AQA A-Level Physics: Refraction, Diffraction & Interference – Calculation Questions

Praneel Physics

1. Calculate the refractive index of a material where light travels at 2.0×10^8 m/s. **(P)**

Working and Answer:

Use $n = \frac{c}{v}$.
$n = \frac{3.0 \times 10^8}{2.0 \times 10^8} = 1.5$.

2. Calculate the angle of refraction when light enters glass ($n = 1.5$) at an incident angle of $30°$. **(P)**

Working and Answer:

Use Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$.
$\sin\theta_2 = \frac{1 \times \sin 30°}{1.5} = 0.333 \Rightarrow \theta_2 \approx 19.5°$.

3. Calculate the critical angle for a glass-air boundary ($n_{\text{glass}} = 1.6$). **(P)**

Working and Answer:

Use $\sin\theta_c = \frac{n_2}{n_1}$.
$\theta_c = \sin^{-1}\left(\frac{1}{1.6}\right) \approx 38.7°$.

4. Calculate the wavelength of light in water ($n = 1.33$) if its wavelength in air is 600 nm. **(P)**

Working and Answer:

Use $\lambda_{\text{water}} = \frac{\lambda_{\text{air}}}{n}$.
$\lambda_{\text{water}} = \frac{600}{1.33} \approx 451\,\text{nm}$.

5. Calculate the fringe spacing in Young's double-slit experiment if $\lambda = 500\,\text{nm}$, $d = 0.5\,\text{mm}$, and $D = 2\,\text{m}$. **(P)**

Working and Answer:

Use $\Delta x = \frac{\lambda D}{d}$.
$\Delta x = \frac{500\times10^{-9}\times2}{0.5\times10^{-3}} = 2\times10^{-3}\,\text{m} = 2\,\text{mm}$.

6. Calculate the speed of light and wavelength in a medium with refractive index 1.8 for light of frequency 5.0×10^{14} Hz. **(PP)**

Working and Answer:

Step 1: $v = \frac{c}{n} = \frac{3.0\times10^8}{1.8} \approx 1.67 \times 10^8\,\text{m/s}$.
Step 2: $\lambda_{\text{medium}} = \frac{v}{f} = \frac{1.67\times10^8}{5.0\times10^{14}} \approx 334\,\text{nm}$.

7. Calculate the angle of refraction and critical angle for light entering diamond ($n = 2.4$) from air at 20°. **(PP)**

Working and Answer:

Step 1: $\sin\theta_2 = \frac{\sin 20°}{2.4} \approx 0.142 \Rightarrow \theta_2 \approx 8.2°$.
Step 2: $\theta_c = \sin^{-1}\left(\frac{1}{2.4}\right) \approx 24.6°$.

8. Calculate the fringe spacing and position of the 3rd bright fringe in Young's experiment ($\lambda = 600\,\text{nm}$, $d = 0.4\,\text{mm}$, $D = 1.5\,\text{m}$). **(PP)**

Working and Answer:

Step 1: $\Delta x = \frac{600\times10^{-9}\times1.5}{0.4\times10^{-3}} = 2.25\,\text{mm}$.
Step 2: $y_3 = 3\Delta x = 6.75\,\text{mm}$.

9. Calculate the refractive index and speed of light in a medium where the critical angle is $40°$. **(PP)**

Working and Answer:

Step 1: $n = \frac{1}{\sin 40°} \approx 1.56$.
Step 2: $v = \frac{c}{n} \approx 1.92 \times 10^8\,\text{m/s}$.

10. Calculate the path difference and phase difference (in radians) for two waves with a wavelength of 500 nm if one travels 1.25 μm further. **(PP)**

Working and Answer:

Step 1: Path difference $= 1.25\,\mu\text{m} = 1250\,\text{nm}$.
Step 2: $\Delta\phi = \frac{2\pi\times1250}{500} = 5\pi\,\text{rad}$.

11. Calculate the refractive index, speed of light, and critical angle for a medium where light of wavelength 450 nm in air has a wavelength of 300 nm in the medium. **(PPP)**

Working and Answer:

Step 1: $n = \frac{\lambda_{\text{air}}}{\lambda_{\text{medium}}} = \frac{450}{300} = 1.5$.
Step 2: $v = \frac{c}{n} = 2.0 \times 10^8\,\text{m/s}$.
Step 3: $\theta_c = \sin^{-1}\left(\frac{1}{1.5}\right) \approx 41.8^\circ$.

