# Physics Notes

Sorted by topics

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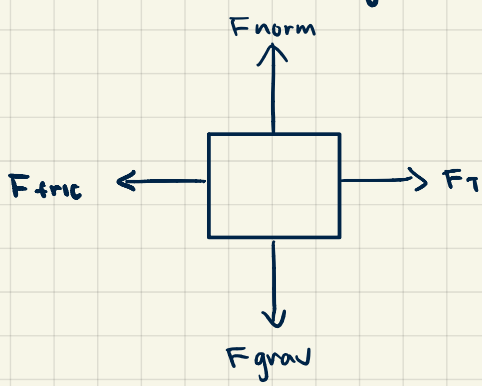
# Mechanics

$$v = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

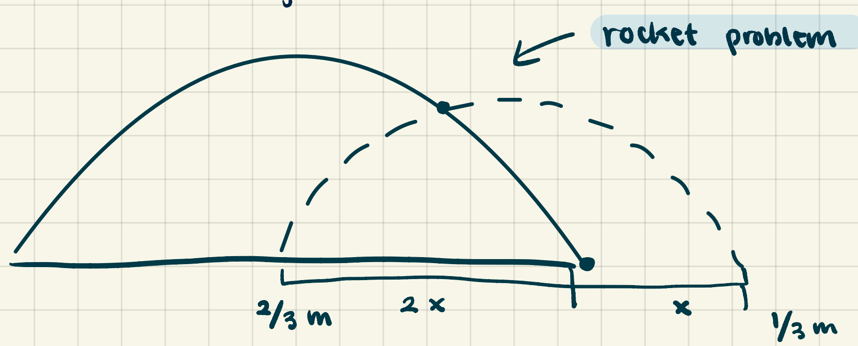
$$a = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

## Free body diagram:




## Kenematic equations:

$$\begin{cases} v_t = v_0 + at \\ \Delta x = v_0 t + \frac{1}{2} a t^2 \\ v_t^2 - v_0^2 = 2a\Delta x \\ \Delta x = \left(\frac{v_0 + v_t}{2}\right) t \end{cases}$$




## Newtons law of forces:

$F_{net} = ma$

$F_{fric} = \mu \cdot F_{norm}$

**static fric:** object at rest

Maximum $F_f = \mu_{static\ fric} \cdot F_n$

**Kenetic fric:** moving object

$$\frac{2}{3} m(-2x) + \frac{1}{3} m(x) = m \cdot 0$$

## momentum

$\Delta p = F \cdot \Delta t$

$\vec{p} = m\vec{v}$

## Conservation of momentum:

initial momentum = final momentum

The momentum of a system is **not** conserved when a force is exerted by an object that's **not** in the system.

**Elastic collision:** initial kenetic energy = final kenetic energy

**Inelastic collision:** initial kenetic energy > final kenetic energy

## Motion of the center mass:

$$Mx_{cm} = m_1 x_1 + m_2 x_2 + \ldots$$

Standard units: m, sec, kg

# Work & Energy

Translational kenetic energy: $KE = \frac{1}{2} m v^2$

Rotational kenetic energy: $\frac{1}{2} I \omega^2$

Gravitational potential energy: $GPE = mgh$

Between planets: $GPE = -G \frac{M_1 M_2}{d}$

Elastic potential energy: $SPE = \frac{1}{2} k x^2$

$F = kx$

Internal energy: < Microscopic energy: Tempertvre of objects / Potential energy

Mechanical Energy: Potential + kenetic energy

Work: $W = \vec{F} \cdot \vec{s}$ or $W = F \Delta x \parallel$ or $W = |F| \cdot |s| \cdot \cos\theta$

Power: energy per second / work done per second.

Work energy Theorem: net work = work done by all forces [conservative + nonconservative]

use with senario ⟶ $W_{NC} = \Delta KE + \Delta PE + \Delta E_{internal}$

$= \frac{1}{2} m v^2 + mgh + \mu F_{Norm} \cdot \Delta x$

Power = energy / time    units: watts or J/s

$P = \vec{F} \cdot \vec{v}$

1HP = 745.7 watts

# Rotation

Centripetal acceleration =

$$\frac{\Delta v}{v} = \frac{\Delta s}{r}$$

$$\Delta v = \frac{v}{r}\Delta s$$

$$\frac{\Delta v}{\Delta t} = \frac{v}{r} \times \frac{\Delta s}{\Delta t}$$

$$a = \frac{v^2}{r}$$

$[a_c = \frac{\Delta v}{\Delta t}]$

$[\frac{\Delta s}{\Delta t} = v]$

* $a_c$ ratio > 0.1 => noticible

Centripetal force: $F = ma_c$

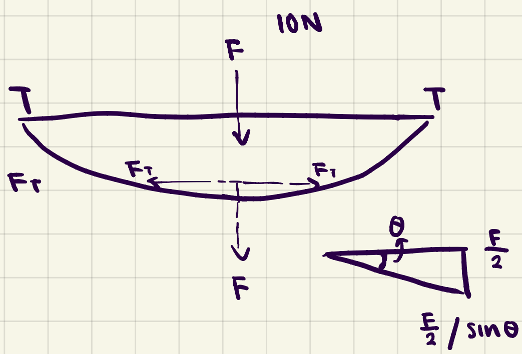
$$= \frac{mv^2}{r}$$

angular velocity x $2\pi r$ = $v$

Torque = force applied x level arm $\tau = Fd_\perp$

* level arm is always perpendicular to the force

$\omega = \frac{\Delta\theta}{\Delta t}$ ← angular velocity




$$\begin{cases} \omega_f = \omega_0 + \alpha t \\ \Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \\ \omega_t^2 = \omega_0^2 + 2\alpha\Delta\theta \end{cases}$$

