The Fundamental Idea of Wave Mechanics

When a ray of light passes through an optical instrument, such as a telescope or a photographic lens, it undergoes a change of direction as it strikes each refractive or reflective surface. We can describe the path of the light ray once we know the two simple laws which govern the change of direction. One of these is the law of refraction, which was discovered by Snell about three hundred years ago; and the other is the law of reflection, which was known to Archimedes nearly two thousand years before. Figure 1 gives a simple example of a ray, A–B, passing through two lenses and undergoing a change of direction at each of the four surfaces in accordance with Snell’s law.

From a much more general point of view, Fermat summed up the whole career of a light ray. In passing through media of varying optical densities light is propagated at correspondingly varying speeds, and the path which it follows is such as would have to be chosen by the light if it had the purpose of arriving within the shortest possible time at the destination which it actually reaches. (Here it may be remarked, in parenthesis, that any two points along the path of the light ray can be chosen as the points of departure and arrival respectively). Any deviation from the path which the ray has actually chosen would mean a delay. This is Fermat’s famous Principle of Least Time. In one admirably concise statement it defines the whole career of a ray of light, including also the more general case where the nature of the medium does not change suddenly but alters gradually from point to point. The atmosphere surrounding our earth is an example of this. When a ray of light, coming from outside, enters the earth’s atmosphere, the ray travels more slowly as it penetrates into deeper and increasingly denser layers. And although the difference in the speed of propagation is extremely small, yet under these circumstances Fermat’s Principle demands that the ray of light must bend earthwards (see Figure 2), because by doing so it travels for a somewhat longer time in the higher “speedier” layers and comes sooner to its destination than if it were to choose the straight and shorter way (the dotted line in Figure 2, the small quadrangle to be ignored for the present). Most people will have noticed how the sun no longer presents the shape

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of a circular disk when it is low on the horizon, but is somewhat flattened, its vertical diameter appearing shortened. That phenomenon is caused by the bending of the light rays as they traverse the earth’s atmosphere.

According to the wave theory of light, what we call light rays have, correctly speaking, only a fictitious meaning. They are not the physical tracks of any particles of light, but a purely mathematical construction. The mathematician calls them “orthogonal trajectories” of the wave-fronts, that is, lines which at every point run at right angles to the wave-surface. Hence they point in the direction in which the light is propagated and, as it were, guide the light’s propagation. (See Figure 3, which represents the simplest case of concentric spherical wave-fronts and the corresponding rectilinear rays, while Figure 4 illustrates the case of bent rays.) It seems strange that a general principle of such great importance as that of Fermat should be stated directly in reference to these mathematical lines, which are only a mental construction, and not in reference to the wave-fronts themselves. One might therefore be inclined to take it merely for a mathematical curiosity. But that would be a serious mistake. For only from the viewpoint of the wave theory does this principle become directly and immediately intelligible and cease to be a miracle. What we called bending of the light ray presents itself to the wave theory as a turning of the wave-front, and is much more readily understood. For that is just what we must expect in consequence of the fact that neighbouring portions of the wave-front advance at various speeds; the turning is effected in the same