12. Calculate the slit separation, fringe spacing, and angle to the 2nd dark fringe in Young's experiment ($\lambda = 550\,\text{nm}$, $\Delta x = 2.2\,\text{mm}$, $D = 2\,\text{m}$). **(PPP)**

Working and Answer:

Step 1: $d = \frac{\lambda D}{\Delta x} = \frac{550\times10^{-9}\times2}{2.2\times10^{-3}} = 0.5\,\text{mm}$.
Step 2: $\Delta x = 2.2\,\text{mm}$ (given).
Step 3: For dark fringes, $y = (m + \frac{1}{2})\frac{\lambda D}{d}$. For $m = 1$,
$\theta \approx \tan^{-1}\left(\frac{1.5\times2.2\times10^{-3}}{2}\right) \approx 0.094°$.

13. Calculate the wavelength, angle of deviation, and frequency of light refracted through a $60°$ prism ($n = 1.5$) if the incident angle is $45°$. **(PPP)**

Working and Answer:

Step 1: Use Snell's Law twice. First refraction:
$\sin\theta_2 = \frac{\sin 45°}{1.5} \approx 0.471 \Rightarrow \theta_2 \approx 28.1°$.
Step 2: Inside prism, angle to second face: $60° - 28.1° = 31.9°$. Second refraction: $\sin\theta_4 = 1.5 \times \sin 31.9° \approx 0.793 \Rightarrow \theta_4 \approx 52.5°$.
Step 3: Deviation $\delta = 45° + 52.5° - 60° = 37.5°$. Frequency remains unchanged.

14. Calculate the number of slits per mm, angular position of the 1st order, and resolving power for a diffraction grating ($\lambda = 589\,\text{nm}$, 2nd order at $20°$). **(PPP)**

Working and Answer:

Step 1: $d\sin\theta = m\lambda \Rightarrow d = \frac{2\times589\times10^{-9}}{\sin 20°} \approx 3.44\times10^{-6}\,\text{m}$. Slits per mm $= \frac{1}{d} \approx 290$.

Step 2: 1st order: $\theta_1 = \sin^{-1}\left(\frac{589\times10^{-9}}{3.44\times10^{-6}}\right) \approx 9.8°$.

Step 3: Resolving power $R = mN$. Assume $N = 10^4$, $R = 2\times10^4$.

15. Calculate the thickness of a soap film ($n = 1.33$) that gives constructive interference for $\lambda = 600\,\text{nm}$ at normal incidence. **(PPP)**

Working and Answer:

Step 1: For constructive interference, $2nt = (m + \frac{1}{2})\lambda$. For $m = 0$:
Step 2: $t = \frac{\lambda}{4n} = \frac{600\times10^{-9}}{4\times1.33} \approx 113\,\text{nm}$.

16. Calculate the refractive index, critical angle, minimum thickness for antireflection coating ($n = 1.38$) for $\lambda = 550\,\text{nm}$, and Brewster's angle for air-glass ($n = 1.5$). **(PPPP)**

Working and Answer:

Step 1: Assume n is given as 1.5 for glass. $\theta_c = \sin^{-1}\left(\frac{1}{1.5}\right) \approx 41.8°$.
Step 2: Antireflection: $t = \frac{\lambda}{4n} = \frac{550}{4\times1.38} \approx 99.6\,\text{nm}$.
Step 3: Brewster's angle: $\theta_B = \tan^{-1}(1.5) \approx 56.3°$.

17. Calculate the slit width, angular width of central maximum, and intensity ratio at $\theta = 5°$ for a single slit ($\lambda = 500\,\text{nm}$, central max width $= 2°$). **(PPPP)**

Working and Answer:

Step 1: $a \sin\theta = \lambda \Rightarrow a = \frac{500\times10^{-9}}{\sin 1°} \approx 28.6\,\mu\text{m}$.
Step 2: Angular width $= 2°$ (given).
Step 3: Intensity ratio: $I = I_0\left(\frac{\sin\beta}{\beta}\right)^2$, $\beta = \frac{\pi a \sin 5°}{\lambda} \approx 0.156$. $I \approx 0.99 I_0$.

18. Calculate the grating spacing, number of slits, and resolving power to distinguish $\lambda =$ 589.0 nm and 589.6 nm in 2nd order. **(PPPP)**

Working and Answer:

Step 1: Assume $\theta = 20°$: $d = \frac{2\times589\times10^{-9}}{\sin 20°} \approx 3.44 \times 10^{-6}$ m.
Step 2: Resolving power $R = \frac{\lambda}{\Delta\lambda} = \frac{589.3}{0.6} \approx 982$.
Step 3: $R = mN \Rightarrow N = \frac{982}{2} = 491$ slits.

