Electromagnetic Waves

There is a spectrum of electromagnetic waves. See below.

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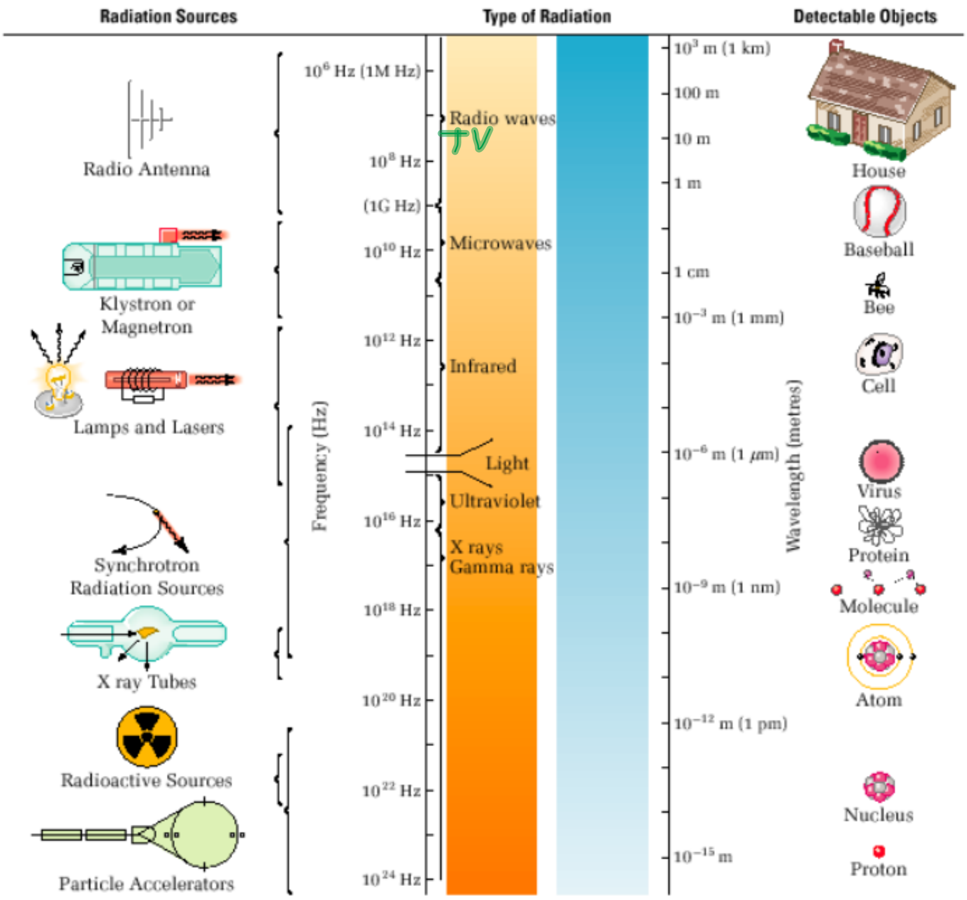
Figure 9.7 The electromagnetic spectrum includes a range of frequencies that covers more than 18 orders of magnitude. The subdivisions are artificial and, to some extent, determined by the mechanism that is used to produce them.



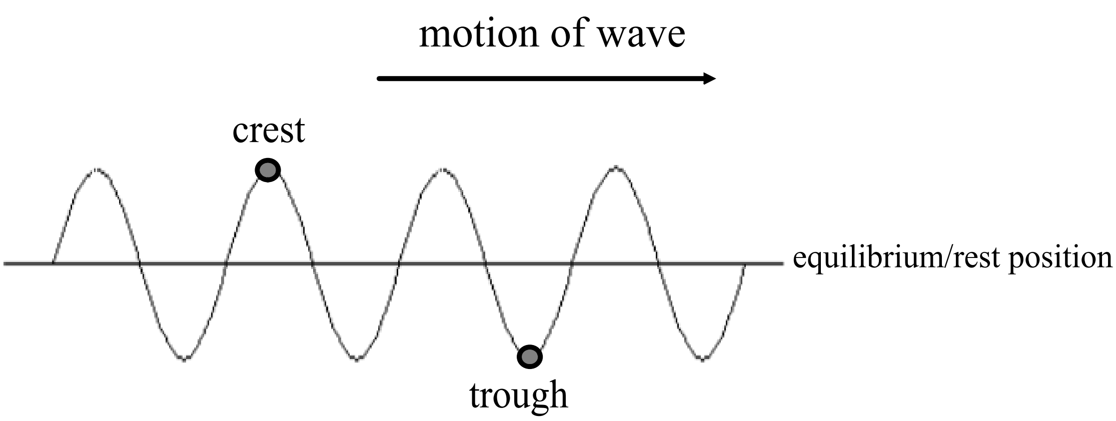
All electromagnetic waves travel at the speed of light in a vacuum.

