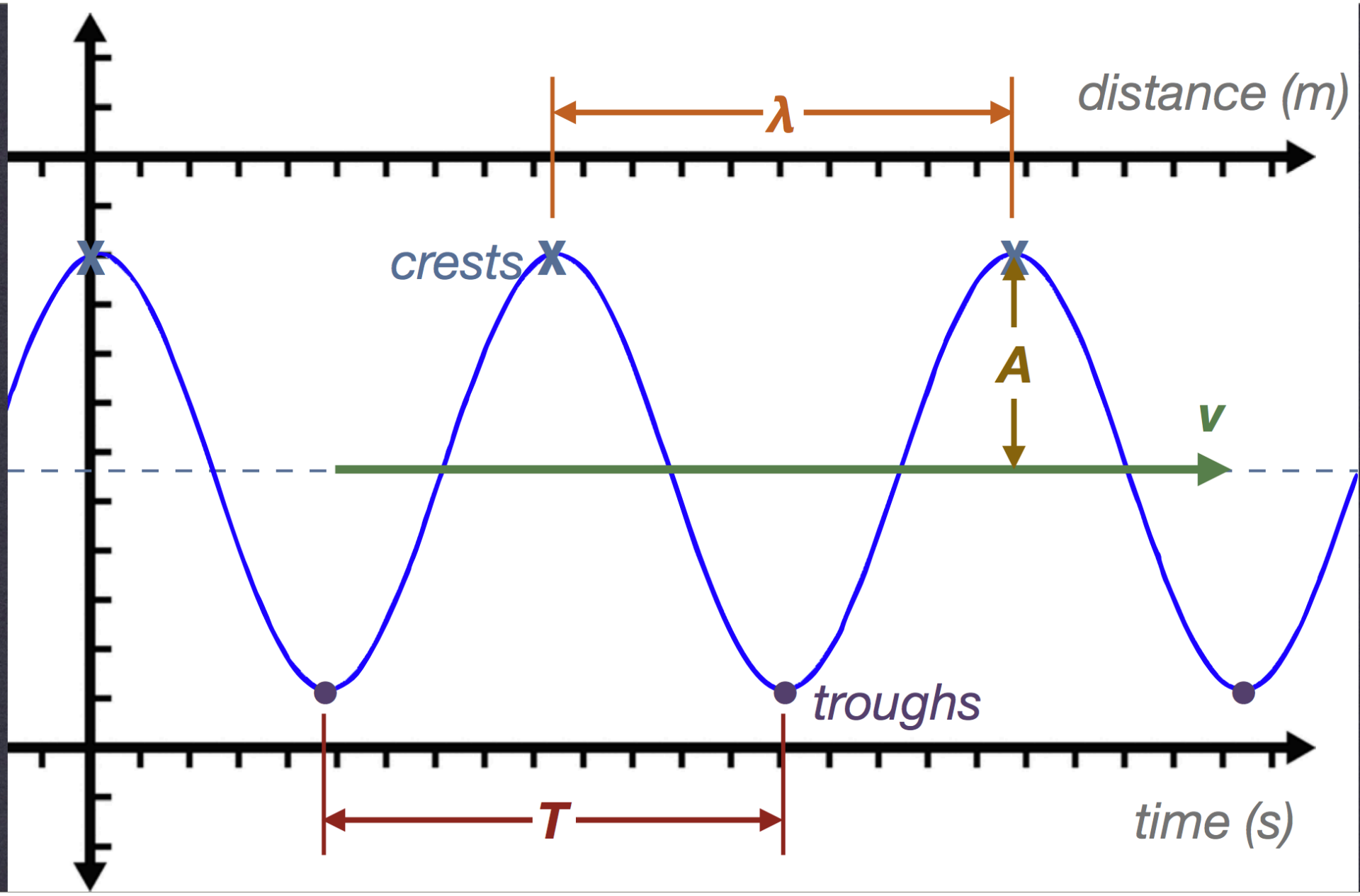
What's a wave?

- A **wave** is a wiggle in time and space
- The source of a wave is a **vibration**
  - Vibrations are wiggles in time
  - Wave is essentially a traveling vibration

Wave does **not** transfer matter, it transfers **energy**

Qualities of a wave

- **Period (T)** – time it takes for 1 cycle, in seconds (s)
- **Wavelength (λ)** (Greek letter lambda)– distance between successive identical parts of the wave, in meters (m)
- **Frequency (**f**)** - # vibrations in given time, in Hertz (Hz)
  - $f = \frac{1}{T}$
- **Velocity (v)** – speed and direction of the wave, in m/s
  - $v = \lambda f$
- **Crests** – peaks or high points of the wave
- **Troughs** – low points of the wave
- **Amplitude** –distance from midpoint to crest (or trough), maximum displacement from equilibrium

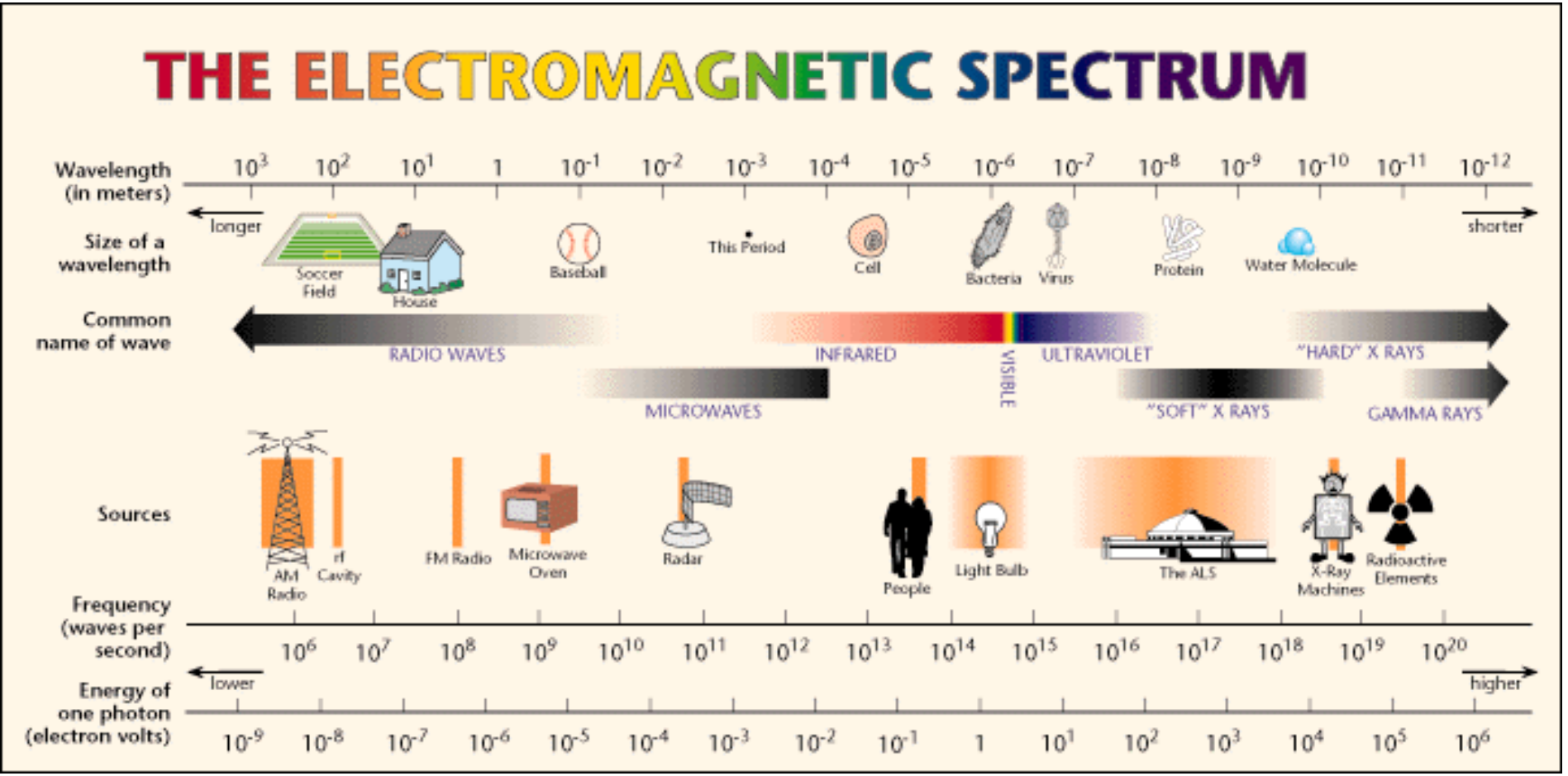

λ
distance (m)
crests
A
v
troughs
T
time (s)

Wave Speed

- In a freight train, each car is 10 m long. If two cars roll by you every second, how fast is the train moving?
  - v = d/t = 2x(10 m)/(1 s) = 20 m/s
- A wave has a wavelength of 10 m. If the frequency is 2 Hz, how fast is the wave traveling?
  - $v = \lambda f$ = (10 m)(2 Hz) = 20 m/s

- Speed of a light wave
  - c = 3.0 x 10^8 m/s
- Speed of sound (in dry air at 20º C)
  - v = 340 m/s
- Speed of sound in a vacuum (in space)?
  - v = 0 m/s

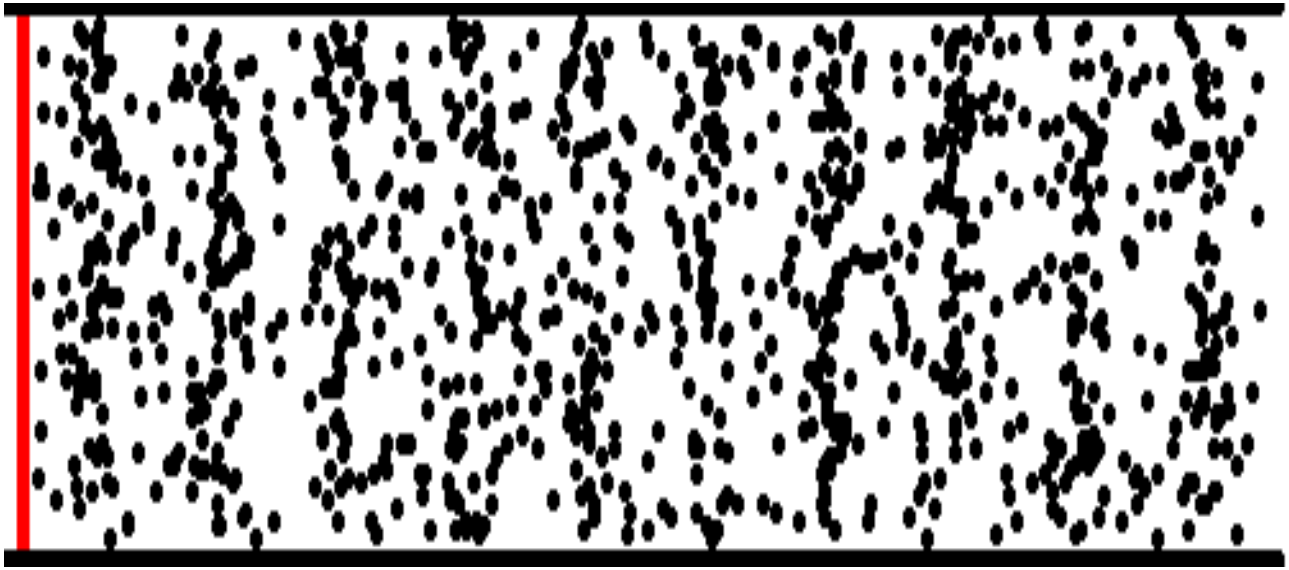
All waves on the electromagnetic spectrum have a wave speed of 3.0 x 10^8 m/s, they differ in their wavelengths and frequencies.



Transverse vs. Longitudinal

- **Transverse:** Motion of the medium is perpendicular to the direction in which the wave travels
  - Examples: Ripples in the water, A whip, Light, Earthquake secondary waves
- **Longitudinal:** Motion of the medium is parallel to ("along") the direction in which the wave travels
  - Examples: earthquake primary waves, sound

Sound waves are longitudinal



http://www.kettering.edu/~drussell/Demos/waves/wavemotion.html

1. The distance from trough to trough on a periodic wave is called its...

a) frequency.

b) period.

c) wavelength.

d) amplitude.

