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Vision: Phototransduction in Rods & Cones

Study Guide — Vision

High school / pre-med / IB questions that teach phototransduction: what light does inside rods and cones, the cGMP pathway, neurotransmitter changes, bleaching, adaptation, and key rod/cone differences.

30 items — Study Guide with Answers

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1 **In complete darkness, which situation best describes a rod photoreceptor?**

A cGMP is low, cGMP-gated channels are closed, the rod is hyperpolarized

B **cGMP is high, cGMP-gated channels are open, the rod is relatively depolarized and releases glutamate** ✓

C cAMP is high, voltage-gated Na^+ channels open, the rod fires action potentials

D Glutamate release stops completely because rods are inactive in darkness

E The Na^+/K^+ pump reverses direction to generate light

▶ **Explanation:** In darkness, rods have high cGMP, which keeps cGMP-gated cation channels open (the 'dark current'). This keeps the rod relatively depolarized and it releases glutamate continuously. Rods do not fire action potentials (ganglion cells do), and the Na^+/K^+ pump does not reverse direction.

2 **After a photon is absorbed by rhodopsin in a rod, which sequence MOST accurately leads to the electrical response?**

A Light -> cAMP rises -> cAMP-gated channels open -> rod depolarizes -> glutamate release increases

B **Light -> 11-cis retinal becomes all-trans -> transducin activates PDE -> cGMP decreases -> cGMP-gated channels close -> rod hyperpolarizes** ✓

C Light -> all-trans retinal becomes 11-cis -> transducin is inhibited -> cGMP increases -> channels close -> rod depolarizes

D Light -> voltage-gated Na^+ channels open -> rod fires action potentials to the optic nerve

E Light -> acetylcholine is released from rods -> pupil constricts

▶ **Explanation:** Phototransduction in rods: photon converts 11-cis retinal to all-trans, activating rhodopsin -> transducin (a G-protein) -> phosphodiesterase (PDE) -> cGMP falls -> cGMP-gated cation channels close -> rod hyperpolarizes. Rods do not send action potentials down the optic nerve, and cAMP is not the key second messenger here.

3 **In rod phototransduction, phosphodiesterase (PDE) most directly causes which change?**

- A **Hydrolyzes cGMP, lowering its concentration** ✓
- B Hydrolyzes ATP to ADP, powering channel closure
- C Hydrolyzes glucose into pyruvate
- D Converts all-trans retinal back to 11-cis retinal
- E Directly opens cGMP-gated channels by adding phosphate groups

▶ **Explanation:** Activated PDE breaks down cGMP to GMP, decreasing cGMP. That causes cGMP-gated channels to close. PDE does not hydrolyze ATP for this signal, does not run glycolysis, and retinal is regenerated by the visual cycle (not PDE).

4 **Compared with darkness, shining light on a rod photoreceptor causes the rod membrane potential to:**

- A Depolarize because Na^+ channels open
- B **Hyperpolarize because cGMP-gated cation channels close** ✓
- C Stay exactly the same because rods cannot change membrane potential
- D Generate action potentials at higher frequency
- E Depolarize because glutamate binds back to the rod

▶ **Explanation:** Light closes cGMP-gated channels, reducing inward cation flow and hyperpolarizing the rod. Photoreceptors primarily use graded potentials, not action potentials. Glutamate is released by the rod; it does not depolarize the rod by binding back to it as the primary mechanism.

5 **When light hits a rod, what happens to glutamate release from the rod terminal?**

A It increases because the rod depolarizes

B **It decreases because the rod hyperpolarizes** ✓

C It stays constant because neurotransmitter release is unrelated to membrane potential

D It switches from glutamate to acetylcholine

E It becomes zero permanently after the first photon (bleaching destroys synapses)

▶ **Explanation:** In darkness rods are relatively depolarized and release glutamate continuously. Light hyperpolarizes rods, reducing Ca^{2+} entry at the terminal and decreasing glutamate release. Phototransduction does not permanently destroy synapses after one photon.

