Higher Physics
Unit 2: Particles & Waves
Refraction of Light

Refraction

1.a. $n_p = \frac{\sin \theta_a}{\sin \theta_p}$ $\quad \theta_a = 45°$, $n_p = 1.5$

$$1.5 = \frac{\sin 45}{\sin \theta_p}$$

$$\sin \theta_p = \frac{\sin 45}{1.5}$$

$$\theta_p = \sin^{-1}\left(\frac{\sqrt{2}}{3}\right)$$

$$\theta_p = 28°$$

b. $n_p = \frac{\sin \theta_a}{\sin \theta_p}$ $\quad \theta_a = 30°$, $n_p = 1.5$

$$1.5 = \frac{\sin 30}{\sin \theta_p}$$

$$\sin \theta_p = \frac{\sin 30}{1.5}$$

$$\theta_p = \sin^{-1}\left(\frac{1}{3}\right)$$

$$\theta_p = 19.5° = 20°$$

c. $n_p = \frac{\sin \theta_a}{\sin \theta_p}$ $\quad \theta_a = 10°$, $n_p = 1.5$

$$1.5 = \frac{\sin 10}{\sin \theta_p}$$

$$\sin \theta_p = \frac{\sin 10}{1.5}$$

$\theta_p = \sin^{-1}(0.116)$

$\underline{\theta_p = 6.7^\circ = 7^\circ}$

2. A: $n_A = \frac{\sin\theta_a}{\sin\theta_A}$ $\theta_a = 55^\circ$, $\theta_A = 40^\circ$

$n_A = \frac{\sin 55}{\sin 40}$

$\underline{n_A = 1.27}$

B: $n_B = \frac{\sin\theta_a}{\sin\theta_B}$ $\theta_a = 75^\circ$, $\theta_B = 45^\circ$

$n_B = \frac{\sin 75}{\sin 45}$

$\underline{n_B = 1.37}$

C: $n_c = \frac{\sin\theta_a}{\sin\theta_c}$ $\theta_a = 50^\circ$, $\theta_c = 30^\circ$

$n_c = \frac{\sin 50}{\sin 30}$

$\underline{n_c = 1.5}$

3. a. $n_w = \frac{\sin\theta_a}{\sin\theta_w}$ $n_w = 1.33$, $\theta_a = 45^\circ$

$1.33 = \frac{\sin 45}{\sin\theta_w}$

$\sin\theta_w = \frac{\sin 45}{1.33}$

$\theta_w = \sin^{-1}(0.532)$

$\underline{\theta_w = 32^\circ}$

b. $n_i = \frac{\sin \theta a}{\sin \theta i}$

$\theta i = 30°$

$n_i = 1.31$

$1.31 = \frac{\sin \theta a}{\sin 30}$

$\sin \theta a = 1.31 \times \sin 30$

$\theta a = \sin^{-1}(0.655)$

$\underline{\theta a = 41°}$

c. $n_d = \frac{\sin \theta a}{\sin \theta d}$

$\theta d = 20°$

$n_d = 2.42$

$2.42 = \frac{\sin \theta a}{\sin 20}$

$\sin \theta a = 2.42 \times \sin 20$

$\theta a = \sin^{-1}(0.828)$

$\underline{\theta a = 56°}$

4. $n_d = \frac{\sin \theta a}{\sin \theta d}$

$n_d = 2.4$

$\theta a = 40°$

$2.4 = \frac{\sin 40}{\sin \theta d}$

$\sin \theta d = \frac{\sin 40}{2.4}$

$\theta d = \sin^{-1}(0.268)$

$\underline{\theta d = 16°}$

5. $n_g = \frac{\sin \theta a}{\sin \theta g}$

$\theta a = 50°$

$\theta g = 42.5°$

$n_g = \frac{\sin 50}{\sin 42.5}$

$\underline{n_g = 1.13}$

6. a. $n_b = \frac{\sin \theta_a}{\sin \theta_b}$ $\theta_a = 53°$, $\theta_b = 30°$

$n_b = \frac{\sin 53}{\sin 30}$

$n_b = 1.60$

b. $n_b = \frac{\sin \theta_a}{\sin \theta_b}$ $\theta_a = 55°$, $\theta_b = 45°$

$n_b = \frac{\sin 55}{\sin 45}$

$n_b = 1.16$

7. $n_m = \frac{\sin \theta_a}{\sin \theta_m}$ $n_m = 1.35$, $\theta_m = 30°$

$1.35 = \frac{\sin \theta_a}{\sin 30}$

$\sin \theta_a = 1.35 \times \sin 30$

$\theta_a = \sin^{-1}(0.675)$

$\theta_a = 42.5° = 43°$

The ray of light emerges from the material at an angle of 43°.

