Course announcement

- Final midterm score is posted on eLearn. If you have any questions about score, please directly contact me (yhlin@phys.nthu.edu.tw).
- Review midterm exam: 11/11 after class, 11/14 office hours
- Homework set 3 will be posted on eLearn today. It will be due on 11/18 Friday at 5PM

Simple Harmonic Motion (SHM)

- A particle that is oscillating about the origin of an x axis, repeatedly going left and right by identical amounts. A simple harmonic motion (SHM) is that the displacement can be described as a sinusoidal function of time t:

$$x(t) = x_m \cos(\omega t + \phi)$$

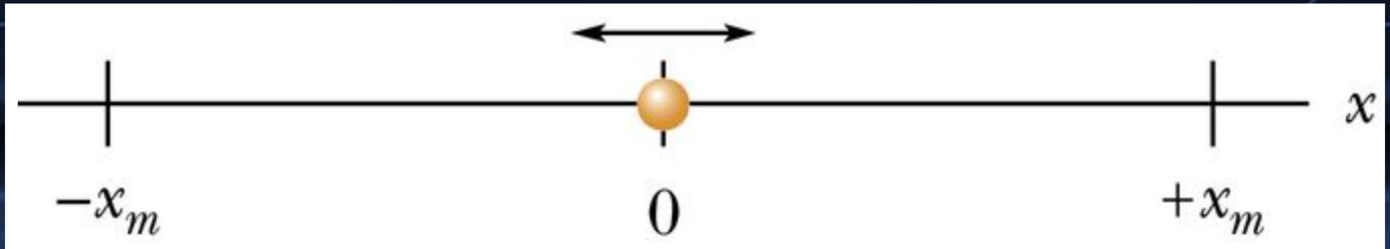
Phase

Displacement as a function of time t

Amplitude

Angular frequency

Phase constant



The position, velocity, and acceleration of SHM

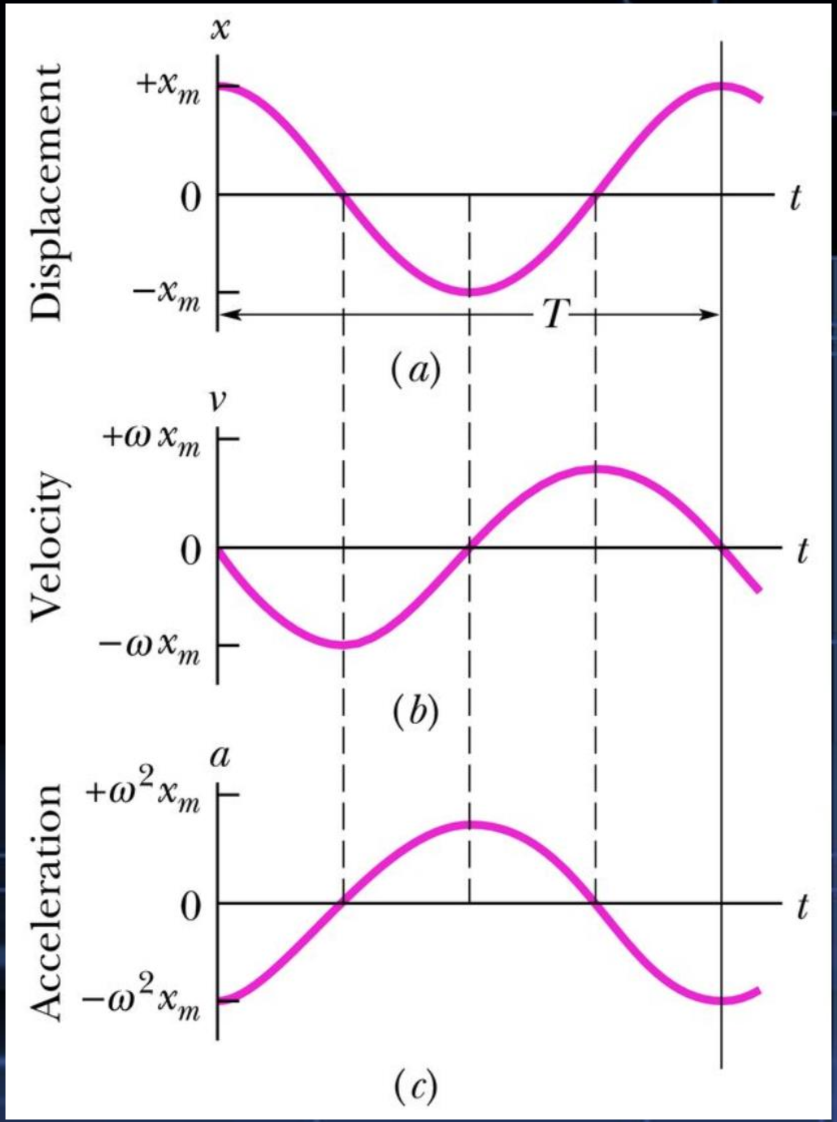
$$x(t) = x_m \cos(\omega t + \phi)$$

$$v(t) = -\omega x_m \sin(\omega t + \phi) \quad \text{(velocity)}$$

$$a(t) = -\omega^2 x_m \cos(\omega t + \phi) \quad \text{(acceleration)}$$

- We can also find that:

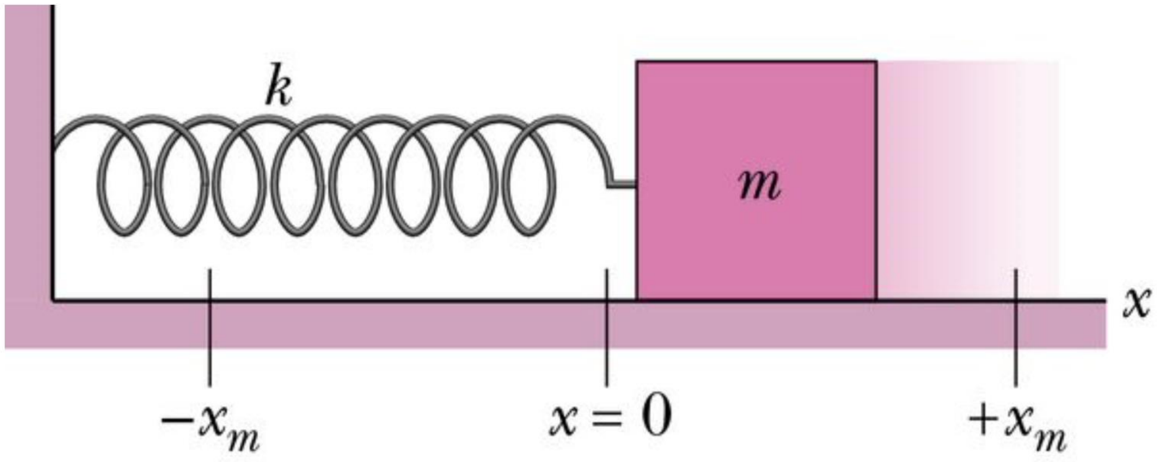
$$a(t) = -\omega^2 x(t)$$



The force law of simple harmonic oscillation

- From Newton’s second law we can know that the force in the SHM should have the form of:

$$F = ma = m\left(-\omega^2 x\right) = -\left(m\omega^2\right) x$$



- Thus:

$$\omega = \sqrt{\frac{k}{m}} \quad \text{(angular frequency)}$$

$$T = 2\pi\sqrt{\frac{m}{k}} \quad \text{(period)}$$

Energy in SHM

- When we discussed about spring force, we know the potential energy due to spring force is:

$$U(t) = \frac{1}{2}kx^2 = \frac{1}{2}kx_m^2 \cos^2(\omega t + \phi)$$

- The Kinetic energy:

$$K(t) = \frac{1}{2}mv^2 = \frac{1}{2}kx_m^2 \sin^2(\omega t + \phi)$$

- The total energy is:

