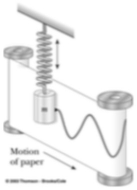
January 28, 2020

Damping in Oscillations

Damping: the result of a force that acts on a system in the opposite direction to the direction of motion of the oscillating particle



When a force acts this way it is known as a . . . dissipative force

Examples of a dissipative force: friction, air resistance, fluid viscosity

Effects of damping:

a) system loses energy and amplitude (energy α ampl^2)

b) frequency and period remain constant

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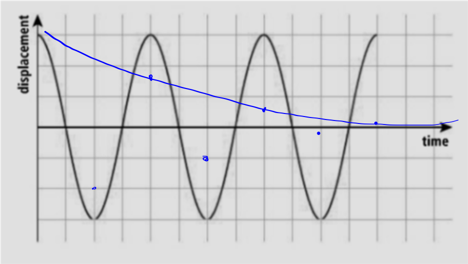
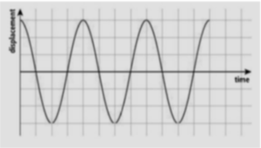
1. The diagram at right shows the oscillation of a system without damping. Sketch the oscillations with damping.

$x = \_\_\_(x_o \cos(\omega t))$

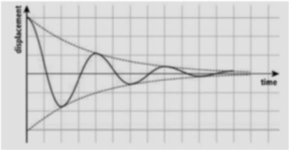


2. Write the equation for each motion.



Without damping

$$x = x_o \cos(\omega t)$$



With light damping

$$x = \underline{e^{-bt}}\, x_o \cos(\omega t)$$

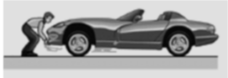
Degrees of Damping

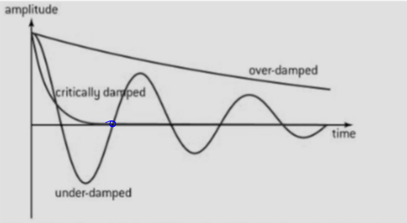
a) **Light damping (under-damping):** small resistive force so only a small percentage of energy is removed each cycle – period is not affected – can take many cycles for oscillations to die out

b) **Critical damping:** the smallest degree of damping that completely eliminates the oscillations – object settles back to rest in the shortest amount of time

eg. – electric meters with pointers,
automatic door closers

eg. – car shock absorbers





Variation of amplitude with time for different degrees of damping.

c) **Heavy damping (over-damping):** large resistive force – can completely prevent any oscillations from taking place – takes a long time for object to return to mean position

eg.- oscillations in viscous fluid

Resonance

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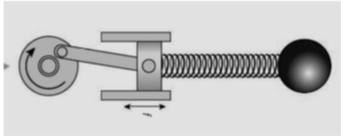
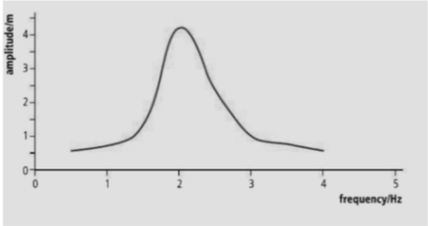
Natural Frequency of Vibration: when a system is displaced from equilibrium and allowed to oscillate freely, it will do so at its natural frequency of vibration

Forced Oscillations – a system may be forced to oscillate at any given frequency by an outside force that is applied to it (called a driving force) – this driving force supplies a **periodic stimulus** to the system

Driving Frequency – the frequency of a periodic stimulus or driving force that is forcing a system to oscillate

1. What happens to a system when it is made to oscillate by a driving force, that is, what is the response of a system to forced oscillations? For example, a mass on a spring is given a periodic stimulus by a rotating piston. A graph of the amplitude of the resulting oscillation as a function of the driving frequency is shown.





What is the significance of the peak on the graph?

