curve.

*Wave Length and Frequency.—*If the waves are continuous and each of the same shape they form a “ train,” and the displacement curve repeats itself. The shortest distance in which this repetition occurs is called the *wave-length.* It is usually denoted by λ. In fig. 3, AC=λ∙ If the source makes *n* vibrations in one second it is said to have “ frequency ” *n.* It sends out *n* waves in each second. If each wave travels out from the source with velocity U the *n* waves emitted in one second must occupy a length U and therefore U = nλ.

*Distribution of Compression and Extension in a Wave.—*Let fig. 4 be the displacement diagram of a wave travelling from left to right.

At A the air occupies its original position, while at H it is displaced towards the right or away from A since HP is above the axis. Between A and H, then, and about H, it is extended. At J the dis­placement is forward, but since the curve at Q is parallel to the axis the displacement is approximately the same for all the points close to J, and the air is neither extended nor compressed, but merely displaced bodily a distance represented by JQ. At B there is no displacement, but at K there is displacement towards B represented by KR, *i.e.* there is compression. At L there is also displacement towards B and again compression. At M, as at J, there is neither extension nor compression. At N the displacement is away from C and there is extension. The dotted curve represents the distribution of compression by height above the axis, and of extension by depth below it. Or we may take it as representing the pressure—excess over the normal pressure in compression, defect from it in extension.

The figure shows that when the curve of displacement slopes down in the. direction of propagation there is compression, and the pressure is above the normal, and that when it slopes up there is extension, and the pressure is below the normal.

*Distribution of Velocity in a Wave.—*If a wave travels on without alteration the travelling may be represented by pushing on the displacement curve. Let the wave AQBTC (fig. 5) travel to A'QB'TC' in a very short time. In that short time the displace­ment at H decreases from HP to HP' or by PP'. The motion of the particle is therefore backwards towards A. At J the displace­ment remains the same, or the particle is not moving. At K it increases by RR' forwards, or the motion is forwards towards B. At L the displacement backward decreases, or the motion is forward

At M, as at J, there is no change, and at N it is easily seen that the motion is backward. The distribution of velocity then is represented by. the dotted curve and is forward when the curve is above the axis and backward when it is below.

Comparing figs. 4 and 5 it is seen that the velocity is forward in compression and backward in extension.

*The Relations between Displacement, Compression and Velocity.—* The relations shown by figs. 4 and 5 in a general manner may easily be put into exact form. Let OX (fig. 6) be the direction of travel, and let *x* be the distance of any point M from a fixed point O. Let ON=x+dx. Let MP=y represent the forward dis­placement of the particle originally at M, and NQ = y+dy that of the particle originally at N. The layer of air originally of thick­ness *dx* now has thickness *dx+dy,* since N is displaced forwards *dy* more than Μ.. The volume *dx,* then, has increased to *dx+dy* or volume 1 has increased to 1+dy∕dx and the increase of volume 1 is *dy/dx.*

Let E be the bulk modulus of elasticity, defined as increase of pressure ÷ decrease of volume per unit volume where the pressure increase is so small that this ratio is constant, ω the small increase of pressure, and — *(dy/dx)* the volume *decrease,* then

E=ω/(-*dy∣dx)* or ω /E = *-dy∣dx* (1)

This gives the relation between pressure excess and displacement. To find the relation of the velocity to displacement and pressure we shall express the fact that the wave travels on carrying all its conditions with it, so that the displacement now at M will arrive at N while the wave travels over MN. Let U be the velocity of the wave and let *u* be the velocity of the particle originally at N. Let MN=dx=Udt. In the time *dt* which the wave takes to travel over MN the particle displacement at N changes by QR, and QR= —*udt,* so that QR/MN=-*u∣∖5.* But QR/MN = *dy∣dx.* Then

u/U = -*dy/dx .* (2)

This gives the velocity of any particle in terms of the displacement. Equating (1) and (2)

u/U = ω/E (3)

which gives the particle velocity in terms of the pressure excess.

Generally, if any condition *φ* in the wave is carried forward unchanged with velocity U, the change of *φ* at a given point in time *dt* is equal to the change of *φ* as we go *back* along the curve a distance dx = Udt at the beginning of *dt.* τhen ■ È—Ü2F·

*The Characteristics of Sound Waves Corresponding to Loudness, Pitch and Quality.—*Sounds differ from each other only in the three respects of loudness, pitch and quality.

The *loudness* of the sound brought by a train of waves of given wave-length depends on the extent of the to and fro excursion of the air particles. This is obvious if we consider that the greater the vibration of the source the greater is the excursion of the air in the issuing waves, and the louder is the sound heard. Half the total excursion is called the amplitude. Thus in fig. 4 QJ is the amplitude. Methods of measuring the amplitude in sound waves in air have been devised and will be described later. We may say here that the energy or the intensity of the sound of given wave-length is proportional to the square of the amplitude.

The *pilch* of a sound, the note which we assign to it, depends on the number of waves received by the ear per second. This is generally equal to the number of waves issuing from the source per second, and therefore equal to its frequency of vibration. Experiments, which will be described most conveniently when