6 **A light spot increases illumination in the center of a receptive field. Which bipolar cell type is designed to depolarize when photoreceptors reduce glutamate release?**

A **ON bipolar cell** ✓

B OFF bipolar cell

C Rod photoreceptor

D Ganglion cell axon

E Ciliary muscle cell

▶ **Explanation:** ON bipolar cells are wired so that less glutamate from photoreceptors (in light) causes ON bipolars to depolarize. OFF bipolar cells do the opposite (they depolarize in darkness when glutamate is higher). Rods themselves hyperpolarize in light.

7 **In darkness, photoreceptors release more glutamate. Which statement best matches the typical effect on ON vs OFF bipolar cells?**

A Both ON and OFF bipolar cells depolarize strongly

B **ON bipolar cells tend to be hyperpolarized, while OFF bipolar cells tend to be depolarized** ✓

C ON bipolar cells depolarize, OFF bipolar cells hyperpolarize

D Neither ON nor OFF bipolar cells respond to glutamate

E Bipolar cells use rhodopsin and directly detect light without synapses

▶ **Explanation:** In the dark, glutamate release is high. ON bipolars are inhibited by glutamate (so they tend to be hyperpolarized), whereas OFF bipolars are excited by glutamate (so they tend to be depolarized). Bipolar cells do not contain rhodopsin; they receive synaptic input from photoreceptors.

8 **Which statement correctly compares rods and cones in terms of sensitivity and typical function?**

A Cones are more sensitive than rods and dominate night vision

B **Rods are more sensitive and dominate dim-light vision; cones dominate color and high-acuity vision in bright light** ✓

C Rods provide color vision; cones provide only black-and-white vision

D Rods and cones have identical sensitivity and function

E Cones contain rhodopsin; rods contain three photopsins

▶ **Explanation:** Rods are extremely sensitive and support scotopic (dim-light) vision but not color. Cones are less sensitive, function best in bright light, and provide color and sharp detail (especially in the fovea).

9 **Where are the light-absorbing photopigments (rhodopsin/photopsins) located within rods and cones?**

A In the nucleus of the photoreceptor

B In mitochondria of the inner segment

C **In membranes of the outer segment (discs or folds)** ✓

D In the synaptic cleft between rods and bipolar cells

E In the vitreous humor

▶ **Explanation:** Photopigments sit in the outer segment membranes (rod discs or cone membrane folds). The nucleus and mitochondria are not where light is detected, and photopigments are not in the synaptic cleft or vitreous humor.

10 **Rhodopsin can be thought of as which combination?**

A A carbohydrate + a lipid

B **Opsin (protein) + retinal (vitamin A-derived molecule)** ✓

C Hemoglobin + heme

D DNA + histones

E Transducin + phosphodiesterase

▶ **Explanation:** Rhodopsin consists of the protein opsin bound to retinal (a vitamin A derivative). Hemoglobin/heme and DNA/histones are unrelated, and transducin/PDE are downstream signaling proteins, not the photopigment itself.

11 **The FIRST chemical change triggered by photon absorption in a rod is typically described as:**

A ATP is converted to cAMP

B **11-cis retinal isomerizes to all-trans retinal** ✓

C cGMP rises sharply

D Glutamate is produced by glycolysis

E Voltage-gated Na^+ channels open in the optic nerve

▶ **Explanation:** Light causes isomerization of retinal within rhodopsin (11-cis -> all-trans), activating the opsin. This then triggers transducin/PDE and lowers cGMP. The other options are unrelated or occur downstream.

12 **In simple terms, 'bleaching' of visual pigment most accurately refers to:**

A Permanent destruction of photoreceptors after exposure to any light

B **A temporary loss of light sensitivity because the pigment has changed form and must be regenerated** ✓

C Opening of cGMP-gated channels in bright light

D The pupil becoming smaller

E The optic nerve firing faster because it is 'bleached'

▶ **Explanation:** Bleaching happens when retinal changes configuration (and can detach from opsin), leaving the pigment temporarily unable to absorb another photon until it is regenerated by the visual cycle. It is not permanent cell destruction, and it is not simply a pupil change.