2. Dipping a finger in water faster and faster causes the wavelength of the spreading waves to

a) increase

b) decrease

c) stay the same

3. If you double the frequency of a vibrating object, what happens to the period?

a) the period doubles

b) the period stays the same

c) the period is cut in half

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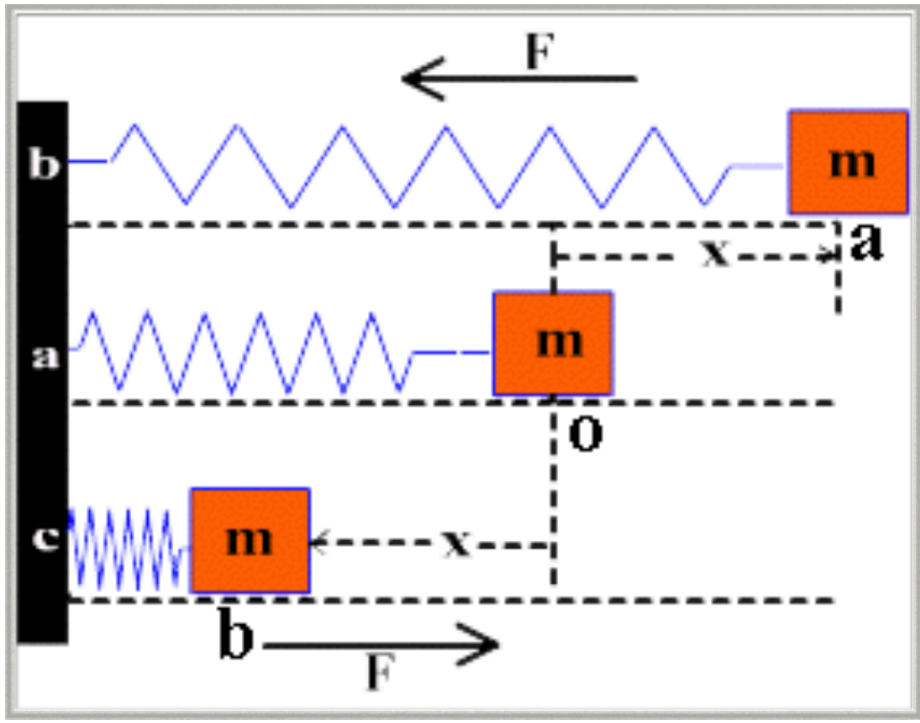
Simple Harmonic Motion

- Oscillatory motion under a restoring force proportional to the amount of displacement from equilibrium
- A **restoring force** is a force that tries to move the system back to equilibrium
- For a spring-mass system like the one on the right, the restoring force is the spring force

- Important because SHM is a good model to describe vibrations of a guitar string, vibrations of atoms in molecules, etc.



Spring force

$$F_s = -kx$$

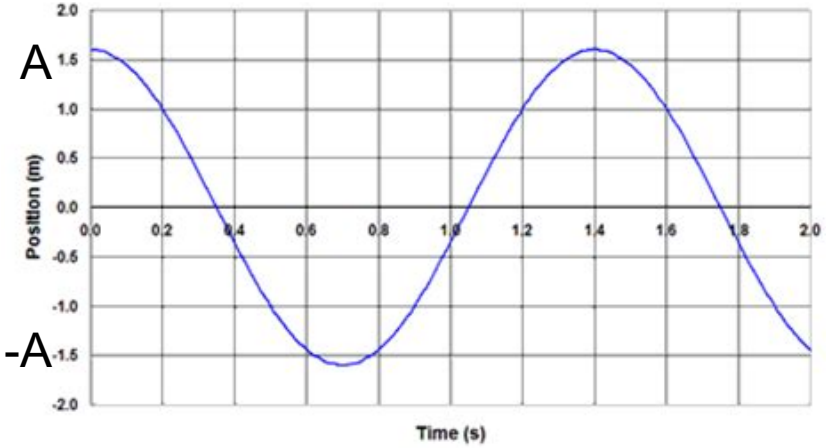
Spring potential energy

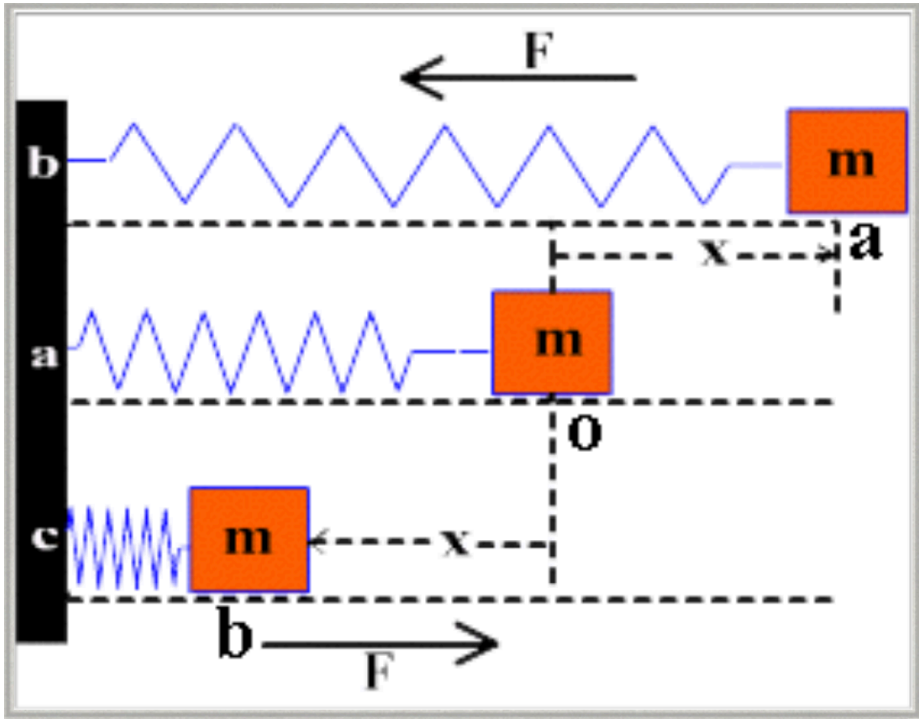
$$PE_s = \frac{1}{2}kx^2$$

K = spring constant, measure of stiffness of spring

Assumption: **No friction and massless spring**

$$a = \frac{F}{m}, \qquad a = -\frac{kx}{m}$$





Left: Graph of position vs. time when mass is released at position (amplitude) A

Equation of the line:

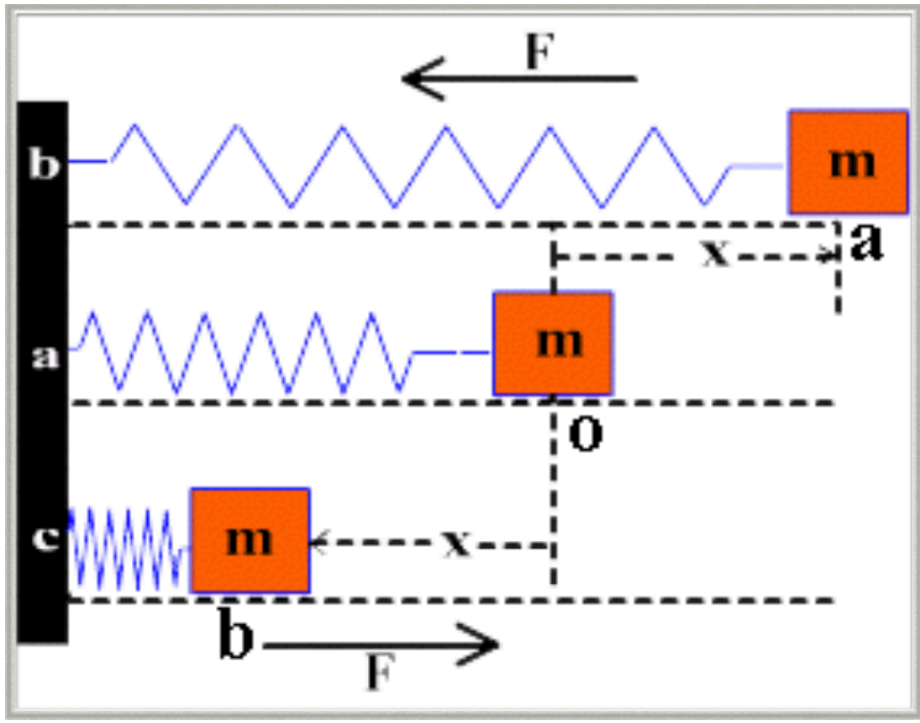
$$x = Acos(\omega t)$$

Displace mass to x = A and let go

Fill in the blank:

- Net force and acceleration are toward which direction?

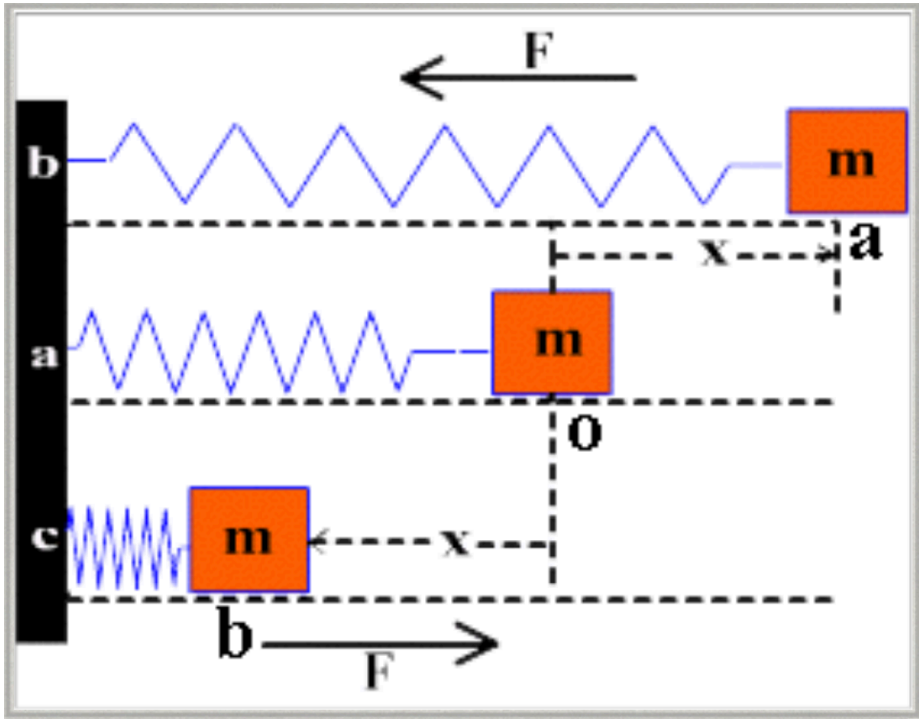
  _____
- Max velocity is at x = _____
- Net force at *O* is _____
- Overshoots and compresses spring to x = _____
- Net force and acceleration are toward _____
- Max KE and max velocity at point 0 (equilibrium)
- Max PE, Max force, max acceleration, KE = 0, v= 0 at point A and B



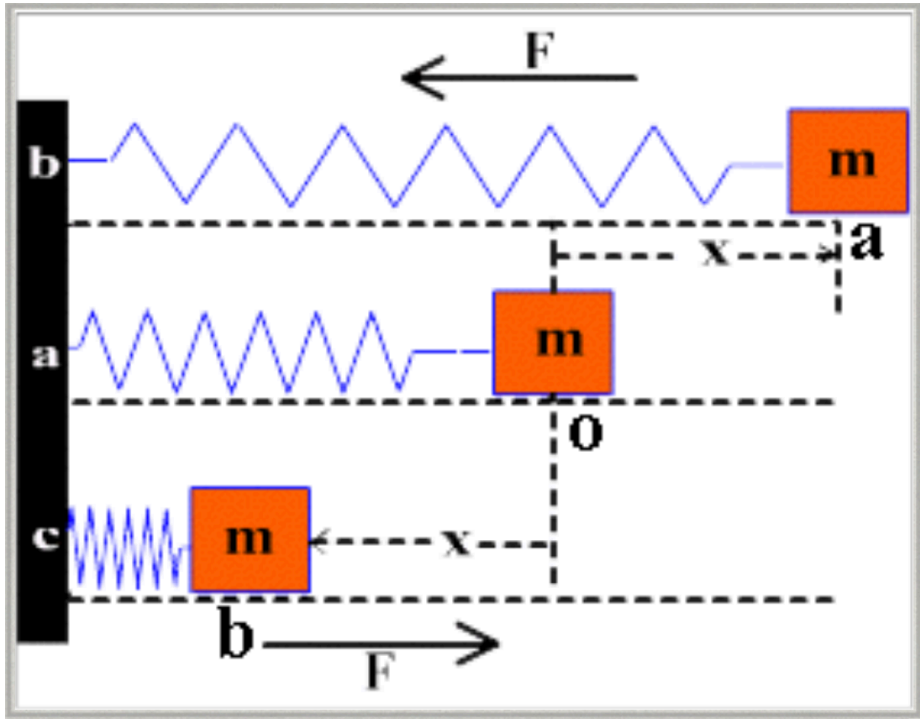
Displace mass to x = A and let go

Fill in the blank:

- Net force and acceleration are toward which direction? **Left**
- Max velocity is at x = **0**
- Net force at *O* is **0 N**
- Overshoots and compresses spring to x = **-A**
- Net force and acceleration are toward **Right**