$$E = U + K = \frac{1}{2}kx_m^2$$

Simple pendulums

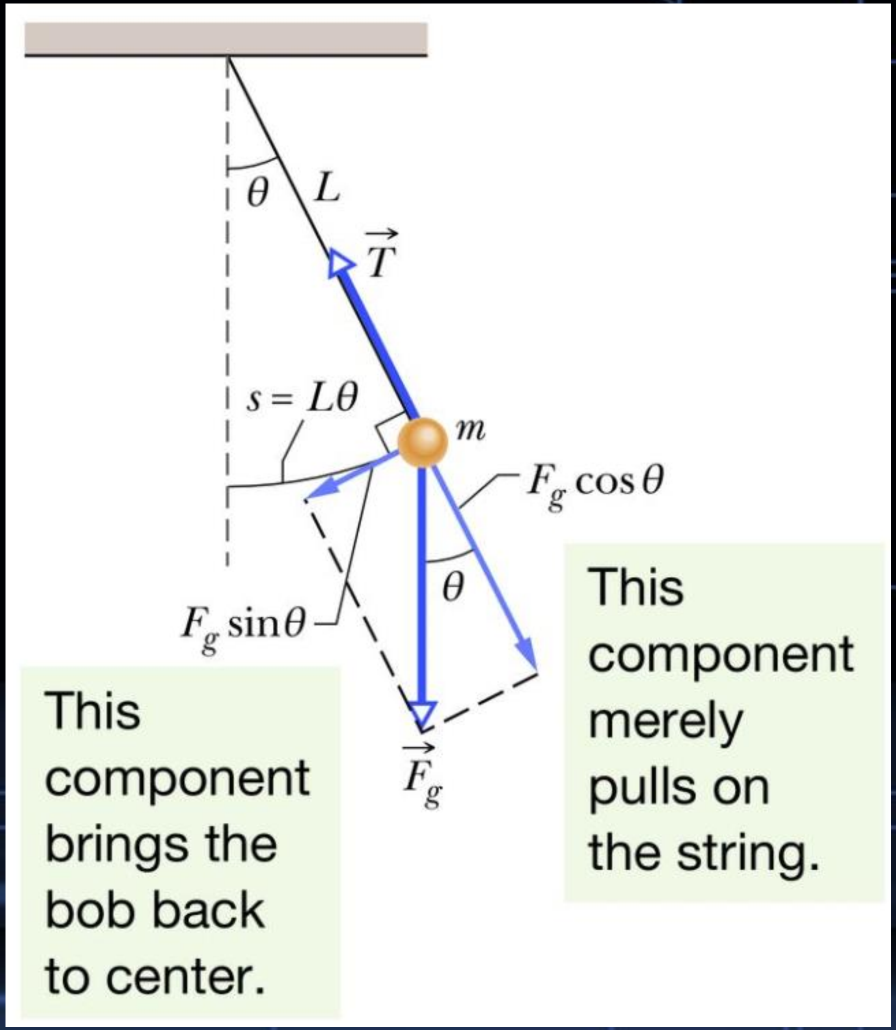
- We can find that:

$$\omega = \sqrt{\frac{mgL}{I}}$$

$$T = 2\pi\sqrt{\frac{I}{mgL}}$$

- With $I = mL^2$, we have

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



GENERAL PHYSICS B1
OSCILLATION & WAVE

Damped, Forced Oscillation, and Wave

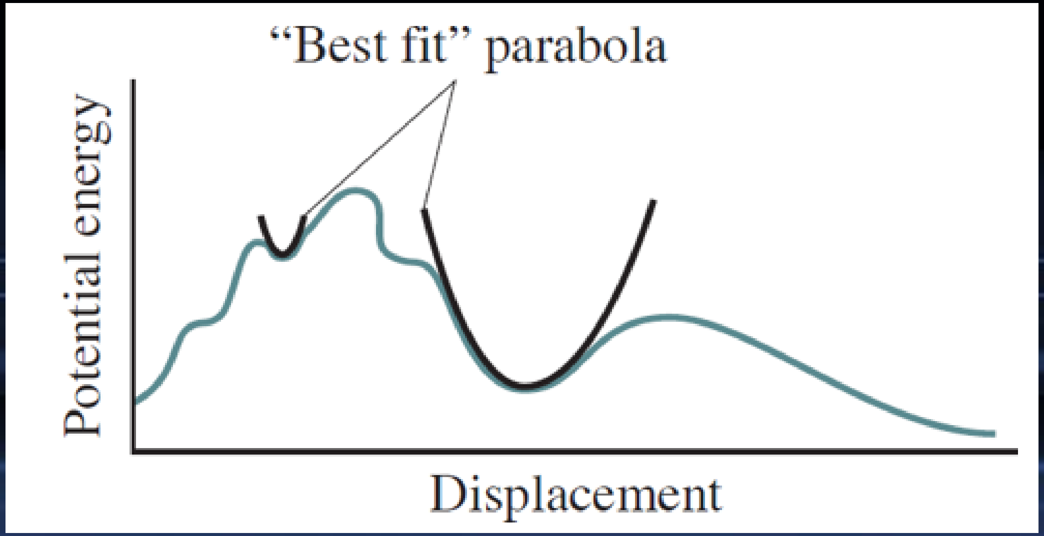
2022/11/11

Today’s topic

- Damped Oscillation
- Forced Oscillation
- Wave

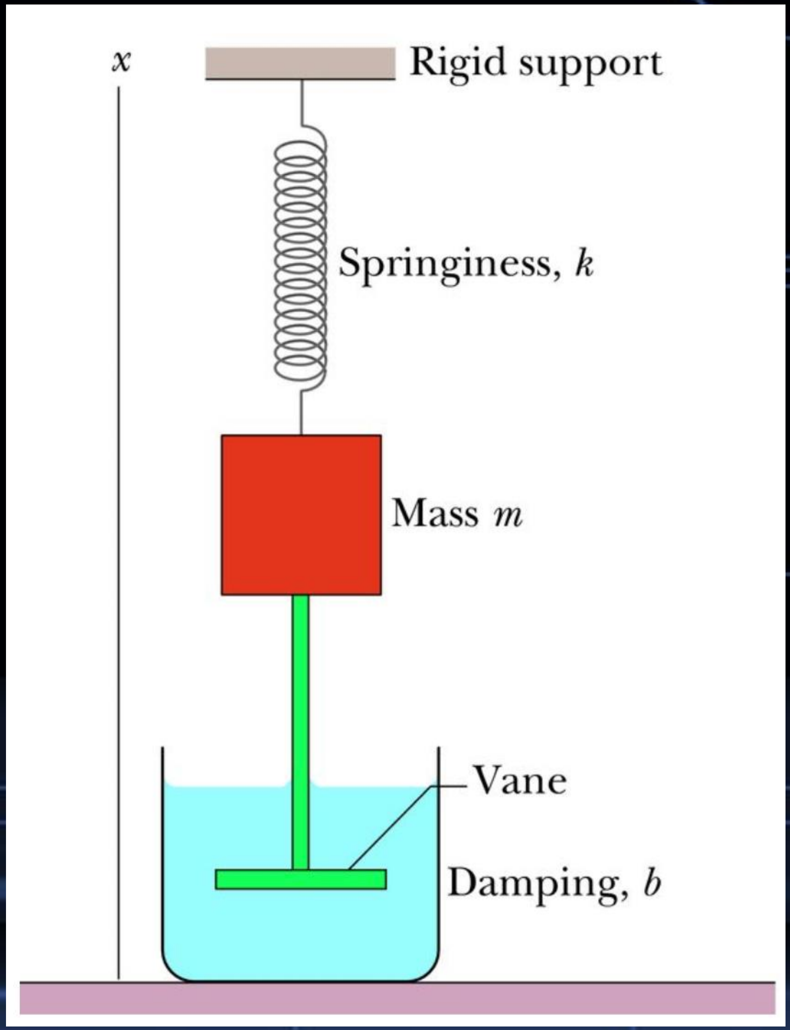
Potential Energy Curves and SHM

- Simple harmonic motion is common because many conservative systems have potential-energy curves that are approximately parabolic near a point of stable equilibrium.
  - Ideal spring: $U = \frac{1}{2}kx^2 = \frac{1}{2}m\omega^2x^2$
  - Typical potential-energy curve of an arbitrary system:



Damped Simple Harmonic Oscillation

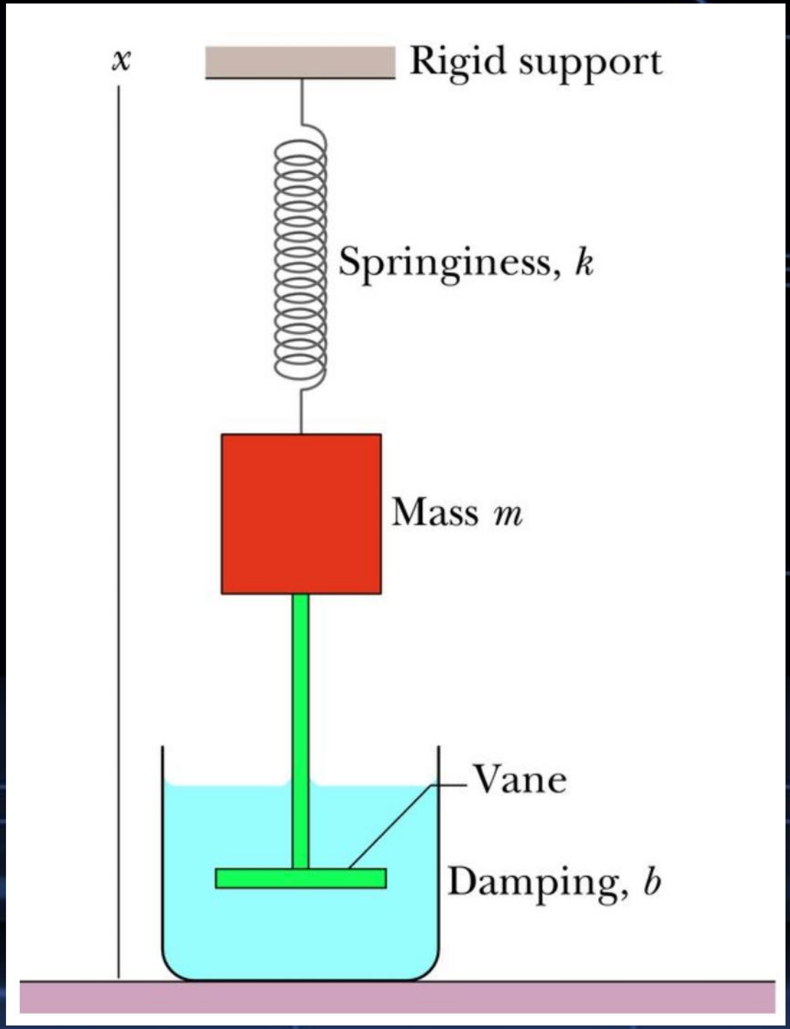
When the motion of an oscillator is reduced by an external force, the oscillator and its motion are said to be damped.



Damped Simple Harmonic Oscillation

Let us assume the liquid exerts a damping force $\overrightarrow{F_d}$ that is proportional to the velocity $\vec{v}$ of the vane and block (an assumption that is accurate if the vane moves slowly). Then, for force and velocity components along the x axis in we have $F_d = -bv$

where b is a damping constant.



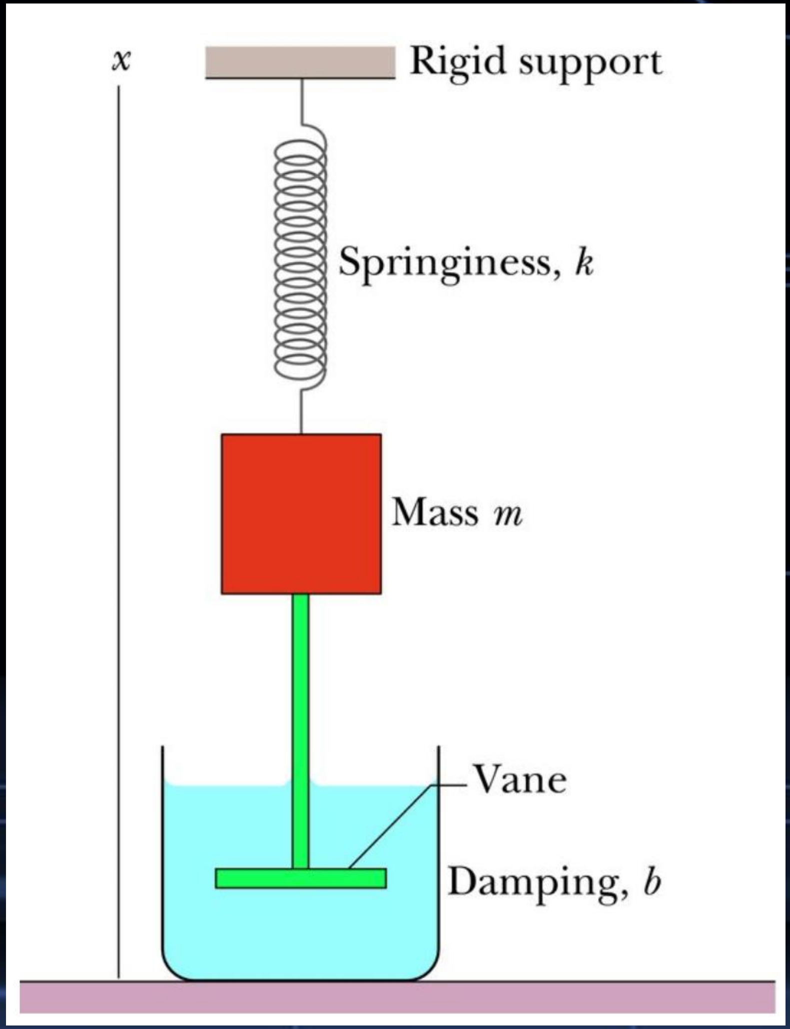
Damped Simple Harmonic Oscillation

Add spring force and let us assume that the gravitational force on the block is negligible. We have:

$$-bv - kx = ma$$

And we have the EOM

$$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0$$

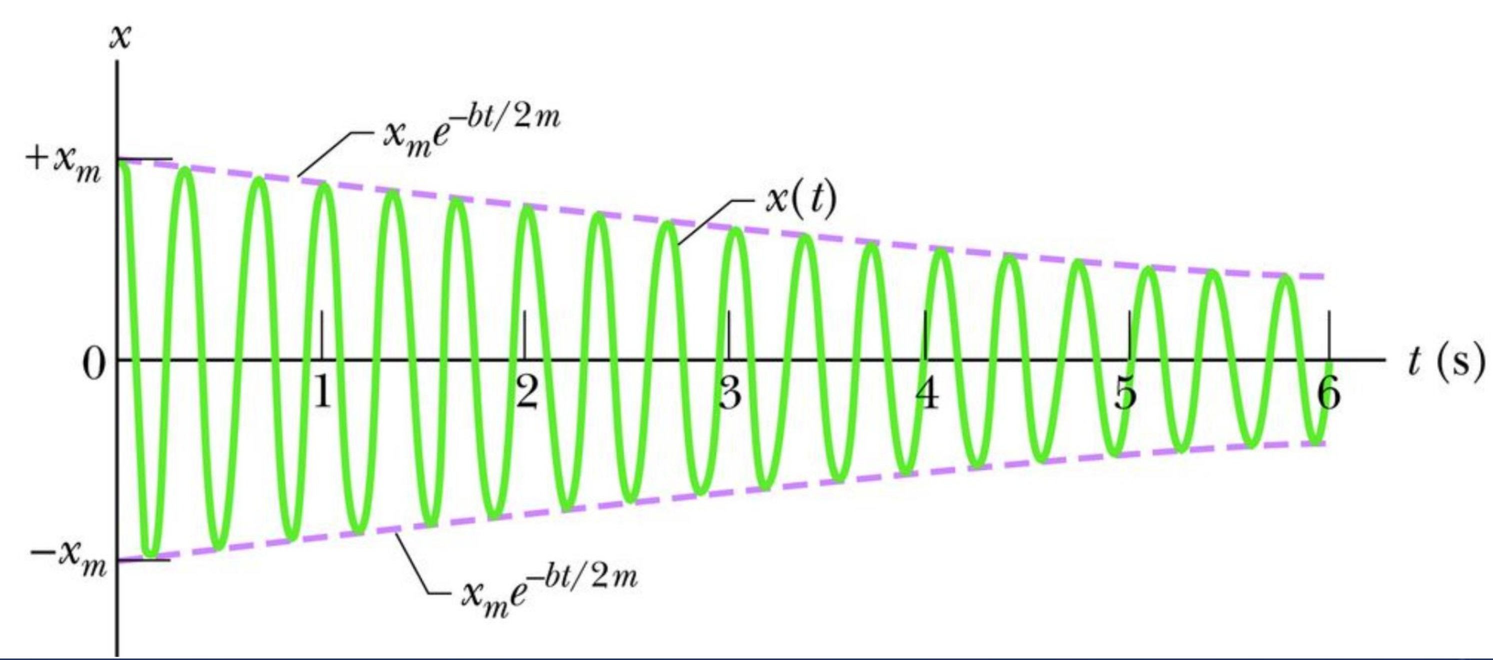


Damped Simple Harmonic Oscillation

The solution of the EOM is:

$$x(t) = x_m\, e^{-bt/2m} \cos(\omega' t + \phi)$$

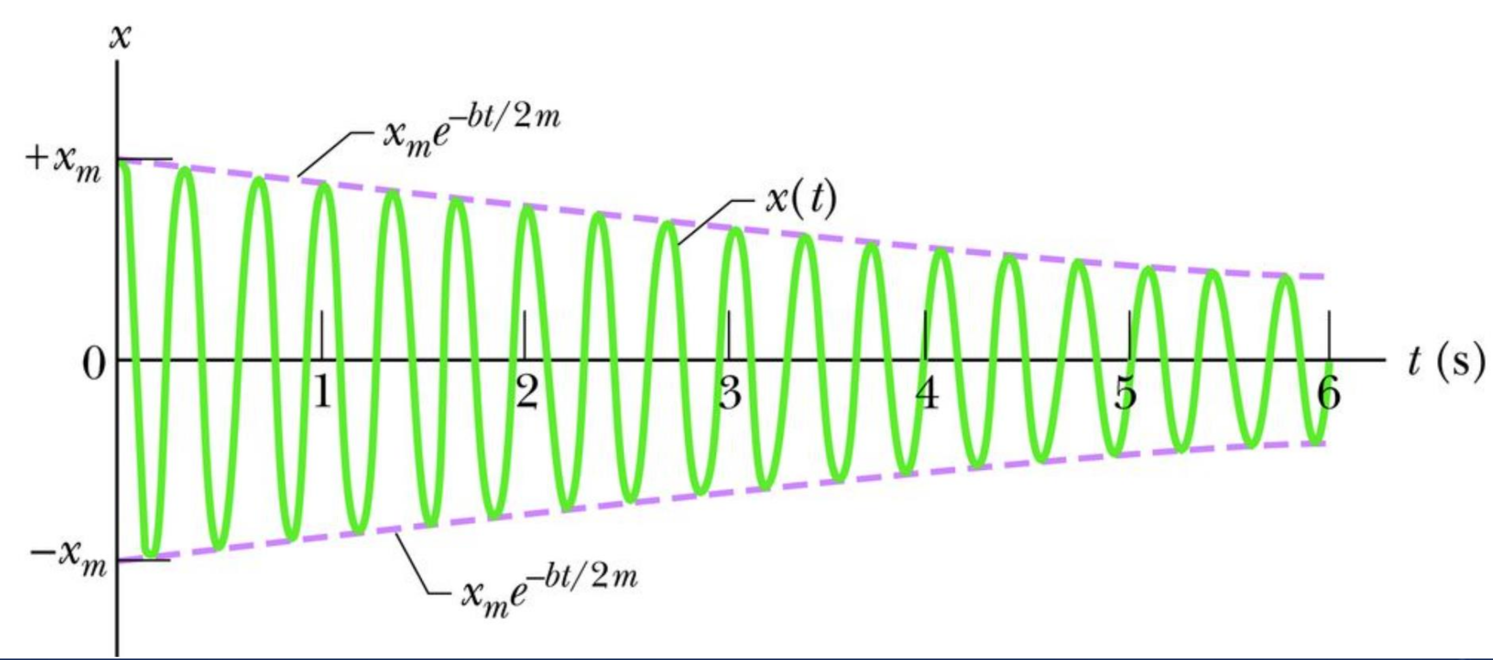
$$\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$



Energy in Damped SHM

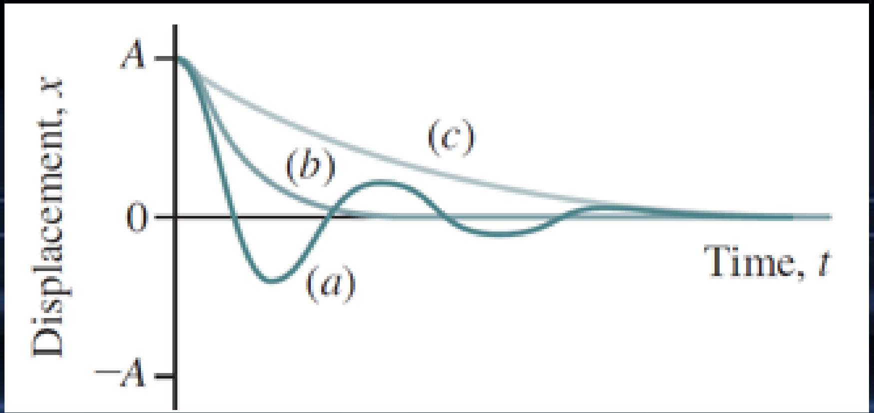
Since the amplitude of the oscillation is decreasing, the total energy is also decreasing as (when damp is small):

$$E(t) \approx \frac{1}{2} k x_m^2 \, e^{-bt/m}$$



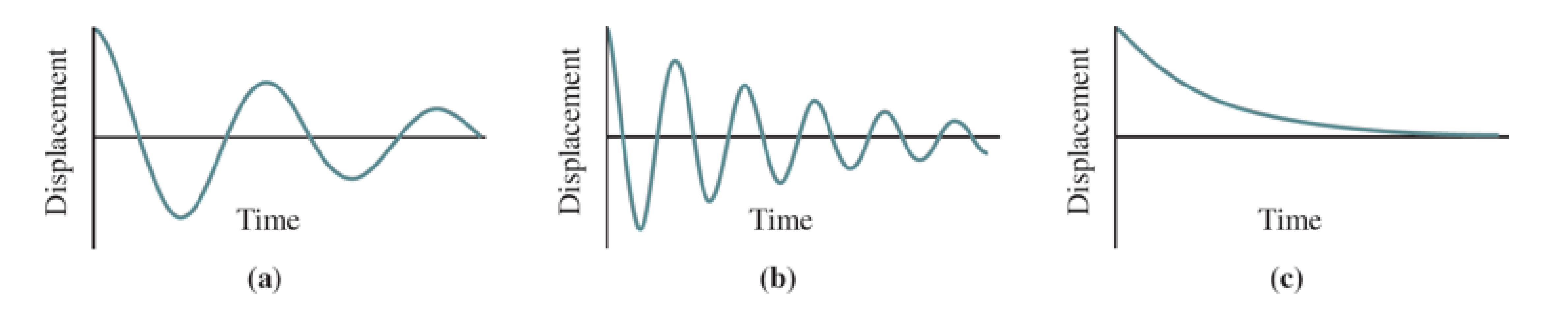
Damped Harmonic Motion

- For weak damping, oscillations can still occur and the motion is said to be **underdamped: (a) in the plot**
- As the damping increases, the oscillation frequency decreases significantly below its undamped value of $\omega = \sqrt{k/m}$.
- When the damping is just large enough to stop oscillations, the system is **critically damped: (b) in the plot**
- When the damping exceeds the requirement for critical damping, the system is **overdamped: (c) in the plot**