13 **A student walks into a dark cinema after being outside in bright sunlight. It takes minutes for their vision to improve. Which process best explains this time course?**

A The cornea slowly thickens to let in more light

B **Regeneration of rod photopigment (rhodopsin) and increasing rod sensitivity (dark adaptation)** ✓

C The optic nerve grows new axons

D The retina moves forward to be closer to the lens

E Bipolar cells switch from electrical to chemical synapses

▶ **Explanation:** Dark adaptation largely reflects rods recovering sensitivity as rhodopsin regenerates after bleaching in bright light (plus neural adaptation). Pupil dilation helps quickly but doesn't explain the slow minutes-long improvement by itself.

14 **In very bright light, rods often contribute little to vision because rods:**

A Stop containing photopigment after childhood

B **Become saturated/bleached and cannot increase their response further, so cones dominate** ✓

C Are only located in the optic nerve

D Require vitamin C to work in sunlight

E Only detect green light

▶ **Explanation:** Rods are extremely sensitive and can saturate in bright conditions (their signaling reaches a maximum). Cones operate better in bright light and take over for color and detailed vision. Rods are in the retina, not the optic nerve, and are not limited to green only.

15 **Vitamin A is essential for normal vision mainly because it is required to:**

A Make neurotransmitter glutamate in photoreceptors

B **Regenerate 11-cis retinal for visual pigments (rhodopsin/photopsins)** ✓

C Produce melanin in the iris for pupil constriction

D Increase the number of rods in the retina each day

E Convert oxygen into ATP in the lens

▶ **Explanation:** Retinal (from vitamin A) is the light-sensitive part of visual pigments. Without adequate vitamin A, pigment regeneration is impaired, especially affecting rod function and causing night blindness. The other options describe unrelated processes.

16 **In darkness, cGMP levels in the rod outer segment are kept relatively high mainly because:**

A Phosphodiesterase (PDE) constantly produces cGMP

B **Guanylate cyclase synthesizes cGMP from GTP when the phototransduction cascade is inactive** ✓

C Transducin hydrolyzes cGMP into GMP

D Light continuously activates rhodopsin even in darkness

E cGMP is stored inside the nucleus and released only at night

▶ **Explanation:** In the dark, rhodopsin/transducin/PDE are relatively inactive, and guanylate cyclase makes cGMP, keeping cGMP-gated channels open. PDE breaks down cGMP (it doesn't make it), and transducin is a G-protein, not an enzyme that hydrolyzes cGMP directly.

17 **Rods use MORE ATP in darkness than in bright light mainly because:**

A Darkness turns on glycolysis, while light turns it off

B **The dark current brings Na^+ into the cell, requiring active pumping to maintain ion gradients** ✓

C Light forces rods to fire action potentials repeatedly

D In darkness, rods stop releasing neurotransmitter, requiring ATP to restart release

E ATP is only produced in the outer segment when light is present

▶ **Explanation:** In darkness, cGMP-gated channels allow continuous Na^+ (and Ca^{2+}) entry. Maintaining gradients requires strong activity of ion pumps (like Na^+/K^+ ATPase), consuming ATP. Rods do not fire action potentials, and they release neurotransmitter more (not less) in darkness.

18 **A mutation locks rod cGMP-gated cation channels CLOSED permanently. In complete darkness, the rod would most likely be:**

A Depolarized with high glutamate release (like normal darkness)

B **Hyperpolarized with low glutamate release (like being exposed to light)** ✓

C Unaffected because channels are not involved in phototransduction

D Firing action potentials to compensate for closed channels

E Producing extra rhodopsin to reopen the channels

▶ **Explanation:** Closing cGMP-gated channels removes the dark current, making the rod more negative (hyperpolarized) and reducing glutamate release - mimicking a 'light-like' state even in darkness. Photoreceptors don't compensate by firing action potentials.