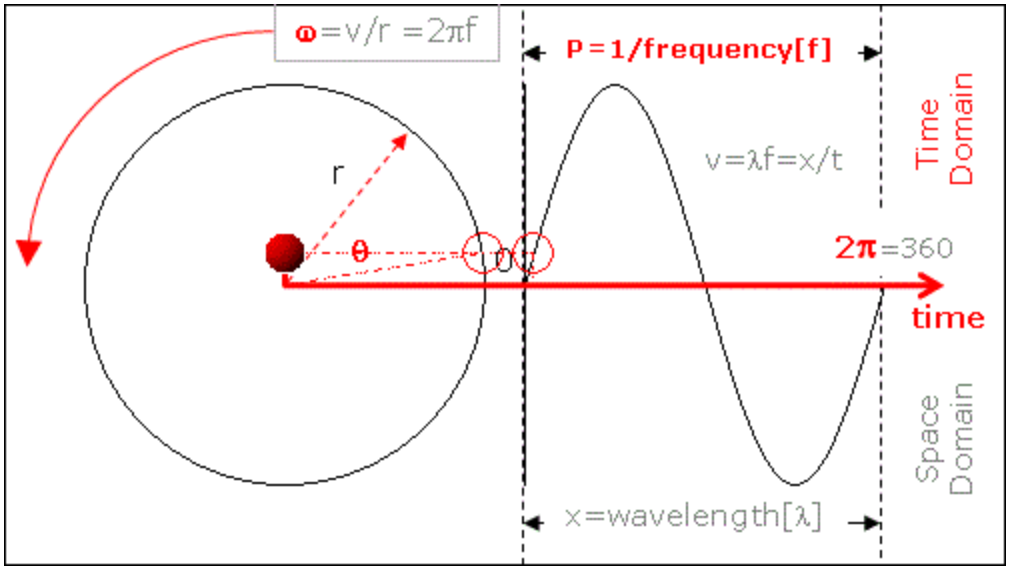


- Amplitude (A) — magnitude of displacement from
- Period (T) — seconds per cycle;
  - T = 1/f
- Frequency (f) — cycles per second
  - f = 1/T
- Angular speed (ω) — ω = 2πf = 2π/T



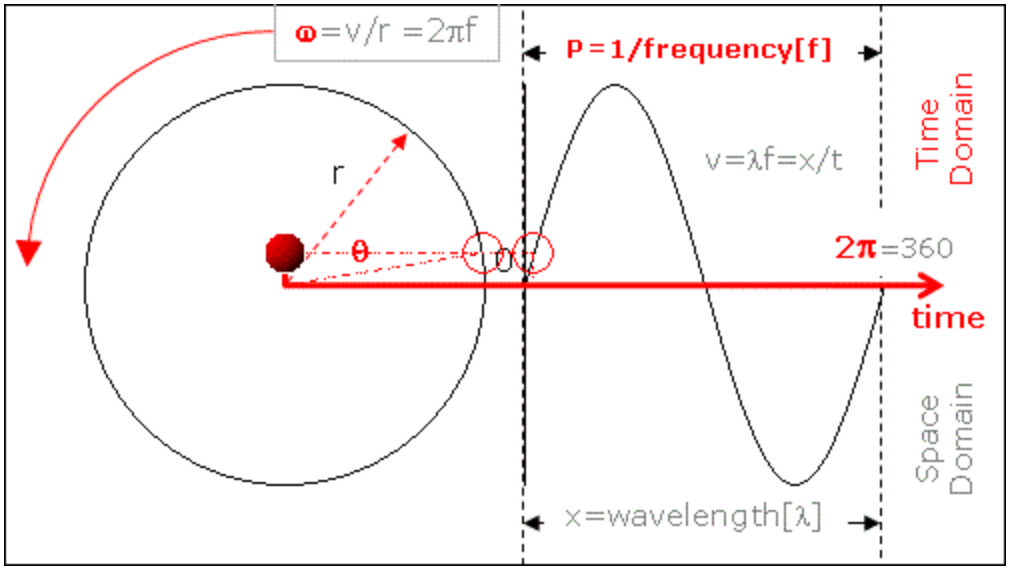
Terms for periodic motion

- Amplitude (A) — magnitude of displacement from
- Period (T) — seconds per cycle;
  - T = $1/f$
- Frequency (f) — cycles per second
  - f = 1/T
- Angular speed (ω) — ω = $2\pi f$ = $2\pi/T$



SHM and Circular Motion

- If the amplitude of the mass's oscillation is equal to the radius of the object in circular motion, and angular speed of the object in SHM = angular speed of object in circular motion
- Their motions are identical



SHM and Circular Motion

(Don't need to know derivation, but be able to use the equation in the red box)

- Acceleration of circular motion:

$$a = \frac{v_t^2}{r} = \omega^2 r$$

- Acceleration of spring-mass system:

$$a = \frac{km}{x}$$

Motion is the same, so you can set accelerations equal to each other, and r = x because radius = amplitude (maximum displacement)

$$\omega = \sqrt{\frac{k}{m}}$$

A small 0.7 ***gram*** fly is caught in Lucas the Spider's web. If the web has a spring constant of 1.77 N/m, calculate the ***angular speed*** and ***frequency*** of the fly's oscillation. Model the web as a spring in SHM.

$$\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T} = 2\pi f$$

ω = 50 radians/second

f = 8 Hz

Things to note

- Period and frequency don't depend on amplitude A, even though object is traveling farther with larger A
  - Bigger A = larger restoring Force = higher average velocity

SHM of simple pendulum

- Almost exactly same as spring- mass system, except the restoring force is **gravity**
- $T = 2\pi\sqrt{\frac{L}{g}}$
- Independent of Amplitude (A)
- Independent of mass *m*

Pendulum Practice

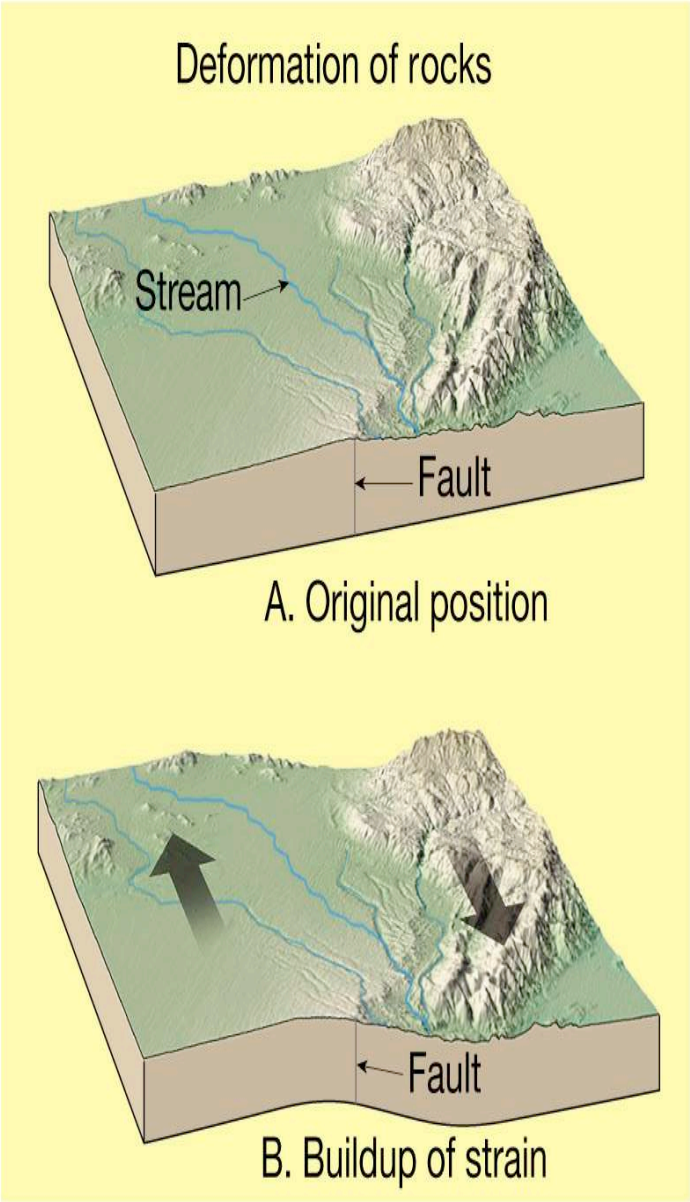
- You find yourself on a strange planet armed only with a simple pendulum. The bob of the pendulum hangs on a 0.45 m long string and will swing through a full oscillation in 1.7 seconds once set in motion. Use this information to find the acceleration due to gravity on this planet.
- $T = 2\pi \sqrt{\frac{L}{}}$

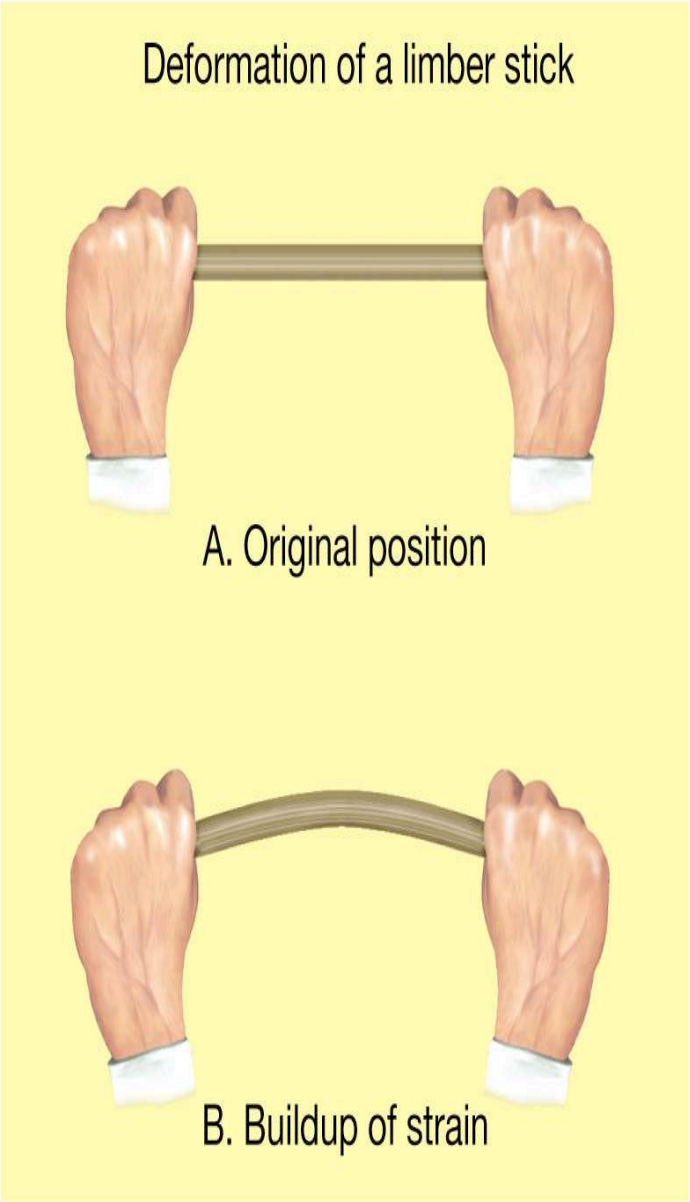
Earthquakes and seismic waves

- What I would like you to know:
  - Differences between P waves, S waves, and surface waves
  - How to figure out the epicenter of an earthquake
  - How to find the magnitude of an earthquake

How do earthquakes occur?

- Stresses build up in the crust, usually due to lithospheric plate motions
- Rock deform (strain) as the result of stress. The strain is energy stored in the rocks.