Rotational Inertia (moment of inertia): $I = mr^2$


$I = \frac{1}{12}ML^2$


$I = \frac{1}{3}ML^2$

Newton's 2nd law of rotation: $\tau_{net} = I\alpha$ ← a

$F = ma$

* uniform objects has smaller inertia

Inertia: $I = mr^2$

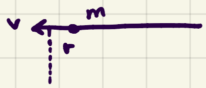
← single point

## Angular momentum: $\Delta L = \tau \cdot \Delta t$

L (angular momentum) =

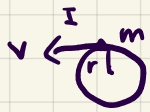
① (circle) 

$L = mvr$

② (straight line) 

$L = mvr$

③ (extended object w/ known rotational inertia:




$L = I\omega$

$\vec{p} = m \cdot \vec{v}$

## Rotational kenetic energy: $\frac{1}{2} I\omega^2$

## 2 things that changes inertia:

1). mass of objects

2). how far away the masses are from the center of rotation

# Gravitation ⇓

$mg = \frac{mv^2}{r}$

1st cosmic velocity: 7.9 km/s        *[7.8 km/s] satellites

2nd cosmic velocity: 11.2 km/s

3rd cosmic velocity: 16.7 km/s

4th cosmic velocity: ≈ 525 km/s

Newton's gravitation equation: $F_{grav} = \frac{G \cdot m_1 \cdot m_2}{d^2}$        $g = G\frac{M}{r^2}$

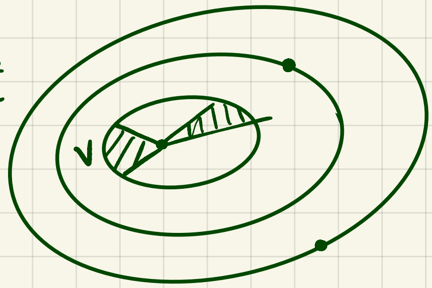
Constant of porportionality: $G = 6.673 \times 10^{-11}$ $N \cdot m^2/kg^2$
(universal gravitation constant)

gravitation acceleration: $g = a = \frac{G \cdot m_{central}}{R^2}$

Kepler's 3 Laws:

- Law of ellipses
- Law of equal areas
- Law of harmonies

$m\frac{v^2}{R}$




Law of harmonies: $\frac{T_1^2}{R_1^3} = \frac{T_2^2}{R_2^3} = 2.97 \times 10^{-19}\ s^2/m^3$

$= \frac{4 \cdot \pi^2}{G \cdot m_{central}}$

$v = \sqrt{\frac{G \cdot M_{central}}{R}}$

$v = \frac{2\pi R}{T}$

# Thermal Physics

## Kelvin Temperture Scale:

$C° = K - 273.15°$

$K = °C + 273.15°$

## Methods of heat transfer:

1). Conduction

2). Convection — Cold (more dense) / Hot (less dense)

3). Radiation

Kelvin temp

**Radiation rate:** $k \cdot T^4$

Thermal conductivity

**Heat Transfer rate equation:** $k \cdot A \cdot (T_1 - T_2) / d$

**Specific heat capacity:** amount of heat required to cause a unit of mass to change its temperature by 1 C°

**Normal:** $Q = m \cdot C \cdot \Delta T$

**Melting & freezing:** $Q = m \cdot \Delta H_{fusion}$

**Vaporization and condensation:** $Q = m \cdot \Delta H_{vaporization}$

# Fluids ≈

**density** = $\frac{\text{mass}}{\text{volume}}$

$$\rho = \frac{m}{V}$$

$\rho$ ethyl alcohol = 0.8 g/cm$^3$ = $0.8\times10^3$ kg/m$^3$

$\rho$ ice = 0.9 g/cm$^3$ $0.9\times10^3$ kg/m$^3$

$\rho$ water = 1g / cm$^3$ 1000 kg / m$^3$

$\rho$ steel (Fe) = 7.8g / cm$^3$ $7.8\times10^3$ kg / m$^3$

$\rho$ Aluminum (Al) = 2.7 g/cm$^3$ $2.7\times10^3$ kg / m$^3$

**STP** = standard temperture and pressure

temperture ↓ 0°c

pressure ↓ $1\times10^5$ Pa

**Pressure** = $\frac{\text{force (N)}}{\text{Area (m}^2\text{)}}$

$$P = \frac{F_\perp}{A}$$

**$P_{ATM}$** = $1\times10^5$ Pa

= 0.1 MPa

= 100 KPa

$$F_g = mg = \rho V g = \rho(lwh)g$$

$$P_{liquid} = \frac{\text{force}}{\text{area}} = \frac{F_{g\ liquid}}{A} = \frac{\rho(lwh)g}{lw}$$

