specification of the ultimate internal stimulus, nevertheless, it is possible to correct the external stimulus for some of the simpler pre-X-point variables, notably pupil size and light losses in the optic media, to obtain *intermediate internal stimuli.* The data and formulas of this section are mainly concerned with the optical stages of the visual process involved in deriving intermediate internal stimuli.

2.2 PARTS OF THE HUMAN EYE: NOMENCLATURE; DIMENSIONS

Figure 2.1 shows the general plan of the human eye with the names of its principal parts.

The Fine-Structure of the Retina

The fine-structure of the retina is shown in the schematic section of Fig. 2.2 taken from Polyak's

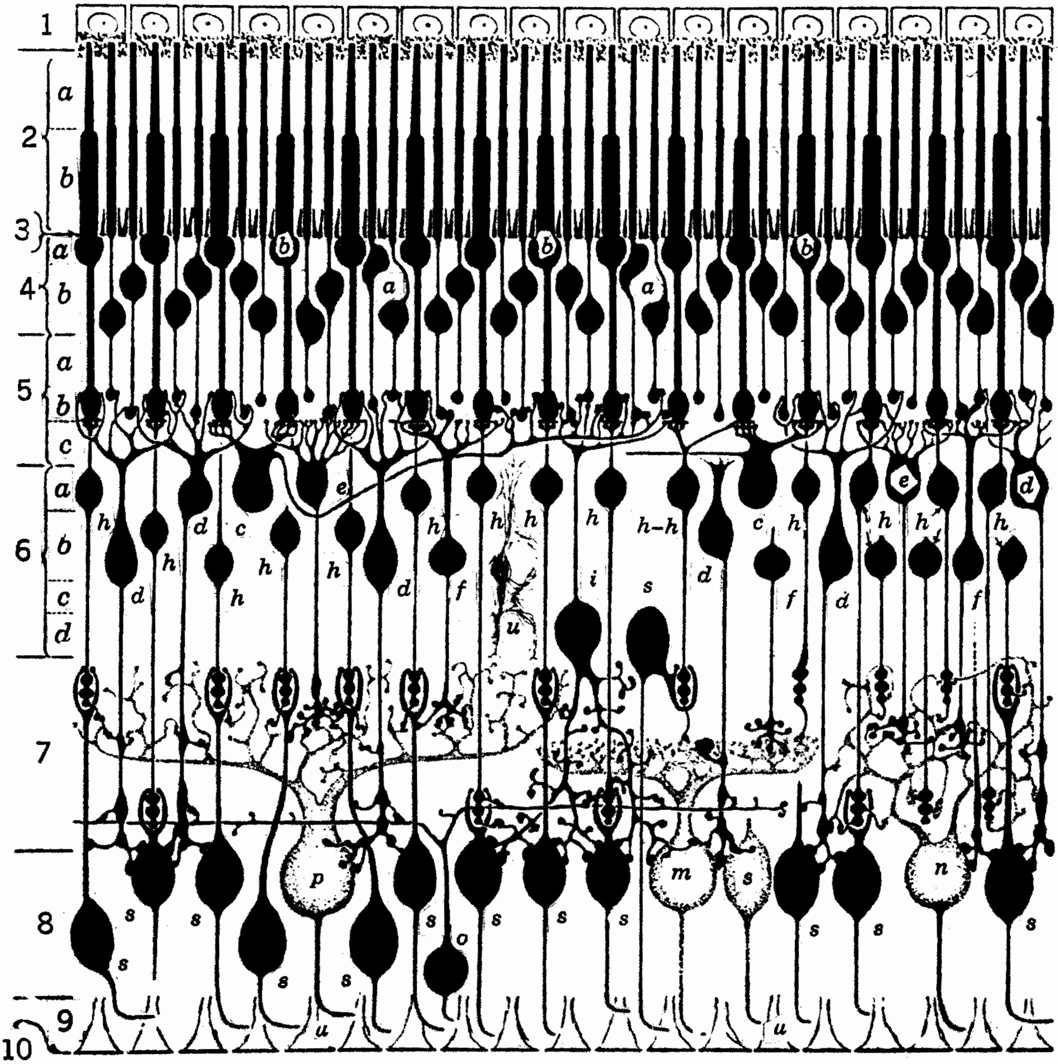

Fig. 2.2. Structures of the primate retina as revealed by the method of Golgi (Reprinted from *The Retina* by S. L. Polyak by permission of the University of Chicago Press. Copyright 1941 by the University of Chicago). The numbered layers are those enumerated in the text. The letters show Polyak's designations of the nerve cells: (*a*) rods; (*b*) cones; (*c*) horizontal cells; (*d, e, f, h*) bipolar cells; (*i, l*) so-called amacrine cells; (*m, n, o, p, s*) ganglion cells; (*u*) 'radial fibers' of Müller. Polyak comments: "In this scheme the nervous elements are reduced to their essentials, with, however, the characteristic features of each variety preserved—the location of the bodies, the size, shape, and the spreading of the dendrites and of the axis cylinders—and with the synaptical contacts presented accurately."

treatise, "The Retina" (1941). Polyak's intensive study of the retinas of primates, covering and extending much earlier work, is the source of most of the factual material given in this Section.

The different retinal layers distinguished are the following:

1. *Pigment epithelium.* Cells with processes interdigitating to a small degree the outer segments (2), and containing nonphotosensitive melanin pigment in which most of the light traversing the retina is finally absorbed.
2. *Rod and cone layer* (bacillary layer).
   (a) Outer segments of the rods and cones containing the actual light-sensitive pigments of vision.
   (b) Inner segments.
3. *Outer limiting membrane.* Thin sheet made up of fibers of the cells (Müller's fibers) sustaining the framework of the retina.
