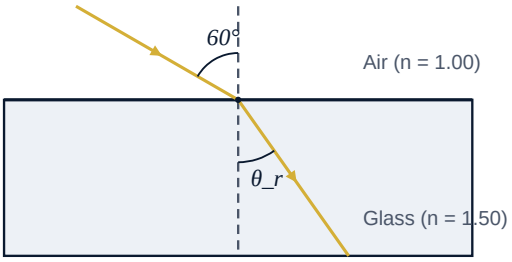
Topic: Waves & Optics (Refraction & Total Internal Reflection)

Instructions: Choose the best answer for each of the following 30 questions. Diagrams depict highly precise physical setups mapped accurately to the stated geometries. Assume ideal conditions, monochromatic light, and air to have a refractive index of strictly $n = 1.00$ unless otherwise stated.

1 A monochromatic ray of light travelling in air strikes a rectangular glass block of refractive index $n = 1.50$ at an angle of incidence of 60°. The setup is depicted below with exact geometric proportions. What is the angle of refraction θ_r inside the glass block?



A. 30.0°

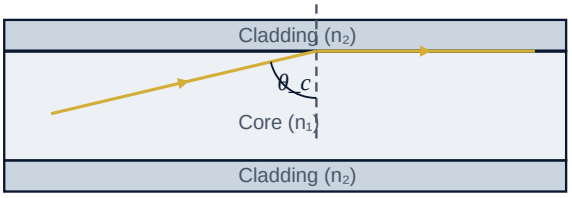
B. 35.3°

C. 41.8°

D. 45.0°

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2 The diagram below shows a step-index optical fiber. A light ray inside the core (refractive index $n_1 = 1.48$) strikes the boundary with the cladding (refractive index $n_2 = 1.44$) at the exact critical angle θ_c. What is the value of θ_c?



A. 13.3°

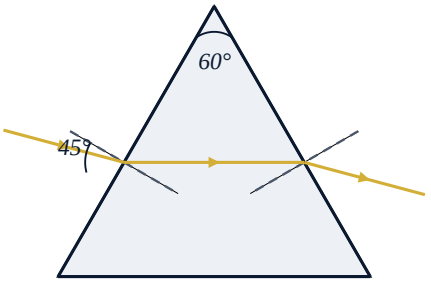
B. 76.7°

C. 79.5°

D. 82.2°

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3 A ray of monochromatic light passes through an equilateral glass prism (apex angle $A = 60^\circ$). The ray travels perfectly parallel to the base of the prism inside the glass, indicating minimum deviation. If the angle of incidence is exactly 45°, what is the refractive index n of the glass?



A. 1.33

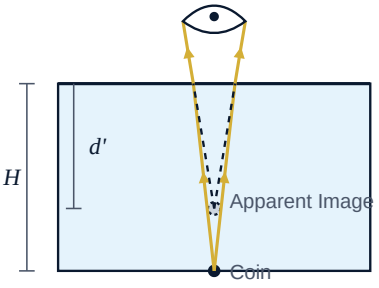
B. 1.41

C. 1.50

D. 1.73

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4 A small coin rests at the bottom of a pool of water of real depth $H = 2.0\ \text{m}$ and refractive index $n = 1.33$. An observer looks down vertically from above the surface. At what apparent depth d' does the coin appear to be?



A. $1.33\ \text{m}$

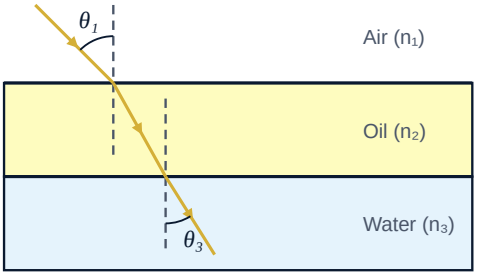
B. $1.50\ \text{m}$

C. $2.00\ \text{m}$

D. $2.66\ \text{m}$

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5 A ray of light passes through three parallel layers of transparent media. Medium 1 is air ($n_1 = 1.00$), Medium 2 is oil ($n_2 = 1.45$), and Medium 3 is water ($n_3 = 1.33$). If the angle of incidence at the first boundary is $\theta_1 = 45^\circ$, what is the final angle of refraction θ_3 as the ray enters the water?



