# Standard Model of Particle Physics

| | Role | Boson (Force Carrier) |
|---|---|---|
| Strong | Acts between Quarks<br>Holds nucleus together<br>Responsible for attraction between protons & neutrons | Gluon |
| EM | Acts between charged particles<br>Ex: proton & electron | Photon |
| Weak | Responsible for radioactive decay | W Z |
| Gravity | attraction between masses | Graviton |

Protons – Hadron & Baryon
+1e or $1.6 \times 10^{-19}$ C
composed of uud quarks
mass $1.67 \times 10^{-27}$ kg
– Strong force

Neutrons – Hadron & Baryon
0 charge
Composed of udd quarks
Strong force

Electrons → leptons
No Strong force

Rules for combining quarks
Quarks combine to make stable particles with whole # ~~(+ or -)~~ (positive or negative) charge or 0 charge
Baryon is 3 quarks
Meson quark & anti-quark

Annihilation
when a particle and antiparticle meet they annihilate to form a pair of gamma photons

$E = mc^2$

Other Standard Model
A moving charged particle creates a magnetic field
An accelerating charge particle creates an EM wave

# Waves – Variables, equations, vocabulary

Waves- transfer energy not mass

Wavelength-
$\lambda$ meters/cycle (meters)

Amplitude-
height or depth of a wave. Associated with loudness of sound wave

Period-
T seconds/cycle (seconds)

Frequency –
f cycles/second (Hz)

Phase-

Mechanical Wave
requires a medium

Electromagnetic Wave
(light) no medium required

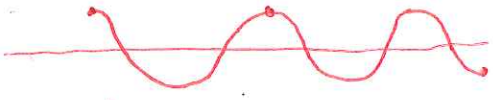
Transverse Wave
particles vibrate perpendicular to energy

Longitudinal Wave
particles vibrate parallel to energy

Pulse
a disturbance in a wave

Periodic Wave
a repeating wave

Finding wavelength, frequency, period and amplitude



2.5 cycles

$\lambda = \frac{\text{meters}}{\text{cycle}}$ $f = \frac{\text{cycles}}{\text{second}}$ $T = \frac{\text{seconds}}{\text{cycle}}$

$T = 1/f$

Converting between frequency and period

$T = 1/f$ $5\text{Hz} = 1/5$

$f = 1/T$ or $T = 1/f$

Speed of a wave (other than sound or em)

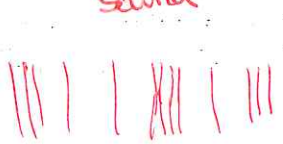
$V = f\lambda$

V sound at STP = 331 m/s

V EM in vacuum = $3 \times 10^8$ m/s

V of EM in a substance $v = c/n$

Longitudinal wave
sound



Transverse Waves all EM waves

COMPARING EM AND MECHANICAL WAVES

Electromagnetic Waves
- move at $3 \times 10^8$ m/s in a vacuum or air
- Energy related to frequency
- Can move through a vacuum
- Speed decrease with ↑ "n"

Mechanical Waves
Energy related to amplitude
require a medium
Speed ~~decreases~~ increases with density (gas > liquid > solid)

# Wave Phenomena

## Polarization

Only light waves can be polarized

see glossary

## Reflection vs Refraction

### Reflection

$\theta_i = \theta_r$

same medium

$\theta$ measured from normal line

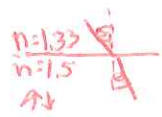
happens to waves & particles

frequency remains the same

### Refraction

$n = c/v$ $n_1 \sin\theta_1 = n_2 \sin\theta_2$

if $n \uparrow$ $\lambda \downarrow$, $e \downarrow$, $v \downarrow$ & vice versa

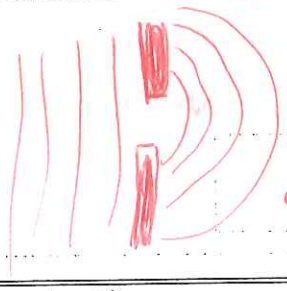



Bending of a wave due to change in n

When waves hit a boundary they partially refract & reflect

## Diffraction

Bending of a wave due to an obstruction or opening



amount of curving is dependent on how close ~~red~~ $\lambda$ is to size of opening

$\lambda$ doesn't change unless characteristic of medium changes

## Interference – Superposition

Constructive Interference (2 waves in phase)