$$= \rho g h$$

**total (absolute) Pressure** = $P_0 + P_{liquid}$

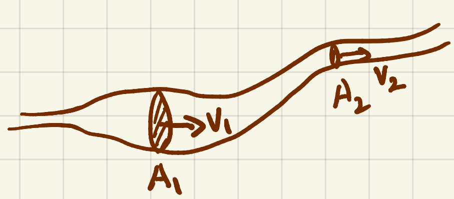
$$P_{total} = P_0 + \rho g h$$

**Buoyant force:** $F_{bouy} = \rho_{fluid} V_{sub}\, g$ (Archimedes principle)

$$\frac{V_{sub}}{V} = \frac{\rho_{object}}{\rho_{fluid}}$$

**Volume flow rate:** $f = A \cdot v$ (m$^3$/s)

**Continuity equation:** $A_1 v_1 = A_2 v_2$



**Bernoulli's equation:** $P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$

[Conditions]

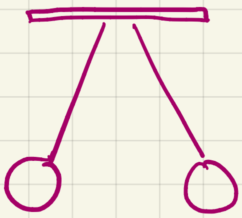
- the fluid is incompressible
- the fluid's viscosity is negligible
- the flow is a streamline

**Bernoulli's effect:** At comparable heights, the pressure is lower where the speed is greater.

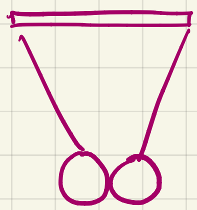
# Static Electricity ⚡

| | Protons | Neutrons | Electrons |
|---|---|---|---|
| positions | In nucleus | In nucleus | outside of nucleus |
| bonds | tightly | tightly | weakly |
| charge | positive | no charge | negative |
| Mass | massive | massive | tiny |

1 Coulomb = $6.25 \times 10^{18}$ electrons
1 electron = $-1.6 \times 10^{-19}$ coulombs
1 proton = $+1.6 \times 10^{-19}$ coulombs



+ +
− −



+ −
+ Neutral
− Neutral

## Coulomb's law equation:

$$F = \frac{K \cdot Q_1 Q_2}{d^2} > F_{grav}$$

$$K = 9.0 \times 10^9 \frac{N m^2}{C^2}$$

Electric force is an action at a distance force

## Electric potential $= \frac{PE}{Q}$

$$\Delta V = V_B - V_A = \frac{\text{Work}}{\text{charge}} = \frac{\Delta PE}{\text{charge}}$$

Current $= I = \frac{Q}{t}$

1 ampere = 1 coulomb / 1 second

Power $= \frac{\text{work done on charge}}{\text{time}} = \frac{\text{Energy consumed by load}}{\text{time}}$

$P = \Delta V \times I$

$R = \frac{\rho l}{A}$

Ohm's law: $\frac{V}{I} = R$ or $V = IR$ or $I = \frac{V}{R}$

$P = \frac{V^2}{R}$ or $P = I^2 \times R$

series resistors: $R_{eq} = R_1 + R_2$ $R_s = \Sigma R_i$

parallel resistors: $\frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$ $R_p = \Sigma \left(\frac{1}{R_i}\right)$

internal resistance = r

terminal voltage = $V_0 - Ir$

Loop Rule: Sum of the potential differences ( + & - ) that traverse any closed loop in a circuit must be zero

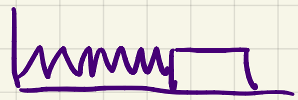
Junction Rule: Total current that enters a junction must equal the total current that leaves the junction.

series capacitors: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$

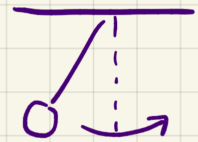
parallel capacitors: $C_{eq} = C_1 + C_2$

# Simple Harmonic Motion

Simple harmonic oscillators:



$F_s = -kx$



equallibrium position: $\Sigma F = 0$

$A$ = amplitude (maximum displacement)