A. 29.2°

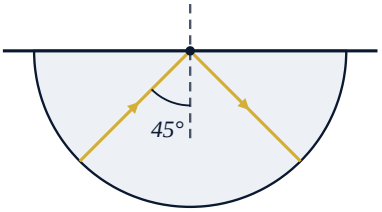
B. 32.1°

C. 45.0°

D. 48.6°

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6 A ray of light enters a semi-circular glass block of refractive index n along a radius, thus passing un-deviated into the block. It strikes the exact geometric center of the flat edge at an angle of incidence of 45° and is totally internally reflected. What is the condition for the minimum possible refractive index of this glass?



A. $n \geq 1.33$

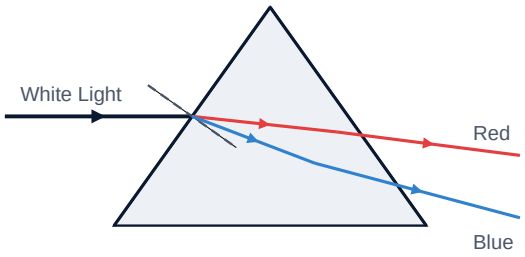
B. $n \geq 1.41$

C. $n \geq 1.50$

D. $n \geq 1.73$

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7 A narrow beam of white light is incident on a glass prism as shown. The light undergoes dispersion, splitting into a spectrum. Which physical principle fundamentally explains why the blue component of the light bends more than the red component?



A. The frequency of blue light is higher, causing it to travel faster in the glass.

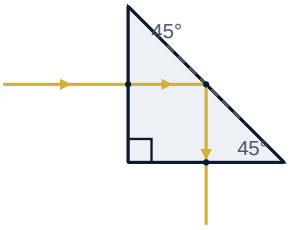
B. The refractive index of glass is marginally higher for shorter wavelengths.

C. Red light is totally internally reflected inside the prism while blue is not.

D. The wavelength of blue light increases in the glass, reducing its speed.

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8 A perfectly right-angled isosceles prism ($45^\circ - 90^\circ - 45^\circ$) is made of crown glass ($n = 1.52$). A monochromatic ray enters normal to one of the shorter faces. Which diagram accurately traces the complete path of the ray through the prism?



A. The ray passes straight through the hypotenuse un-deviated.

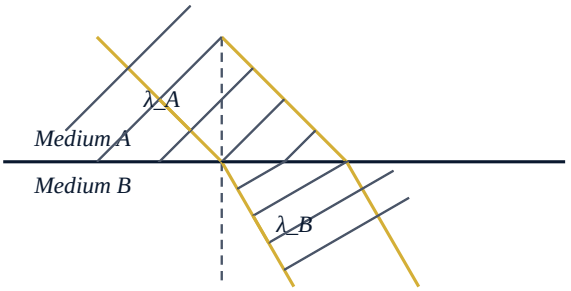
B. The ray undergoes TIR at the hypotenuse and exits normal to the second short face, deviated by 90°.

C. The ray undergoes total internal reflection twice and returns back towards the source.

D. The ray refracts out of the hypotenuse, bending away from the normal.

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9 The diagram shows successive plane wavefronts of monochromatic light passing from Medium A into Medium B. The distance between wavefronts in Medium A is λ_A and in Medium B is λ_B. If the speed of light in Medium A is v_A, what is the correct expression for the speed of light v_B in Medium B?