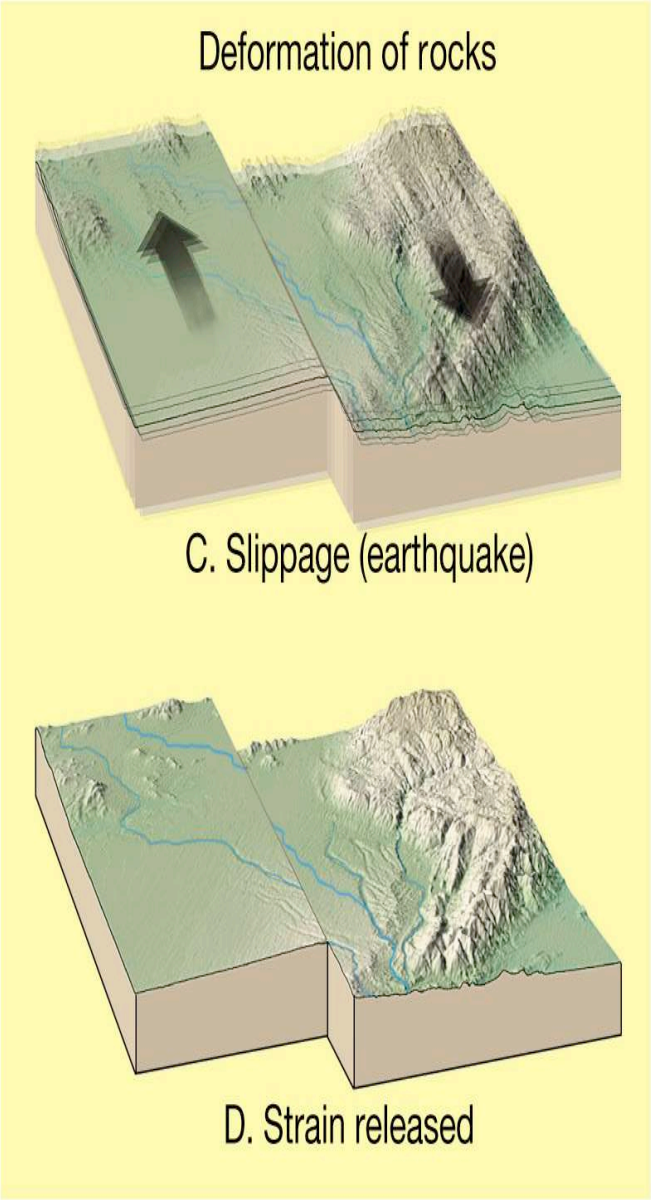


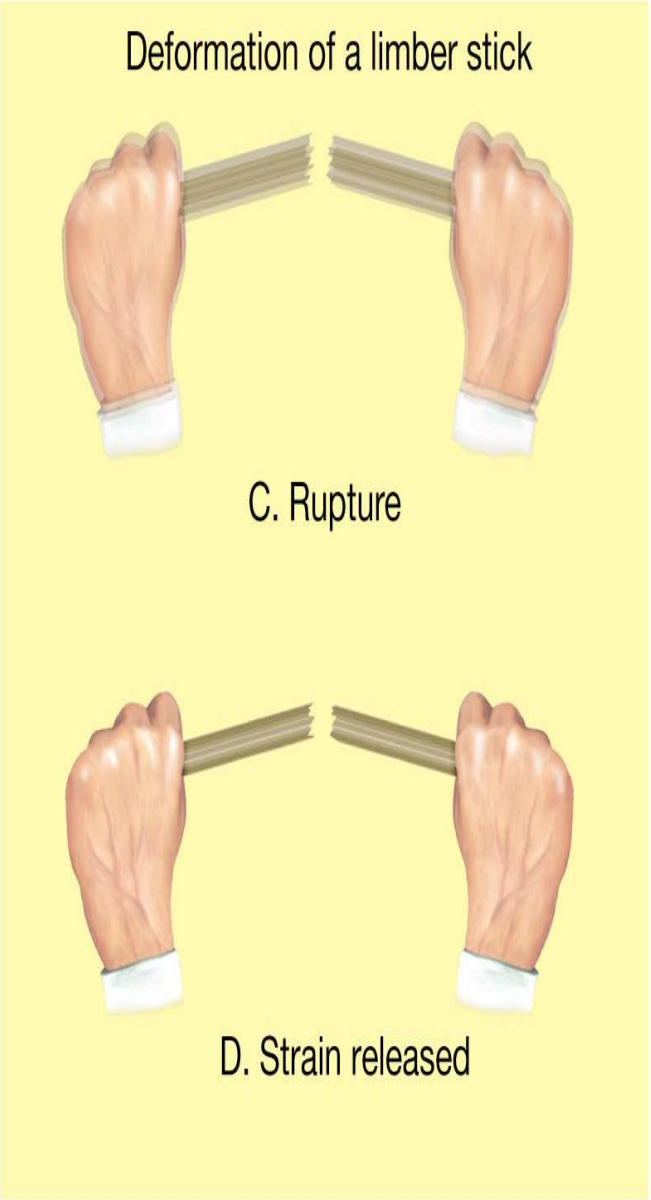


How do earthquakes occur?

- When the rocks reach their elastic limit, they break, and energy is released in the form of seismic waves, radiating out from the earthquake focus

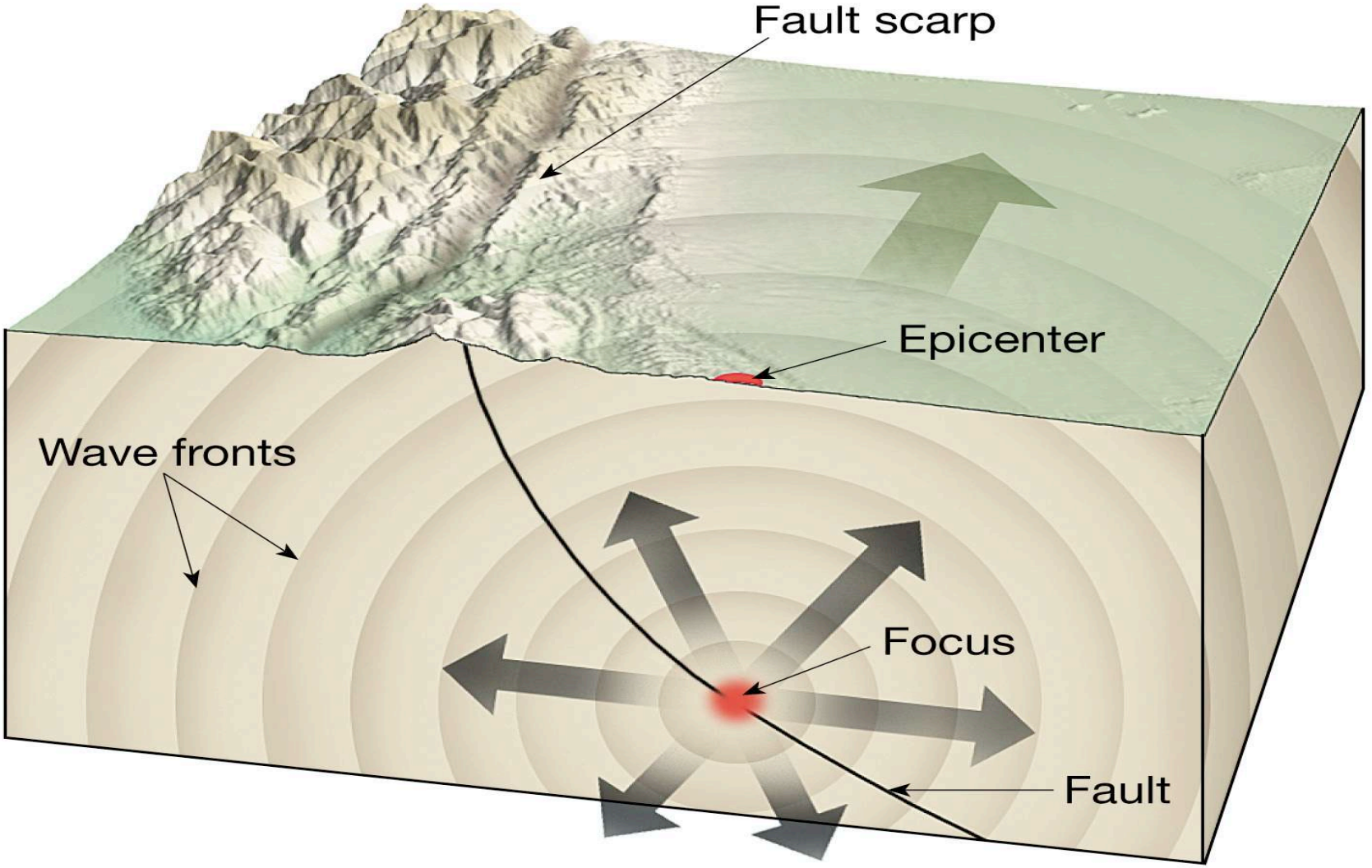
- The rocks return to their original shape, with a displacement (slip) along the fault





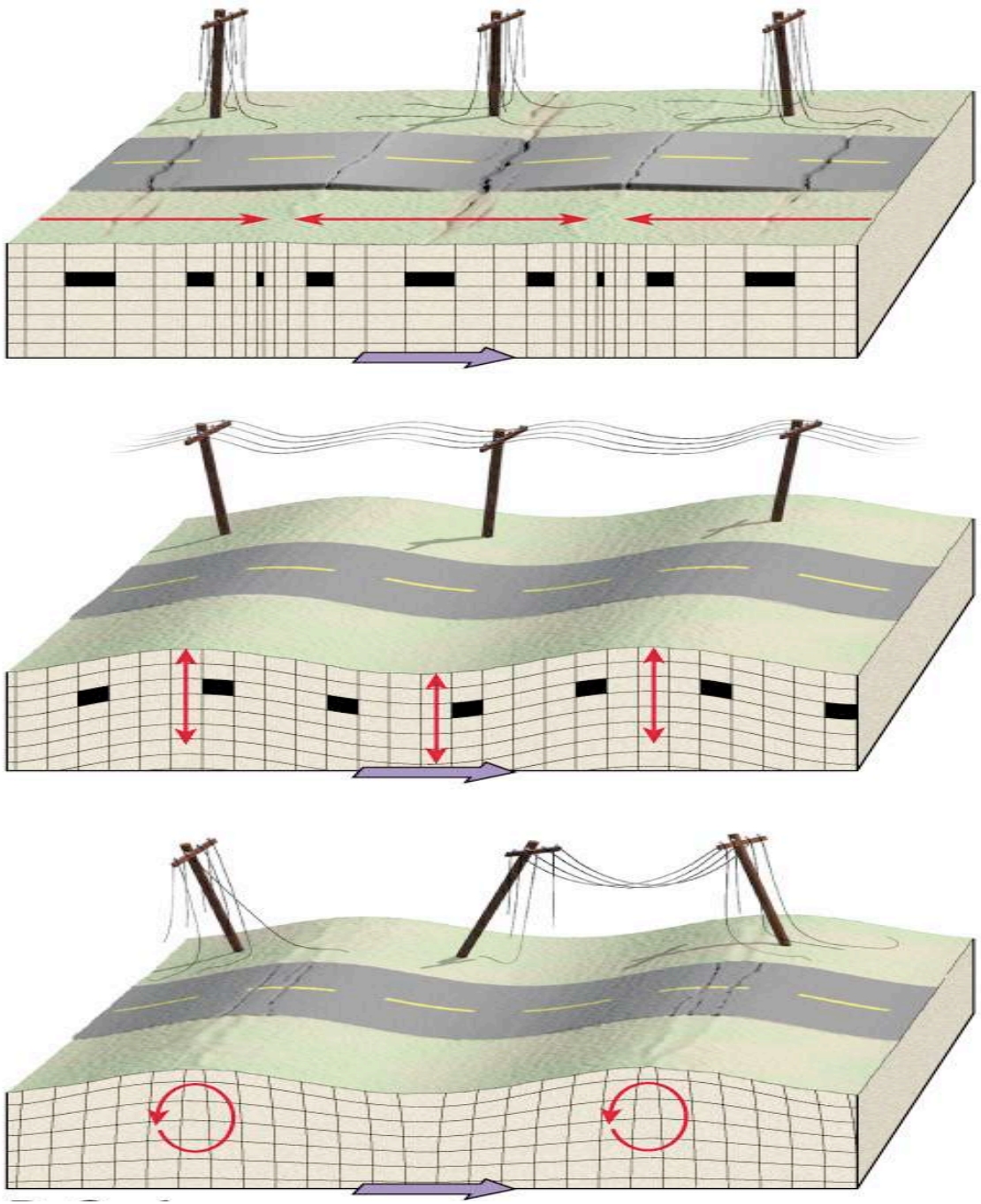
Earthquake focus*: center of rupture or slip, seismic waves radiate out from the *focus

