Bonds

1. Cite three practical challenges in forming a clear image on the retina and describe briefly how each is met by the biological structure of the eye. Note that by challenges I do not refer to optical flaws (i.e., myopia, etc).

This question addresses OPTICAL factors in image formation, not issues involving retinal or other brain structures.

a) Image focus requires strong refraction, implemented by multiple refractive surfaces and aided by the graded refractive index of the lens.

b) Focus must be dynamic, i.e., suitable for objects at varying distances, implemented by variable refractive strength of the lens.

c) Imaging quality is optimized for available light by variable aperture of the iris. (Note that this does not address light adaptation, not an optical issue.)

2. How does knowledge of an optical linespread permit complete characterization of the behavior of an optical system?

The characterization may be done by using a Modulation Transfer Function (MTF), which describes the response of the system to all spatial frequencies. The linespread is the response to an impulse, which contains all spatial frequencies at uniform power. The inverse Fourier transform of the linespread is equal to the MTF.

3. The title of the course is The Visual System. What is meant by that? How is the visual system represented in living organisms?

The visual system is embodied in an anatomically-diffuse set of mechanisms in the brain (central nervous system) that are associated with detection, representation, processing and behavioral response associated with image information. While it may seem to be concentrated in the primary visual pathway, perhaps dozens of other brain structures are involved in this complex process.

4. Cells in the retina are represented by two general classes, linear and non-linear. State a functional advantage and disadvantage of each general class in the context of visual processing.

Linear (P, X): Advantage: High acuity, linear image representation, dense population
Disadvantage: Slow conduction, slow temporal reponse, low contrast sensitivity

Nonlinear (M, Y): Advantage: Rapid conduction, sensitive to high temporal frequency/motion, High contrast sensitivity

Disadvantage: Low acuity, nonlinear image representation, sparse population

Casagrande

5) Identify the following brain areas based upon their function. Do these areas receive direct axonal input from the retina, Yes or No (circle one).

A) The suprachiasmatic nucleus (or hypothalamus) an important visual area for the control of circadian rhythms . Does it receive direct input from retina? Yes

B) The pretectum (or midbrain)is important for the control of pupillary reflexes and accommodation. Does it receive direct input from retina? Yes

C) The superior colliculus (or midbrain) is important for the control eye movements and orientation in space. Does it receive direct input from retina? Yes

D) The lateral geniculate nucleus is an important relay for visual information important for conscious visual perception. Does it receive direct input from retina? Yes

E) Striate cortex (or V1 or area 17). (They could also answer V2)is an important early visual cortical area that receives its primary input from the thalamus. Does it also receive direct input from retina? No

6) Describe the path of light through the eye and retina. Identify *in order* all structures and retinal layers through which the light will pass before it hits the retinal receptors assuming the light beam you are describing strikes receptors located peripheral to the fovea. Be specific and precise in your answer.

Cornea –(pupil…not essential to put)- aqueous – lens – vitreous – (blood vessels …not essential) ganglion cell layer –inner plexiform layer - inner nuclear layer –outer plexiform layer – outer nuclear layer (technically this would do since this layer is the layer containing cell bodies of the receptors). Some might have put additionally receptors because they don't understand that the cell bodies of receptors are what make up the outer nuclear layer. This was considered ok.

Lappin (Many of the following answers are more detailed than was required or expected on the esam.)

7. A classic study by Hecht, Shlaer, & Pirenne (1942) used psychophysical methods to reach conclusions about responses of rods to photons. Describe very briefly:

A) What did they find?

Two basic results were: (1) A single photon is sufficient to produce a visually effective excitation of a rod. (Reliable detections, however, require simultaneous excitations of several rods — roughly 3 – 8.) (2) The trial-to-trial variability in individual observers' behavioral detections was attributable primarily to the random physical processes that govern the absorption of photons by photoreceptors. The physiological between the photoreceptors and the observer's behavior contributed very little additional variability.

B) What is the logic that permits this link from psychophysics to physiology of the retina?

Behavioral discrimination (e.g., of differences in the number of photons in the stimulus) implies differences in retinal responses (in responses of photoreceptors and ganglion cells to variations in the stimulus energy). This follows from the 2nd law of thermodynamics: Information about retinal stimulation can only be lost but not increased by visual processes.

8. Stuart Anstis (1974) published a frequently reproduced "chart demonstrating variations in retinal acuity with retinal position." (Actually, he showed three different charts.)

A) What was the structure of these charts illustrating this relationship between acuity and retinal position?

The sizes of characters in all three of these charts increased in direct proportion to eccentricity in the visual field. That is, spatial resolution decreases in inverse proportion to retinal eccentricity.

B) What is thought to be the anatomical basis for this relationship?

Two anatomical properties exhibit approximately the same relationship to retinal eccentricity: (a) diameters of dendritic fields of ganglion cells [true for both M-cells and P-cells, though the proportionality is very different for both], and (b) cortical magnification of the visual field in area V1, which is inversely proportional to eccentricity. That is, the ratio of linear extent of primary visual cortex (V1) relative to angular extent of the visual field, in mm of cortex per degree of visual angle, is inversely proportional to retinal eccentricity. [This proportionality is NOT exhibited by changes in the density of photoreceptors over the retina, nor by the sizes of the ganglion cells.]

9. (A) What are "metamers" in color vision?

Metamers are beams of light with different wavelength compositions that have visually indistinguishable colors.

(B) What is the physiological explanation for metameric colors?