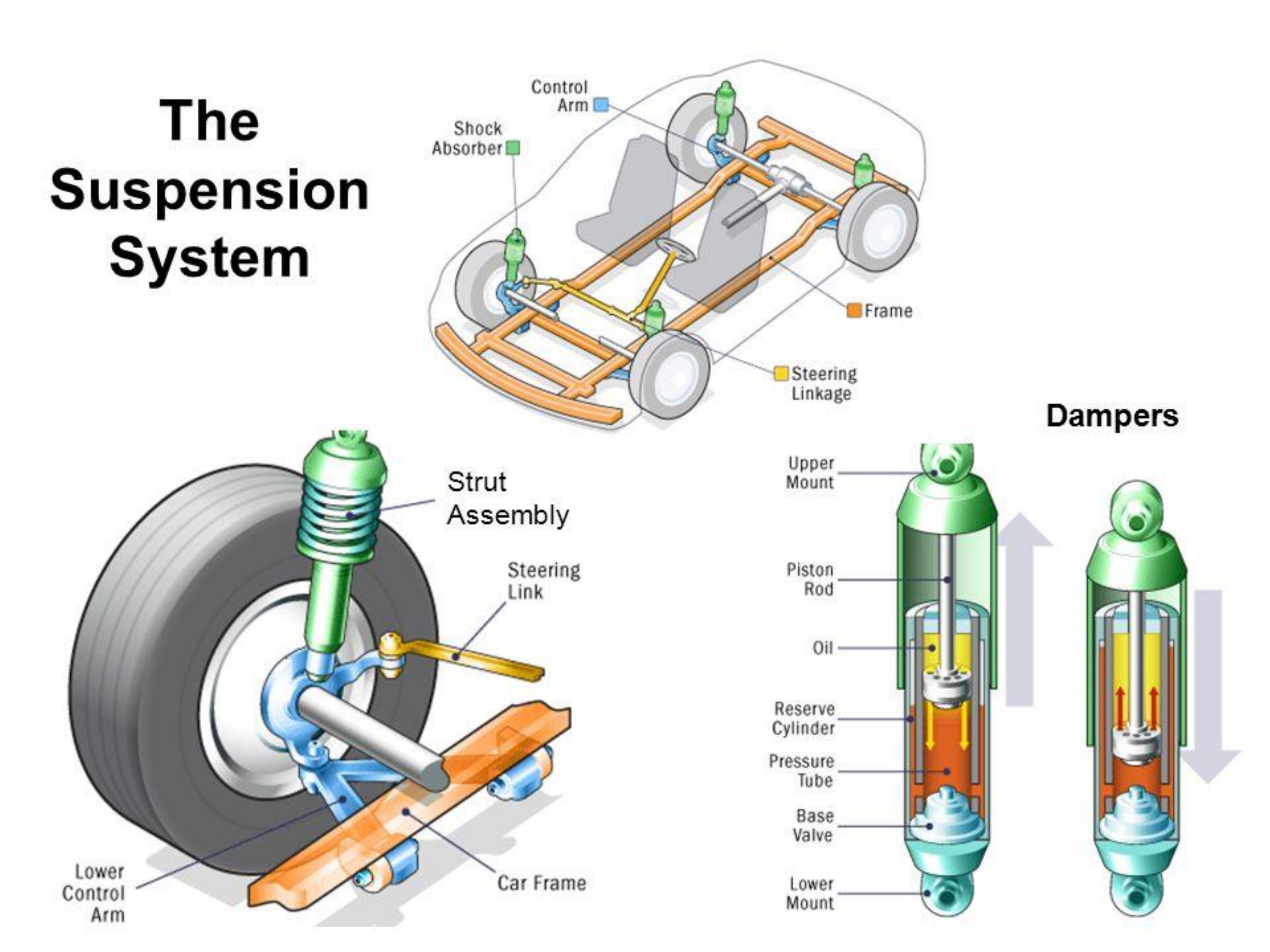


Think about it…

- The figure below depicts three different mass-spring systems. The time scale on all three graphs is the same:
  - For which system is damping the most significant?
  - For which system is damping the least significant?



Application of Damped Oscillation



https://slideplayer.com/10721689/37/images/slide_1.jpg

Free vs Forced Oscillation

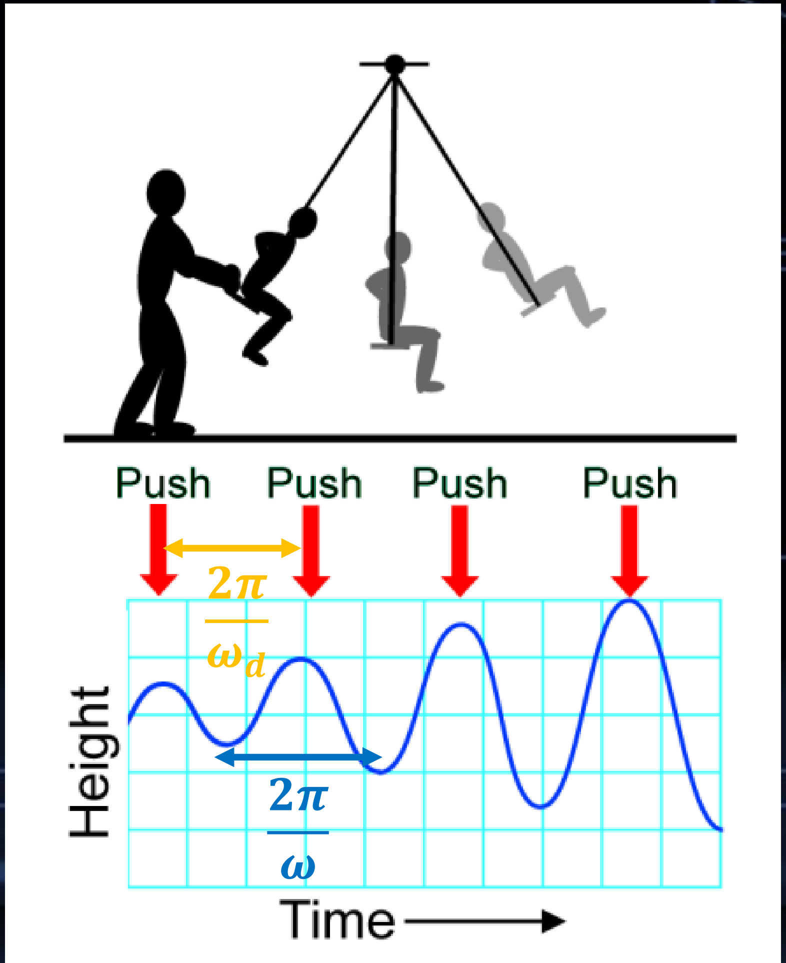
- A person swinging in a swing without anyone pushing it is an example of free oscillation. However, if someone pushes the swing periodically, the swing has forced, or driven, oscillations.

https://cheezburger.com/6878478592/wheee

https://tenor.com/search/swing-baby-gifs

Force oscillation

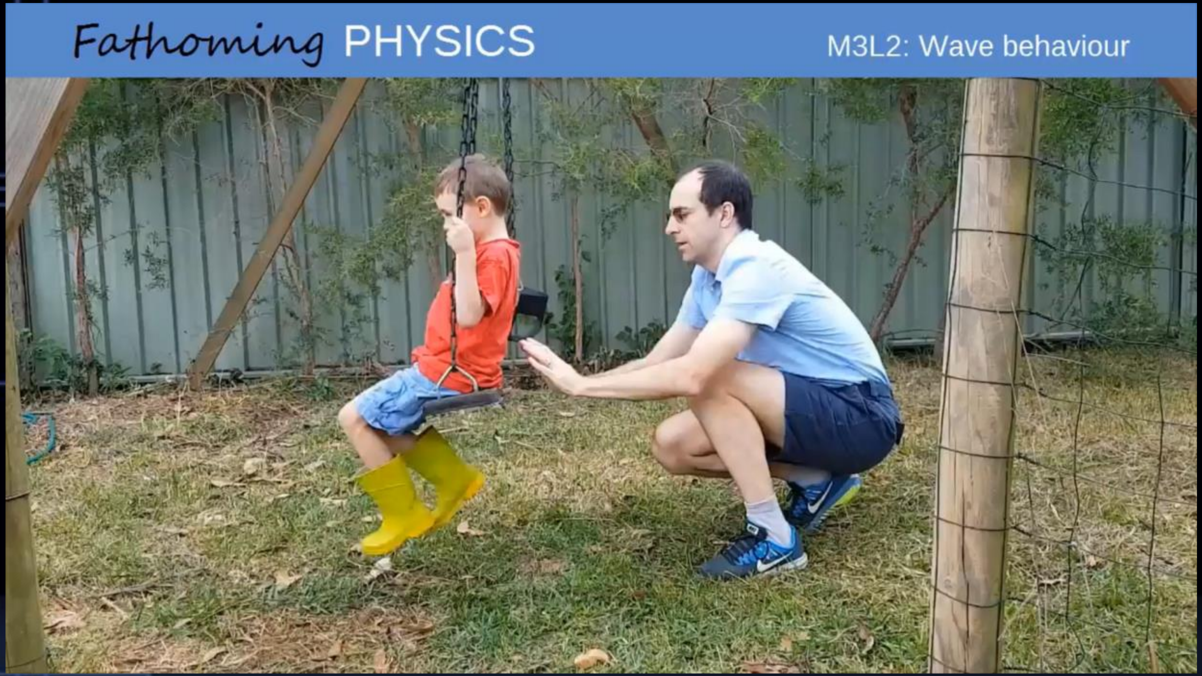
- To effectively enhance the oscillation’s amplitude, one need to push the swing at right time!
- The natural angular frequency of the swing is ω.The angular frequency of pushing is ω_d. The amplitude can reach maximum when on resonance: $\omega = \omega_d$