$T$ = period

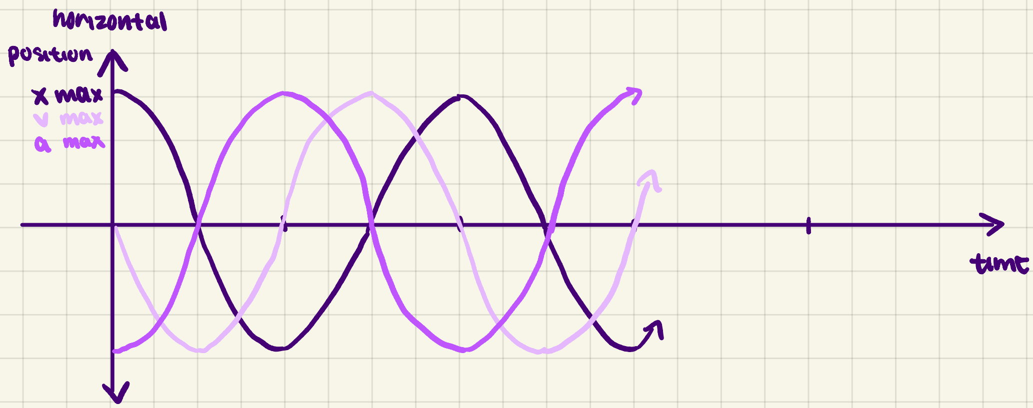
$f = \frac{1}{T}$

$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T}$

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

$x(t) = A\cos(\frac{2\pi}{T}t)$

$x(t) = A\cos(2\pi f t)$



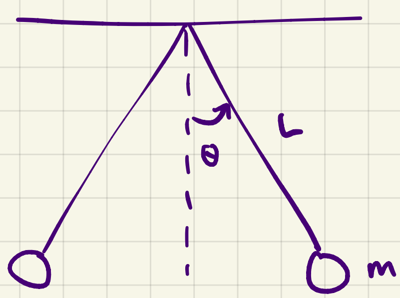

$T_{\text{mass on spring}} = 2\pi\sqrt{\frac{m}{k}}$

$\Sigma F = ma$

$= F_s - F_g$

$= kx - mg$

Simple Pendulum:




$\theta(t) = \theta_{max}\cos(\frac{2\pi}{T}t)$

*mass does't effect period

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

$I = mr^2$ $\quad$ $\tau = rF\sin\theta$

$I = mL^2$ $\quad$ $\tau = LF_g\sin\theta$

↑ ↑ $\quad$ ↑ ↑

| θ max | → | off by |
|---|---|---|
| < 20° | | < 1% |
| < 40° | | < 3% |
| < 70° | | < 10% |

restoring force

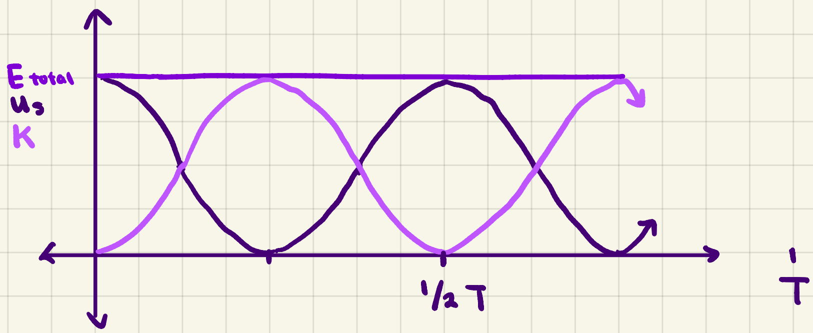
$F = -mg\sin\theta$

When $\theta < 15°$ -> $\sin\theta$ , $F \approx -mg\theta$

$\Delta U_g = mg\Delta y$

$\Delta y = L - L\cos\theta$

$mgh_{max} = \frac{1}{2}mv^2 + mg\Delta y$



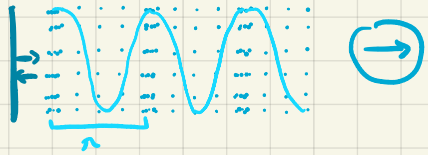

When tension increase, velocity increases.

# Waves & Sound

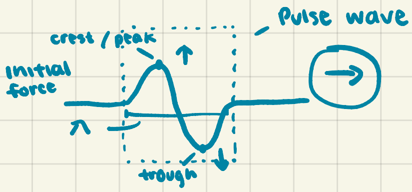
(mechanical) **wave:** a disturbance propagating through space

**wave:** an oscillation that transfers energy and momentum

**longitudinal wave = compression wave**

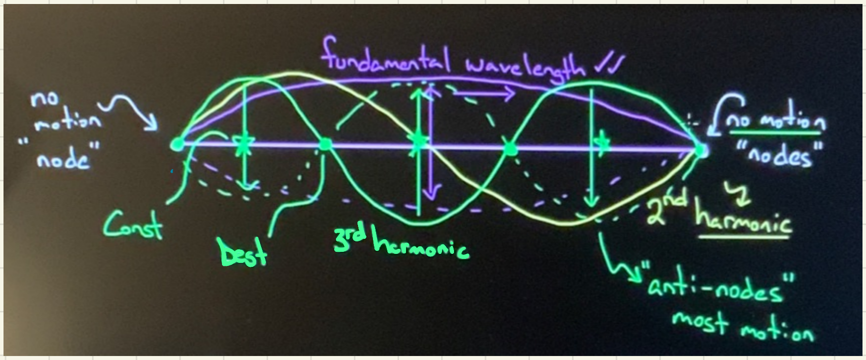



**transverse wave:**

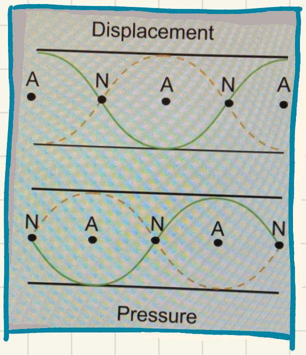



$v = \frac{\text{wave length}}{\text{period}} = \frac{\lambda}{T} = \lambda \cdot f$

**super position principle:** $y_T = y_1 + y_2$




Displacement vs. Pressure




**Open displacement:** $\lambda_n = \frac{2(L)}{n}$ $f_1 = \frac{v}{2L}$ $\lambda_1 = 2L$

**medium:** the material the sound waves travel

**speed of sound in 20°C** = 343 m/s = 767 mph

**Closed displacement:** $\lambda_n = \frac{4L}{n}$ $n = 1, 3, 5, 7, 9$ $f_1 = \frac{v}{4L}$ $\lambda_1 = 4L$

**Beat frequncy:** $f_B = |f_1 - f_2|$

**Wavefront:** points on a disturbance that all vibrate in unison

**Doppler effect:** change in frequncy and wavelength of a wave do to relative motion between the wave source and observer.

