

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

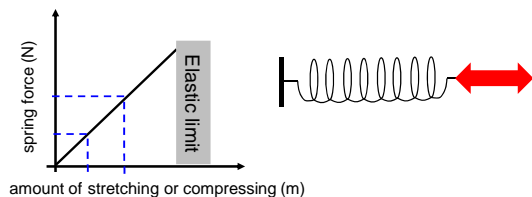
- Mass and spring on air track
- Mass hanging on spring
- Pendulum
- Torsional oscillator

All vibrating systems have one thing in common

→ **restoring force**

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Springs obey Hooke's Law

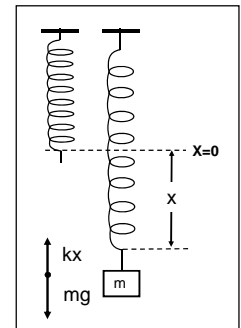


- the strength of a spring is measured by how much force it provides for a given amount of stretch
 - we call this quantity **k**, **the spring constant in N/m**
 - magnitude of spring force = **k × amount of stretch**
- **$F_{\text{spring}} = kx$** ←

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example

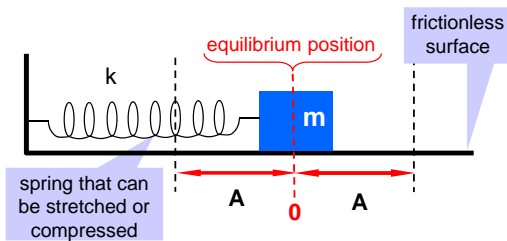
- A mass of 2 kg is hung from a spring that has a spring constant $k = 100 \text{ N/m}$. By how much will it stretch?
- The downward weight of the mass is balanced by the upward force of the spring.
- $w = mg = kx$
 $= 2 \text{ kg} \times 10 \text{ m/s}^2$
 $= (100 \text{ N/m}) \times x$
 $20 \text{ N} = 100 \text{ N/m} \times x$
 → $x = 0.2 \text{ m}$ or **20 cm**



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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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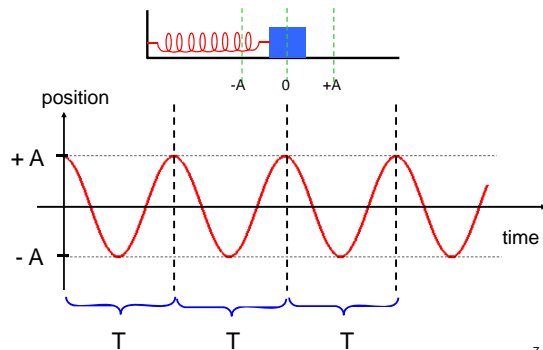
Terminology

- **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 not independent quantities, but are related inversely:

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

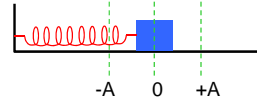
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follow the mass – position vs. time



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

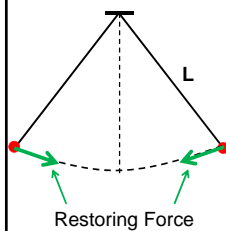


$$T = 2\pi\sqrt{\frac{m}{k}}$$

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

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Period and frequency of the pendulum



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

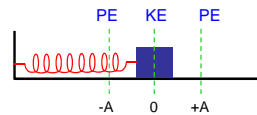
- The period depends on L and g
- The period does not depend on the mass, m

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

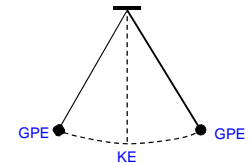
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Energy in the simple harmonic oscillator

$$E_{\text{total}} = KE + PE = \text{constant}$$



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. [Video](#)
 - 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 responds**
 - 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

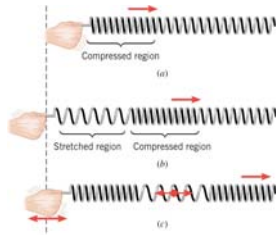


- jiggle the end of the string to create a disturbance
- the disturbance moves down the string
- as it passes, the string moves up and then down
- the **string motion in vertical** but the wave moves in the **horizontal (perpendicular) direction** → **transverse wave**
- this is a single pulse wave (non-repetitive)

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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

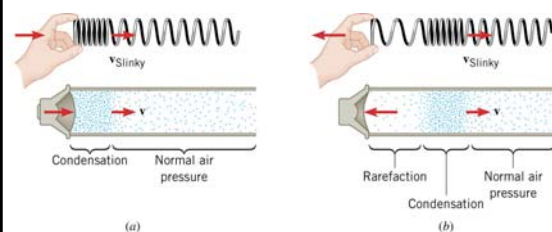
produced by jiggling the end of the string up and down continuously

→ **produces a continuous wavetrain**



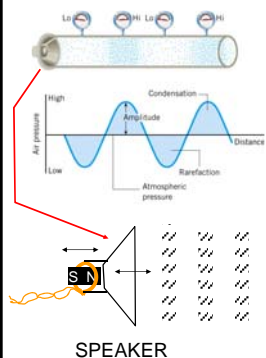
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Sound – a longitudinal wave



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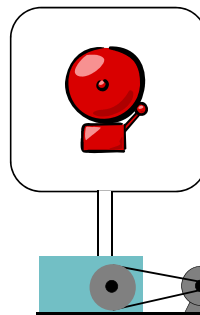
Sound Waves



- **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!

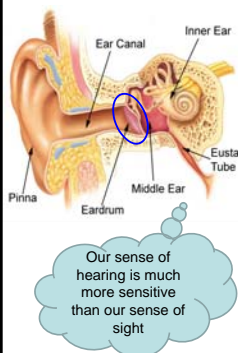


- Sound is a disturbance in a gas (air)
- In vacuum, there are no sound waves
- → there is no sound in outer space

vacuum pump

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Human sense of hearing



- 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 $\approx 1/5$ 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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