Waves

Chapter 16: Travelling waves

Chapter 18: Standing waves, interference

Chapter 37 & 38: Interference and diffraction of electromagnetic waves

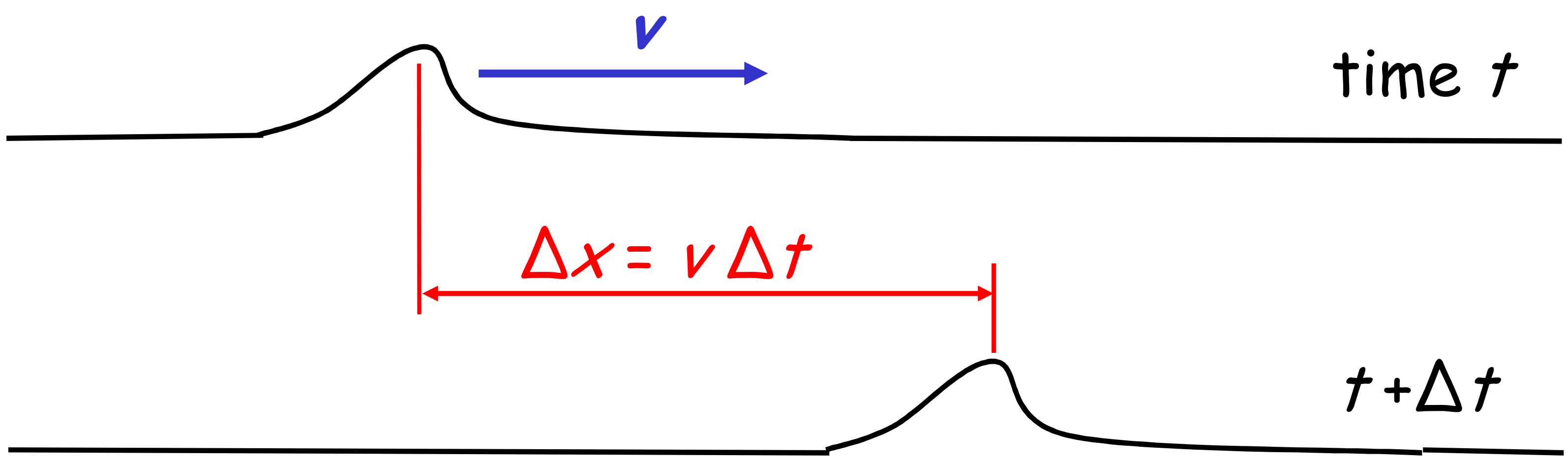
Wave Motion

Text sections 16.1 – 16.4

- Qualitative properties of wave motion
- Mathematical description of waves in 1-D

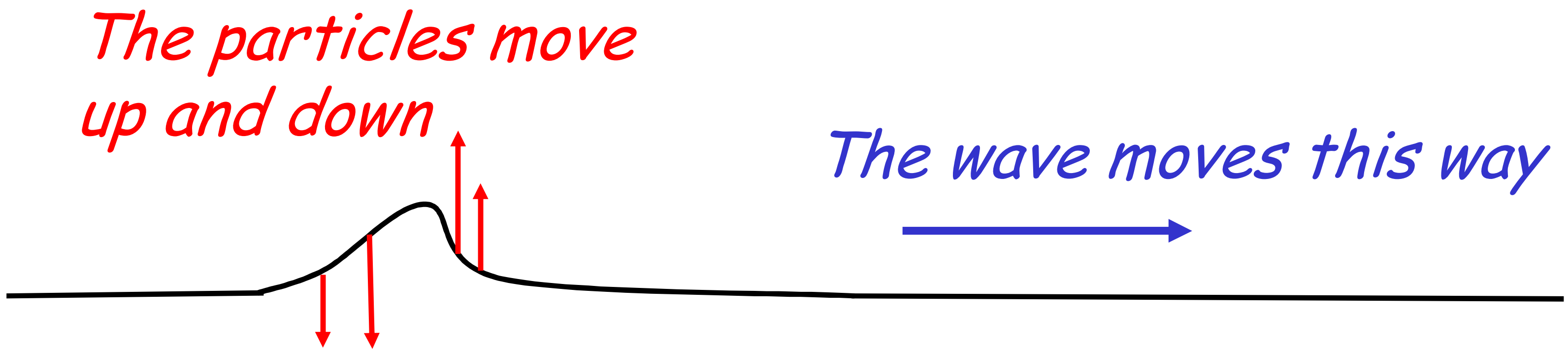
Practice: Chapter 16,
Objective Questions 2, 6, 7
Conceptual Questions 1, 2, 3, 4, 9
Problem 3

