CHAPTER SIX

Light and General Radiation Physics

I. General

189. Models of light. In ordinary life we refer unhesitatingly to a *ray of light* – a convenient concept and one that is easy to picture, though it does not actually state anything about the nature of light. Light rays are in fact no more than the paths along which light energy is propagated. Since we have already mentioned the connection between light and electromagnetic phenomena (Sections 156 and 188), we may rightly surmise that light energy is electromagnetic energy. Of course, the “rays” seen when light enters a dark room through a small aperture are not light rays at all; they are merely illuminated dust particles along the light’s path. The rays themselves are invisible. Only when light reaches the eye, when it has been absorbed in the retina, does it produce a sensation of light.

The concept of the light ray is merely what we call a *model* of light – a convenient mental picture which, though it has nothing to do with the real nature of light, enables us, within well-defined limits, to arrive at a correct description of light phenomena – a description consonant with experience and therefore, within these limits, useful also to the physicist.

Once we step beyond the range of ordinary everyday experience we are apt to encounter light phenomena which can no longer be described by the concept of the light ray but only by means of another model, the *light wave* (Section 213). Throughout a considerable range of experience no precise idea is needed of what it is that oscillates in a light wave. There are, however, certain phenomena which can only be correctly described in terms of light as an *electromagnetic wave process*. This model is entirely adequate to describe all propagation processes of light. The only point on which the waves of visible light differ from the electromagnetic waves of electronics is their very much smaller wavelength, lying roughly between $0.8 \times 10^{-4}$ cm = 800 nm (for red light) and $0.4 \times 10^{-4}$ cm = 400 nm (for violet light) (Section 215).

The wave model, however, fails us the moment we are dealing with the *interactions between individual atoms and light*, i.e. the elementary processes during which light is created and annihilated. To describe these processes we need an entirely different model, the *light quantum (photon*, Section 234) which enables us to view light as a stream of minute particles. (It is true that Newton’s emission theory regarded light as consisting of very small corpuscular particles, but its analogies with the quantum model are entirely superficial.)

The model of the light ray may be regarded as a simplification of both the wave concept and the quantum concept of light, and the conclusions drawn from it, within its limitations, do not run counter to either of these. The wave model and
The quantum model, on the other hand, are mutually totally incompatible – at least if seen as concepts implying definite statements about the nature of light. We shall see later (Section 238) how this difficulty has been solved. For the complete description of all light phenomena both the latter models are indispensable whereas that of the light ray could be dispensed with.

But since it is particularly simple and clear we shall use it here as long as possible (for geometrical optics). We shall then move on to the phenomena which can only be described with the aid of the wave model (wave optics), and finally to those requiring the model of the light quantum (quantum optics).

190. Rectilinear propagation of light. The mere appearance of the “light rays” penetrating into a darkened room through fine apertures, or of the “beams of sunlight” in murky air, convince us that in an extensive homogeneous medium light propagates in a straight line, i.e. by the shortest possible path. Naturally, this applies even more to a vacuum. It is on this linking of the concept of a light ray and the concept of straightness that all visual determination of direction and indeed all those familiar procedures covered by the term “sighting” (such as looking along an edge to see if it is straight) are based.

The casting of a shadow is likewise a consequence of the rectilinear propagation of light. A point source of light $A$ casts a (to our eye) sharply defined, entirely dark shadow $S$ of the outlines of a body $B$, while the surroundings $L$ of the shadow are fully illuminated (Fig. 207a). An extensive light source, provided its luminous surface is less than the cross-sectional area of the body $B$, casts a dark full shadow or umbra $U$, surrounded by a half-shadow or penumbra $P$ which blends continuously into the fully illuminated area $L$ (Fig. 207b). If the luminous surface is greater than the cross-section of the shadow-casting body then, above a certain distance of the body from the screen, the umbra is entirely absent.

The production of an image by a pinhole camera is also due to the rectilinear propagation of light, as will be seen from Fig. 208. The image $I$ is inverted with respect to the object (top and bottom, and the two sides, are reversed) and its size is less or greater than that of the object $O$ in accordance with the ratio $i:o$, where these are the distances of the image and the object from the pinhole. In a darkened room into which light is allowed to enter only through a small aperture it is possible to observe images of the sun, of trees, and of other objects outside the room.