4. *Outer nuclear layer.* Mainly cell bodies (nuclei) of the rod and cone cells.
5. *Outer plexiform layer.* Inner fibers of rod and cone cells and their synaptic contacts with outer fiber expansions of the cells of layer 6.
6. *Inner nuclear layer.* Mainly nuclei of various types of bipolar cells and horizontal and amacrine cells.
7. *Inner plexiform layer.* Inner fiber expansions of bipolar cells and dendritic expansions of ganglion cells of all kinds.
8. *Layer of ganglion cells.*
9. *Layer of optic nerve fibers.* Fibers from the ganglion cells proceeding across the retina to leave the eyeball at the optic disk.
10. *Inner limiting membrane.* Thin sheet made up of the inner terminations of Müller's fibers.

Main Topographical Features of the Retina

1. *Optic disk, papilla.* The gap in the retina proper, occupied by the optic disk which is not light sensitive and corresponds to the *blind spot* in the visual field. The optic disk is roughly oval with its longer diameter vertical.

   Approximate dimensions. Vertical, 2 to 2.4 mm (7 to 8°); horizontal, 1.5 to 1.8 mm (5 to 6°).

   Approximate position of center. 4.8 mm to nasal side of visual pole and 0.47 mm above horizontal meridian (16° temporal and 1.6° below in external field).
2. *Ora serrata.* The abrupt boundary of the retina toward the front of the eye. Vision is impossible for stimuli beyond the ora serrata but in fact may not reach as far as this.
3. *Fovea.* Small region about the visual pole where vision is most acute.
4. *Rod-free area.* Small area centered on the visual pole which is blind to weak stimuli in dark-adaption.
5. *Central avascular region.* This area is also centered on the visual pole (it probably corresponds to the region of a very bright external field, particularly of shortwave light, in which "dancing dots" of light are not observable).
6. *Yellow spot.* (macula lutea). A central area extending beyond the fovea in which a yellow pigmentation can be seen in retinal preparations and associated with the Maxwell spot (observable as a shaded spot in the direction of vision, on intermittent observation of a uniform field of deep blue light, and also as a more complicated pattern with various other colored stimuli).
7. *Parafoveal area.* Retinal region immediately surrounding the fovea.
8. *Peripheral area.* Region between the parafovea and the ora serrata.