***Earthquake epicenter* – the point on the Earth's surface over the focus**

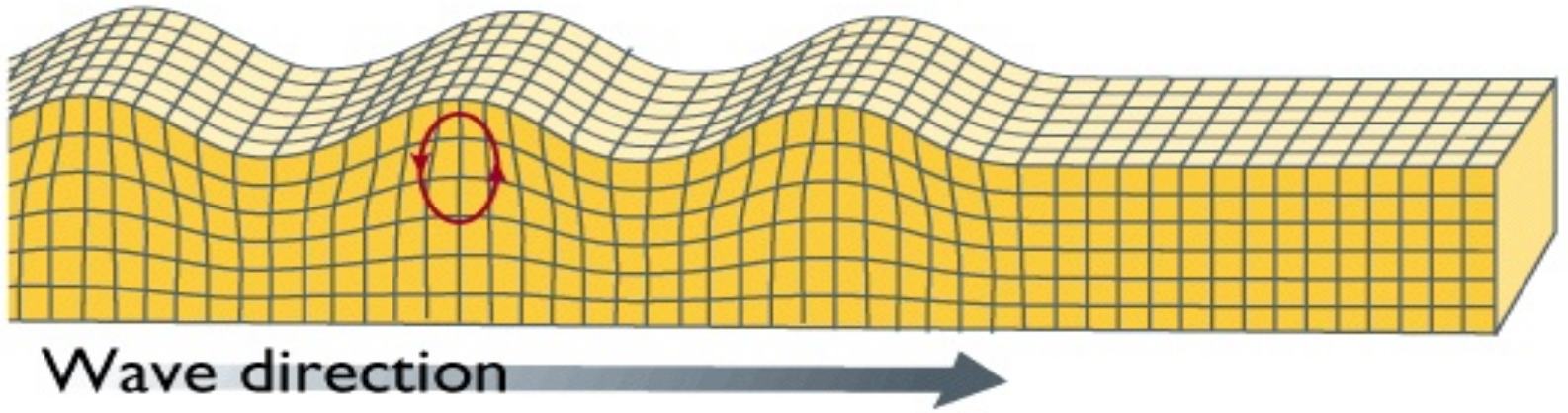


Kind of seismic waves

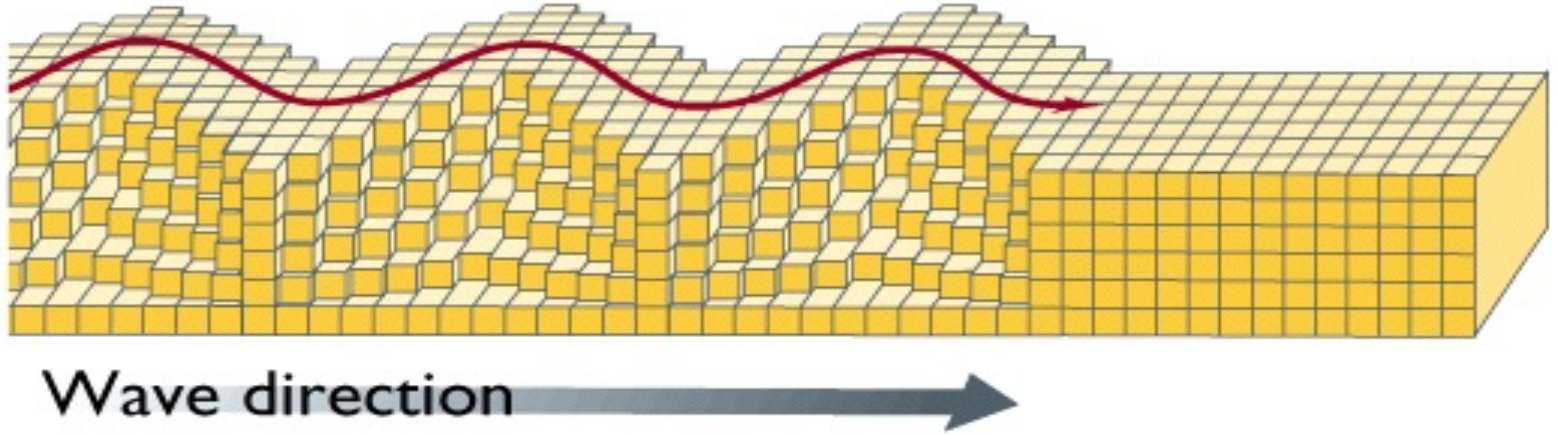
- **P-waves** – most rapid (8 km/sec)
- **S-waves** – slower (5 km/sec), cannot move through liquids
- **Surface waves** – even slower, move only on surface, most destructive



Surface waves

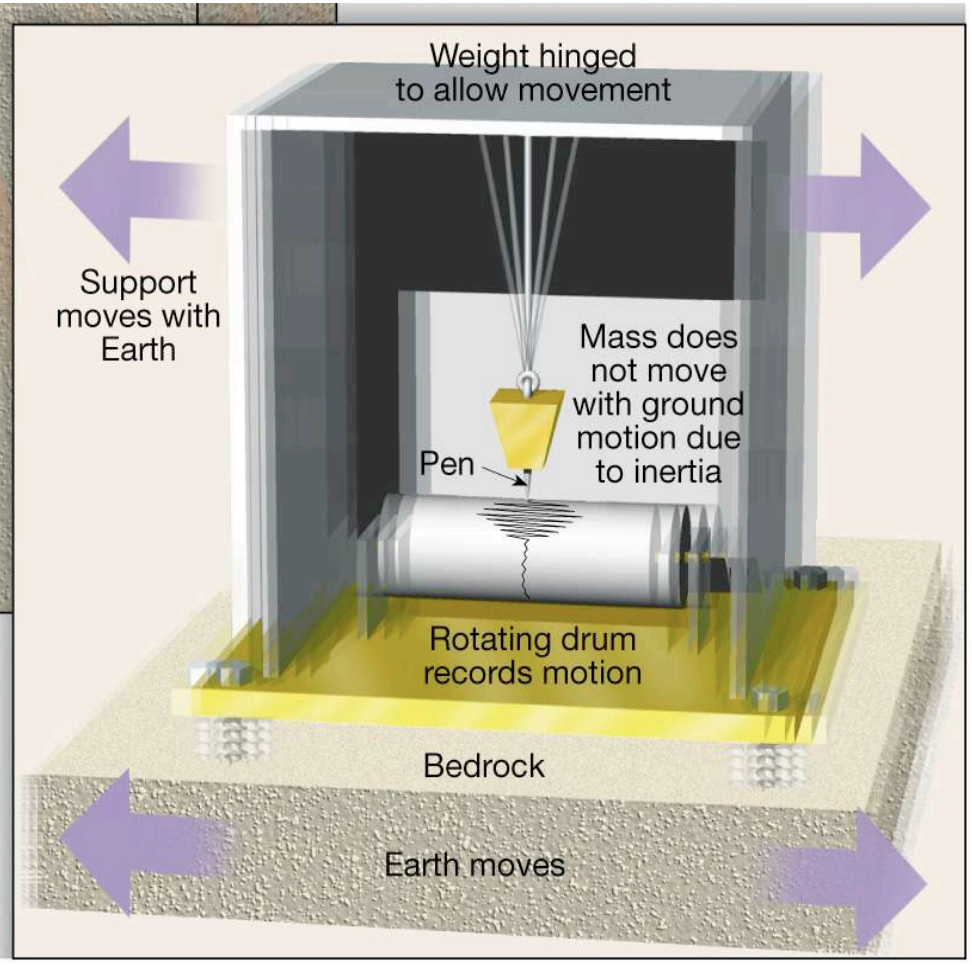


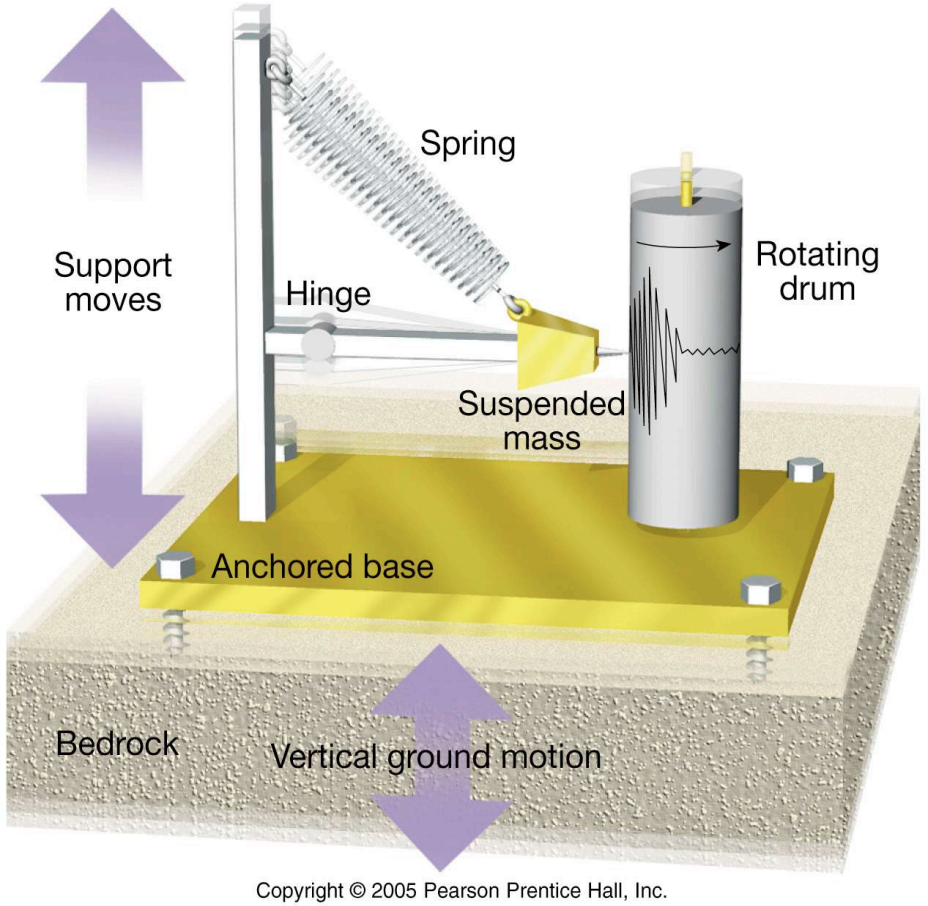
(a)



(b)

Detecting and measuring seismic waves

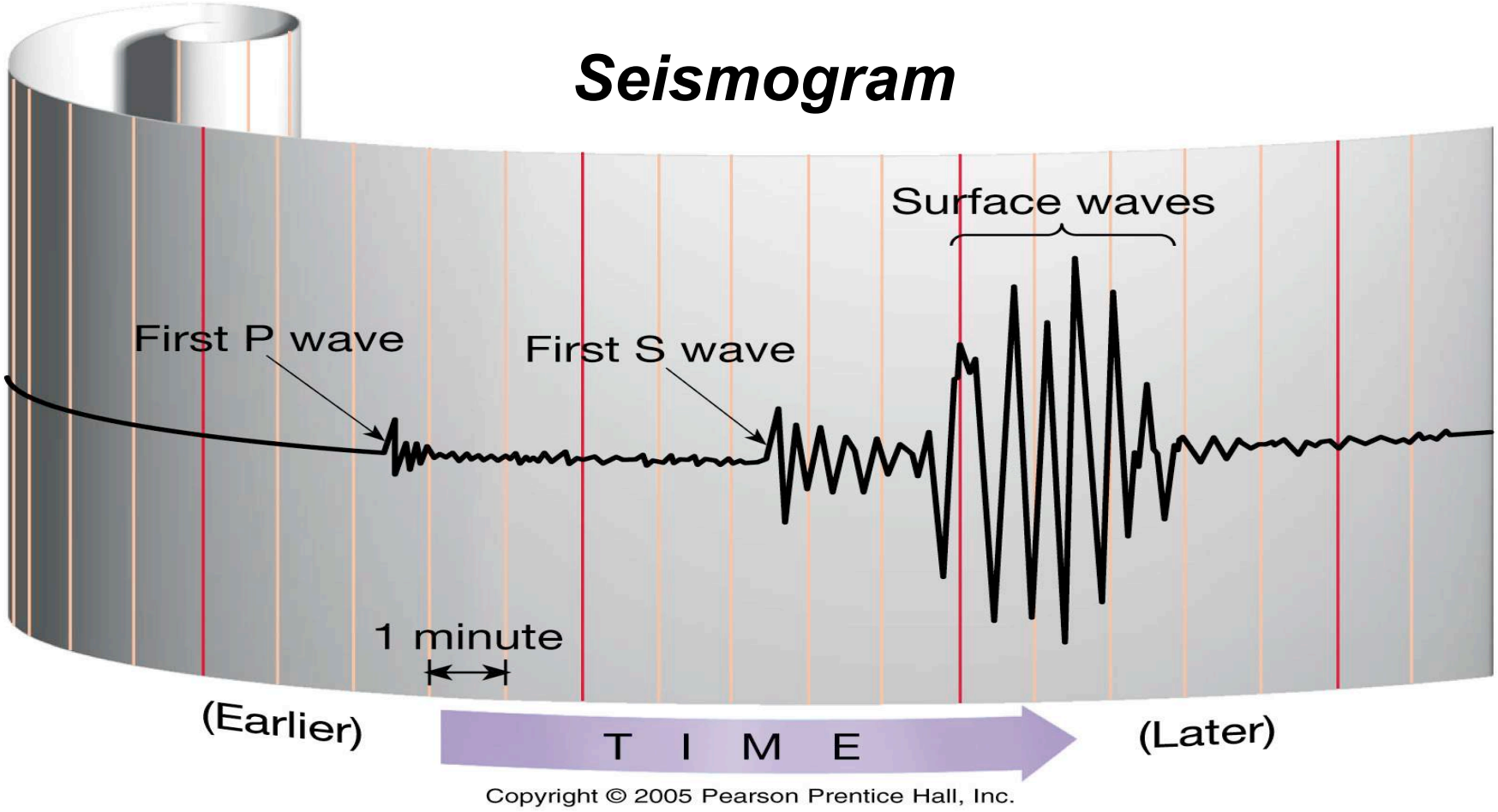




***Seismometers*:**

- **The paper roll moves with the ground**
- **The pen remains stationary, because of the spring, hinge and weight**