A wave is a moving ***pattern***. For example, a wave on a stretched string:



The **wave speed** *v is the speed of the pattern. No* particles *move at this wave speed, but the wave does carry energy and momentum.*

Transverse waves



If the particle motion is perpendicular to the direction the wave travels, the wave is called a "transverse wave".

Examples: Waves on a string;
light & other electromagnetic waves;
some sound waves in solids (shear waves)

Longitudinal waves

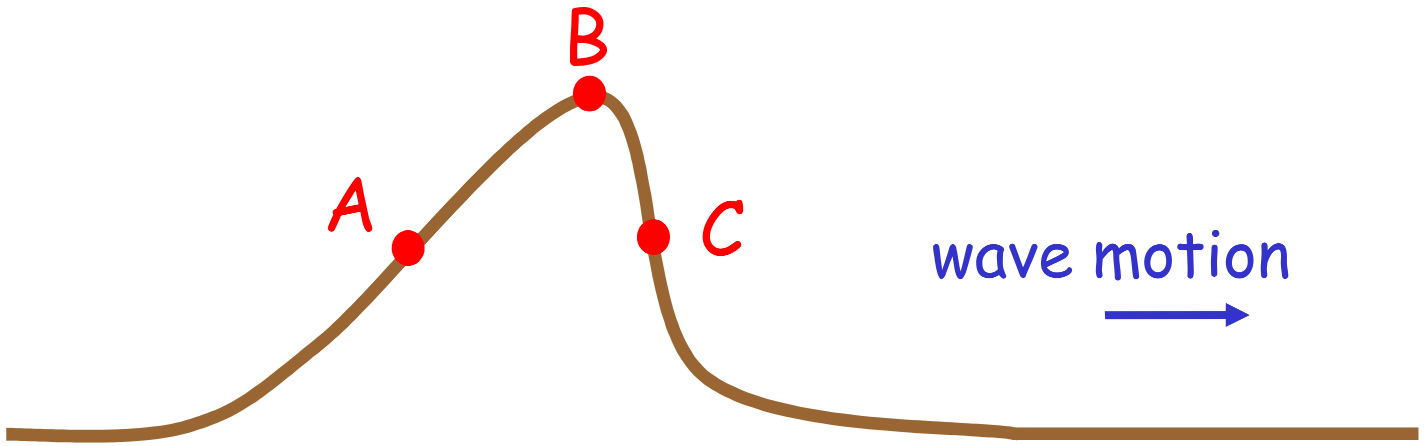
The particles move back and forth.

The wave moves long distances parallel to the particle motions.

Example: sound waves in fluids

Even in longitudinal waves, the **particle velocities** *are quite different from the* **wave velocity**. *The speed of the wave can be orders of magnitude larger than the particle speeds.*

