L 21 – Vibration and Waves [2]

- Vibrations (oscillations)
  - resonance
  - pendulum
  - springs
  - harmonic motion
- Waves
  - mechanical waves
  - sound waves
  - musical instruments

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REVIEW: Vibrating systems

- Mass and spring on air track
- Mass hanging on spring
- Pendulum
- Torsional oscillator

All vibrating systems have one thing in common ➔ *restoring force*

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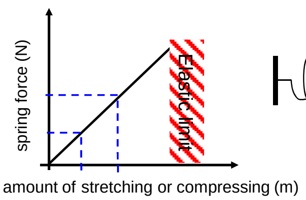
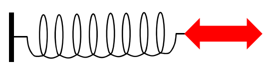
Springs obey Hooke's Law





- the strength of a spring is measured by how much force it provides for a given amount of stretch
- we call this quantity **k, <u>the spring constant in N/m</u>**
- magnitude of spring force = **k** × **amount of stretch**

➔ $\mathbf{F_{spring} = k\,x}$ ➔

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example

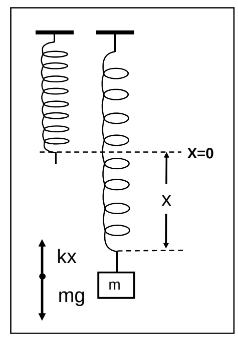
- *A mass of 2 kg is hung from a spring that has a spring constant k = 100 N/m. By how much will it stretch?*
- The downward weight of the mass is balanced by the upward force of the spring.
- $w = mg = k\,x$

  = 2 kg × 10 m/s^2

  = (100 N/m) × x

20 N = 100 N/m × x

➔ <u>x = 0.2 m or 20 cm</u>



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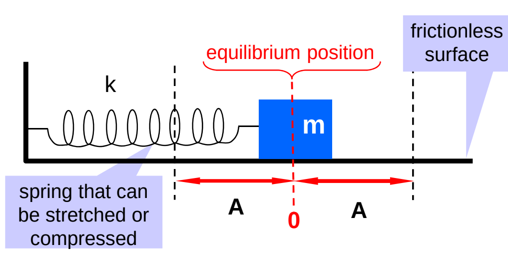
simple harmonic oscillator

mass and spring on a frictionless surface



k is the spring constant, which measures the *"stiffness"* of the spring in Newtons per meter

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Terminology

- **AMPLITUDE A:** maximum displacement from equilibrium (starting position)
- **PERIOD T:** time for one complete cycle
- **FREQUENCY *f* :** number of complete cycles per unit time; one cycle per second = 1 Hertz (Hz)
- Frequency and period are <u>not</u> independent quantities, but are related inversely:

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

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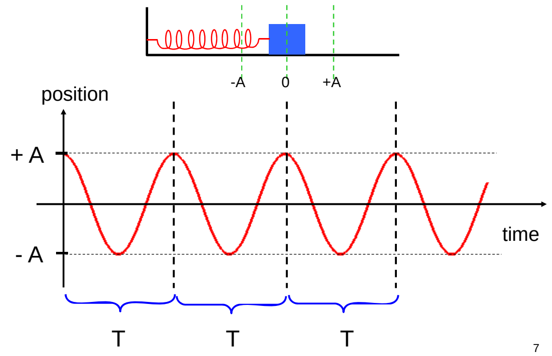
follow the mass – position vs. time



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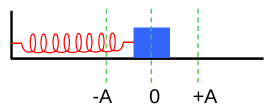
Period (T) and frequency (*f*) of the mass-spring system



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

$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

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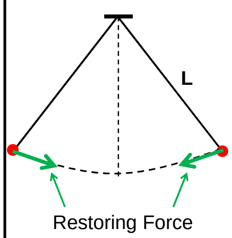
Period and frequency of the pendulum



$$T = 2\pi\sqrt{\frac{L}{g}} \rightarrow f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$$

- The period depends on L and g
- The period does not depend on the mass, m

For L = 1 m, $T = 2\pi\sqrt{\frac{L}{g}} = 2\pi\sqrt{\frac{1\ m}{10\ m/s^2}} = 2\pi(0.316) \cong 2\ s$

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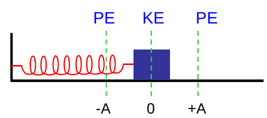
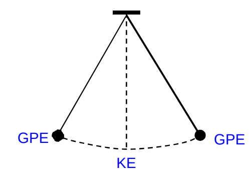
Energy in the simple harmonic oscillator

E_{total} = KE + PE = constant



The spring has *elastic potential energy*



The pendulum has *gravitational potential energy*

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Waves → vibrations that *move*

- What is a wave? A *disturbance* that moves (*propagates*) through a medium
- Due to the elastic nature of materials
- The *"people wave"* – you stand up and sit down, then the person next to you does the same, and so on, so the *"disturbance"* goes all around the stadium the standing and sitting is the disturbance
  - notice that the people move up and down but the disturbance goes sideways- this is called a *transverse wave*

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Why are waves important?