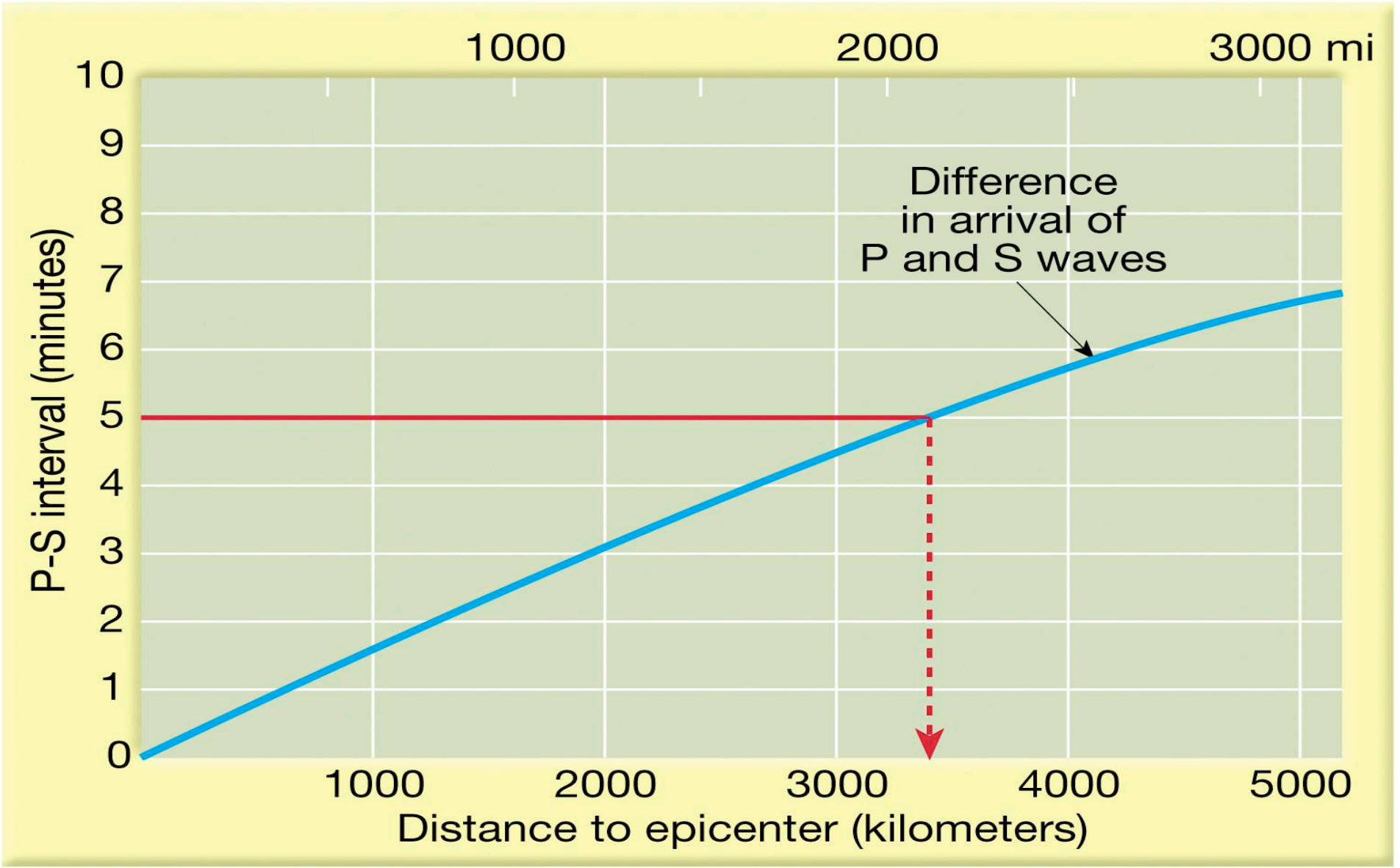
Seismogram



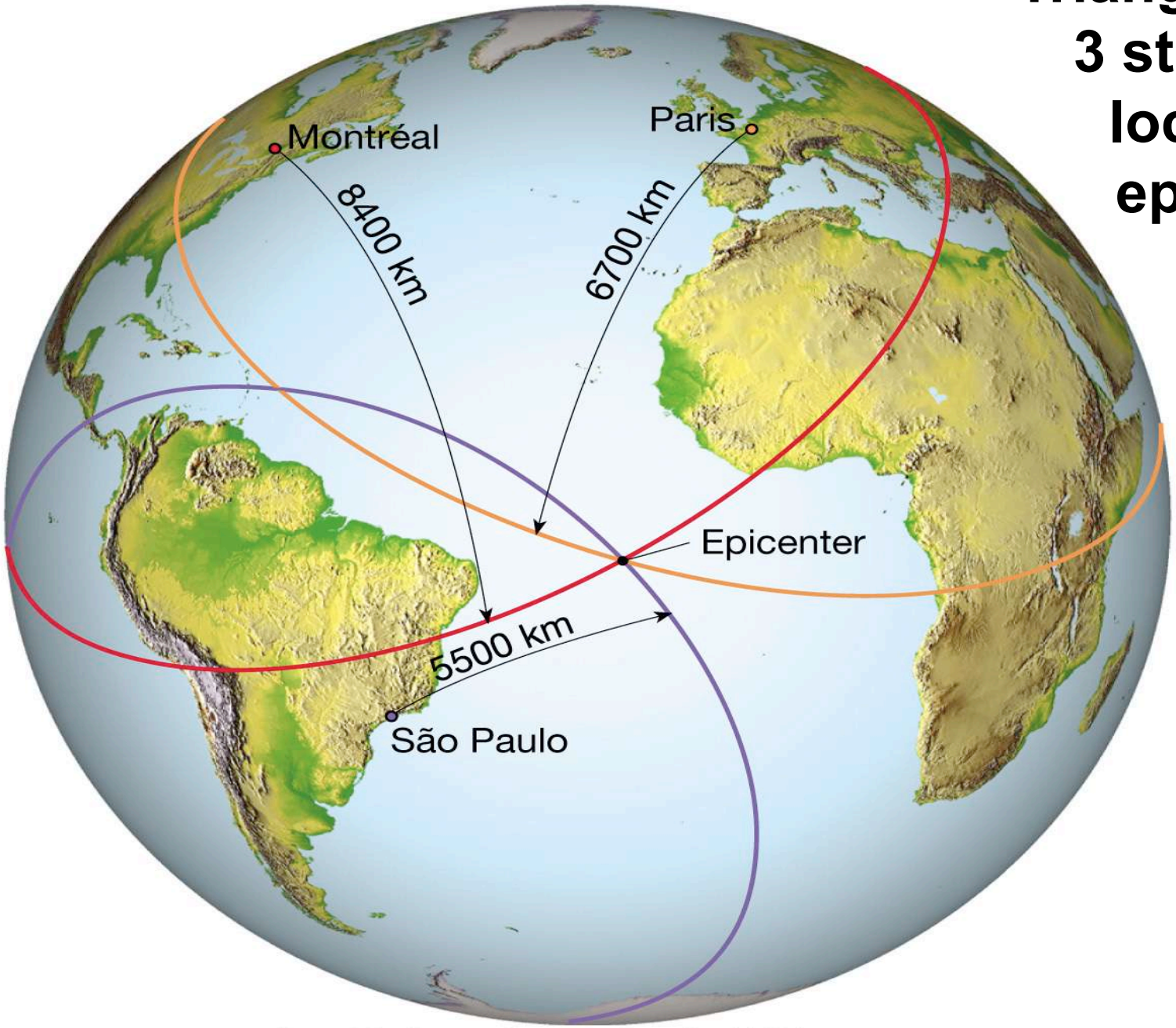
Tells you:

1) **How far away the earthquake occurred, based on the time difference between p and s –wave arrivals**
2) **Magnitude of ground motion, based on the amplitude of the surface waves**

The time interval between p and s-wave arrivals tells you how far away the epicenter is

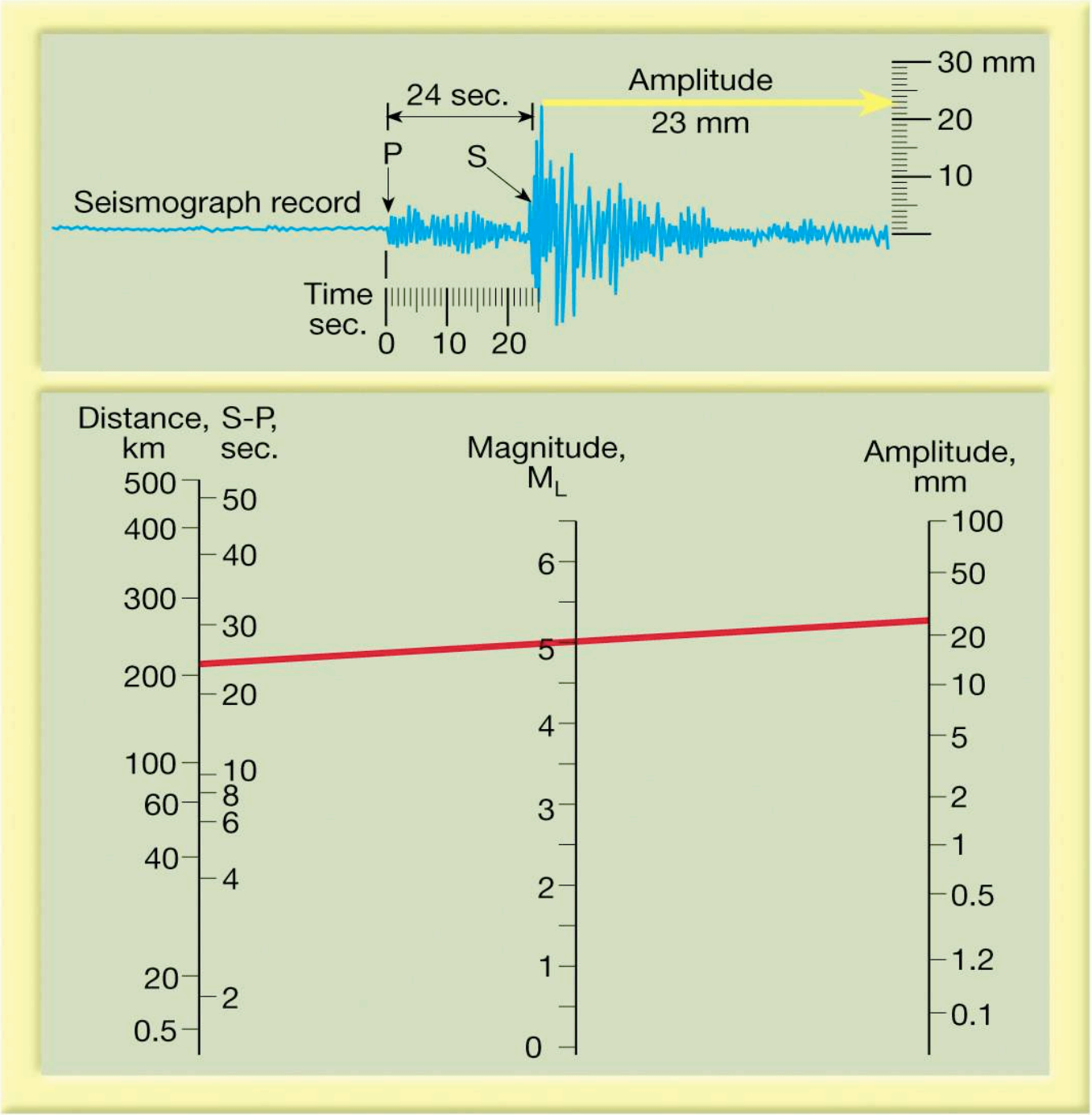


Triangulate from 3 stations to locate the epicenter

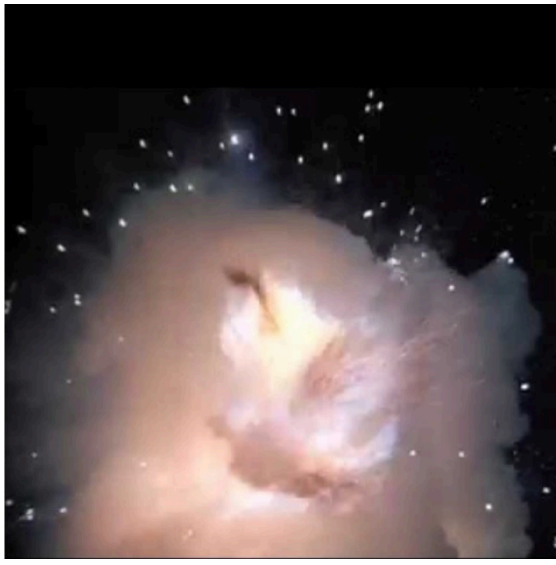


Earthquake ***magnitude*** *is related to the amount of energy released by the earthquake.*

