Chapter 24 & 26

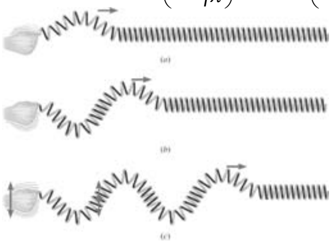
Electromagnetic Waves & Wave Properties

16.1 The Nature of Waves

1. A wave is a traveling disturbance.
2. A wave carries energy from place to place.

Waves travel to the right $y = A\sin 2\pi f\left(t - \frac{x}{f\lambda}\right) = A\sin\omega\left(t - \frac{x}{f\lambda}\right)$

Waves travel to the left $y = A\sin 2\pi f\left(t + \frac{x}{f\lambda}\right) = A\sin\omega\left(t + \frac{x}{f\lambda}\right)$



16.2 Periodic Waves

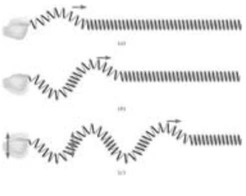
Mathematical description of a traveling wave

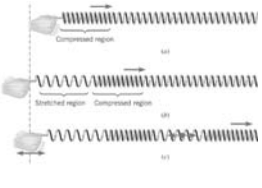
$$y = A\sin\omega\left(t \mp \frac{x}{f\lambda}\right) = A\sin\omega\left(t \mp \frac{x}{v}\right)$$

Where v is the wave speed $v = f\lambda$

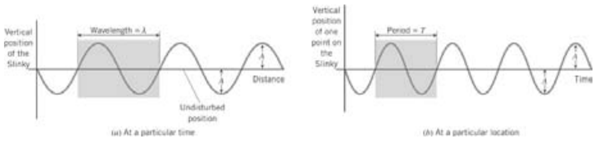
Transverse wave
Disturbance vertical direction
Wave move right or left

Longitudinal wave
Disturbance & wave move in the same direction





16.2 Periodic Waves



In the drawing, one ***cycle*** is shaded in color.

The ***amplitude*** A is the maximum vertical displacement from the particles undisturbed position.

The ***wavelength*** is the horizontal length of one cycle of the wave..

The ***period*** is the time taken for one complete cycle.

The ***frequency*** is the number of cycles in a second in units of Hz, or s-1

$$f = \frac{1}{T}$$

16.2 Periodic Waves

Example 1 **The Wavelengths of Radio Waves**

AM and FM radio waves are transverse waves consisting of electric and magnetic field disturbances traveling at a speed of $3.00\text{x}10^8$m/s. A station broadcasts AM radio waves whose frequency is $1230\text{x}10^3$Hz and an FM radio wave whose frequency is $91.9\text{x}10^6$Hz. Find the distance between adjacent crests in each wave.

$$v = \frac{\lambda}{T} = f\lambda \quad \Rightarrow \quad \lambda = \frac{v}{f}$$

AM $\lambda = \frac{v}{f} = \frac{3.00\times10^8\ \text{m/s}}{1230\times10^3\ \text{Hz}} = 244\ \text{m}$

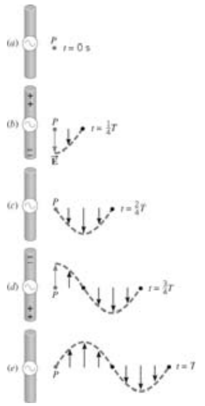
FM $\lambda = \frac{v}{f} = \frac{3.00\times10^8\ \text{m/s}}{91.9\times10^6\ \text{Hz}} = 3.26\ \text{m}$

24.2 The Electromagnetic Spectrum

Conceptual Example 2 **The Diffraction of AM and FM Radio Waves**

Diffraction is the ability of a wave to bend around an obstacle or the edges of an opening. Would you expect AM or FM radio waves to bend more readily around an obstacle such as a building?

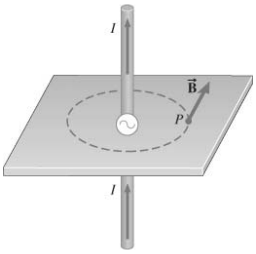
24.1 The Nature of Electromagnetic Waves



Two straight wires connected to the terminals of an AC generator can create an ***electromagnetic wave***.