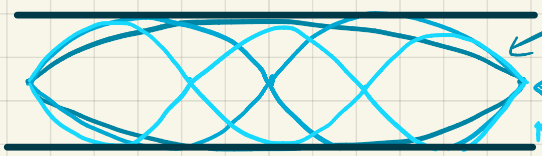
$$v = \sqrt{\frac{F_T}{\mu}}$$

$$f = \left(\frac{c \pm v_r}{c \mp v_s}\right) f_0$$

$V_r$: + moving towards the source
− moving away from the source

$V_s$: − moving towards the reciever
+ moving away from the reciever

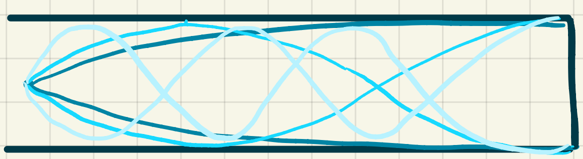
## Open tube:



First harmonic / Foundamental $\lambda_1 = 2L$

Second harmonic $\lambda_2 = L$

Third harmonic $\lambda = \frac{2L}{3}$



First harmonic / Foundamental $\lambda_1 = \frac{L}{2}$

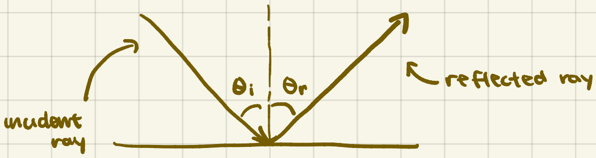
Third harmonic $\lambda_3 = \frac{4L}{3}$

Fifth harmonic $\lambda_5 = \frac{4L}{5}$

# Geometric Optics

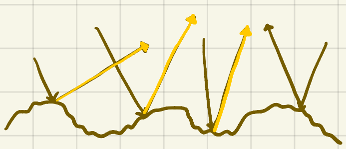
## Reflection:

### Specular Reflection



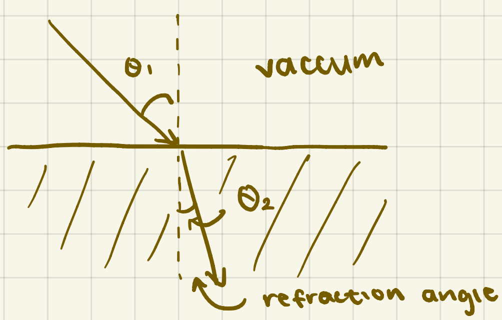

$\theta_i = \theta_r$

### Diffuse Reflection



Reflects in all direction

### Refraction




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

↑ light in vacuum

**Snell's law:**

$$\frac{V_1}{\sin\theta_1} = \frac{V_2}{\sin\theta_2}$$

**Index refraction:**

$$n = \frac{c}{v}$$

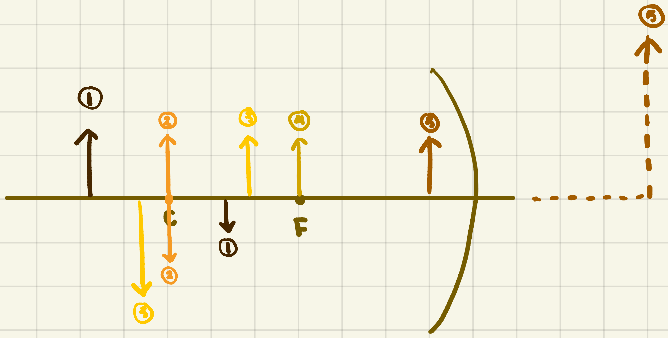
$$v = \frac{c}{n}$$

$\Rightarrow$ $n_2 \sin\theta_2 = n_1 \sin\theta_1$

Smaller wavelength => more bend angle

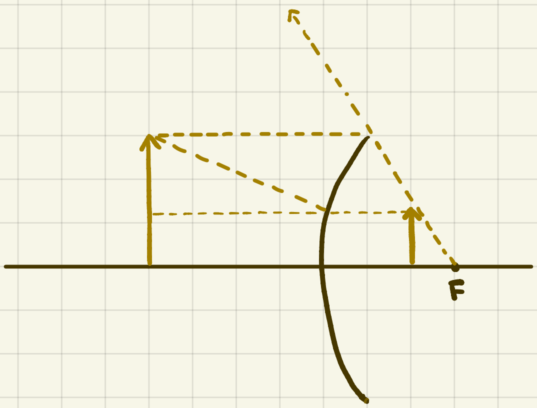
For water vs. air
- Maximum refraction angle = 48.8°
- Greater than 48.8°, no refraction, only reflection

## Concave parabolic mirror




| | Image | Size | Direction |
|---|---|---|---|
| 1 | Real | Smaller | Reversed |
| 2 | Real | same | Reversed |
| 3 | Real | larger | Reversed |
| 4 | N/A | N/A | N/A |
| 5 | Virtual | larger | same |