The ***Richter magnitude*** M_L *is measured using the amplitude of the seismic waves. Another measure is called the* ***moment magnitude*** M_w



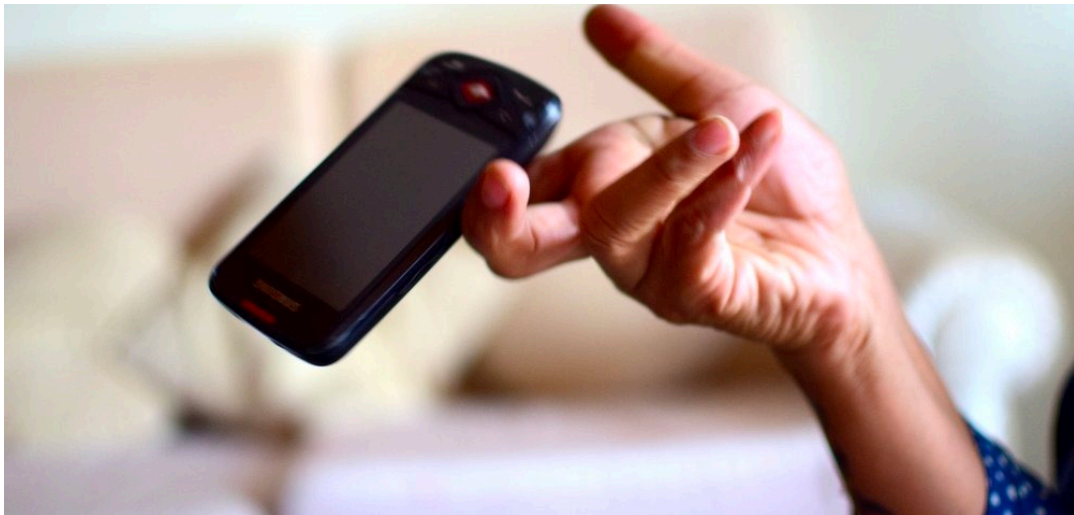
- Richter Scale is log based and aims to scale the *energy* of the wave
- $M = \frac{2}{3}\log(E_1/E_0)$
  - $E_0 = 10^{4.4}$ J = ”standard earthquake”
  - So a magnitude 18.6 earthquake releases $E_1 = 2.0 \times 10^{32}$ J, which is the gravitational binding energy of the Earth
  - The Death Star caused a M= 18.6 earthquake on Alderaan



- Your cell phone falling off the desk will hit the ground with about 1.2 J of energy. What magnitude earthquake will that create?
- $M = \frac{2}{3}\log(E_1/E_0)$

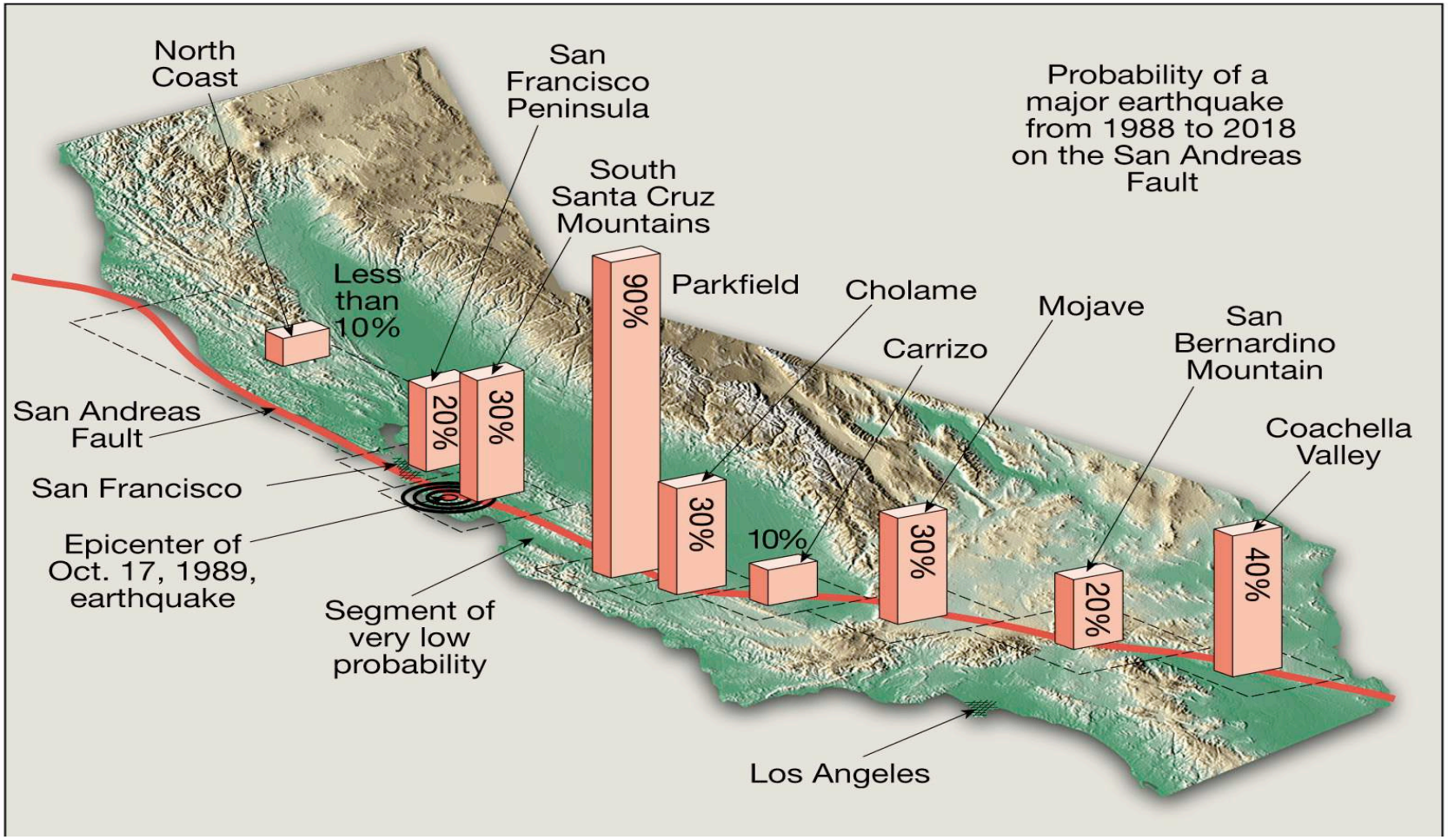
  $E_0 = 10^{4.4}$ J

  $M = -2.9$



Forecasting Earthquakes:

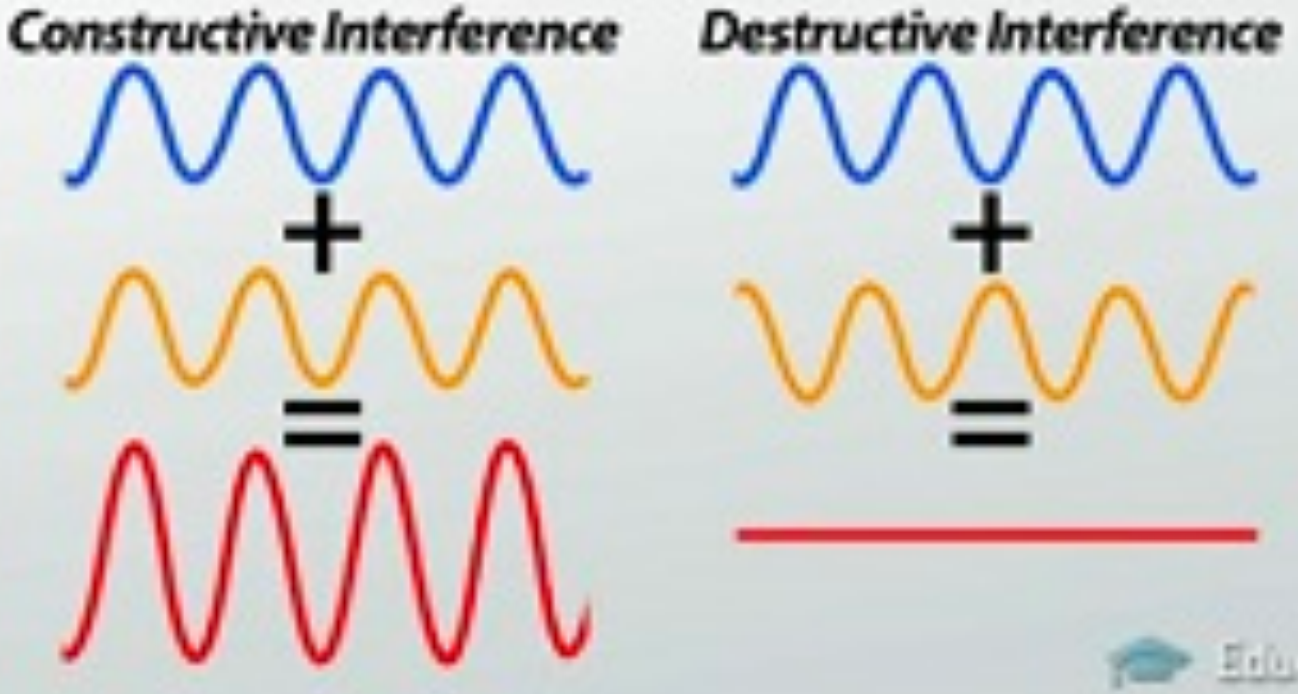
- **Unlike, volcanic eruptions, short-term warnings (*precursors*) are not well known**
- **Real-time warning (after earthquake has occurred) can be effective – radio waves & fiber optic transmissions to shut down reactors, close gas lines, etc. within seconds or minutes**
- **Long term earthquake probability is estimated using the *Seismic Gap Method***

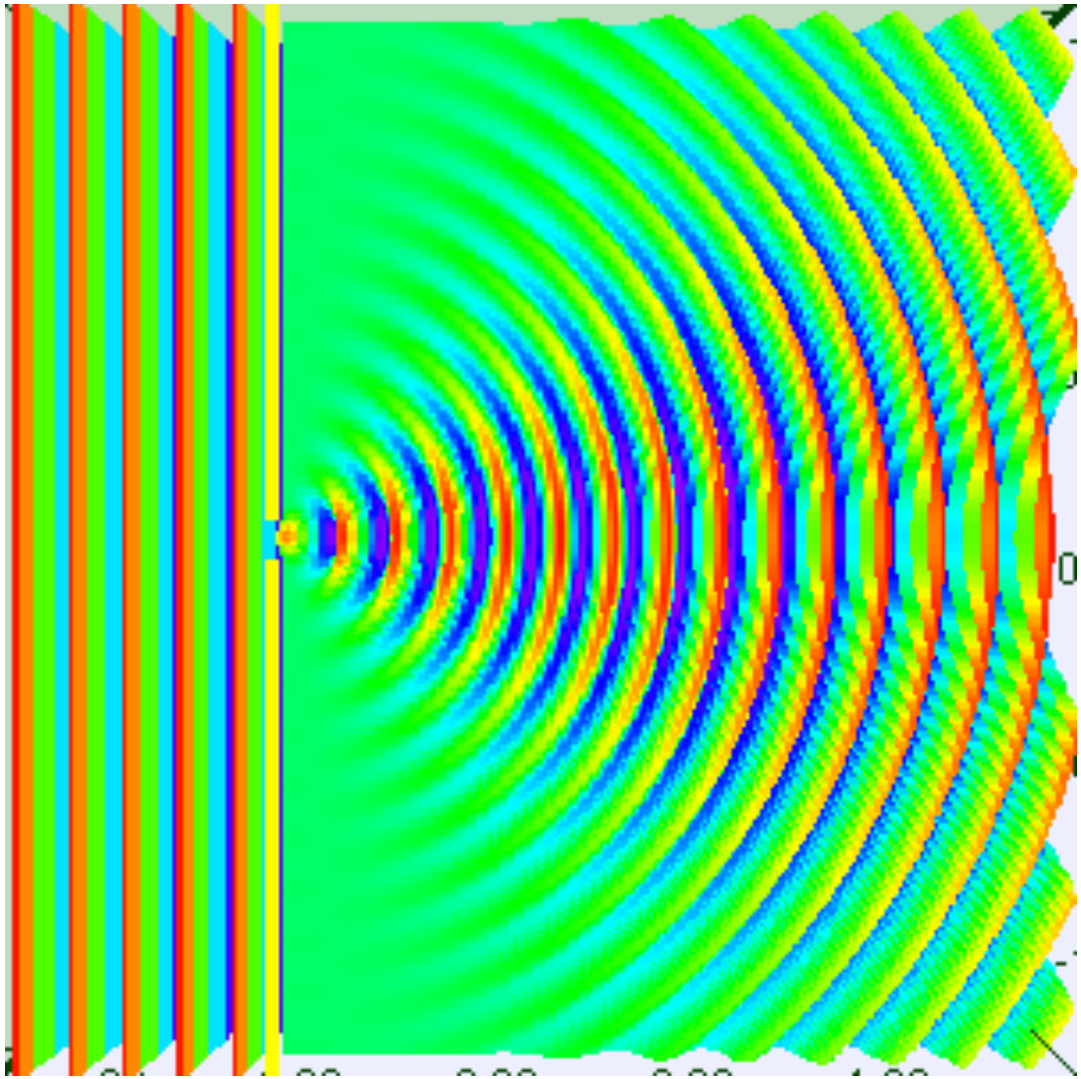


Interference (click here for double slit experiment video)

