of the dome. The whisper seems to creep round the gallery horizontally, not necessarily along the shorter arc, but rather along that arc towards which the whisperer faces. This is a consequence of the very unequal audibility of a whisper in front and behind the speaker, a phenomenon which may easily be observed in the open air ” *(Sound,* ii. § 287).

Let fig. 12 represent a horizontal section of the dome through the source P. Let OPA be the radius through P. Let PQ represent a ray of sound making the angle *θ* with the tangent at A. Let ON( = OP cos 0) be the perpendicular on PQ. Then the reflected ray OR and the ray reflected at R, and so on, will all touch the circle drawn with ON as radius. A ray making an angle less than 0 with the tangent will, with its reflections, touch a larger circle. Hence all rays between =0 will be confined in the space between the outer dome and a circle of radius OP cos 0, and the weakening of in­tensity will be chiefly due to vertical spreading.

Rayleigh points out that this clinging of the sound to the surface of a concave wall does not depend on the exactness of the spherical form. He suggests that the propagation of earthquake disturbances is probably affected by the curvature of the surface of the globe, which may act like a whispering gallery.

In some cases of echo, when the original sound is a compound musical note, the octave of the fundamental tone is reflected much more strongly than that tone itself. This is explained by Rayleigh *(Sound,* ii. § 296) as a consequence of the irregu­larities of the reflecting surface. The irregularities send back a scattered reflection of the different incident trains, and this scattered reflection becomes more copious the shorter the wave­length. Hence the octave, though comparatively feeble in the incident train, may predominate in the scattered reflection constituting the echo.

*Refraction of Sound.*

When a wave of sound travelling through one medium meets a second medium of a different kind, the vibrations of its own particles are communicated to the particles of the new medium, so that a wave is excited in the latter, and is propagated through it with a velocity dependent on the density and elasticity of the second medium, and therefore differing in general from the previous velocity. The direction, too, in which the new wave travels is different from the previous one. This change of direction is termed *refraction,* and takes place, no doubt, accord­ing to the same laws as does the refraction of light, viz. (1) The new direction or *refracted ray* lies always in the *plane of incidence,* or plane which contains the incident ray *(i.e.* the direction of the wave in the first medium), and the normal to the surface separating the two media, at the point in which the incident ray meets it; (2) The *sine* of the angle between the normal and the incident ray bears to the *sine* of the angle between the normal and the refracted ray a ratio which is constant for the same pair of media. As with light the ratio involved in the second law is always equal to the ratio of the velocity of the wave in the first medium to the velocity in the second; in other words, the *sines* of the angles in question are *directly* proportional to the velocities.

Hence sound rays, in passing from one medium into another, are bent in towards the normal, or the reverse, according as the velocity of propagation in the former exceeds or falls short of that in the latter. Thus, for instance, sound is refracted *towards* the per­pendicular when passing into air from water, or into carbonic acid gas from air; the converse is the case when the passage takes place the opposite way.

It further follows, as in the analogous case of light, that there is a certain angle termed the *critical angle,* whose sine is found by dividing the less by the greater velocity, such that all rays of sound meeting the surface separating two different bodies will not pass onward, but suffer total reflection back into the first body, if the velocity in that body is less than that in the other body, and if the angle of incidence exceeds the limiting angle.

The velocities in air and water being respectively 1090 and 4700 ft. the limiting angle for these media may be easily shown to be slightly above 15½°. Hence, rays of sound proceeding from a distant source, and therefore nearly parallel to each other, and to PO (fig. 13), the angle POM being greater than 15½°, will not pass into the water at all, but suffer total reflection. Under such circumstances, the report of a gun, however powerful, should be inaudible by an ear placed in the water.

*Acoustic Lenses.—*As light is concentrated into a focus by a convex glass lens (for which the velocity of light is less than for the air), so sound ought to be made to converge by passing through a convex lens formed of carbonic acid gas. On the other hand, to produce convergence with water or hydrogen gas, in both which the velocity of sound exceeds its rate in air, the lens ought to be concave. These results have been confirmed experimentally by K. F. J. Sondhauss *(Pogg. Ann.,* 1852, 85. p. 378), who used a collodion lens filled with carbonic acid. He found its focal length and hence the refractive index of the gas, C. Hajech *(Ann. chim. phys.,* 1858, (iii). vol. 54) also measured the refractive indices of various gases, using a prism containing the gas to be experimented on, and he found that the deviation by the prism agreed very closely with the theoretical values of sound in the gas and in air.

Osborne Reynolds *(Proc. Roy. Soc.,* 1874, 22, p. 531) first pointed out that refraction would result from a variation in the tempera­ture of the air at different heights. The velocity of sound in air is independent of the pressure, but varies with the temperature, its value at *t°* C. being as we have seen

U=U0(1+½*at*),where Uois the velocity at oo C., and α is the coefficient of expansion ∙00365. Now if the temperature is higher overhead than at the surface, the velocity overhead is greater. If a wave front is in a given position, as o 1 (fig. 14), at a given instant the upper part, moving faster, gains on the lower, and the front tends to swing round as shown by the successive positions in *a* 2, 3 and 4; that is, the sound tends to come down to the surface. This is well illustrated by the remarkable horizontal carriage of sound on a still clear frosty morning, when the surface layers of air are decidedly colder than those above. At sunset, too, after a warm day, if the air is still, the cooling of the earth by radiation cools the lower layers, and sound carries excellently over a level surface. But usually the lower layers are warmer than the upper layers, and the velocity below is greater than the velocity above. Consequently a wave front such as *b* 1 tends to turn upwards, as shown in the successive positions & 2, 3 and 4. Sound is then not so well heard along the level, but may still reach an elevated observer. On a hot summer’s day the temperature of the surface layers may be much higher than that of the higher layers, and the effect on the horizontal carriage of sound may be very marked.

It is well known that sound travels far better with the wind than against it. Stokes showed that this effect is one of refraction, due to variation of velocity of the air from the surface upwards *(Brit. Assoc. Rep.,* 1857, p. 22). It is, of course, a matter of common observation that the wind increases in velocity from the surface upwards. An excellent illustration of this increase was pointed out by F. Osler in the shape of old clouds; their upper portions always appear dragged forward and they lean over, as it were, in the