19 **A drug inhibits phosphodiesterase (PDE) in rod outer segments. When light shines on the rods, the most likely result is:**

A cGMP will fall more than normal, causing extra hyperpolarization

B **cGMP will not fall normally, so cGMP-gated channels stay more open and the light response is reduced** ✓

C Rods will depolarize more in response to light than normal

D Rhodopsin will be unable to absorb photons

E Glutamate release will increase in response to light

▶ **Explanation:** Normally, activated PDE lowers cGMP to close channels. If PDE is inhibited, cGMP remains higher, channels remain more open, and the rod does not hyperpolarize as much - so the light signal is weakened. Light still can be absorbed by rhodopsin; the block is downstream.

20 **Transducin is best described as:**

A A voltage-gated Na^+ channel

B **A G-protein that becomes active when it binds GTP** ✓

C An enzyme that directly converts 11-cis retinal to all-trans retinal

D A neurotransmitter released by rods

E A structural protein that forms the lens

▶ **Explanation:** Transducin is a G-protein activated by rhodopsin; activation involves exchange of GDP for GTP. It is not an ion channel, not the retinal isomerization step, and not a neurotransmitter.

21 **Light adaptation in photoreceptors involves feedback from Ca^{2+}. Which statement is MOST accurate?**

A Light opens cGMP-gated channels, increasing Ca^{2+} entry, which increases sensitivity

B **Light closes cGMP-gated channels, lowering Ca^{2+} entry; the fall in Ca^{2+} helps increase cGMP production and partially restores channel opening** ✓

C Light has no effect on Ca^{2+} movement in photoreceptors

D Ca^{2+} enters mainly through voltage-gated Ca^{2+} channels in the optic nerve

E Ca^{2+} feedback is only used by cones, never by rods

▶ **Explanation:** When light closes cGMP-gated channels, Ca^{2+} influx decreases. Lower Ca^{2+} contributes to recovery/adaptation by promoting cGMP restoration (helping reopen channels). Light does not open these channels, and Ca^{2+} feedback mechanisms are present in rods and cones (with different kinetics).

22 **Cones typically recover faster than rods after bright light exposure. The best explanation is that cones generally:**

A Have no photopigments, so they cannot bleach

B **Regenerate photopigment and shut off the transduction cascade faster, allowing quicker return to baseline** ✓

C Use hemoglobin to carry oxygen to the retina

D Are located at the optic disc where there is no light detection

E Only function in complete darkness, so bright light does not affect them

▶ **Explanation:** Cones have faster kinetics and faster pigment recycling than rods, which supports vision in changing light conditions and bright environments. They still bleach; they just recover more quickly than rods. They are not located at the optic disc.

23 Why does the peripheral retina generally detect faint movement better than the fovea in dim light?

A Peripheral retina has a high density of rods and more convergence, increasing sensitivity at the cost of acuity ✓

B Peripheral retina has more cones and less convergence, increasing sensitivity

C The fovea contains the optic disc and has no photoreceptors

D Peripheral retina receives more light because the pupil is on the side

E Rods are only found in the fovea, where movement is detected

▶ **Explanation:** Peripheral retina is rod-rich and often has high convergence (many rods feeding fewer downstream neurons), boosting sensitivity to faint stimuli and motion. The fovea is cone-rich for detail and is not the optic disc.

24 Which statement about electrical signaling is correct for photoreceptors?

A Rods and cones normally send action potentials directly down the optic nerve

B Rods and cones mainly use graded changes in membrane potential, while ganglion cells generate action potentials ✓

C Only rods use graded potentials; cones fire action potentials

D Photoreceptors cannot change membrane potential; only synapses change

E Bipolar cells are the only cells that detect photons

▶ **Explanation:** Photoreceptors respond with graded potentials (hyperpolarization with light). Ganglion cells are the main retinal output neurons that fire action potentials whose axons form the optic nerve. Cones do not fire action potentials as their primary light response.