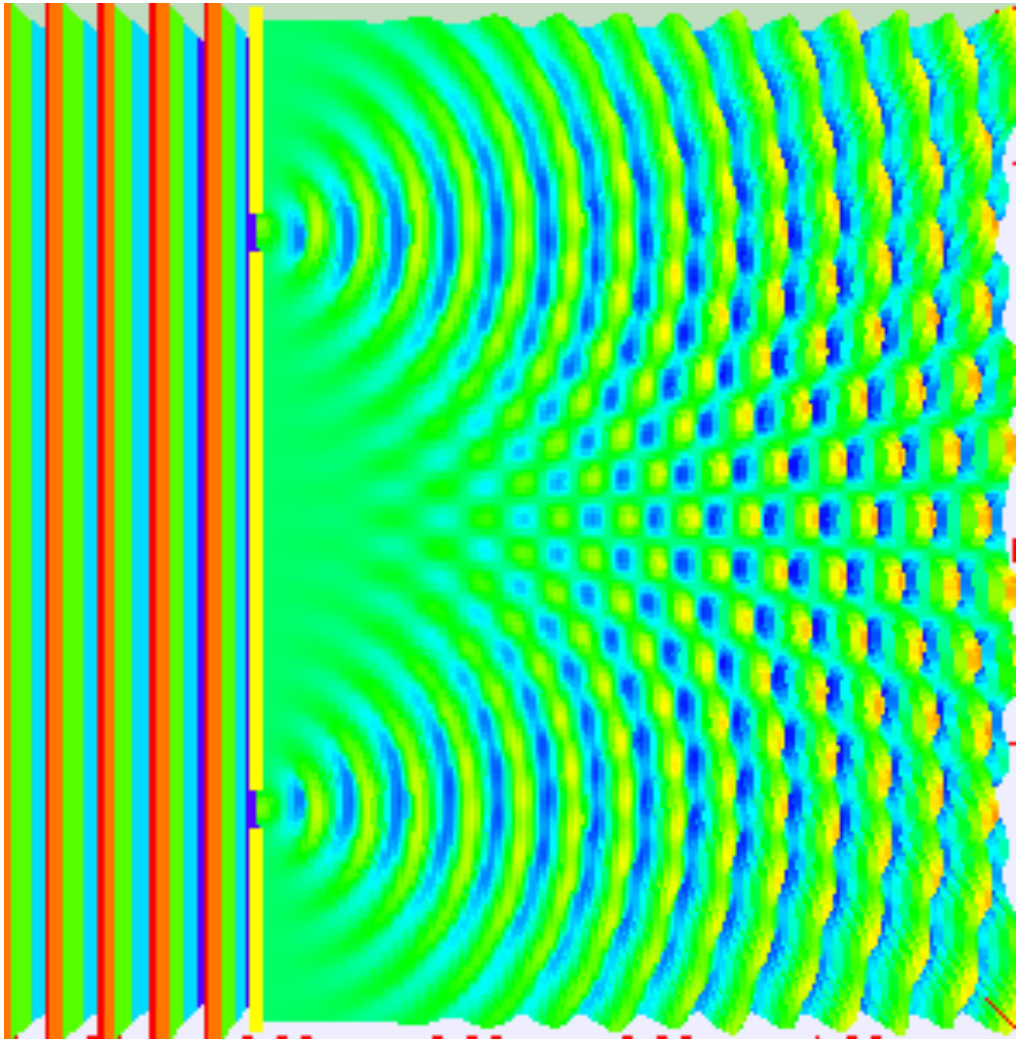
- Occurs when two of more waves meet
- Parts of the waves may overlap and form an interference pattern
  - Wave effects may be increased, decreased, or neutralized
- When the crest of one wave overlaps with the crest of another, their individual effects add up
  - Called constructive interference
- When the crest of one wave meets the trough of another, their individual effects decrease
  - Called destructive interference
- Characteristic of all wave motion, whether water waves, sound waves, or light waves

PRINCIPLE OF SUPERPOSITION





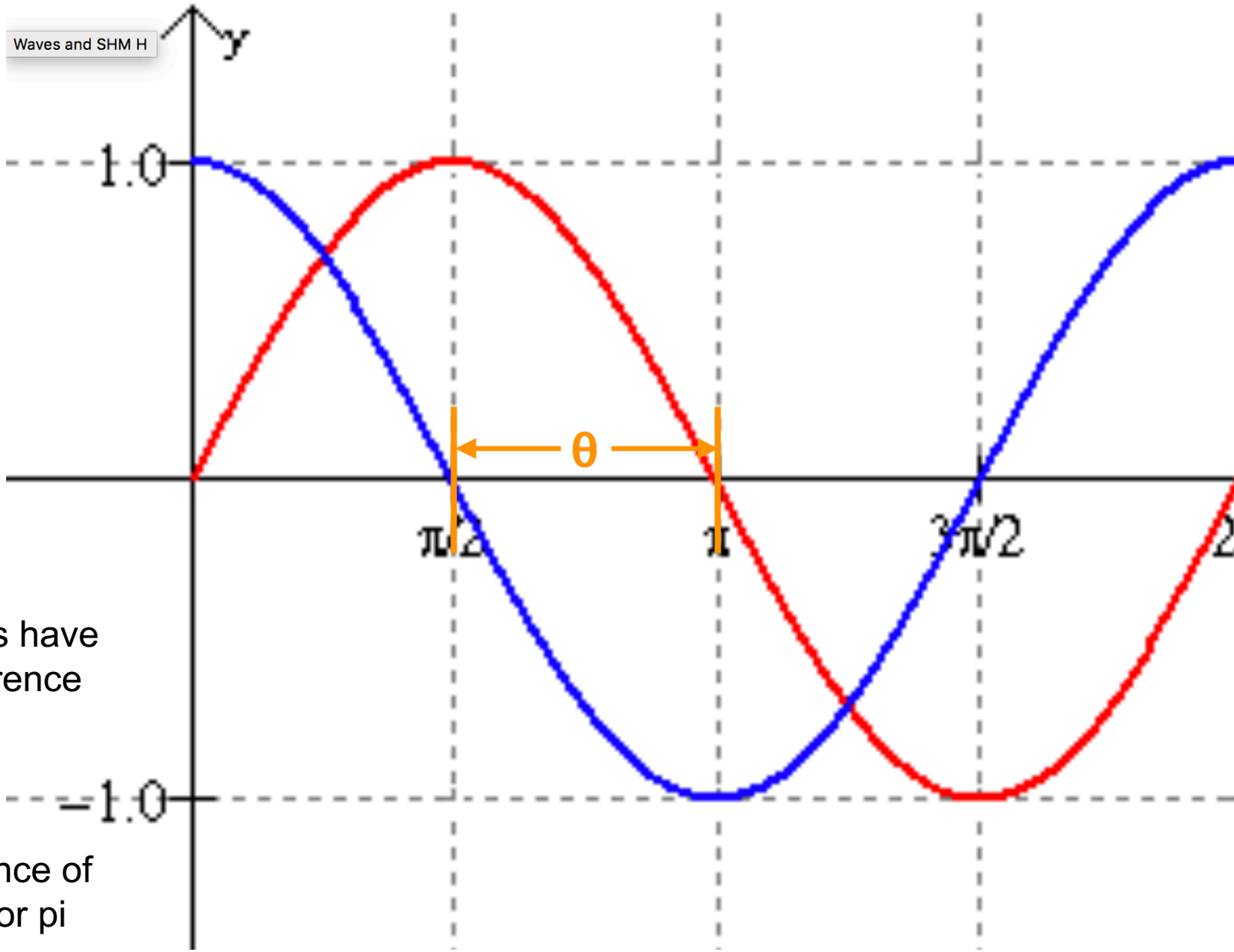
- Diffraction: Spreading out of waves from a narrow aperture
- Reflection: waves bouncing off a boundary
  - Why we see different colors



- Constructively interfere: extra large crests and troughs
- Destructively interfere - green sections

Phase

- Phase is the relationship between the period of a wave and an external reference point
  - Two waves which are *in phase* are in synch
  - Two waves which are *out of phase* are out of synch

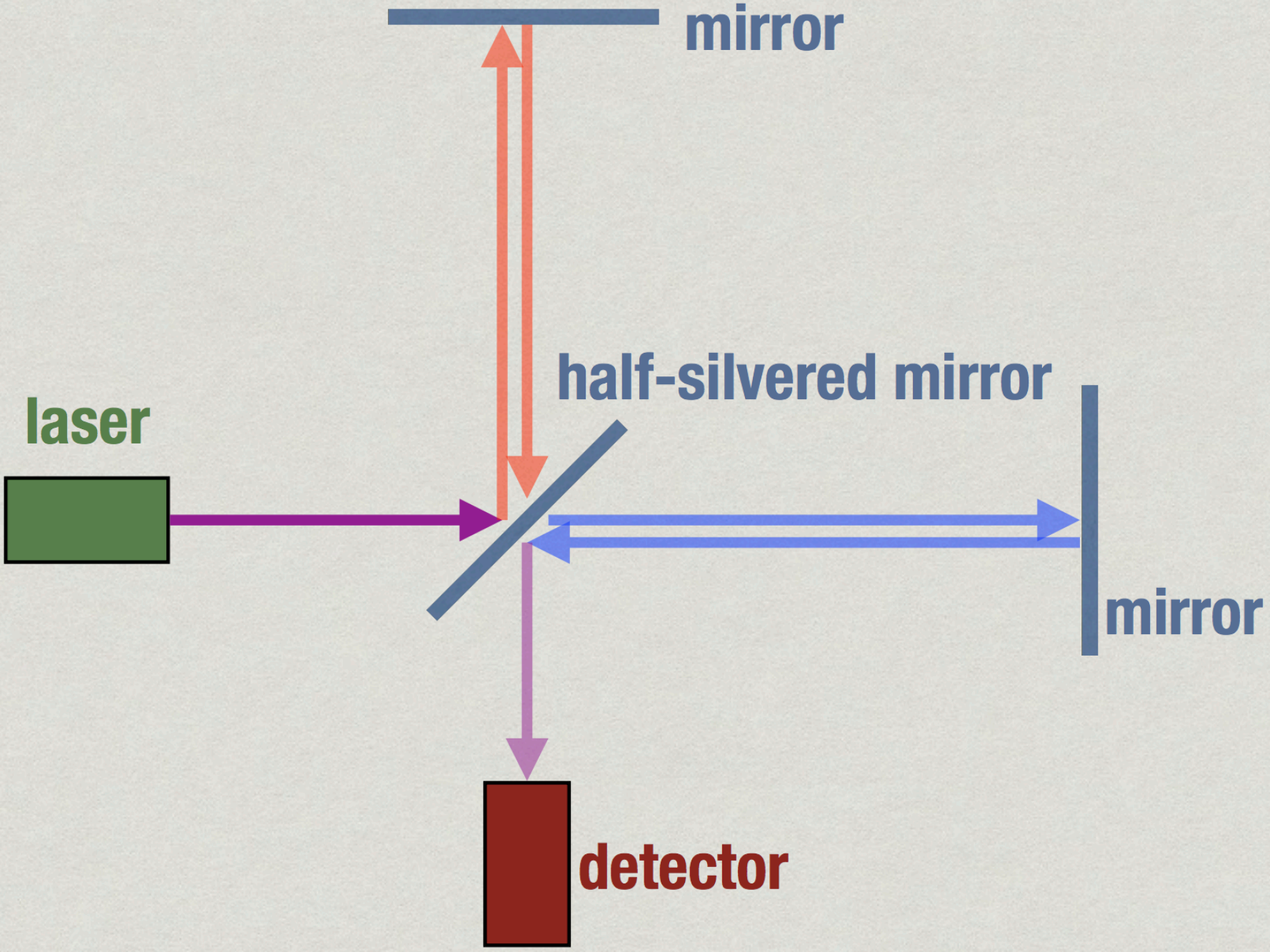


θ= “phase difference”
-These waves have a phase difference of $\frac{\pi}{2}$ radians

Waves with a phase difference of 180 degrees or pi radians will perfectly destructively interfere

Interferometry

- A family of techniques in which you use interference patterns to extract information about the wave is called **interferometry**
- Usually measures difference between light waves (especially lasers)
- How we discovered gravitational waves


mirror
half-silvered mirror
laser
mirror
detector