8. a. Glass has a range of possible values for the refractive index because there are different grades of glass (purity).

b. $n_w = \frac{\sin \theta_a}{\sin \theta_w}$ $n_w = 1.33$, $n_i = 1.31$, $\theta_a = 30°$

$1.33 = \frac{\sin 30}{\sin \theta_w}$

$\sin \theta_w = \frac{\sin 30}{1.33}$

8.b. $\theta_w = \sin^{-1}(0.376)$

$\theta_w = 22°$

$$n_i = \frac{\sin \theta a}{\sin \theta i}$$

$$1.31 = \frac{\sin 30}{\sin \theta i}$$

$$\sin \theta i = \frac{\sin 30}{1.31}$$

$$\theta i = \sin^{-1}(0.382)$$

$\theta i = 22°$

c. $$n_d = \frac{\sin \theta a}{\sin \theta d}$$

$\theta d = 15°$

$n_d = 2.42$

$$2.42 = \frac{\sin \theta a}{\sin 15}$$

$$\sin \theta a = 2.42 \times \sin 15$$

$$\theta a = \sin^{-1}(0.626)$$

$\theta a = 39°$

d. A spectrum is produced when white light passes through a prism of crown glass because the different colours are refracted by different amounts by the glass of the prism. Violet light is refracted most by a prism and red light is refracted least.

9. $$\frac{V_1}{V_2} = \frac{n_2}{n_1}$$

$\lambda_1 = 700nm = 700 \times 10^{-9} m$

$n_2 = 1.52$

$v_1 = 3 \times 10^8 m/s$

$n_1 = 1$

$$\frac{3 \times 10^8}{V_2} = \frac{1.52}{1}$$

$$V_2 = \frac{3 \times 10^8}{1.52}$$

$V_2 = \underline{1.974 \times 10^8 \text{ m/s}}$

$$\frac{V_1}{V_2} = \frac{\lambda_1}{\lambda_2}$$

$$\frac{3\times10^8}{1.974\times10^8} = \frac{700\times10^{-9}}{\lambda_2}$$

$$\lambda_2 = \frac{700\times10^{-9} \times 1.974\times10^8}{3\times10^8}$$

$$\lambda_2 = \underline{4.606 \times 10^{-7} \text{ m}}$$

$$V_2 = f_2 \lambda_2$$

$$1.974\times10^8 = f_2 \times 4.606\times10^{-7}$$

$$f_2 = \frac{1.974\times10^8}{4.606\times10^{-7}}$$

$$f_2 = \underline{4.286\times10^{14} \text{ Hz}}$$

10.

$$\frac{V_1}{V_2} = \frac{n_2}{n_1}$$

$$\frac{3\times10^8}{1.24\times10^8} = \frac{n_2}{1}$$

$$n_2 = \underline{2.42}$$

$V_2 = 1.24\times10^8 \text{ m/s}$
$V_1 = 3\times10^8 \text{ m/s}$
$n_1 = 1$
$n_2 = ?$

11. a.

$$n_g = \frac{\sin\theta_a}{\sin\theta_g}$$

$$1.45 = \frac{\sin 50}{\sin\theta_g}$$

$$\sin\theta_g = \frac{\sin 50}{1.45}$$

$$\theta_g = \sin^{-1}(0.528)$$

$$\theta_g = \underline{32^\circ}$$

$n_g = 1.45$
$\theta_a = 50$
$\theta_g = ?$

11.b. $\frac{v_1}{v_2} = \frac{n_2}{n_1}$

$\frac{3\times10^8}{v_2} = \frac{1.45}{1}$

$v_2 = \frac{3\times10^8}{1.45}$

$v_2 = 2.069\times10^8 \text{ m/s}$

$\lambda_1 = 600\text{nm} = 600\times10^{-9}\text{m}$

$v_1 = 3\times10^8 \text{ m/s}$

$v_2 = ?$

$n_2 = 1.45$

$n_1 = 1$

c. $\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

$\frac{3\times10^8}{2.069\times10^8} = \frac{600\times10^{-9}}{\lambda_2}$

$\lambda_2 = \frac{600\times10^{-9}\times2.069\times10^8}{3\times10^8}$

$\lambda_2 = 4.138\times10^{-7}\text{m}$

$v_1 = 3\times10^8 \text{ m/s}$

$v_2 = 2.069\times10^8 \text{ m/s}$

$\lambda_1 = 600\times10^{-9}\text{m}$

$\lambda_2 = ?$

d. $v_2 = f_2\lambda_2$

$2.069\times10^8 = f_2 \times 4.138\times10^{-7}$

$f_2 = \frac{2.069\times10^8}{4.138\times10^{-7}}$

$f = 5\times10^{14}\text{Hz}$

e. The frequency of the light in air is the same as it was in the glass, 5×10^{14}Hz.