Driving frequency = natural (resonant) frequency of the system

Resonance – a transfer of energy in which a system is subject to a forced oscillation whose driving frequency matches the natural frequency of the system resulting in a large amplitude of vibration

Useful Examples of Resonance:

a) **Musical Instruments:** Many musical instruments (including the human voice) produce their sounds by arranging for a column of air or a string to be driven at its natural frequency which causes the amplitude of oscillation (the volume) to increase.

b) **Microwave Generators:** Microwave ovens produce electromagnetic waves in the microwave portion of the EM spectrum. The driving frequency of these microwaves provides energy which is transferred to water molecules in the substance being heated so that their temperature increases.

c) **Quartz Oscillators:** When an AC voltage is applied to a quartz crystal, the crystal vibrates. If the driving frequency of the AC voltage matches the natural frequency of the quartz crystal, the crystal will vibrate with a large enough amplitude to be used to provide accurate clocks for microprocessors and to produce and detect sound waves in a medical test known as ultrasound.

d) **Greenhouse Effect:** The natural frequency of oscillation of the molecules of the greenhouse gases (water vapor, carbon dioxide, methane, nitrous oxide) is in the infrared region of the EM spectrum. Radiation from the Earth's surface can be readily absorbed by the greenhouse gases and then reradiated back down to Earth increasing the surface and air temperature of the Earth.

e) **Lasers:** The optical cavities in lasers set up standing waves for light in order to produce powerful coherent beams.

f) **MRI (magnetic resonance imaging) scans:** These use magnetic fields and oscillating radio frequency waves that resonate with protons in hydrogen atoms which emit energy to produce pictures of body tissue.

Wave Phenomena – Part I

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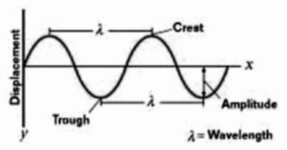
Pulse – single oscillation or disturbance

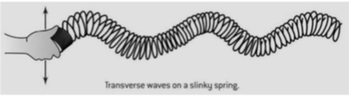
Traveling wave (progressive wave, continuous wave) – succession of oscillations (series of periodic pulses)

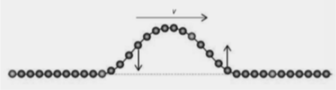
Period: (T, seconds)
a) time taken for one complete oscillation
b) time for one complete wave (cycle) to pass a given point

Wavelength: (λ, meters)
a) shortest distance along the wave between two points that are in phase
b) the distance traveled by a wave in one period



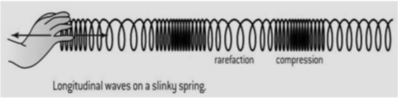
Transverse Wave – the particles of the medium move perpendicular to the direction of the wave (energy)

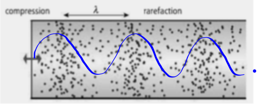




Note the direction of motion of the particles.

Longitudinal Wave – the particles of the medium move parallel to the direction of the wave (energy)





A sound wave is a longitudinal wave of varying air pressure.

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1. Distinguish between the motion of the wave (energy) and the motion of the particles.

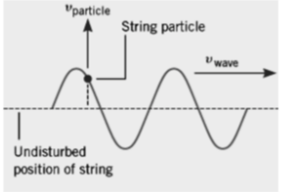
Motion of the Wave (Motion of Energy Transfer)

constant speed

$v = \lambda \cdot f$

Derivation of the Wave Equation

In time t = 1 period:



Motion of a Particle

SHM

$V = V_0 \cos(\omega t)$

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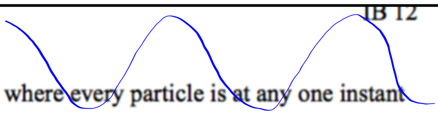
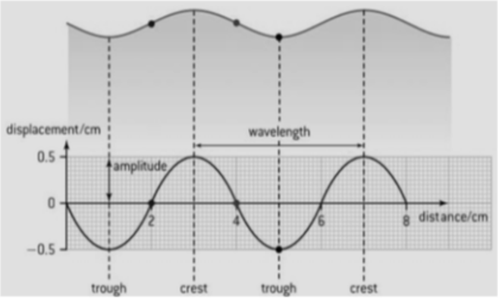
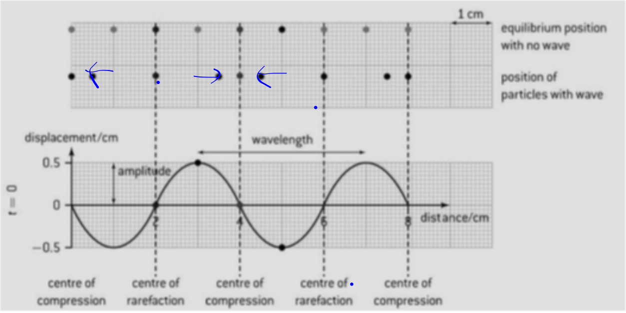
Graphs of motion

a) Displacement versus distance (position): shows where every particle is at any one instant