Only the electric wave traveling to the right is shown here.

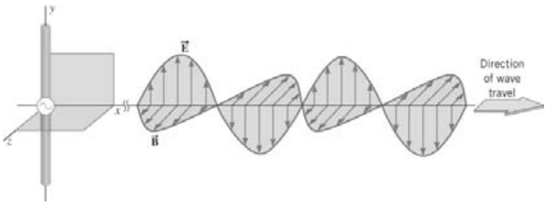
24.1 The Nature of Electromagnetic Waves



The current used to generate the electric wave creates a magnetic field.

24.1 The Nature of Electromagnetic Waves

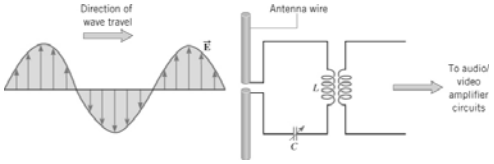
This picture shows the wave of the radiation field far from the antenna.



The speed of an electromagnetic wave in a vacuum is:

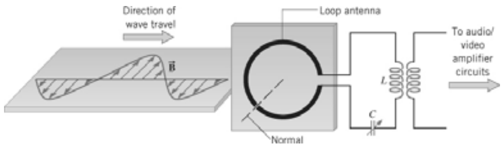
$$c = 3.00 \times 10^8 \text{ m/s}$$

24.1 The Nature of Electromagnetic Waves



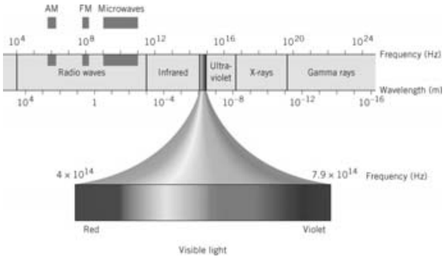
A radio wave can be detected with a receiving antenna wire that is parallel to the electric field.

24.1 The Nature of Electromagnetic Waves



With a receiving antenna in the form of a loop, the magnetic field of a radio wave can be detected.

24.2 The Electromagnetic Spectrum



Like all waves, electromagnetic waves in vaccum have a wavelength and frequency, related by:

$$c = f\lambda = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

In other medium, the speed *v* is less than in vacuum. (*v* < c), but the frequency remains the same

$$v = f\lambda$$

24.2 The Electromagnetic Spectrum

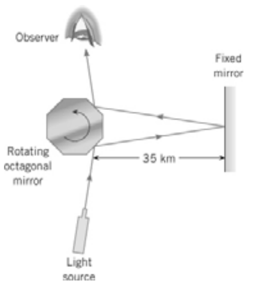
Example 1 **The Wavelength of Visible Light**

Find the range in wavelengths for visible light in the frequency range between 4.0x10^{14}Hz and 7.9x10^{14}Hz.

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \mathrm{m/s}}{4.0\times10^{14}\ \mathrm{Hz}} = 7.5\times10^{-7}\ \mathrm{m} = 750\ \mathrm{nm}$$

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \mathrm{m/s}}{7.9\times10^{14}\ \mathrm{Hz}} = 3.8\times10^{-7}\ \mathrm{m} = 380\ \mathrm{nm}$$

24.3 The Speed of Light



The speed of light in a vacuum

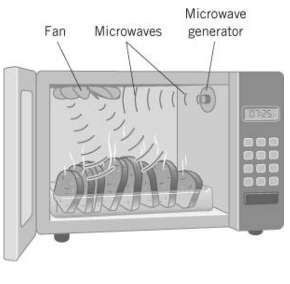
$$c = 299\,792\,458\ \mathrm{m/s}$$

Maxwell's prediction of the speed of light

$$c = \frac{1}{\sqrt{\varepsilon_o\mu_o}} = \frac{1}{\sqrt{\left(8.85\times10^{-12}\ \mathrm{C^2/\left(N\cdot m^2\right)}\right)\left(4\pi\times10^{-7}\ \mathrm{T\cdot m/A}\right)}} = 3.00\times10^{8}\ \mathrm{m/s}$$

24.4 The Energy Carried by Electromagnetic Waves

Electromagnetic waves, like water waves, carry energy.



