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Answer Key: Operation Fermat's Path: 12th Grade Advanced Wave Optics Quest

Evaluate non-paraxial ray behavior and thin-film interference patterns to prepare physics students for university-level electrodynamics and engineering labs.

1. An unpolarized light beam is incident on a series of two linear polarizers. If the transmission axis of the second polarizer is rotated to 60 degrees relative to the first, what fraction of the original unpolarized intensity (I_0) emerges?

Answer: A) $0.125 I_0$

According to Malus's Law, the first polarizer reduces unpolarized light to $0.5 I_0$. The second polarizer reduces it by $\cos^2(60^\circ)$, which is 0.25. Thus, $0.5 * 0.25 = 0.125$.

2. In a Michelson Interferometer, if one mirror is moved a distance of $\lambda/4$, the interference pattern will shift by exactly one full fringe.

Answer: B) False

False. Because the light travels to the mirror and back, a physical displacement of $\lambda/4$ results in a path length change of $\lambda/2$, which corresponds to a half-fringe shift (constructive to destructive).

3. A soap bubble ($n=1.33$) appears green ($\lambda=530\text{nm}$) at its thinnest point due to constructive interference. This occurs because of a _____ phase shift at the first boundary.

Answer: C) 180-degree

When light reflects off a medium with a higher refractive index (air to soap), it undergoes a 180-degree (π radians) phase shift.

4. Standard glass lenses ($n=1.5$) often suffer from chromatic aberration. Which physical property primarily accounts for this phenomenon in high-precision optical systems?

Answer: B) Optical Dispersion

Dispersion is the phenomenon where the phase velocity of a wave depends on its frequency; different wavelengths of light refract at different angles through the same glass.

5. To eliminate reflection for a specific wavelength utilizing a non-reflective coating, the thickness of the coating ($n_{\text{coat}} < n_{\text{glass}}$) should ideally be _____.

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Answer: B) $\lambda / (4n)$

To cause destructive interference for the reflected wave when there are two phase shifts, the path difference ($2t$) must equal $\lambda/2$, leading to a thickness (t) of $\lambda/4n$.

6. According to the Rayleigh Criterion, increasing the diameter of a telescope's primary mirror decreases its angular resolution.

Answer: B) False

False. The Rayleigh Criterion ($\theta = 1.22\lambda/D$) shows that as Diameter (D) increases, the minimum resolvable angle (θ) decreases, which means resolution actually improves.

7. A beam of light travels from water ($n=1.33$) toward a boundary with air ($n=1.00$). What is the critical angle for Total Internal Reflection?

Answer: B) 48.8 degrees

The critical angle is calculated as $\theta_c = \arcsin(n_2/n_1)$. Here, $\arcsin(1.00/1.33)$ is approximately 48.8 degrees.

8. In a double-slit experiment, if the distance between the two slits is halved while keeping all other variables constant, the fringe spacing on the screen will ____.

Answer: C) Double

The fringe spacing (Δy) is given by $\lambda L/d$. Since the slit separation (d) is in the denominator, halving d results in doubling the spacing Δy .

9. Which of the following conditions is required to produce a 'Gibeon' style Mirage, where distant objects appear higher than their actual position (Superior Mirage)?

Answer: A) A temperature inversion (cold air below warm air)

Superior mirages occur when the air below the line of sight is colder than the air above it (temperature inversion), causing light rays to bend down toward the denser cold air.

10. A paraxial approximation is valid only when the angle between the light ray and the principal axis is small enough that $\sin(\theta) \approx \theta$.

Answer: A) True

True. The paraxial approximation simplifies optical calculations by assuming rays stay close to the axis, allowing for the linearization of Snell's Law.

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