19. Calculate the path difference, phase difference, and intensity ratio for two coherent sources (I_0) with a path difference of 1.25λ. **(PPPP)**

Working and Answer:

Step 1: Path difference $= 1.25\lambda$.
Step 2: $\Delta\phi = \frac{2\pi\times 1.25\lambda}{\lambda} = 2.5\pi\,\text{rad}$.
Step 3: Intensity $I = 4I_0\cos^2\left(\frac{2.5\pi}{2}\right) = 4I_0\cos^2(2.25\pi) = 2I_0$.

20. Calculate the refractive index, angle of minimum deviation, and wavelength in a prism ($A = 60^\circ$, $\delta_{\min} = 40^\circ$, $\lambda_{\text{air}} = 600\,\text{nm}$). **(PPPP)**

Working and Answer:

Step 1: $n = \frac{\sin\left(\frac{A+\delta_{\min}}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin 50^\circ}{\sin 30^\circ} \approx 1.53.$
Step 2: $\delta_{\min} = 40^\circ$ (given).
Step 3: $\lambda_{\text{prism}} = \frac{600}{1.53} \approx 392\,\text{nm}.$

21. Calculate the thickness of a Michelson interferometer mirror movement for 200 fringes ($\lambda = 633\,\text{nm}$), refractive index of inserted glass ($n = 1.5$), and new number of fringes. **(PPPPP)**

Working and Answer:

Step 1: $d = \frac{m\lambda}{2} = \frac{200\times633\times10^{-9}}{2} = 63.3\,\mu\text{m}$.
Step 2: Optical path difference: $2(n-1)t = m\lambda$. For $t = 63.3\,\mu\text{m}$:
Step 3: $m = \frac{2(1.5-1)\times63.3\times10^{-6}}{633\times10^{-9}} \approx 100$ fringes.

22. Calculate the grating spacing, angular positions of 1st and 2nd orders, resolving power, and wavelength difference resolvable ($N = 5000$, $\lambda = 500\,\text{nm}$, $\theta_2 = 30°$). **(PPPPP)**

Working and Answer:

Step 1: $d = \frac{2\times500\times10^{-9}}{\sin 30°} = 2.0 \times 10^{-6}\,\text{m}$.
Step 2: 1st order: $\theta_1 = \sin^{-1}\left(\frac{500\times10^{-9}}{2.0\times10^{-6}}\right) \approx 14.5°$.
Step 3: Resolving power $R = mN = 2 \times 5000 = 10,000$.
Step 4: $\Delta\lambda = \frac{\lambda}{R} = 0.05\,\text{nm}$.

23. Calculate the refractive index, critical angle, Brewster's angle, thickness for constructive interference in a soap film ($n = 1.33$, $\lambda = 600\,\text{nm}$), and path difference. **(PPPPP)**

Working and Answer:

Step 1: $n = 1.33$ (given). $\theta_c = \sin^{-1}\left(\frac{1}{1.33}\right) \approx 48.8°$.
Step 2: Brewster's angle: $\theta_B = \tan^{-1}(1.33) \approx 53.1°$.
Step 3: Constructive interference: $2nt = \frac{\lambda}{2} \Rightarrow t = \frac{600}{4\times1.33} \approx 113\,\text{nm}$.
Step 4: Path difference $= 2nt = 300\,\text{nm}$.

24. Calculate the slit width, central maximum width, intensity at $\theta = 2°$, and angular position of 1st minimum for a single slit ($\lambda = 450\,\text{nm}$, screen distance $= 1.5\,\text{m}$). **(PPPPP)**

Working and Answer:

Step 1: $a \sin\theta = \lambda \Rightarrow a = \frac{450\times10^{-9}}{\sin\theta_{\text{min}}}$. For $\theta_{\text{min}} \approx \frac{\lambda}{a}$, assume $a = 0.02\,\text{mm}$:
Step 2: Central max width $= 2\theta_{\text{min}} = 2 \times \sin^{-1}\left(\frac{450\times10^{-9}}{0.02\times10^{-3}}\right) \approx 2.58°$.
Step 3: Intensity at 2°: $\beta = \frac{\pi a \sin 2°}{\lambda} \approx 0.244$, $I \approx 0.97 I_0$.

25. Calculate the prism angle, minimum deviation, refractive index, wavelength in prism, and dispersive power ($n_{\text{red}} = 1.48$, $n_{\text{blue}} = 1.52$, $\delta_{\text{min}} = 35°$). **(PPPPP)**

Working and Answer:

Step 1: Assume $A = 60°$. $n = \frac{\sin\left(\frac{60°+35°}{2}\right)}{\sin 30°} \approx 1.51$.
Step 2: $\delta_{\text{min}} = 35°$ (given).
Step 3: Dispersive power $= \frac{n_{\text{blue}} - n_{\text{red}}}{n_{\text{avg}}} = \frac{0.04}{1.50} \approx 0.0267$.