The frequency must remain unchanged otherwise it would no longer be the same wave.

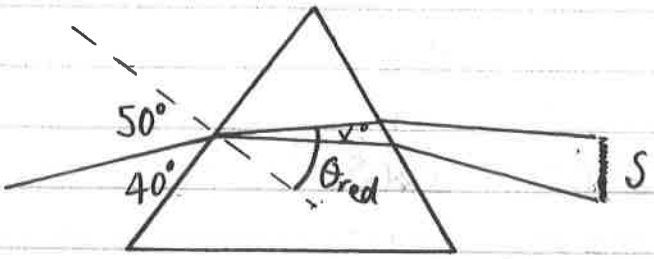
frequency in air = frequency in glass.

$v_1 = f_1\lambda_1$

$3\times10^8 = f_1 \times 600\times10^{-9}$

$f_1 = \frac{3\times10^8}{600\times10^{-9}} = 5\times10^{14}\text{Hz}$

12.



$x° = 0.7°$

$\theta_{blue} = \theta_{red} - x°$

$= 30.5 - 0.7$

$= 29.8°$

$n_{red} = \frac{\sin \theta a}{\sin \theta_{red}}$

$1.51 = \frac{\sin 50}{\sin \theta_{red}}$

$\sin \theta_{red} = \frac{\sin 50}{1.51}$

$\theta_{red} = \sin^{-1}(0.507)$

$\theta_{red} = 30.5°$

$n_{red} = 1.51$

$\theta a = 50°$

$\theta_{red} = ?$

$n_{blue} = \frac{\sin \theta a}{\sin \theta_{blue}}$

$n_{blue} = \frac{\sin 50}{\sin 29.8}$

$n_{blue} = 1.52$

13. $\frac{V_1}{V_2} = \frac{n_2}{n_1}$

$\frac{3 \times 10^8}{V_2} = \frac{1.33}{1}$

$V_2 = \frac{3 \times 10^8}{1.33}$

$V_2 = 2.256 \times 10^8 \text{ m/s}$

$f_1 = 6 \times 10^{14} Hz$

$n_2 = 1.33$

$V_1 = 3 \times 10^8 \text{ m/s}$

$n_1 = 1$

$V = f\lambda$

$3 \times 10^8 = 6 \times 10^{14} \times \lambda_1$

$\lambda_1 = \frac{3 \times 10^8}{6 \times 10^{14}}$

$\lambda_1 = 5 \times 10^{-7} m$

$\frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$

$\lambda_2 = \frac{\lambda_1 \times n_1}{n_2}$

$\lambda_2 = \frac{5 \times 10^{-7} \times 1}{1.33}$

13. $\lambda_2 = 3.759 \times 10^{-7}\ m$

Frequency in air = frequency in water
$= 6 \times 10^{14}\ Hz$

Critical Angle

14. ICE $\quad n = \frac{1}{\sin\theta_c} \qquad n = 1.31$

$$1.31 = \frac{1}{\sin\theta_c}$$

$$\sin\theta_c = \frac{1}{1.31}$$

$$\theta_c = \sin^{-1}\left(\frac{1}{1.31}\right)$$

$$\theta_c = 50^\circ$$

GLASS $\quad n = \frac{1}{\sin\theta_c} \qquad n = 1.54$

$$1.54 = \frac{1}{\sin\theta_c}$$

$$\sin\theta_c = \frac{1}{1.54}$$