## Convex parabolic mirror




Virtual image, smaller, same

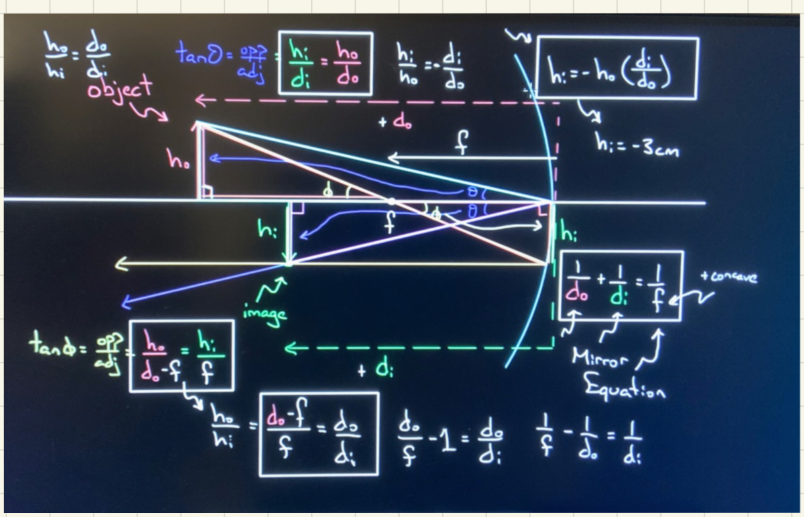
## Mirror equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$f$: ⊕ concave, ⊖ convex

$d_o$: always ⊕

$d_i$: same direction as $d_o$ ⊕, opposite direction as $d_o$ ⊖




## Magnification equation:

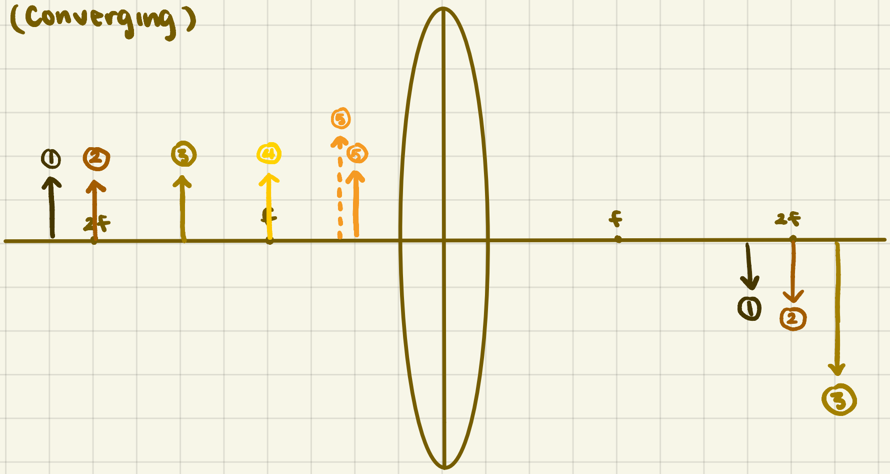
$$h_i = -h_o\left(\frac{d_i}{d_o}\right)$$

$h_i$: same direction as $d_o$ ⊕, opposite direction as $d_o$ ⊖

$h_o$: always ⊕

$\frac{d_i}{d_o}$: always ⊕

## Convex Lenses
(Converging)

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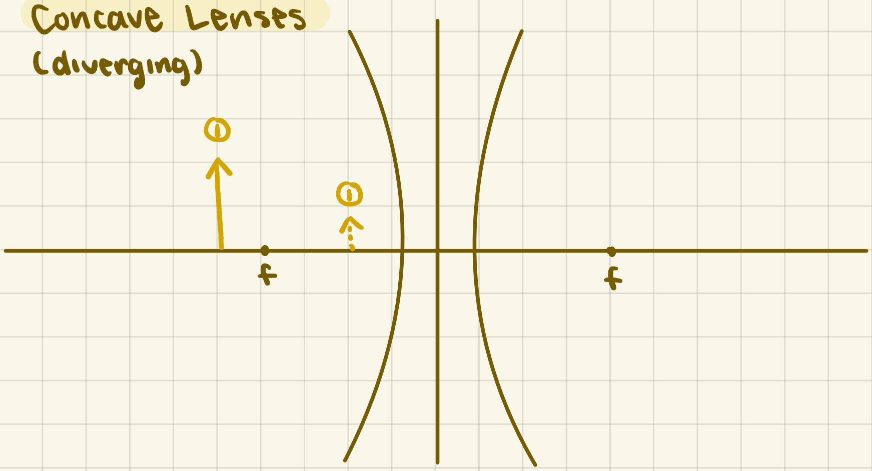
## Concave Lenses
(diverging)