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

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

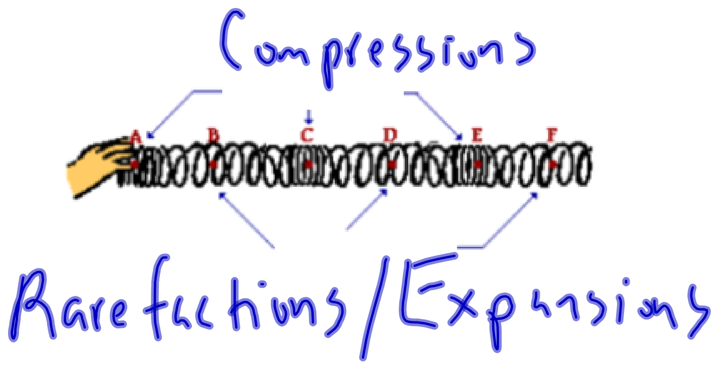
c -> speed of light in a vacuum

Anatomy of a Transverse Wave



Anatomy of a Longitudinal Wave

A region where the coils are pressed together in a small amount of space is known as a ***compression***.

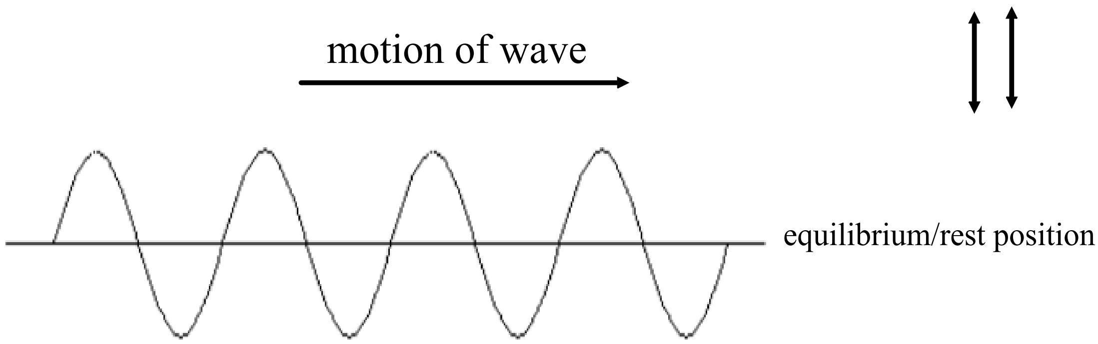


A region where the coils are spread apart, thus maximizing the distance between coils, is known as a ***rarefaction*** or ***expansion***.

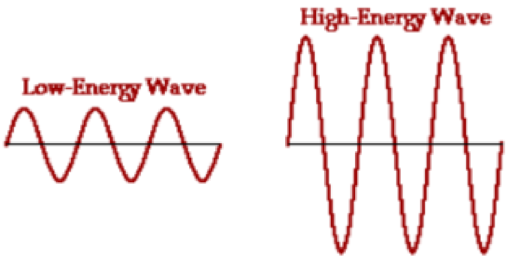
Measures of a Wave

Amplitude (A) units: cm, m

The maximum displacement of the wave from its equilibrium position is called the ***amplitude*** of the wave.



Waves transport energy and the amplitude of a wave is a measure of how much energy the wave is transporting.



To be precise, the energy transported by a wave is directly proportional to the square of the amplitude.

Mathematically,

$$E \propto A^2$$

$A = 10cm$
$E = 5J$

$2A = 20cm$
$4E = 20J$

A	E
2A	4E
3A	9E
$\frac{1}{2}A$	$\frac{1}{4}E$
5A	25E

Wavelength

The ***wavelength*** of a wave is often defined as the distance between two successive crests.