24.4 The Energy Carried by Electromagnetic Waves

The total energy density carried by an electromagnetic wave

$$u = \frac{\text{Total energy}}{\text{Volume}} = u_E + u_B = \frac{1}{2}\varepsilon_o E^2 + \frac{1}{2\mu_o}B^2$$

But $u_E = u_B$; $\frac{1}{2}\varepsilon_o E^2 = \frac{1}{2\mu_o}B^2$

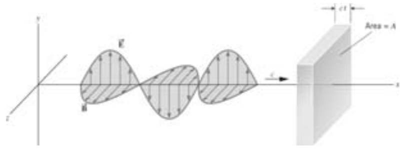
So, total u is; $u = \frac{1}{2}\varepsilon_o E^2 + \frac{1}{2}\varepsilon_o E^2 = \varepsilon_o E^2 = \frac{1}{\mu_o}B^2$

Hence $E^2 = \frac{1}{\varepsilon_o\mu_o}B^2 = c^2B^2$ ***or*** $E = cB$

So $c = \frac{E}{B} = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = 3\times10^{8}\ m/s$

Since E & B are sinusoidal $E_{rms} = \frac{E_0}{\sqrt{2}}$ $B_{rms} = \frac{B_0}{\sqrt{2}}$

24.4 The Energy Carried by Electromagnetic Waves



$$S = \frac{P}{A} = \frac{\text{Total energy}}{t\,A} = \frac{uctA}{tA} = cu$$

Chapter 26

Index of Refraction

26.1 The Index of Refraction

Light travels through a vacuum at a speed $c = 3.00 \times 10^{8}\ \mathrm{m/s}$

Light travels through materials at a speed less than its speed in a vacuum.

DEFINITION OF THE INDEX OF REFRACTION

The index of refraction of a material is the ratio of the speed of light in a vacuum to the speed of light in the material:

$$n = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in the material}} = \frac{c}{v}$$

$$c = f\lambda = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

In other medium, the speed v is less than in vacuum. (v < c), but the frequency remains the same

$$v = f\lambda$$

26.1 The Index of Refraction

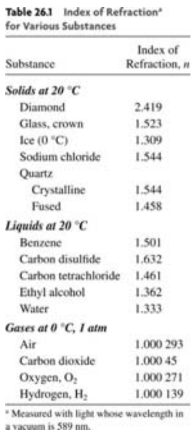


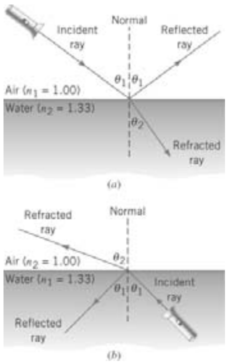
Table 26.1 Index of Refraction[a] for Various Substances

Substance	Index of Refraction, n
Solids at 20 °C	
Diamond	2.419
Glass, crown	1.523
Ice (0 °C)	1.309
Sodium chloride	1.544
Quartz	
Crystalline	1.544
Fused	1.458
Liquids at 20 °C	
Benzene	1.501
Carbon disulfide	1.632
Carbon tetrachloride	1.461
Ethyl alcohol	1.362
Water	1.333
Gases at 0 °C, 1 atm	
Air	1.000 293
Carbon dioxide	1.000 45
Oxygen, O_2	1.000 271
Hydrogen, H_2	1.000 139

[a] Measured with light whose wavelength in a vacuum is 589 nm.