Quiz



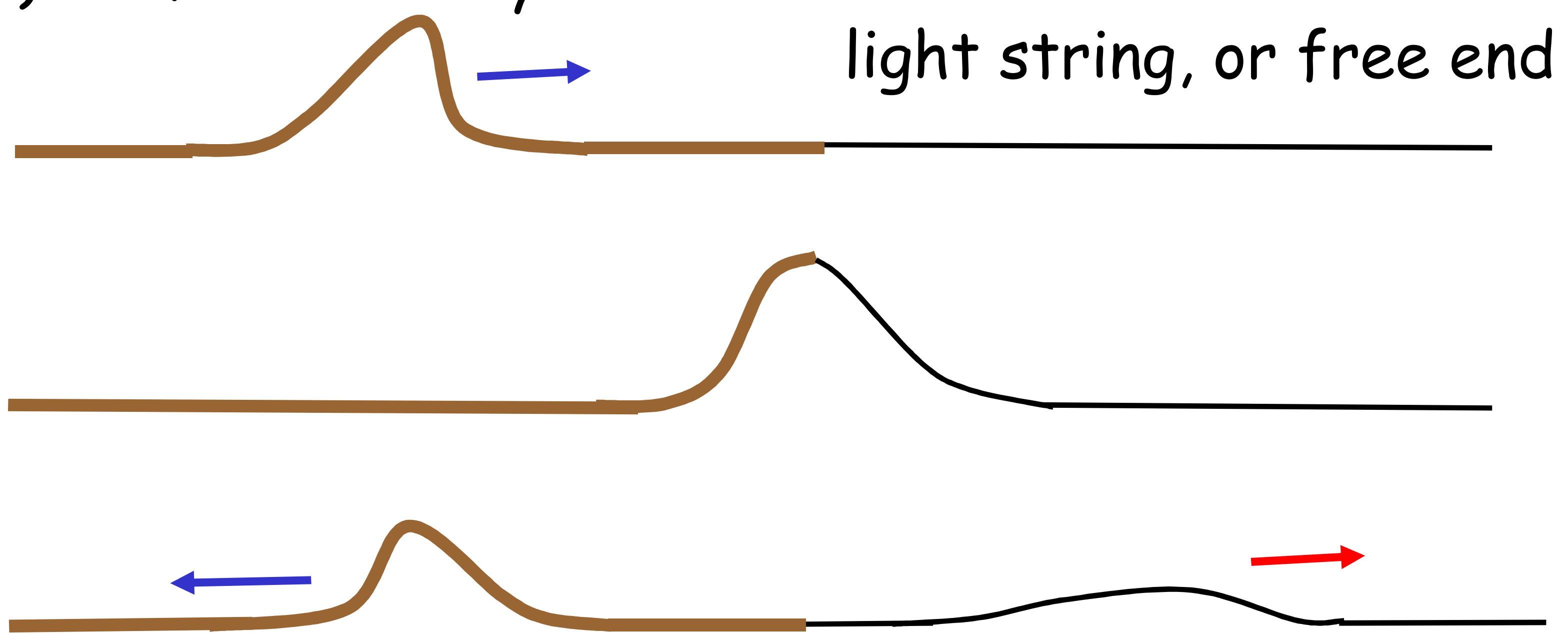
Which particle is moving at the highest speed?

Reflections

Waves (partially) reflect from any boundary in the medium:

1) "Soft" boundary:

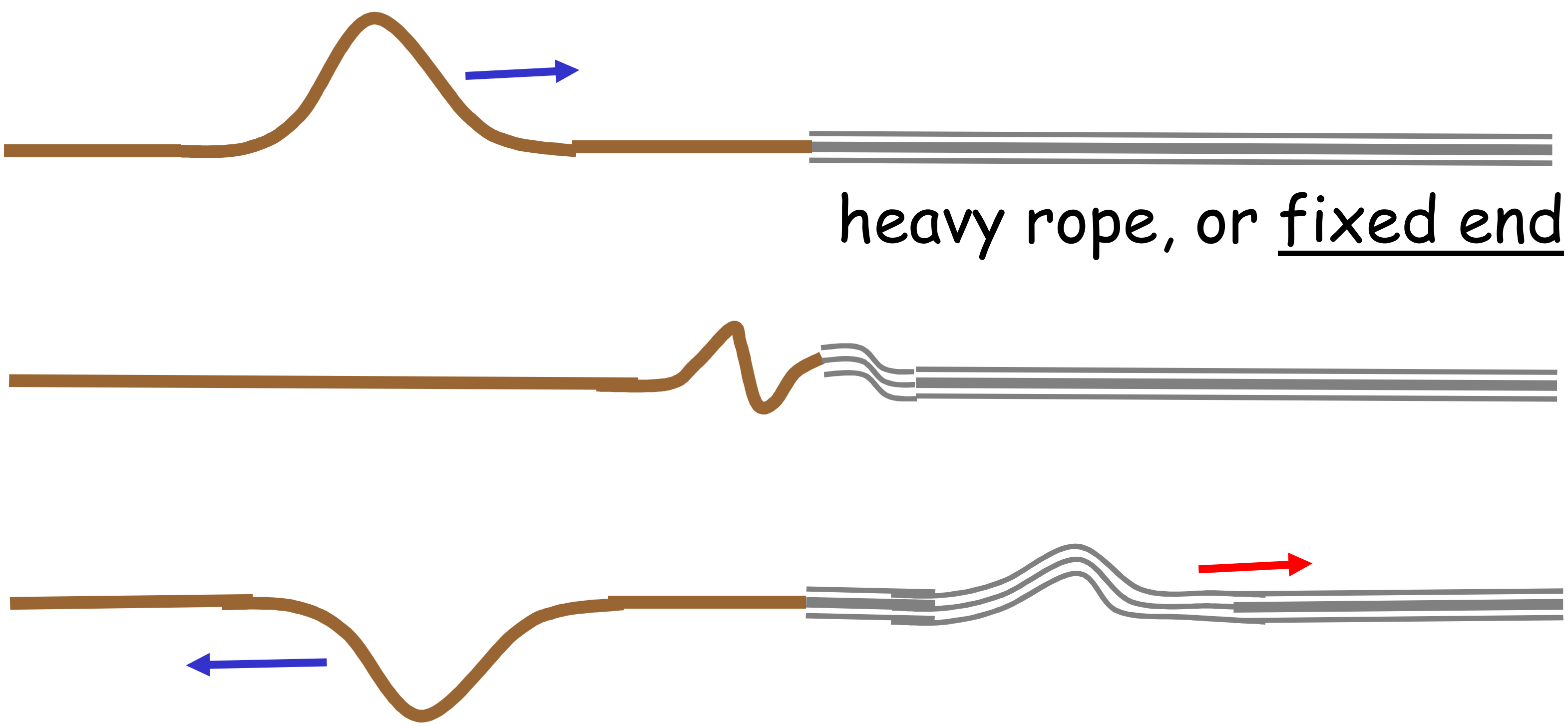
light string, or free end



Reflection is upright

Reflections

2) "Hard" boundary:



Reflection is inverted

Non-dispersive waves: the wave always keeps the same shape as it moves.

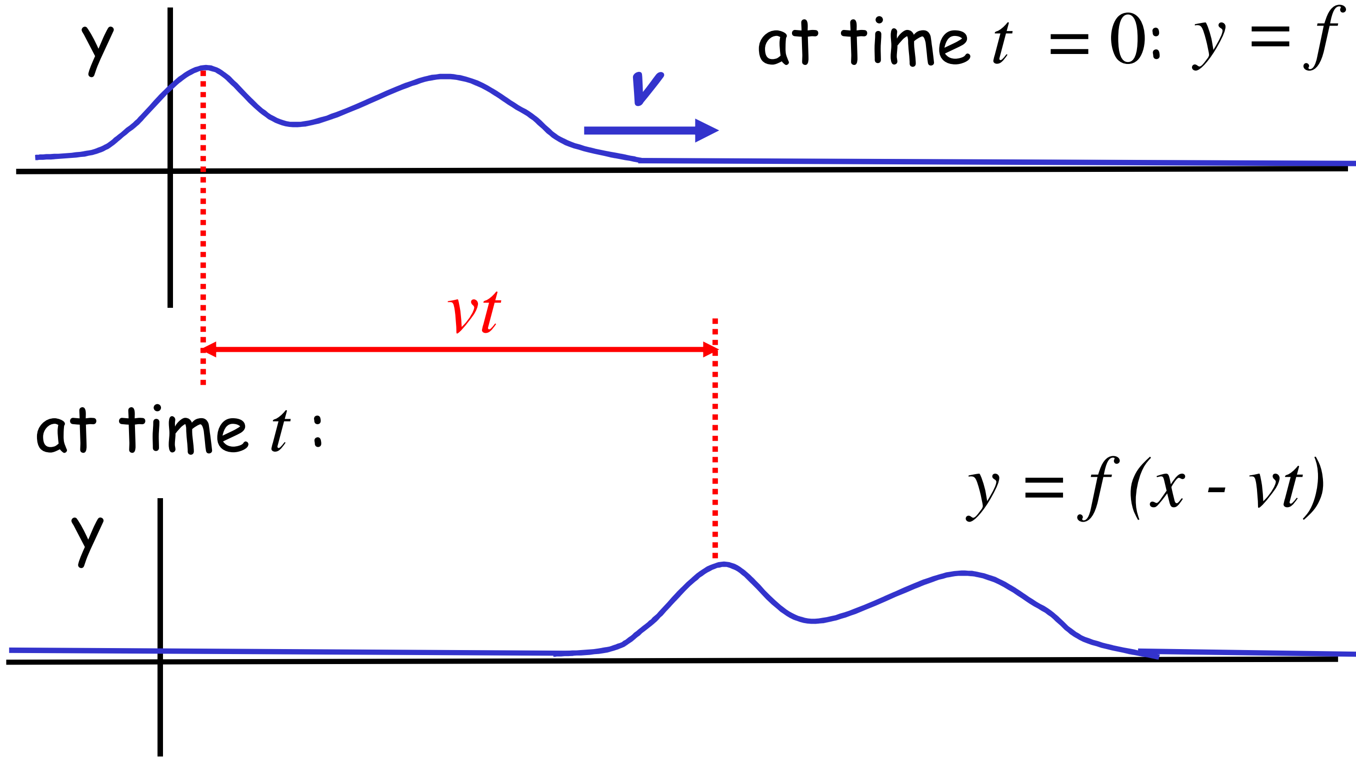
For these waves, the wave speed is determined entirely by the medium, and is the same for all sizes & shapes of waves.