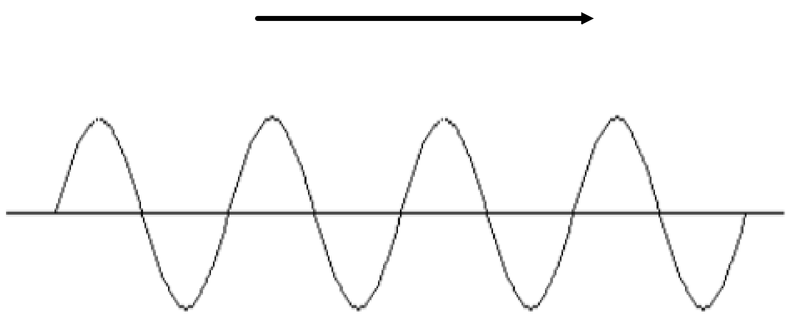
Actually, it is the distance between any two successive points where the wave motion repeats.

Wavelength is given the symbol λ (called *lambda*)

Transverse Wave

λ λ λ

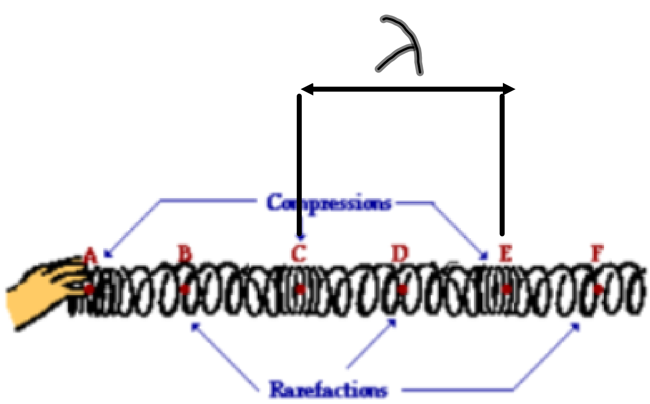
motion of wave



equilibrium/rest position

Longitudinal Wave

A **wavelength**, λ, is defined as the distance between the centers of successive compressions/rarefactions.



Frequency

The ***frequency*** is the number of complete wave cycles that pass a given point per unit time. Frequency is given the symbol ***f*** and is measured in ***hertz***.

$$f = \frac{\# waves}{time}$$

$$1\ \text{Hz} = 1\text{s}^{-1}$$

Simulation

Period

Closely related to frequency is the measurement called ***period***. The period of a wave is the time needed for the wave motion to repeat. The symbol *T* represents period, which is measured in seconds.

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

Speed

The wave speed is the speed at which any part of the wave moves. It is not the speed of the particles of the medium.

$$\text{wave speed} = \frac{distance}{time} = \frac{wavelength}{period} = \frac{\lambda}{T}$$

If we replace the period with 1/*f*, we get a new formula for wave speed.

$$v = f\lambda$$ ← wave equation

f	frequency	Hz
λ	wavelength	m
v	speed	m/s

$v = \frac{d}{t}$ $v = \frac{\lambda}{T}$ $v = f\lambda$

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Chapter 8 – Waves Transferring Energy
Problems – Wave Equation and More

1. A 0.5 Hz wave moves along a rope with a wavelength of 40 cm. What is its speed? (0.2 m/s)

2. The distance between successive crests in a series of water waves is 5.0 m, and the crests travel 8.6 m in 5.0 s. Calculate the frequency of a block of wood bobbing up and down in the water. (0.34 Hz)

3. The wavelength of a water wave is 3.7 m and its period is 1.5 s. Calculate
   a) the speed of the wave (2.5 m/s)
   b) the time required for the wave to travel 100 m (40 s)
   c) the distance travelled by the wave in 1.00 minute (1.5×10^2 m)

4. A water wave travels 60 cm in 2.0 s. If the wavelength of the wave is 5.0 cm, what is the frequency of the wave? (6.0 Hz)

5. A boat at anchor is rocked by waves whose crests are 30 m apart and whose speed is 8.0 m/s. What is the interval of time between crests striking the boat? (3.8 s)

6. A television station broadcasts with a frequency of 90 MHz. What is the wavelength of the waves? (3.3 m)

Wave Behaviors

The speed of a mechanical wave depends on the properties of the medium.