Virtual, smaller, same

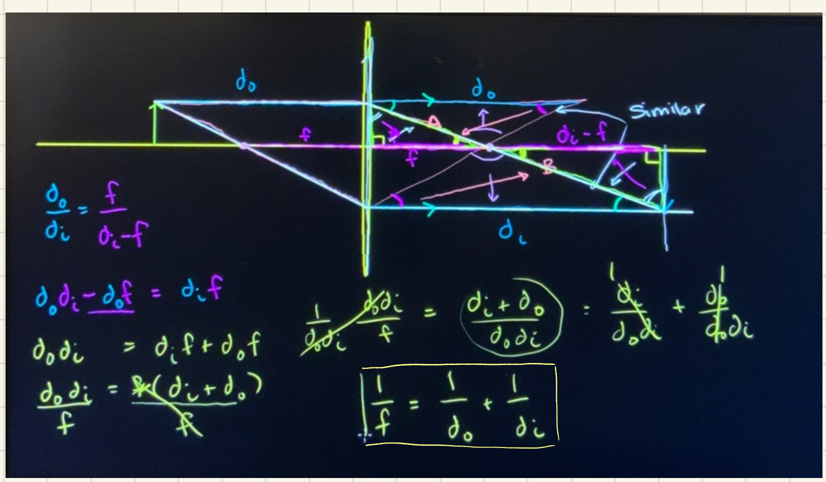
## Lense equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

always ⊕ ($d_o$)

same side as $d_o$ ⊖
opposite side as $d_o$ ⊕

⊖ concave
⊕ convex




## Magnification equation:

$$h_i = -h_o\left(\frac{d_i}{d_o}\right)$$

always ⊕ ($h_o$)

same side as $d_o$ ⊖
opposite side as $d_o$ ⊕

always ⊕ ($d_o$)

Constructive Interference: $\ell = m\lambda$

where $m = 0, 1, 2 \ldots$

Distructive Interference: $\ell = (m + \frac{1}{2})\lambda$

Young's double-slit formula: $x_m = \frac{m\lambda L}{d}$

(bright fringes)

# Magnesium & Electromagnetic Induction

## Electric Field Strength:

$$E = \frac{F_e}{q}$$

$$F = \frac{K \cdot Q_1 Q_2}{d^2}$$

$$F_e = Eq$$

$$K = 9.0 \times 10^9 \ \frac{Nm^2}{C^2}$$

$$Eq = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2}$$

$K = 9.0 \times 10^9$

$$E = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{Q}{r^2}$$

## Cross product:

$$\vec{F} = Q \cdot (\vec{V} \times \vec{B})$$

$$F = qvB\sin\theta$$

unit of B: 1 Tesla $= \frac{N \cdot S}{C \cdot M}$

1 proton $= 1.6 \times 10^{-19}$ C

## Lorentz Force Law:

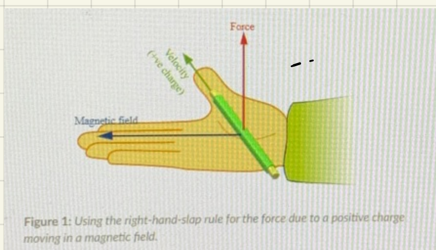
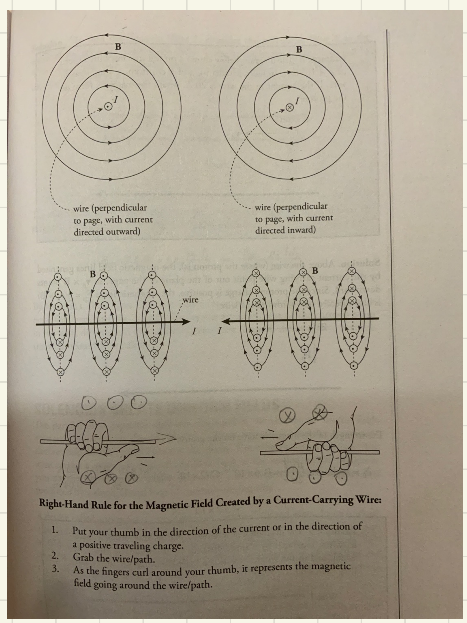


Figure 1: Using the right-hand-slap rule for the force due to a positive charge moving in a magnetic field.

$$\vec{F}_B = I\vec{l} \times \vec{B}$$

$$F_B = BIL\sin\theta$$




## Potential Energy:

EMF $= Blv$ (Nm/C)

## Magnitude of Magnetic field:

$$|\vec{B}| = \frac{\mu_0 I}{2\pi r}$$

$\mu_0 = 4\pi \times 10^{-7}$ (N/A$^2$ or T·m/A)

## Work done:

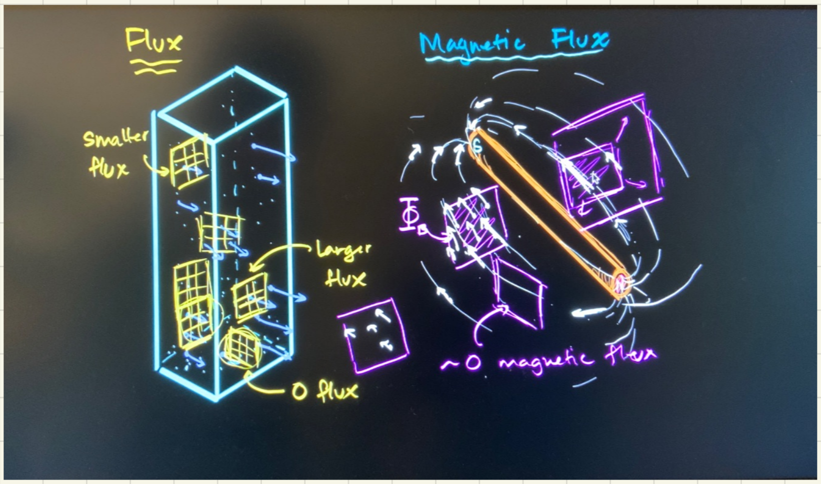
$W_c = \vec{F} \cdot d$

$W = Q \cdot L \cdot \vec{v} \cdot \vec{B}$

$\frac{W}{Q} = L \cdot \vec{v} \cdot \vec{B}$ $\qquad \frac{\text{Joules}}{\text{columb}} = \text{volts}$