eg. stretched string:

$$\boxed{v = \sqrt{\frac{\text{tension}}{\text{mass/unitlength}}}}$$

(A familar example of a **dispersive** wave is an ordinary water wave in deep water. We will discuss only non-dispersive waves.)

The math: *Suppose the shape of the wave at $t = 0$, is given by some function $y = f(x)$.*



Note: $y = y(x,t)$, a function of <u>two</u> variables;
f is a function of <u>one</u> variable

Non-dispersive waves:

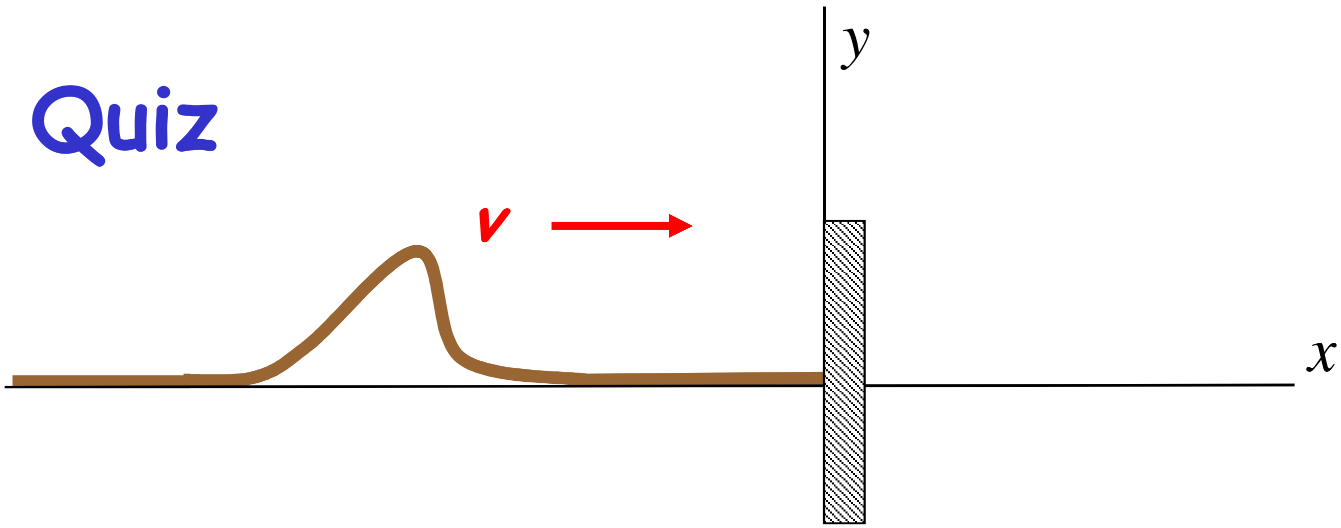
$$\boxed{y\,(x,t) = f\,(x \pm vt)}$$

+ sign: wave travels towards –x
- sign: wave travels towards +x

f is any (smooth) function of <u>one</u> variable.

eg. $f(x) = A \sin(kx)$

Quiz



A wave travels along the x axis. It reflects from a fixed end at the origin. The function describing the reflected wave should have the sign reversed on:

A) x
B) y
C) *time*
D) x and y
E) x, y, and *time*

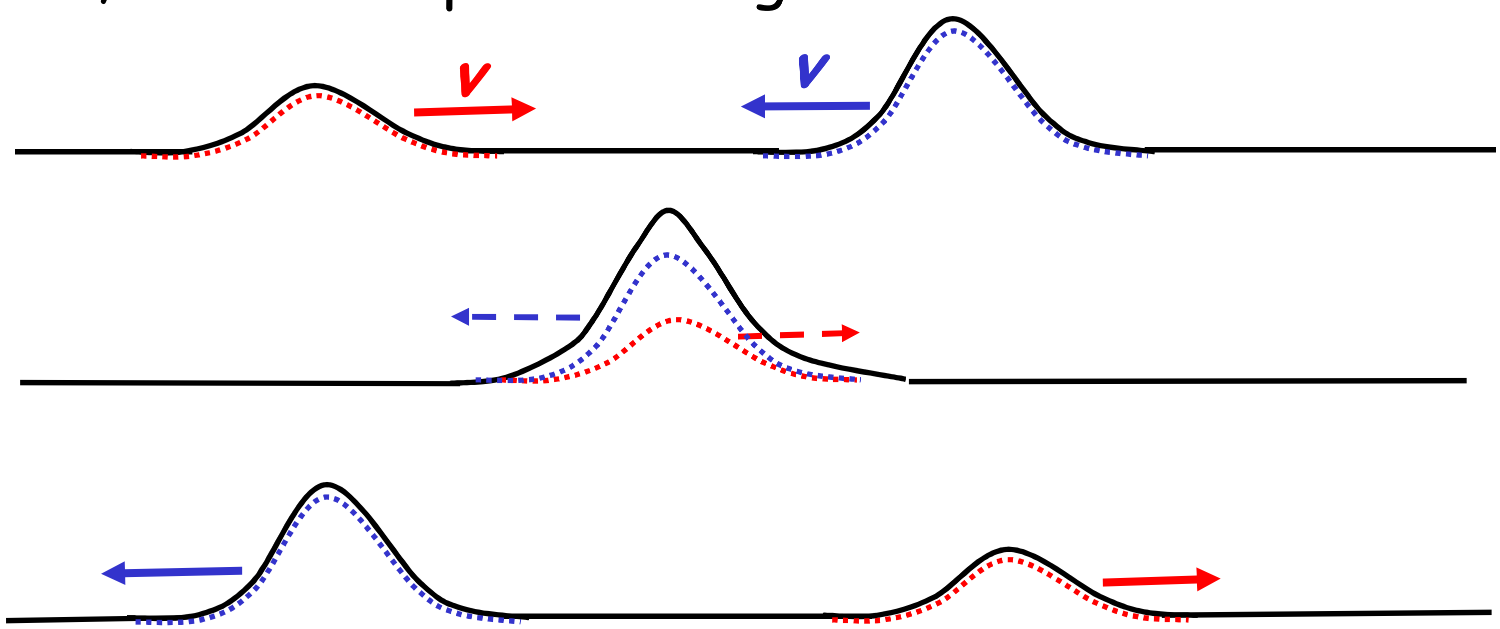
Principle of Superposition

When two waves meet, the displacements add:

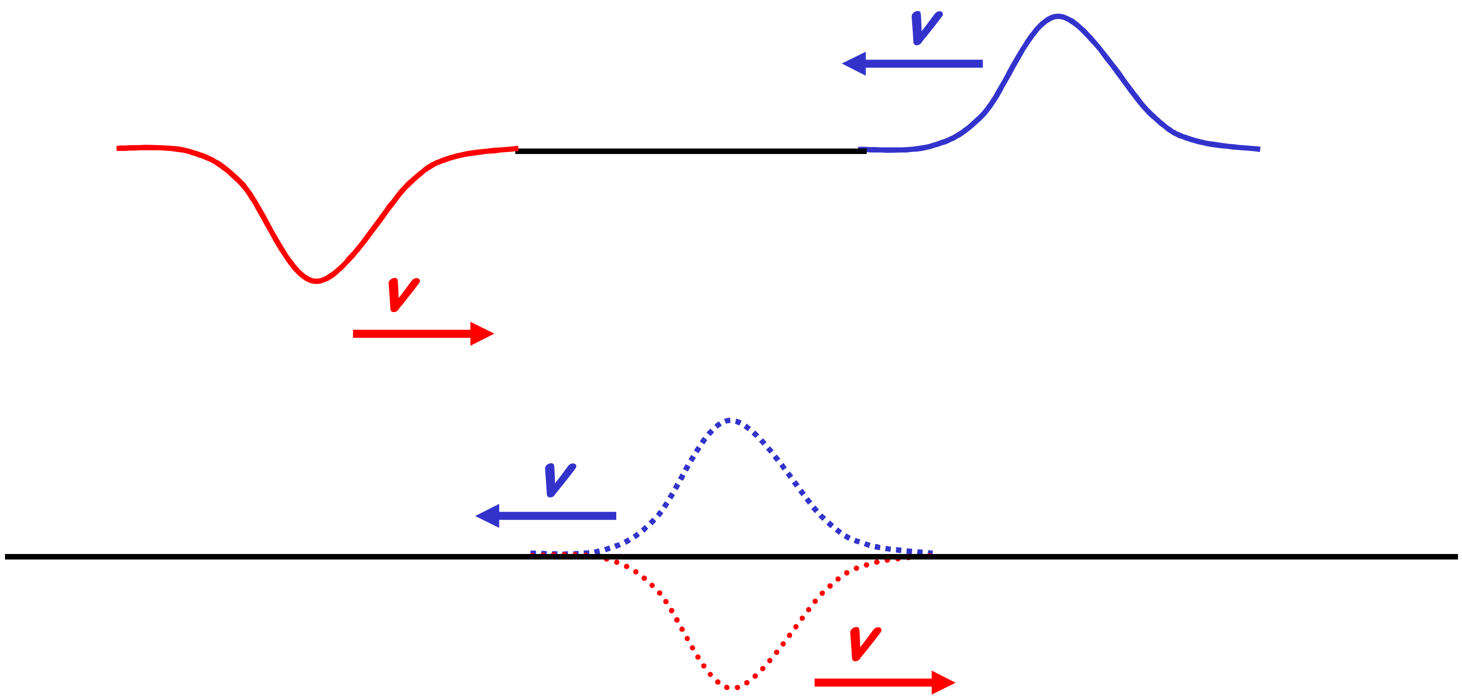
$$y_{\text{observed}}(x,t) = y_1(x,t) + y_2(x,t)$$

(for waves in a "linear medium")

So, waves can pass through each other:

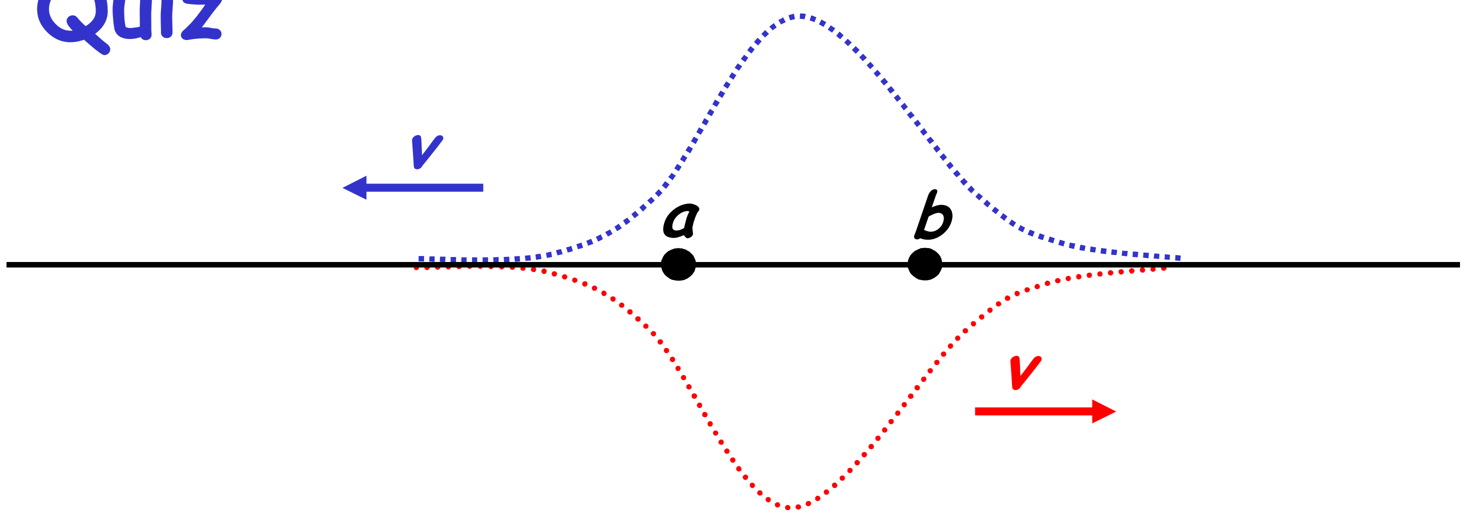


Exercise



*Sketch the **particle** velocities at the instant the string is completely straight.*

Quiz



At the instant the string is completely straight. the particle velocities are:

A) upwards for a, downwards for b
B) downwards for a, upwards for b
C) both downwards
D) both upwards
E) both zero

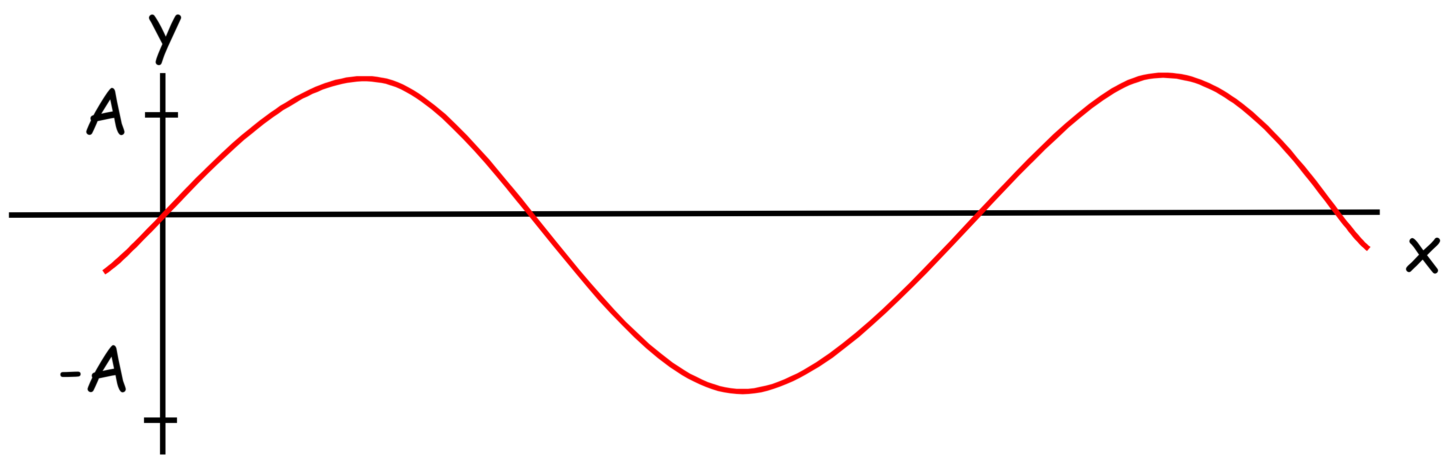
Sine Waves

For a wave travelling in the $+x$ direction, the displacement y is given by

$$y\,(x,t) = f\,(x - vt)$$

For sinusoidal waves, the shape is a sine function, *eg.*,

$$f(x) = y(x,0) = A\sin(kx)$$ (A and k are constants)



Then $y\,(x,t) = f(x - vt) = A\sin[k(x - vt)]$

or $\boxed{y\,(x,t) = A\sin\,(kx - \omega t)}$ with $\omega = kv$

*The displacement of a particle at a fixed location x is a sinusoidal function of time – i.e., **simple harmonic motion:***

$$y = A \sin(kx - \omega t) = A \sin[\text{ constant} - \omega t]$$

*The "angular frequency" of the particle motion is ω; the initial phase is kx (**different** for different particles).*

Review: Recall from last term, SHM is described by functions of the form $y(t) = A\cos(\omega t + \phi) = A\sin(\pi/2 - \phi - \omega t)$, etc., with

$$\omega = 2\pi f$$

"angular frequency"
radians/sec

frequency:
cycles/sec (=hertz)