26.2 Snell's Law and the Refraction of Light

SNELL'S LAW



Light wave bend (direction change) when entering medium of different index of refraction

SNELL'S LAW OF REFRACTION

When light travels from a material with one index of refraction to a material with a different index of refraction, the angle of incidence is related to the angle of refraction by

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

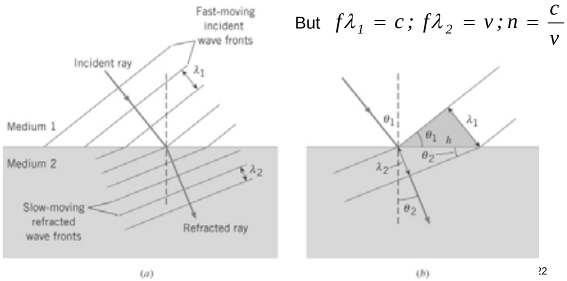
26.2 Snell's Law and the Refraction of Light

THE DERIVATION OF SNELL'S LAW

Taking ratios

$$\sin\theta_1 = \frac{\lambda_1}{h};\quad \sin\theta_2 = \frac{\lambda_2}{h};\qquad \frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{h\dfrac{\lambda_2}{h}} = \frac{\lambda_1}{\lambda_2}$$

But $f\lambda_1 = c;\ f\lambda_2 = v;\ n = \dfrac{c}{v}$

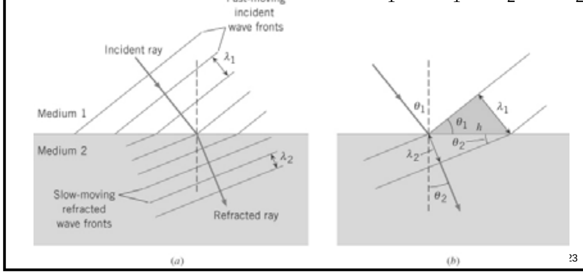


26.2 Snell's Law and the Refraction of Light

THE DERIVATION OF SNELL'S LAW

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{h\dfrac{\lambda_2}{h}} = \frac{v_1/f}{v_2/f} = \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1}$$

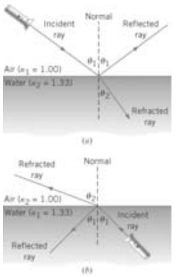
So, $n_1 \sin\theta_1 = n_2 \sin\theta_2$



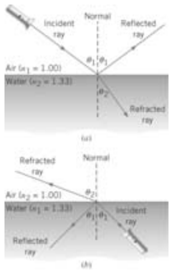
26.2 Snell's Law and the Refraction of Light

Example 1 **Determining the Angle of Refraction**

A light ray strikes an air/water surface at an angle of 46 degrees with respect to the normal. Find the angle of refraction when the direction of the ray is (a) from air to water and (b) from water to air.



26.2 Snell's Law and the Refraction of Light



(a) $$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2} = \frac{(1.00)\sin 46^\circ}{1.33} = 0.54$$

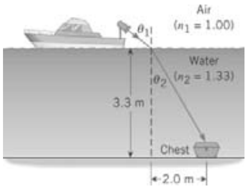
$$\theta_2 = 33^\circ$$

(b) $$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2} = \frac{(1.33)\sin 46^\circ}{1.00} = 0.96$$

$$\theta_2 = 74^\circ$$

26.2 Snell's Law and the Refraction of Light

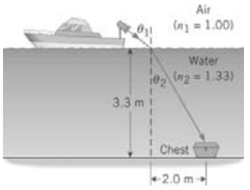
APPARENT DEPTH



Example 2 **Finding a Sunken Chest**

The searchlight on a yacht is being used to illuminate a sunken chest. At what angle of incidence should the light be aimed?

26.2 Snell's Law and the Refraction of Light



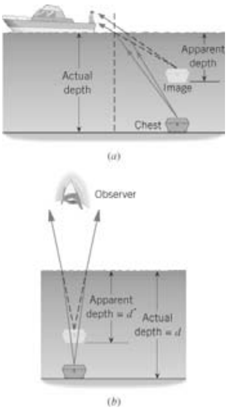
$$\theta_2 = \tan^{-1}(2.0/3.3) = 31^\circ$$

$$\sin\theta_1 = \frac{n_2 \sin\theta_2}{n_1} = \frac{(1.33)\sin 31^\circ}{1.00} = 0.69$$

$$\theta_1 = 44^\circ$$

26.2 Snell's Law and the Refraction of Light

Apparent depth, observer directly above object



$$d' = d\left(\frac{n_2}{n_1}\right)$$