https://reurl.cc/2Z4a3m

Force oscillation

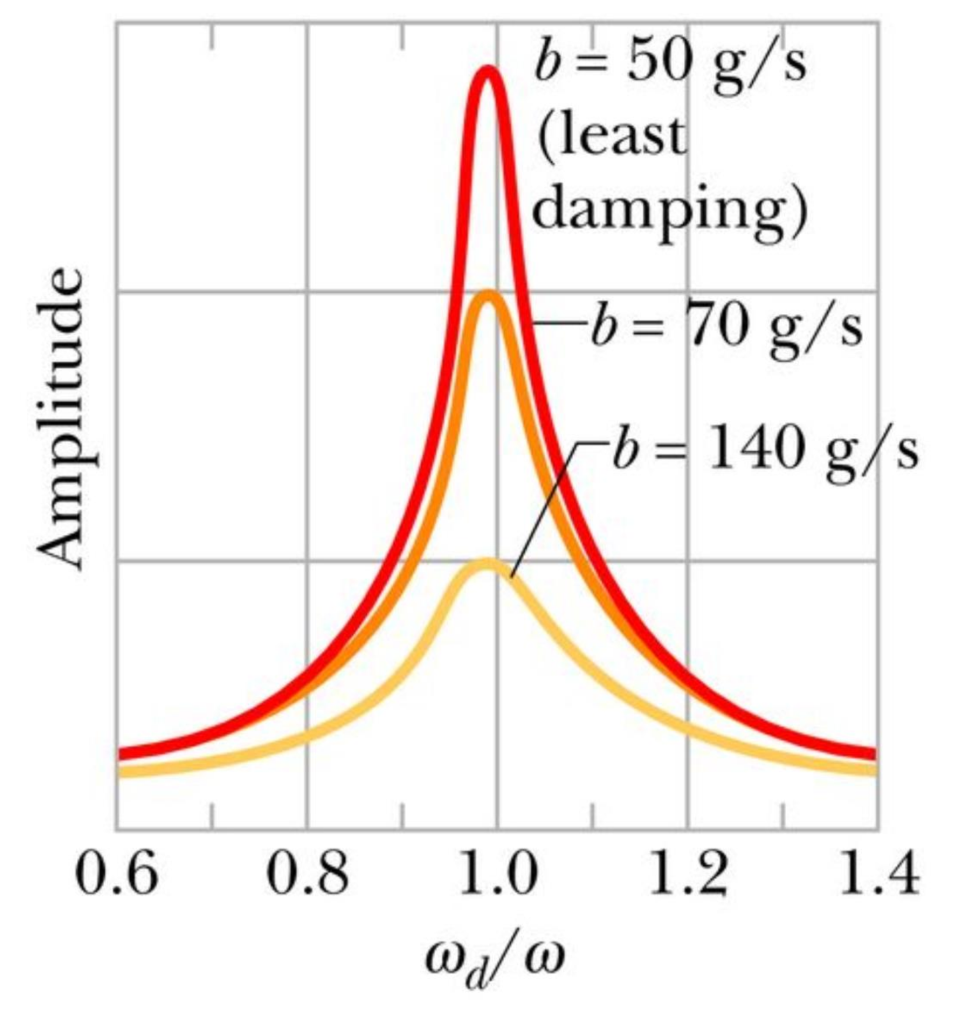
Not on resonance



On resonance

https://www.youtube.com/watch?v=5JbpcsH80us

Amplitude at equilibrium vs driving frequency



Power of resonance

https://makeagif.com/gif/breaking-a-wine-glass-using-resonance-Z6kheL

https://gfycat.com/gifs/search/tacoma+bridge+collapse

Summary

- Damped harmonic motion occurs when nonconservative forces act on the oscillating system.
- Resonance is a high-amplitude oscillatory response of a system driven at near its natural oscillation frequency.

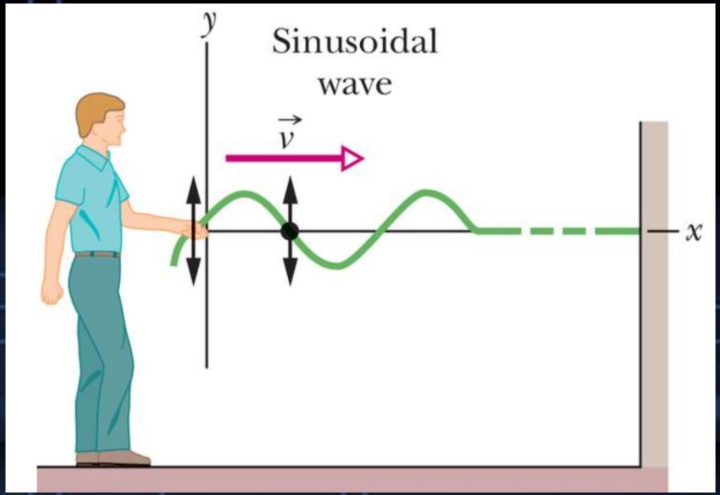
Different types of waves

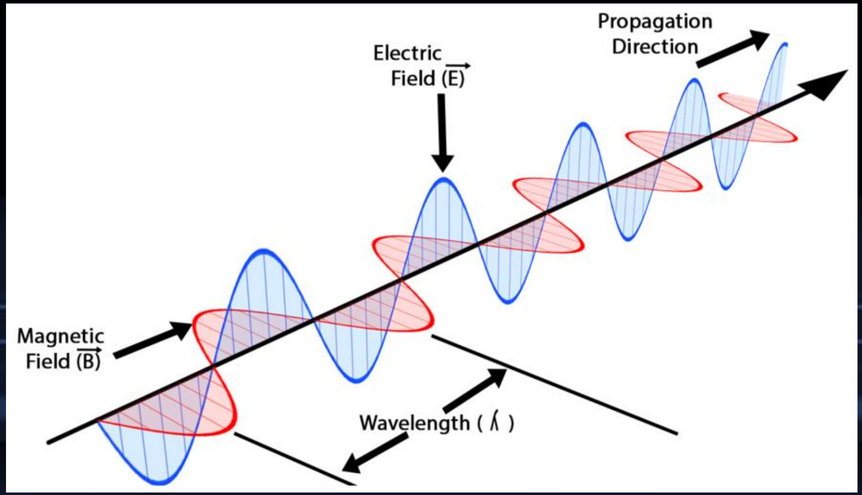
- Waves are of three main types:

Mechanical waves.

Electromagnetic waves.

Matter waves.





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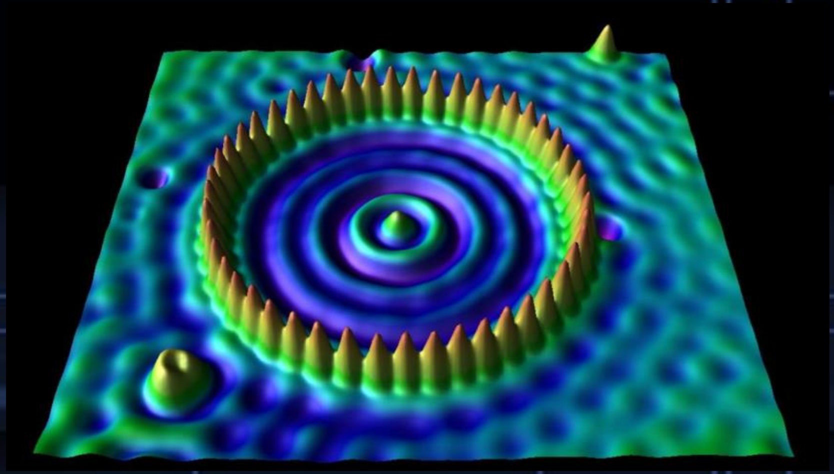

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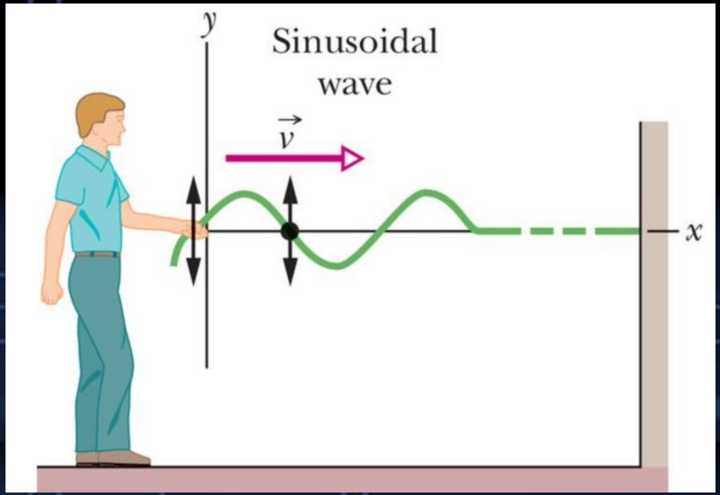