A. $v_B = v_A \left(\frac{\lambda_A}{\lambda_B}\right)$

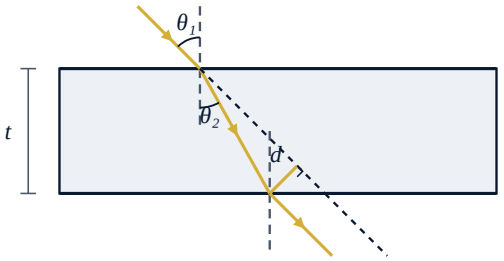
B. $v_B = v_A \left(\frac{\lambda_B}{\lambda_A}\right)$

C. $v_B = v_A \sqrt{\frac{\lambda_B}{\lambda_A}}$

D. $v_B = \frac{v_A}{2}(\lambda_A + \lambda_B)$

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10 A laser beam passes through a parallel-sided glass slab of thickness t and refractive index n, placed in air. The angle of incidence is θ_1 and the angle of refraction is θ_2. The emergent ray is mathematically parallel to the incident ray but is laterally displaced by a distance d. Which geometric formula correctly yields d?



A. $d = t\sin(\theta_1 - \theta_2)$

B. $d = t\frac{\sin(\theta_1 - \theta_2)}{\cos\theta_2}$

C. $d = t\cos(\theta_1 - \theta_2)$

D. $d = t\frac{\sin\theta_1}{\cos\theta_2}$

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11 In a step-index optical fiber, multimode dispersion (pulse broadening) occurs because light rays travelling at different angles take different paths and thus different times to travel the length of the fiber. What is the fundamental physical constraint that limits the maximum delay between the fastest (axial) and slowest (marginal) rays?

A. The wavelength of the monochromatic laser source used.

B. The critical angle between the core and the cladding.

C. The physical diameter of the fiber core.

D. The material dispersion of the glass (refractive index variation with frequency).

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12 The 'numerical aperture' (NA) of an optical fiber is a measure of its light-gathering ability. It is defined as $\mathrm{NA} = n_0 \sin\theta_{max}$, where θ_{max} is the maximum acceptance angle in the external medium (n_0). For a fiber with a core index n_1 and cladding index n_2, what is the correct expression for the Numerical Aperture?

A. $\sqrt{n_1^2 - n_2^2}$

B. $\frac{n_1}{n_2}$

C. $n_1 - n_2$

D. $\sqrt{n_1^2 + n_2^2}$

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13 The absolute refractive index of diamond is 2.42 and that of water is 1.33. A light ray travels from diamond directly into water. What is the critical angle for total internal reflection at this boundary?

A. $\sin^{-1}\left(\frac{1.33}{2.42}\right)$

B. $\sin^{-1}\left(\frac{2.42}{1.33}\right)$

C. $\sin^{-1}\left(\frac{1}{2.42}\right)$

D. Total internal reflection is impossible when moving from diamond to water.

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14 An isotropic point source of light is submerged at a depth h below the surface of a large, perfectly calm lake of refractive index n. All the light that escapes into the air does so through a circular 'window' on the surface (Snell's window). What is the area of this circular window?

A. $\pi h^2(n^2 - 1)$

B. $\frac{\pi h^2}{\sqrt{n^2-1}}$

C. $\frac{\pi h^2}{n^2-1}$

D. $\pi h^2 \sin^{-1}(1/n)$

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15 A pulse of light is sent through a vacuum, covering a distance L in time t_0. If an identical pulse is sent through a straight glass block of length L and refractive index $n = 1.50$, how much longer does it take to cover the same physical distance?

A. It takes $0.5t_0$ longer.

B. It takes $1.5t_0$ longer.

C. It takes $2.0t_0$ longer.

D. The time is identical because the speed of light is a universal constant.

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16 Which of the following wave properties strictly remains invariant when a monochromatic light ray refracts from a less dense optical medium into a more dense optical medium?

A. Wave speed

B. Wavelength

C. Frequency

D. Direction of propagation

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17 A small ink dot is placed on a piece of paper. A thick glass slab of thickness t and refractive index n is placed directly over the dot. When viewed vertically from above, the dot appears raised by a distance Δt. What is the correct expression for this apparent upward shift?