25 Which pairing correctly describes the direction of LIGHT travel and the direction of SIGNAL travel in the retina?

A Light: photoreceptors -> ganglion cells; Signal: ganglion cells -> photoreceptors

B **Light: ganglion/bipolar layers -> photoreceptors; Signal: photoreceptors -> bipolar cells -> ganglion cells** ✓

C Light and signal both travel: photoreceptors -> optic nerve -> lens

D Light: lens -> optic nerve; Signal: retina -> cornea

E Light never reaches photoreceptors; it is detected by the iris

▶ **Explanation:** The retina is 'inverted': light passes through inner retinal layers before reaching photoreceptors at the back. The neural signal then travels forward: photoreceptors -> bipolar cells -> ganglion cells (whose axons form the optic nerve).

26 A student stares at a bright RED image for 30 seconds, then looks at a white wall and sees a greenish/cyan afterimage. The best explanation is:

A The pupil stays constricted and blocks red light only

B **Red-sensitive cones are temporarily bleached/adapted, so the balance of cone activity shifts toward other cones when viewing white** ✓

C Rods suddenly become more sensitive to red

D The optic nerve stops firing for red wavelengths permanently

E White walls emit cyan light after seeing red

▶ **Explanation:** After staring at red, the red-sensitive cones adapt/bleach and respond less. When you then look at white (which stimulates all cones), the reduced red-cone response makes the other cone signals dominate, producing a complementary afterimage. This is sensory adaptation, not a wall emitting new light.

27 **Two different light sources can look the same 'yellow' even if their wavelengths are not identical (e.g., pure yellow vs red+green mixture). What does this demonstrate about color vision?**

A Color is detected by rods only

B **Perceived color depends on the relative activation of different cone types, not a single wavelength label** ✓

C The lens converts all wavelengths into yellow

D The retina measures wavelength with a single cone type

E Yellow perception requires activation of the optic disc

▶ **Explanation:** Color perception is based on comparing activity across cone types (trichromatic coding). Different spectral mixtures can produce the same pattern of cone activation and thus the same perceived color (metamerism). Rods are not the main color detectors.

28 **Why is color vision greatly reduced at night?**

A Cones stop existing at night and regrow during the day

B **Rods dominate in dim light and provide little/no color discrimination, while cones require brighter light to be strongly activated** ✓

C Rods detect only red and green, not blue

D The pupil becomes too small at night

E The cornea blocks all wavelengths except gray

▶ **Explanation:** In low light, cones are not activated enough for strong signaling, while rods are very sensitive and dominate vision. Rods essentially provide monochrome information, so color perception decreases.

29 **Phototransduction is highly sensitive partly because it amplifies signals. Which step best represents amplification?**

A One photon directly closes exactly one channel and nothing else

B **One activated rhodopsin can activate many transducin molecules, leading to large changes in cGMP and many channels closing** ✓

C One photon physically pushes Na^+ out of the cell

D One cone cell divides into many rods when light is dim

E The iris increases sensitivity by generating neurotransmitters

▶ **Explanation:** A single activated rhodopsin can trigger activation of many transducin molecules, which activate PDE and reduce cGMP enough to close many channels - amplifying a tiny light stimulus into a measurable electrical change. The other options are not biological mechanisms.

30 **Which statement about the distribution of rods and cones in the retina is correct?**

A The fovea contains mostly rods for night vision

B The optic disc contains many cones for sharp vision

C **The fovea is cone-rich for high acuity, while peripheral retina is rod-rich for dim-light sensitivity** ✓

D Rods are found only in the optic nerve, not in the retina

E Cones are evenly distributed with the same density everywhere

▶ **Explanation:** The fovea is specialized for high-resolution, color vision and is cone-dense. Rods are more common in the peripheral retina, supporting dim-light sensitivity. The optic disc has no photoreceptors (blind spot).