1. Boundary Behaviors

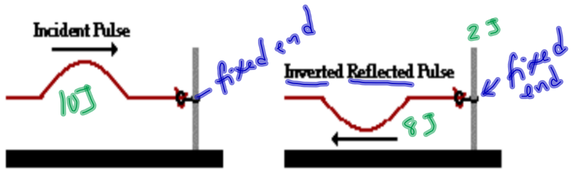
The behavior of a wave (pulse) upon reaching the end of a medium is referred to as boundary behavior. When one medium ends, another begins; the interface of the media is referred to as the boundary.

a) **Fixed End Reflection**

An elastic rope securely tied to a pole can be used to study the behavior of waves at a fixed end.

If a pulse is introduced at the left end of the rope, it will travel through the rope towards the right end of the medium. The pulse is called the incident pulse. When the incident pulse reaches the boundary, two things occur:

• A portion of the energy carried by the pulse is reflected and returns towards the left end of the rope. The disturbance, which returns to the left after bouncing off the pole, is known as the reflected pulse.
• A portion of the energy carried by the pulse is transmitted to the pole, causing the pole to vibrate.

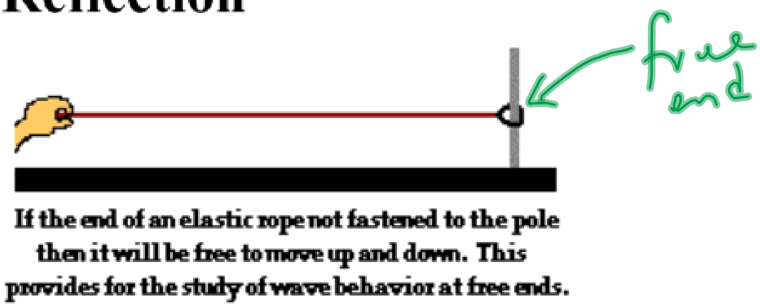


Simulation

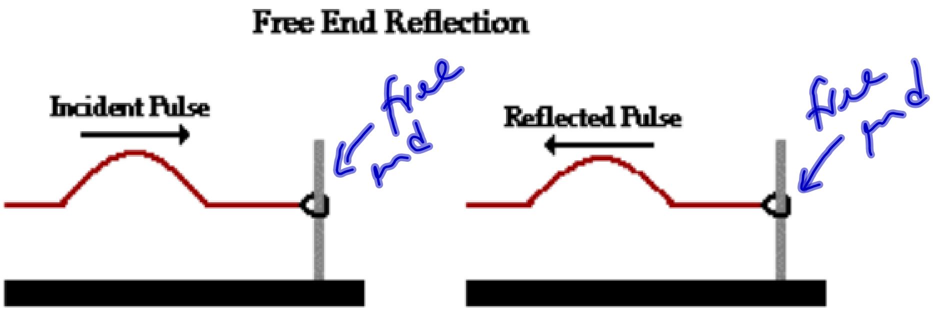
	Incident Pulse		Reflected Pulse	
Source	f_i	=	f_r	
energy	A_i	>	A_r	
medium	v_i	=	v_r	
$V = f\lambda$	λ_i	=	λ_r	

☆

b) **Free End Reflection**



If the end of an elastic rope is not fastened to the pole then it will be free to move up and down. This end of the rope is referred to as a free end.



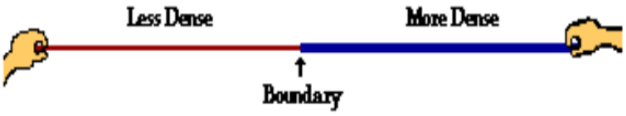
Inversion is not observed in free end reflection.

Comparison of variables will be the same as before

Simulation

c) Less Dense to More Dense Medium (thin rope → thick rope)

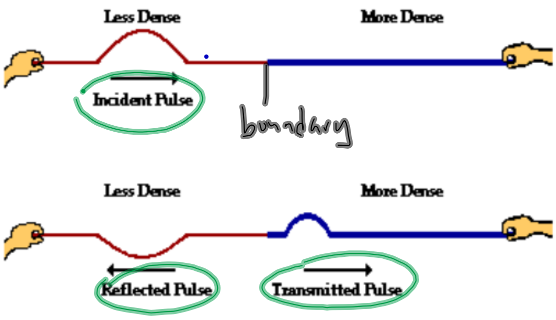
Let's consider a thin rope attached to a thick rope, with each rope held at opposite ends by people. And suppose that a pulse is introduced by the person holding the end of the thin rope. If this is the case, there will be an incident pulse traveling in the less dense medium (thin rope) towards the boundary with a more dense medium (thick rope).