Metamers produce equivalent excitations of the three cone photoreceptors.

10. Say three important things about the "opponent process" mechanism of color vision. For example: What are the functionally important characteristics of such a mechanism — what design or performance problems are solved by such a mechanism? What specific physiological mechanisms are involved? What physiological discoveries revealed the operation of this mechanism? What psychophysical or perceptual phenomena are explained by this mechanism?

1) Several psychophysical phenomena are inconsistent with the Young-Helmholtz trichromatic theory of color vision, suggesting instead that perceived colors are encoded by

opponent processes — the subjective uniqueness of yellow as distinct from red, green, and blue; negative afterimages (e.g., yellow as an afterimage of blue); color blindness and color deficiencies involve loss of discriminations between pairs of colors.

2) The experiments of Russell De Valois and colleagues in the 1960s, recording from cells in LGN, found that "spectrally opponent" ganglion cells gave opposite responses to monochromatic lights in different regions of the spectrum, increasing the firing rate to some wavelengths and decreasing in response to other wavelengths. "Spectrally non-opponent" cells, however, gave the same sign of response, increasing or decreasing, regardless of the wavelength. The spectrally opponent cells encoded variations in wavelength, whereas the non-opponent cells evidently encoded differences in brightness. The opponent cells seemed to be in two main classes, L vs. M (+R-G or +G-R) and S vs. L+M (+B-Y or +Y-B).

3) The experiments by De Valois et al. definitively resolved the controversy between the Young-Helmholtz trichromatic theory and Hering's "opponent process" theory, showing that both were correct but occurred at different stages of a 2-stage process: The initial retinal encoding of color is based on photo-absorption spectra of three different cones, as Helmholtz and others had concluded. The neural encoding of color by the ganglion cells was based on an opponent process, as Hering and others had suggested.

4) The opponent process mechanism of color encoding can explain how only three different cones with very broad and overlapping absorption spectra can result in visual discriminations of wavelength differences of only 1-2 nm in much of the spectrum. This spectral difference signal is also robust over variations in intensity. Similar physiological mechanisms, involving subtraction of one signal from another, are found in many aspects of vision. The mechanism is analogous to that used to guide Nazi bombers at night to precise locations over England — using two slightly different radio signals (e.g., dots & dashes) transmitted from two different but neighboring spatial locations.

11. Several different psychophysical or perceptual phenomena demonstrate that the perceived colors of environmental objects depend not simply on the spectrum of light at any given location but also on spatial distribution of that light.

A) Identify two such phenomena. (1 point each)

1) color constancy

2) Land's demonstrations

3) perceived colors (e.g., gold) and material properties (e.g., smooth, glossy vs. rough, matte surfaces) of natural surfaces

4) simultaneous color contrast

C) Describe how one of these phenomena leads to the conclusion that color perception in the normal environment depends on the spatial and well as the spectral characteristics of light. (3 points)

1) Color constancy — the approximate constancy or stability of perceived surface colors under large variations in the spectral composition of the illumination (e.g., daylight, incandescent lighting, fluorescent lighting) — involves perceiving the reflectance properties of the surface as distinct from the spectrum of the illumination and the specific spectrum of the light in the retinal image. To perceptually analyze and distinguish these two factors, the surface reflectance and the illumination spectrum, one

must obtain information about the illumination spectrum from the spectral composition of the light reflected from many neighboring surfaces illuminated by the same light. The analytical problem is roughly analogous to solving for some unknown factor by adding and subtracting several independent linear equations. That is, one can perceive the reflectance characteristics of one object by comparing it with its neighbors.

2) All of Land's demonstrations showed that the perceived color of any given object is not based simply on the color spectrum reflected from that surface, but involves comparisons of the relative lightnesses of various surfaces as seen through two or three different filters. One of Land's demonstrations involved images of multi-colored natural scenes or patterns photographed with black/white film. One such photograph was made with a red filter over the camera lens, and another was made with no filter. Thus, one image recorded variations in the amount of long-wavelength light reflected from the various surfaces in the image, and the other image recorded the relative lightnesses of the surfaces with a broad wavelength spectrum. Slides made from the negatives of these two images were then projected and superimposed, with a red filter in front of the projector with the slide photographed with the red filter. The surprising result was that the scene appeared approximately normally colored, with a full range of colors, including blues, greens, and yellows. This demonstration indicated that perceived colors are defined by visual comparisons of the relative lightnesses of various surfaces.

3)The glossy vs. matte characteristics of surfaces are determined by variations in the microstructure of surface — its smoothness, roughness — at the level of 100s – 1000s of nm. This microscopic roughness of the surface affects the degree to which the surface reflects and scatters light. Even though the microscopic surface texture is not directly visible, the scattering has directly visible effects on the images. Gold and other metallic surfaces can be effectively painted by adding a small spot of white paint, simulating the specular reflectance of the surface.

Penn

12. Briefly elaborate on the condition of **glaucoma**. In your answer, address the following:

1) What ocular fluid is involved in the development of this condition? Aqueous humor

2) State the sites of entry and exit of this fluid from the normal eye. It is produced by the ciliary body epithelium and leaves the eye through the trabecular meshwork, Schlemm's canal and the venous outflow of the eye.

3) What is the primary defect that leads to alteration of the normal behavior of this fluid in glaucoma? The exit of the fluid from the eye is reduced or blocked while its production continues.

4) What is the immediate result of this defect? Increased intraocular pressure

5) What is the longer-term result if medical intervention is not successful? Death of retinal neurons