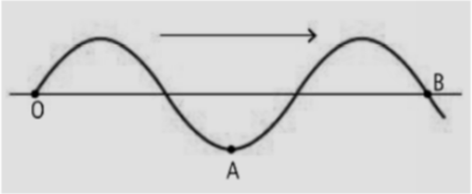


Transverse Wave

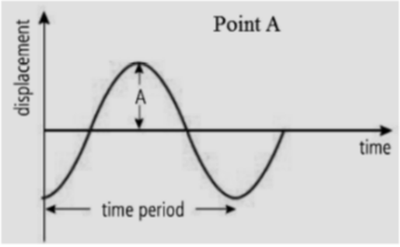


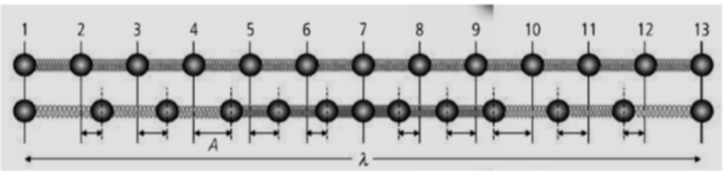
Longitudinal Wave

b) Displacement versus time: shows how the displacement of a single particle varies with time

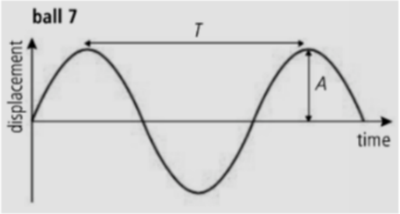


Transverse Wave





Longitudinal Wave



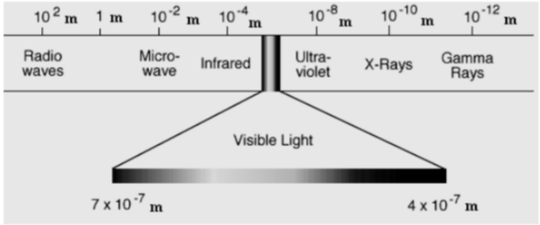
Light:

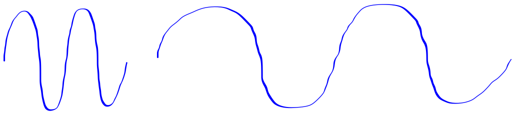
electromagnetic, transverse

Control variable:

speed

The Electromagnetic Spectrum





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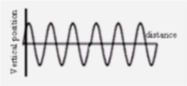
2. What is the control variable for a wave in a single medium? speed

Low frequency, high wavelength

High frequency, low wavelength



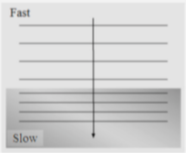
Wave speed depends on . . . the properties of the medium

3. What is the control variable for a wave as it crosses a boundary between two media? frequency

Fast Medium:

high speed

wavelength



Slow Medium:

low speed

wavelength

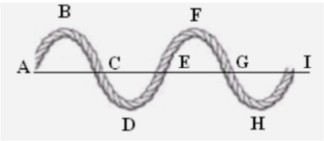
$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Phase: The phase of any particle is its position in its cycle of oscillation.

Phase Difference – difference in phase between two points or the particles of two oscillating systems

In phase: (A,E,I) (B,F) (D,H) (C,G)

The **phase difference** between any points *in phase* is 0.



Completely out of phase: (A,C) (B,D) (A,G)

The **phase difference** between any points *completely out of phase* is π or 180^0.

Fixed End Reflection (Hard Reflection): Reflected pulse is . . .out of phase

Reason for inversion of pulse: Newton's third law

Free End Reflection (Soft Reflection): Reflected pulse is . . . in phase