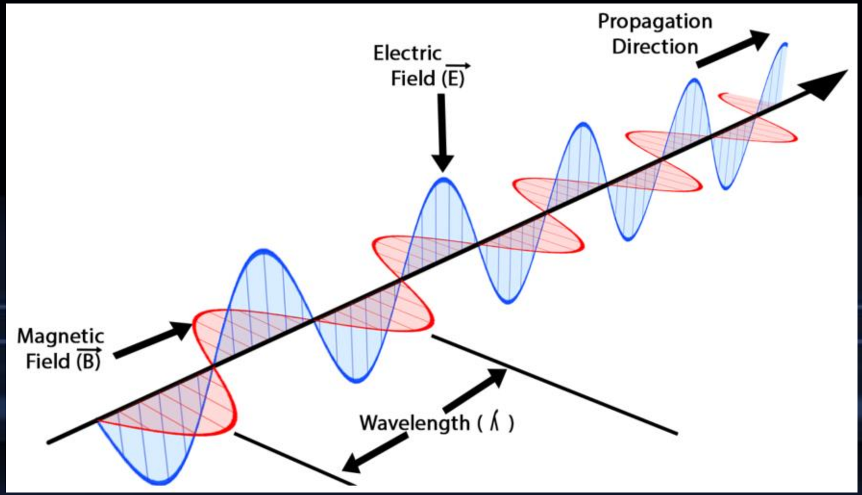

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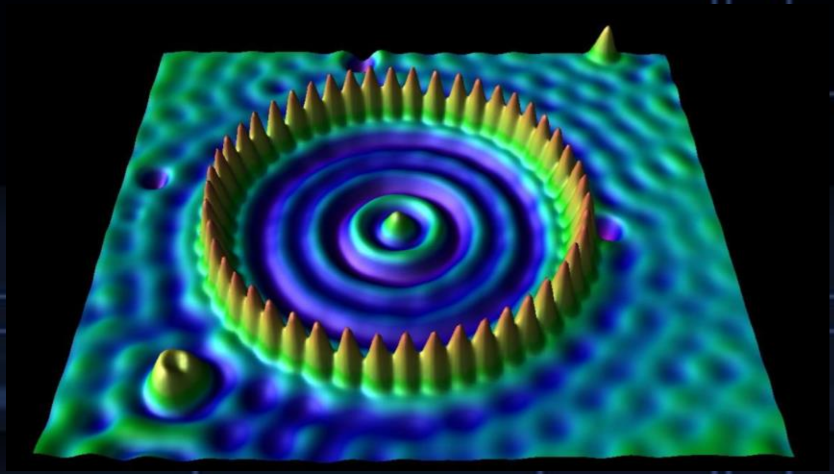
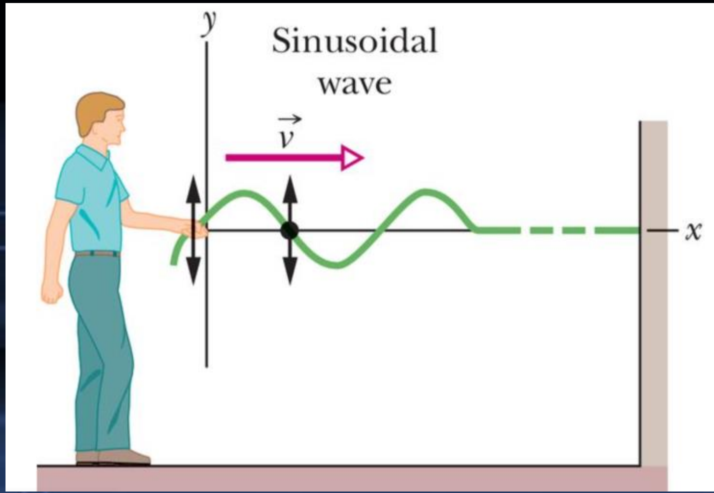
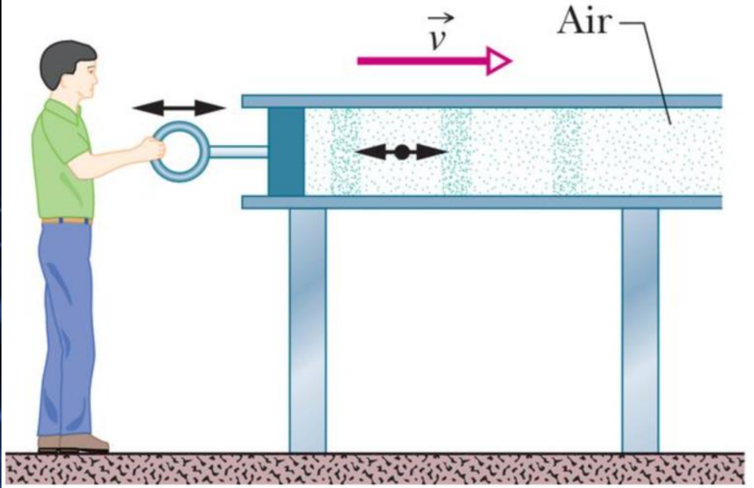


https://www.nisenet.org/catalog/scientific-image-quantum-corral-top-view

Transverse and Longitudinal Waves

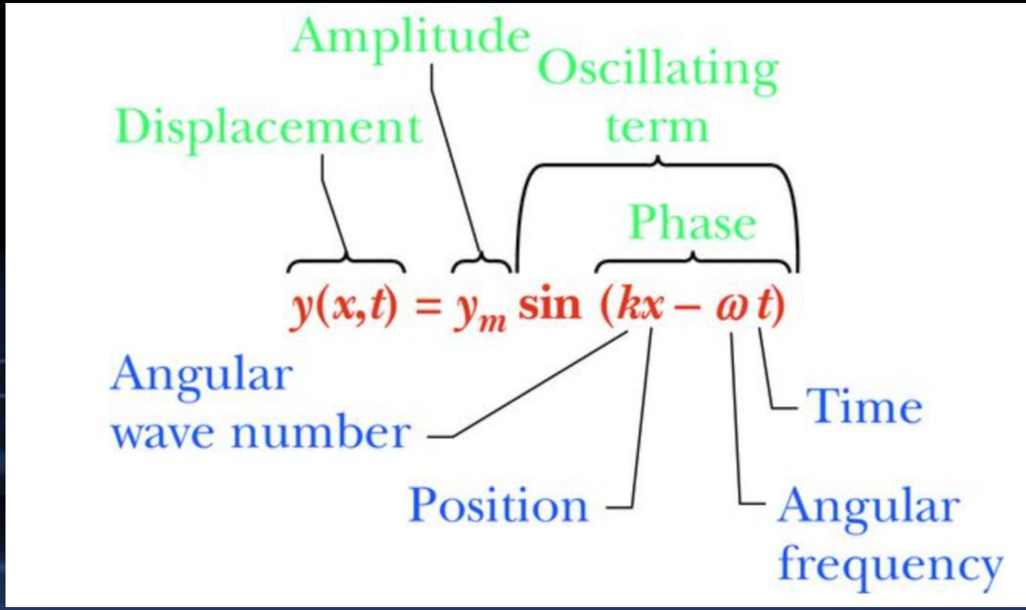
- Transverse waves: the displacement of every oscillating element is perpendicular to the direction of travel of the wave.
- Longitudinal waves: the displacement of the oscillating elements is parallel to the direction of the wave’s travel.