A. $\Delta t = t\left(\frac{1}{n}\right)$

B. $\Delta t = t\left(1 - \frac{1}{n}\right)$

C. $\Delta t = t(n-1)$

D. $\Delta t = \frac{t}{n-1}$

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18 Mirages, such as the appearance of 'puddles' on a hot tarmac road in summer, are an atmospheric optical phenomenon. Which physical principle primarily governs the continuous bending of light rays to form an inferior mirage?

A. The scattering of blue light by hot air molecules (Rayleigh scattering).

B. The diffraction of light around the heated tarmac particles.

C. The continuous decrease in the refractive index of air closer to the hot surface.

D. The total internal reflection of light strictly at the solid road boundary.

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19 Two transparent, immiscible liquids, A and B, are poured into a beaker. Liquid A rests on top of liquid B. The speed of light in liquid A is $2.00 \times 10^8\ \mathrm{m\ s^{-1}}$, and in liquid B is $2.25 \times 10^8\ \mathrm{m\ s^{-1}}$. If a light source is placed in liquid A, can total internal reflection occur at the boundary between A and B?

A. Yes, because liquid A has a lower refractive index than liquid B.

B. Yes, because liquid A has a higher refractive index than liquid B.

C. No, because liquid A has a lower refractive index than liquid B.

D. No, because total internal reflection only occurs at boundaries with air or vacuum.

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20 When a primary rainbow is formed by sunlight interacting with spherical water droplets in the atmosphere, what is the strict chronological sequence of optical phenomena that a single ray of sunlight undergoes to reach the observer's eye?

A. Refraction $\rightarrow$ Refraction $\rightarrow$ Total Internal Reflection

B. Reflection $\rightarrow$ Refraction $\rightarrow$ Dispersion

C. Refraction (with dispersion) $\rightarrow$ Internal Reflection $\rightarrow$ Refraction

D. Total Internal Reflection $\rightarrow$ Diffraction $\rightarrow$ Refraction

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21 A ray of light enters a solid glass sphere of refractive index $n = 1.5$ from the surrounding air. The incident ray is parallel to, but offset from, the principal diameter of the sphere. Assuming the ray does not undergo total internal reflection inside, how many times does the ray refract before entirely leaving the sphere?

A. Once

B. Twice

C. Three times

D. It never refracts, as spheres perfectly collimate light.

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22 In the phenomenon known as 'Frustrated Total Internal Reflection' (FTIR) or quantum tunneling of light, two glass prisms are placed so their hypotenuses are extremely close together, separated by a microscopic air gap of thickness d. A light ray undergoes TIR at the first prism boundary. What happens if d is made significantly smaller than the wavelength of the incident light?

A. The light strictly obeys classical ray optics and is entirely reflected.

B. The evanescent wave completely diffracts along the air gap.

C. A measurable fraction of the light's energy tunnels across the air gap and propagates into the second prism.

D. The frequency of the light shifts into the ultraviolet spectrum to cross the gap.

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23 A student shines a red laser ($\lambda_{air} = 650\ \text{nm}$) into a pool of water ($n = 1.33$). An underwater observer looks up and sees the laser beam. What color does the underwater observer perceive, and why?

A. Blue, because the wavelength decreases in water.

B. Red, because the human eye perceives color based fundamentally on the wave's frequency, which remains constant.

C. Yellow, because the decreased speed shifts the perception along the visual spectrum.

D. Invisible, because red light undergoes total internal reflection back into the air.

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24 Fermat's Principle of Least Time states that light travels between two points along the path that requires the least time. How does this principle mathematically derive Snell's Law ($n_1 \sin\theta_1 = n_2 \sin\theta_2$) for a boundary between two media?