Polyak's more precise subdivision into retinal regions, based on easily identifiable features in the morphology of the retina and not on its function properties, is given in Table 2.1. There is an arbitrary element in assigning some of the boundaries.

Distribution and Dimensions of Rods and Cones

Table 2.2 contains data compiled from Polyak (1941) and Oesterberg (1935) (see also Pirenne, 1961). For data on the distribution of refractive index in rods and cones of various animal eyes, see Sidman (1957).

2.3 SPECIFICATION OF THE EXTERNAL STIMULUS

If, at a given moment, an observing eye is located with its nodal point (or with its pupil center) at O (Fig. 2.4) and its visual axis, produced forward, lying along OQ, positions P in the external field are specified by the polar coordinates r, θ, ϕ, where the azimuth ϕ is the angle by which

Table 2.1 Subdivision of the Retina into Regions (from Polyak, 1941)

	Retinal Region	Approximate Outer Diameter on Retina	Corresponding Angular Diameter in External Field
Central area			
I. *Fovea*	This corresponds to a pit or depression in the retina-vitreous surface (internal limiting membrane) and to a thinning toward the center of layers 5 to 9; at the same time layers 2 and 4 become thicker (see Fig. 2.3).	1,500 μ	5.2°
	The nearly flat central area of the foveal pit where layers 5 to 9 are almost absent is called the *foveola*. There are no blood vessels here.	400 μ	1.4°
	In a *central island* within the foveola the cones have maximum length. There are no rods here.	50–75 μ	0.17–0.24°
II. *Parafovea*	Roughly circular belt of width about 500 μ. In this the thickness of layer 2 has dropped to the value it retains throughout the remainder of the retina.	2,500 μ	8.6°
III. *Perifovea*	Circular belt of approximate width 1500 μ, marked by the progressive reduction in thickness of the ganglion-cell layer from about 4 cells to about 1 cell thick.	5,500 μ	19.0°
Peripheral area			
IV. *Near periphery*	Approximate width 1500 μ	8,500 μ	29.0°
V. *Middle periphery*	Approximate width 3000 μ	14,500 μ	50.0°
VI. *Far periphery*	Approximate width 10,000 μ (temporal side) Approximate width 16,000 μ (nasal side)	40,000 μ (horizontal)	
VII. *Ora serrata* (extreme periphery)	Approximate width 2100 μ (temporal side) Approximate width 700–800 μ (nasal side)	44,000 μ (horizontal)	
	[For the special characteristics distinguishing regions IV to VII, see Polyak (1941)]		
VIII. *Yellow spot*	The yellow pigment permeates diffusely all layers from 4 to 9. Thus pigmentation is very slight in the foveola, intense on the slopes and margin of the fovea, and gradually fades out beyond. However, it is visible in some preparations nearly up to the papilla (Polyak, 1941).	3,000 μ (intense)	10°
	The yellow spot is more extended in the horizontal than in the vertical meridian.	5,000 μ (total)	17°
IX. *Rod-free area*	Diameter	500–600 μ	1.7–2.0° (Polyak)
	[Oesterberg's data (1935) correspond to a smaller value]		1.0° (Oesterberg)
X. *Avascular area*	Diameter	400–660 μ	1.4–2.3°

a half plane bounded by OQ must be rotated from a conventional reference position to a position in which it contains the point P. A suitable convention is to choose the reference position so that the half plane contains the nodal point of the observer's other eye (the nasal position), the rotation being taken in the direction nasal–upper–temporal–lower–nasal.

Under usual conditions of vision, the stimulus from a given direction (θ, ϕ) in the external field is provided by the radiation emitted diffusely by a solid surface at distance r. Let the spectral radiance at the point P (r, θ, ϕ) of the emitting surface in the direction of the eye, be represented by $L_{e\lambda}(\theta, \phi)$ (watts per unit wavelength interval per unit area per unit solid angle of emission). Then by the definition of spectral radiance, an element of area dS of the surface at P acts as a source of radiant intensity towards the eye, which for the wavelength interval $d\lambda$ has the