$$\theta_c = \sin^{-1}\left(\frac{1}{1.54}\right)$$

$$\theta_c = 40.5^\circ$$

$$\theta_c = 41^\circ$$

PERSPEX $\quad n = \frac{1}{\sin\theta_c} \qquad n = 1.50$

$$1.50 = \frac{1}{\sin\theta_c}$$

$$\sin\theta_c = \frac{1}{1.50}$$

$\theta c = \sin^{-1}\left(\frac{1}{1.50}\right)$

$\theta c = 41.8° = 42°$

DIAMOND $n = \frac{1}{\sin\theta c}$ $n = 2.42$

$2.42 = \frac{1}{\sin\theta c}$

$\sin\theta c = \frac{1}{2.42}$

$\theta c = \sin^{-1}\left(\frac{1}{2.42}\right)$

$\theta c = 24.4° = 24°$

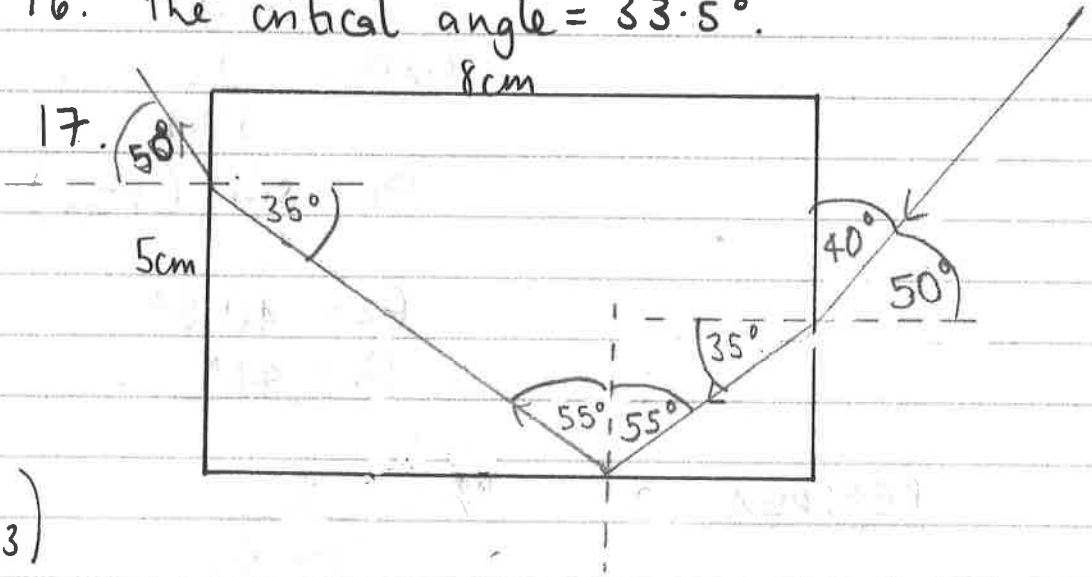
15. $n = \frac{1}{\sin\theta c}$ $\theta c = 43.9°$

$n = \frac{1}{\sin 43.9}$

$n = 1.44$

16. The critical angle = 33.5°.

17.



$n = \frac{1}{\sin\theta c}$

$1.33 = \frac{1}{\sin\theta c}$

$\theta c = \sin^{-1}\left(\frac{1}{1.33}\right)$

$\theta c = 48.8°$

$\theta c = 49°$

$n_b = \frac{\sin\theta a}{\sin\theta b}$

$1.33 = \frac{\sin 50}{\sin\theta b}$

$\theta a = 50°$

$n_b = 1.33$

17. $\sin\theta_b = \frac{\sin 60}{1.33}$

$\theta_b = \sin^{-1}(0.516)$

$\theta_b = 35.2°$

$= \underline{35°}$

18. a. The ray does not change direction on entering the glass prism because the ray of light strikes the surface of the prism at an angle of 90°. Refraction still occurs.

b. Angle X = 45°.

c. $n = \frac{1}{\sin\theta c}$ $n = 1.52$

$1.52 = \frac{1}{\sin\theta c}$

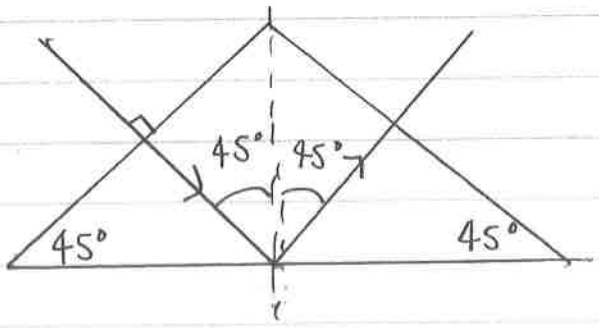
$\sin\theta c = \frac{1}{1.52}$

$\theta c = \sin^{-1}(\frac{1}{1.52})$

$\underline{\theta c = 41°}$

$\underline{X > \theta c = \text{total internal reflection.}}$

d.



e. $n = \frac{1}{\sin\theta c}$ $n = 1.30$

$1.30 = \frac{1}{\sin\theta c}$

$$\sin \theta_c = \frac{1}{1.30}$$

$$\theta_c = \sin^{-1}\left(\frac{1}{1.30}\right)$$

$$\theta_c = \underline{50.3^\circ}$$

<u>This time:</u> $x < \theta_c$ = refraction & weak, partially reflected ray.