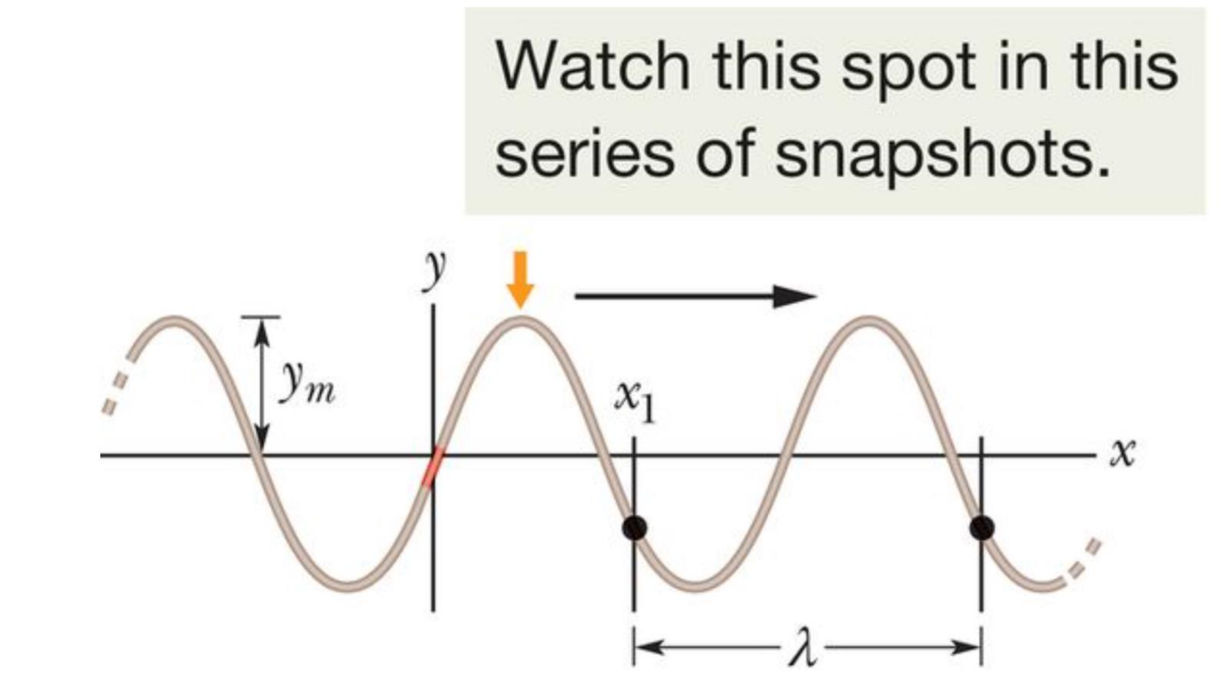


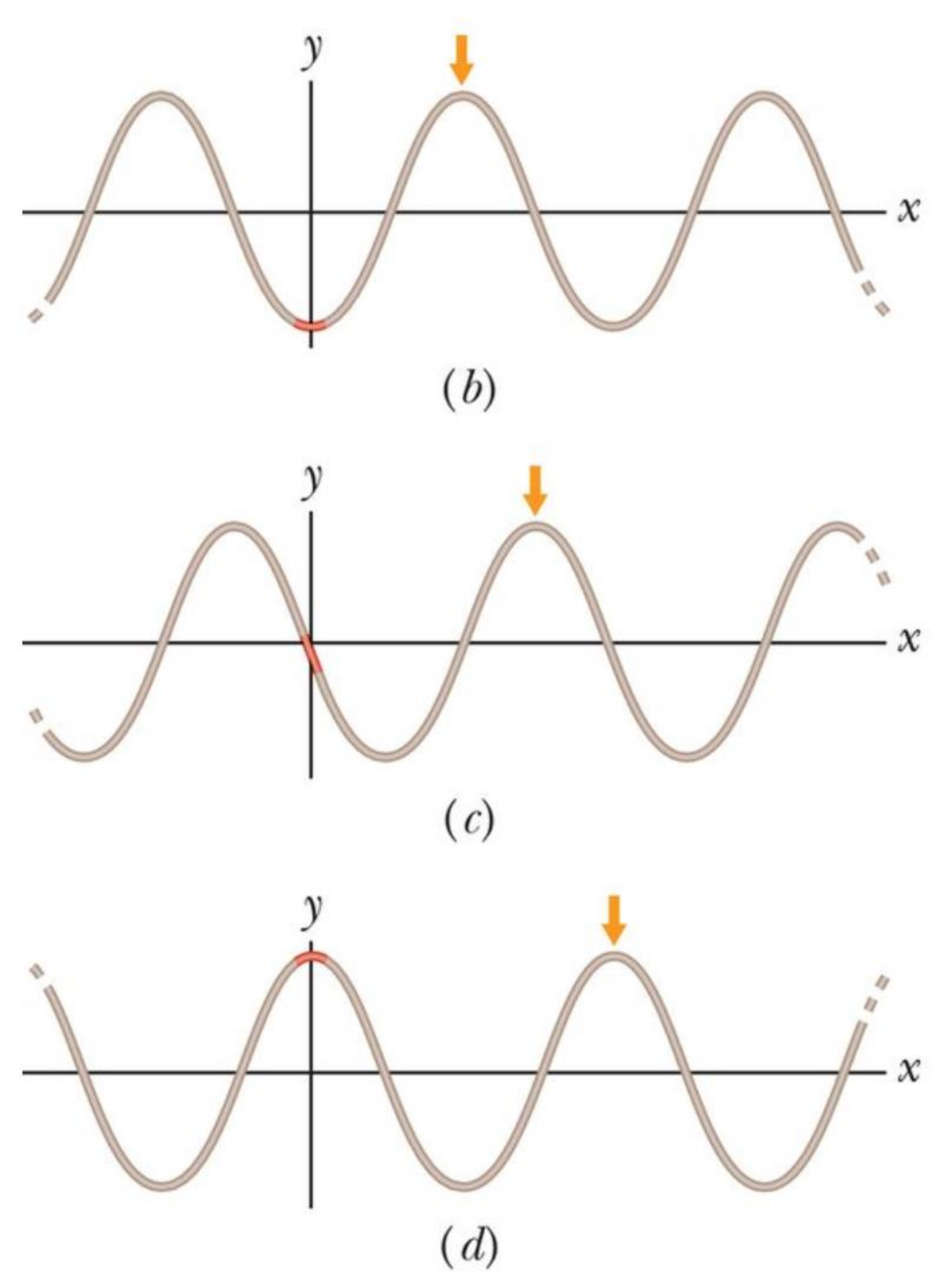


Description of wave

- Use wave on a string as an example. Imagine a sinusoidal wave traveling in the positive direction of an x axis. The elements oscillate parallel to the y axis. At time t, the displacement y(x,t) of the element located at position x is given by

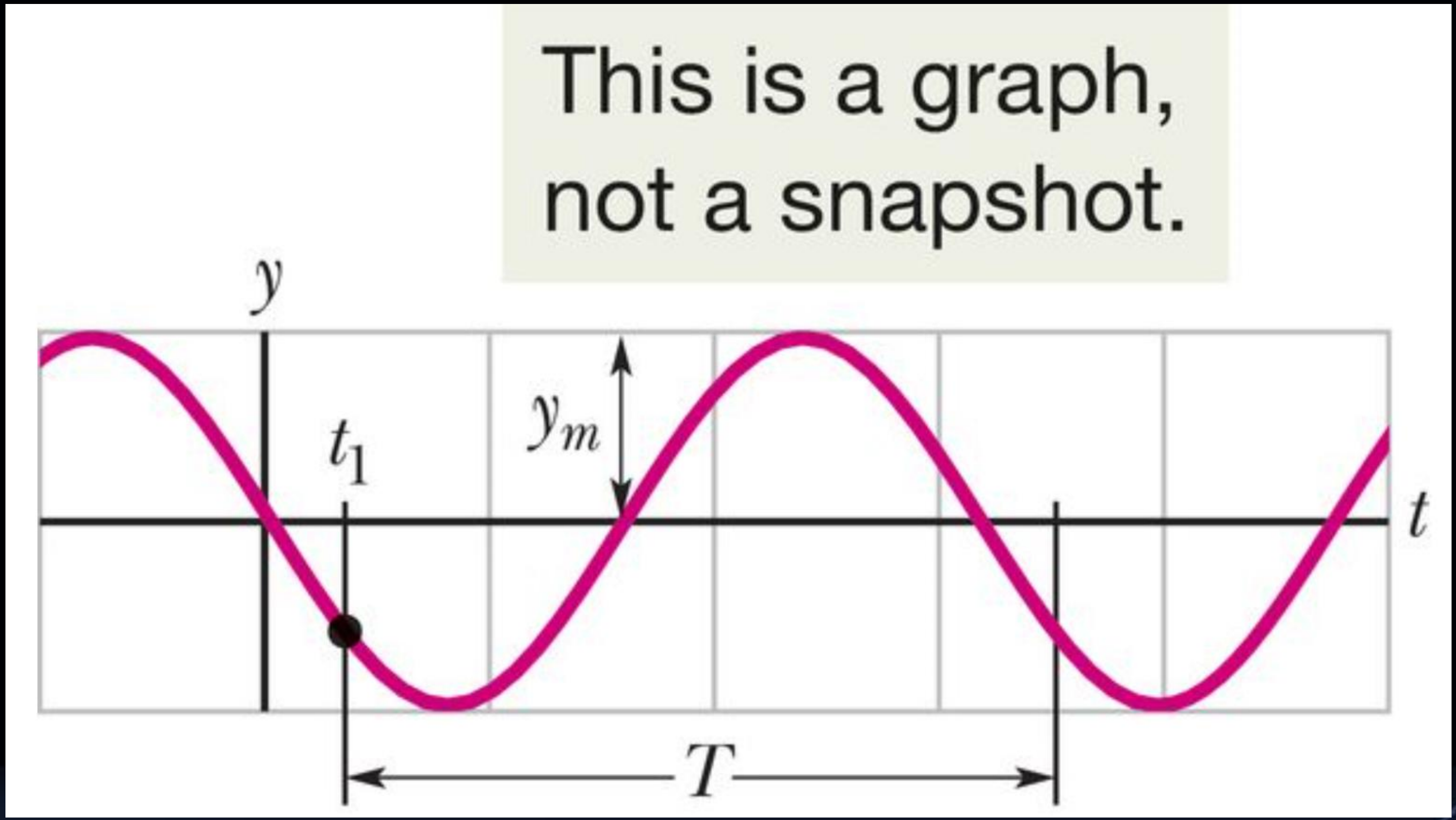






- $k = \frac{2\pi}{\lambda}$ (angular wave number)
- phase of the wave is the *argument* $(kx - \omega t)$ of the sine: a wave traveling to positive x direction

Angular frequency and frequency of wave



- $\omega = \frac{2\pi}{T}$ (angular wave frequency)
- $f = \frac{1}{T} = \frac{\omega}{2\pi}$ (frequency)