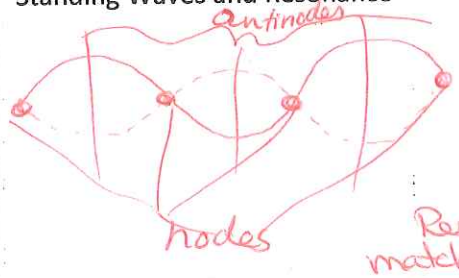
Crest & Crest or trough & trough

Destructive Interference 2 waves 180° out of phase

crest - trough

Evidence of wave behavior of light

## Standing Waves and Resonance

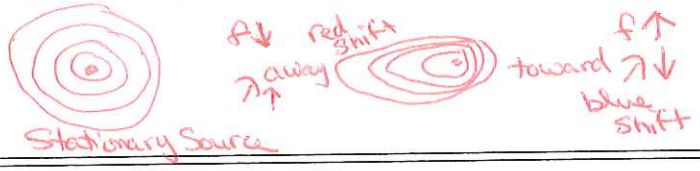



Result from Reflection & Interference

Resonance involves matching frequencies of object to environment

## Doppler Effect

Relative motion between observer and wave source




## Wave/Particle Duality

Wave evidence – Diffraction, Interference, double slit

Particle evidence – Photoelectric effect, collisions & momentum

# Mechanical (ex: Sound, Earthquake, Water) vs Electromagnetic (Visible light, radio, microwave etc)

## Mechanical waves

Requirements

must have a medium

Relationship to energy

Energy related to amplitude

When they change mediums

If density of medium ↑ the speed of sound increases

gas → liquid → solid

Sound moves at 331 m/s at STP

(cannot move through vacuum)

Possible types of vibration

Longitudinal or transverse

## EM Waves (ie photons)

Requirements

- Can move through a vacuum
- created by acceleration of a charged particle

Relationship to Energy

$E = hf$

Energy related to f

Behavior in a vacuum

all move at same speed

$v = c = 3 \times 10^8 m/s$

When they change medium.....

If n increases then $\lambda$, v, $\theta$ decrease

frequency remains the same

$n = c/v$ $v = f\lambda$

Helpful Hints

radio waves are EM

$v = 3 \times 10^8 m/s$

Type of Vibration

Transverse Only

Reference table reminders

To Convert Energy in eV to frequency → convert eV to J → find f using $E = hf$

# Energy of a photon

**Quantum**
discrete, defined values (NOT continuous)

**Energy level**
The amount of energy needed by an electron to ionize an atom

**Ionization**
loss of electron

**Planck's Constant (h)**
$6.63 \times 10^{-34}$ Js

**Absorption**
When a photon in the spectrum disappears because it bounces an electron up

**Emission**
When a photon leave an atom because an electron falls

**Spectrum**
The range of frequency

**Continuous**
~~a type~~ characteristic that can be any value

**Photon**
EM wave produced by accelerating charge

**Energy between levels**
Hydrogen by # Mercury by letter
Find Energy gap between level - if going up electron absorbing photon; if falling down electron emits a photon
→ Energy is in ~~J~~ eVs → you must convert to Joules in order to identify frequency

# of possible falls
~~choose level below~~
add the # of levels below current
Ex: Level 4
add 3+2+1 = 6

**Energy of a photon and frequency or wavelength**
$E = hf = \frac{hc}{\lambda}$ $[f = c/\lambda]$ Must put Energy in Joules

$E_{photon}$ directly related to frequency & Inverse to wavelength

h = Planck's Constant = $6.63 \times 10^{-34}$ Js

**Converting between energy units**
eV → J × $1.6 \times 10^{-19}$ J

J → eV = ÷ $1.6 \times 10^{-19}$ J

**From EM Spectrum to Hydrogen or Mercury diagram (and vice versa)**

1. Starting with frequency use $E = hf$ or $\frac{hc}{\lambda}$ to find Energy in Joules
2. Convert Joules ~~to~~ eV by ÷ $1.6 \times 10^{-19}$ J
3. Compare eVs to gap on charts

$c = 3 \times 10^{8}$ m/s
$h = 6.63 \times 10^{-34}$ Js

1. Starting with gap on chart → find # of eVs
2. Convert eVs to Joules by × $1.6 \times 10^{-19}$ J
3. Use equation ~~E~~ $= hf$ or $hc/\lambda$ to find f or λ use EM spectrum to identify ~~type~~ of wave

# Energy-Mass Equivalence
# $E=mc^2$

**Mass-Defect**

The difference between start mass and end mass

**Nucleon**

Particle in nucleus

**Photon**

EM wave

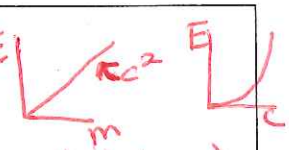
Force carrier of boson

**Conservation of mass-energy**

Energy can become mass and mass can become energy

**Convert energy in Joules to mass in kg**

$E=mc^2$




(annihilation)

for particle & antiparticle interaction be sure to include mass of both

**Convert energy in Mega-electronvolts (eV's) to mass in universal mass units** or atomic mass units

$1u = 9.31\times10^{2}\ MeV$ or $9.31\times10^{8}\ eV$

→ u to MeV $\times 9.31\times10^{2}$ MeV

MeV to u $\div 9.31\times10^{2}$ MeV

**Convert energy in MeV to mass in kg**

$MeV \times \frac{1\times10^{6}\ eV}{1\ MeV} \times \frac{1.6\times10^{-19}\ J}{1\ eV} = 1.6\times10^{-13}\ J$

use $E=mc^2$ to find $m$

$m=\frac{E}{c^2}$

**Other conservation laws that must be obeyed**

Mass and Energy must be conserved

Charge must also be conserved

Momentum must be conserved

**Nuclear reactions**

Governed by the weak force

Involves protons & neutrons in nucleus

Fission & Fusion are nuclear reactions