A. By maximizing the total distance travelled in the less dense medium.

B. By equating the kinetic energy of photons in both media.

C. By finding the minimum of the time function $t(x)$ with respect to the crossing point on the boundary using differential calculus.

D. By assuming light speed is infinite and geometric straight lines are the only physically possible paths.

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25 Unpolarised light strikes a smooth glass surface ($n = 1.52$). At a specific angle of incidence known as Brewster's Angle (θ_B), the reflected ray is 100% perfectly linearly polarised. What is the geometric relationship between the reflected ray and the refracted ray at this specific incident angle?

A. They are perfectly parallel to each other.

B. They are separated by exactly 90°.

C. They both undergo total internal reflection.

D. The refracted ray ceases to exist, transferring all energy to the reflected ray.

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26 An optical fiber of length $L = 5.0\ \text{km}$ has a core refractive index $n_{core} = 1.50$ and a cladding refractive index $n_{clad} = 1.48$. Calculate the maximum theoretical time delay (pulse broadening) Δt between an axial ray travelling straight down the center and a marginal ray travelling at the critical angle. Use $c = 3.0 \times 10^8\ \text{m s}^{-1}$.

A. $3.4 \times 10^{-7}\ \text{s}$

B. $3.4 \times 10^{-6}\ \text{s}$

C. $2.5 \times 10^{-5}\ \text{s}$

D. $2.5 \times 10^{-4}\ \text{s}$

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27 Sound waves also experience refraction. The speed of sound in warm air is greater than the speed of sound in cold air. On a clear, cold night, the air near the ground is significantly colder than the air higher up (a temperature inversion). How does this affect the propagation of sound generated at ground level?

A. The sound waves bend upwards, causing sound to dissipate rapidly into the upper atmosphere.

B. The sound waves are completely absorbed by the cold ground layer.

C. The sound waves bend downwards back towards the ground, allowing sound to be heard clearly over exceptionally long distances.

D. The varying speeds cause destructive interference, resulting in an 'acoustic shadow' around the source.

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28 A rectangular glass slab of thickness t is placed in front of a converging lens. A point object is placed in front of the slab. How does the presence of the glass slab affect the physical position of the final real image formed by the lens?

A. The image shifts away from the lens.

B. The image shifts closer to the lens.

C. The image position remains completely unchanged, only its intensity decreases.

D. The image becomes virtual and inverted.

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29 Light from a star enters the Earth's atmosphere. The refractive index of the atmosphere gradually increases closer to the Earth's surface due to increasing air density. What effect does this continuous refraction have on the apparent position of a star near the horizon?

A. The star appears lower in the sky than its true geometric position.

B. The star appears higher in the sky than its true geometric position.

C. The star undergoes chromatic dispersion and appears strictly as a horizontal rainbow.

D. The apparent position is identical to the true position, but the star appears dimmer.

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30 A diver underwater shines a flashlight vertically upwards at the water-air interface. Slowly, the diver tilts the flashlight, increasing the angle of incidence until the beam entirely reflects back into the water (TIR). As the angle is increased slightly *beyond* this critical angle, what happens to the intensity of the totally internally reflected beam?

A. It continues to increase proportionally with the angle.

B. It decreases rapidly due to phase cancellation.

C. It remains constant at approximately 100% of the incident intensity (ignoring minor absorption).

D. It drops to zero, and the light transforms into an evanescent surface wave exclusively.

Answer Key

Q1: **B**	Q2: **B**	Q3: **B**	Q4: **B**	Q5: **B**
Q6: **B**	Q7: **B**	Q8: **B**	Q9: **B**	Q10: **B**
Q11: **B**	Q12: **A**	Q13: **A**	Q14: **C**	Q15: **A**
Q16: **C**	Q17: **B**	Q18: **C**	Q19: **B**	Q20: **C**
Q21: **B**	Q22: **C**	Q23: **B**	Q24: **C**	Q25: **B**
Q26: **A**	Q27: **C**	Q28: **A**	Q29: **B**	Q30: **C**