Upon reaching the boundary, the usual two behaviors will occur.

- A portion of the energy carried by the incident pulse is reflected and returns towards the left end of the thin rope. The disturbance which returns to the left after bouncing off the boundary is known as the **reflected pulse**.
- A portion of the energy carried by the incident pulse is transmitted into the thick rope. The disturbance which continues moving to the right is known as the **transmitted pulse**.

A wave traveling from a less dense to a more dense medium...



...will be reflected off the boundary and transmitted across the boundary into the new medium. The reflected pulse is inverted.

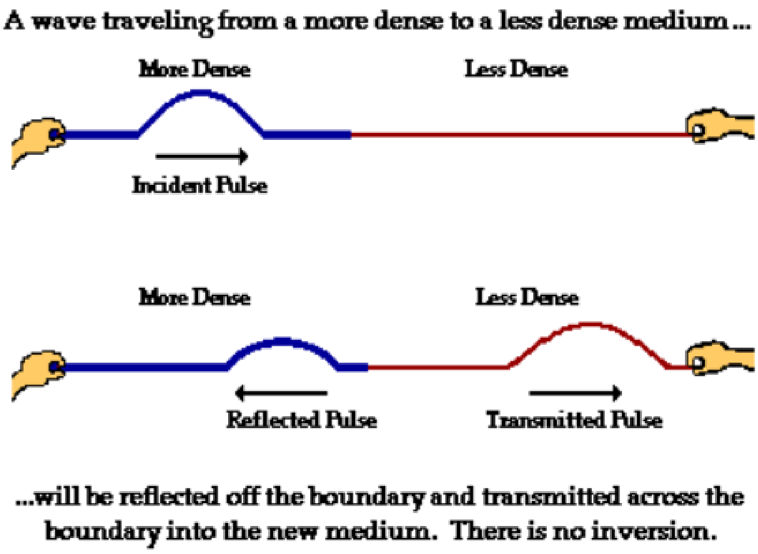
Simulation

$$v = f\lambda$$

independent of medium

Incident Pulse		Reflected Pulse	Incident Pulse		Transmitted Pulse
f_i	=	f_r	f_i	=	f_t
A_i	>	A_r	A_i	>	A_t
v_i	=	v_r	v_i	>	v_t
λ_i	=	λ_r	λ_i	>	λ_t

d) More Dense to Less Dense Medium thick -> thin



Simulation

$$v = f\lambda$$

↑ – ↑

Incident Pulse		Reflected Pulse		Incident Pulse		Transmitted Pulse	
f_i	=	f_r		f_i	=	f_t	
A_i	>	A_r		A_i	>	A_t	
v_i	=	v_r		v_i	<	v_t	
λ_i	=	λ_r		λ_i	<	λ_t	

Check Your Understanding

Case 1: A pulse in a more dense medium is traveling towards the boundary with a less dense medium.

1. The reflected pulse in medium 1 _________ (will, will not) be inverted

2. The speed of the transmitted pulse will be ____________ (greater than, less than, the same as) the speed of the incident pulse.

3. The speed of the reflected pulse will be _______________ (greater than, less than, the same as) the speed of the incident pulse.

4. The wavelength of the transmitted pulse will be ____________ (greater than, less than, the same as) the wavelength of the incident pulse.

5. The frequency of the transmitted pulse will be ____________ (greater than, less than, the same as) the frequency of the incident pulse.

Case 2: A pulse in a less dense medium is traveling towards the boundary with a more dense medium.

6. The reflected pulse in medium 2 _________ (will, will not) be inverted

7. The speed of the transmitted pulse will be ____________ (greater than, less than, the same as) the speed of the incident pulse.

8. The speed of the reflected pulse will be _______________ (greater than, less than, the same as) the speed of the incident pulse.

9. The wavelength of the transmitted pulse will be ____________ (greater than, less than, the same as) the wavelength of the incident pulse.

10. The frequency of the transmitted pulse will be ____________ (greater than, less than, the same as) the frequency of the incident pulse.

Attachments

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