- Waves are a means to transport energy from one place to another without transporting matter
- Electromagnetic waves (light, x-rays, UV rays, microwaves, thermal radiation) are disturbances that propagate through the electromagnetic field, even in *vacuum* (e.g. light from the Sun→ takes about 8 minutes to get to earth)

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Wave Classification

- Classification based on the “medium”
  - Mechanical waves: a disturbance that propagates through a medium
    - waves on strings
    - waves in water (ocean waves, ripples on a lake)
    - sound waves – pressure waves in air
  - Electromagnetic waves → no medium required
- Classification based on how the medium moves
  - transverse
  - longitudinal
- Classification based on time history
  - single pulse (non-repetitive)
  - series of waves – harmonic wave (repetitive)

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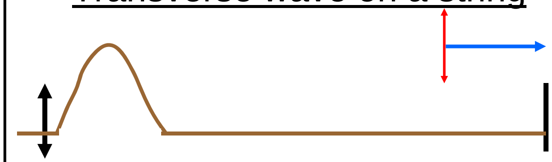
Transverse wave on a string



- jiggle the end of the string to create a disturbance
- the disturbance moves down the string
- as it passes, the string moves up and then down
- the string motion in vertical but the wave moves in the horizontal (perpendicular) direction→ transverse wave
- this is a single pulse wave (non-repetitive)

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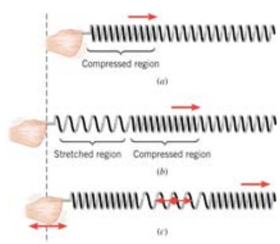
Longitudinal waves

- instead of jiggling the spring up and down, you jiggle it in and out
- the coils of the spring move along the same direction (horizontal) as the wave
- This produces a *longitudinal wave*
- Sound waves are longitudinal waves



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Speed of a wave on a string

- Note that the speed of the wave moving to the right is not the same as the speed of the string as it moves up and down.
- The wave speed is determined by:
  - the tension in the string
    → more tension → higher speed
  - the *mass per unit length* of the string (whether it’s a heavy rope or a light rope)
    → thicker rope → lower speed

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Harmonic waves – keep jiggling the end of the string up and down

→ produces a continuous *wavetrain*

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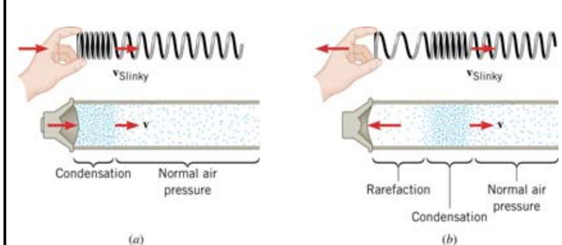
Sound – a longitudinal wave



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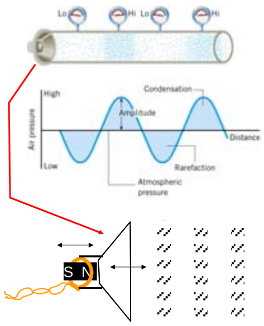
SOUND WAVES



SPEAKER

- longitudinal pressure disturbances in a gas, (liquid, or solid)
- the air molecules jiggle back and forth along the same direction as the wave
- A series of high pressure regions (condensations) and low pressure regions (rarefactions)

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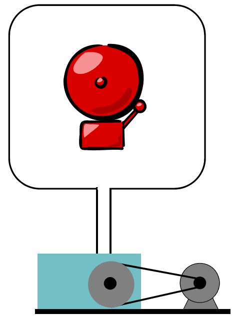
No air --- no sound!



vacuum
pump

- Sound is a disturbance in a gas (air)
- In vacuum, there are no sound waves
- → there is no sound in outer space

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Human sense of hearing

Our sense of hearing is much more sensitive than our sense of sight

- Sound waves cause our eardrums to vibrate
- The eardrum is sensitive to displacements on the order of the size of an atom
- Humans can hear sounds between about 30 Hz and 20,000 Hz
  - Sound below 30 Hz is called infrasound
  - Sound above 20,000 Hz is called ultrasound

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The speed of sound

- Sound→ pressure waves in a solid, liquid or gas
- The speed of sound→ v_s
  - Air at 20 C: 343 m/s = 767 mph ≈ **1/5 mile/sec**
  - Water at 20 C: 1500 m/s
  - copper: 5000 m/s
- Depends on density and temperature

5 second rule for thunder and lightning

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Why do I sound funny when I breath helium?

- The speed of sound depends on the mass of the molecules in the gas
- Sound travels twice as fast in helium, because Helium is lighter than air
- The higher sound speed results in sounds of higher pitch (frequency)

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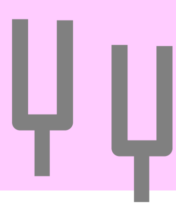
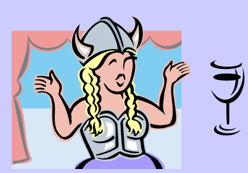
Acoustic resonance

tuning fork resonance



shattering the glass



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