$\boxed{EMF = L\vec{v} \cdot \vec{B}}$

## Magnetic Field and Faraday's law:




$\Phi = \vec{B} \cdot \vec{A}$

$\Phi = BA\cos\theta$

$\Phi$ unit: weber (Wb)

1 weber = $1\, T \cdot m^2$

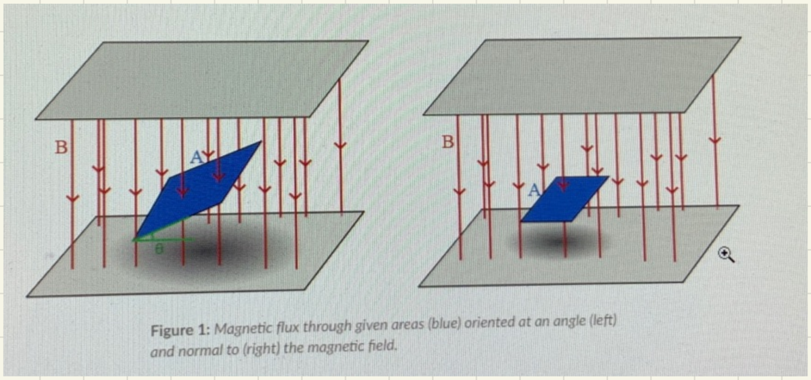
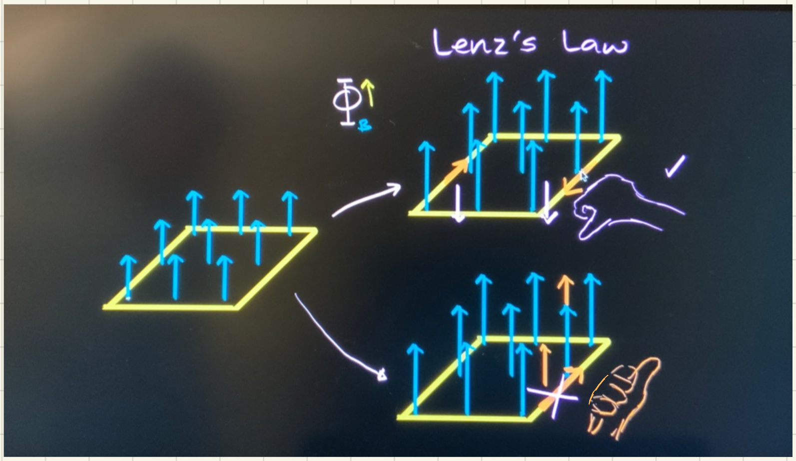



Figure 1: Magnetic flux through given areas (blue) oriented at an angle (left) and normal to (right) the magnetic field.

Change in magnetic flux through loop $\longrightarrow$ induced current

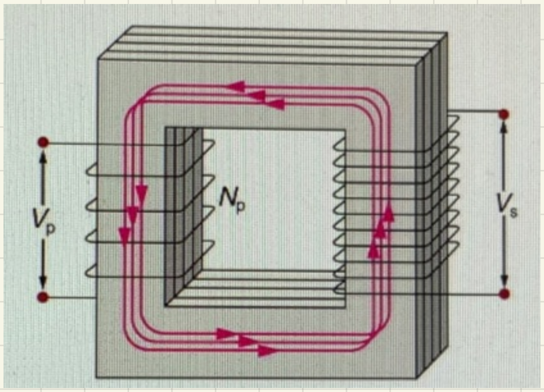
$\mathcal{E} = \frac{\Delta\Phi}{\Delta t}$ or $V_{gen} = -\overset{1}{\cancel{N}} \cdot \frac{\Delta\Phi}{\Delta t}$

Lenz's Law




## Lenz's Law:

An induced electric current flows in a direction such that the current opposites the change that induced it.

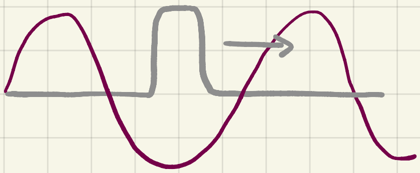



$$\frac{V_s}{n_s} = \frac{V_p}{n_p}$$

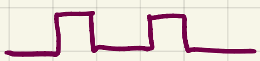
$$\mathcal{E}_{avg} = -\frac{\Delta \Phi}{\Delta t} = -\frac{\Delta B A}{\Delta t} = -\frac{B \Delta A}{\Delta t} = -\frac{BLv\cancel{\Delta t}}{\cancel{\Delta t}}$$

$$= -LvB$$

# Quantum Physics



wave/particle: deposit, discrete, quantum



frequency

$E_{photon} = hf$

Plank's constant: $6.626 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s

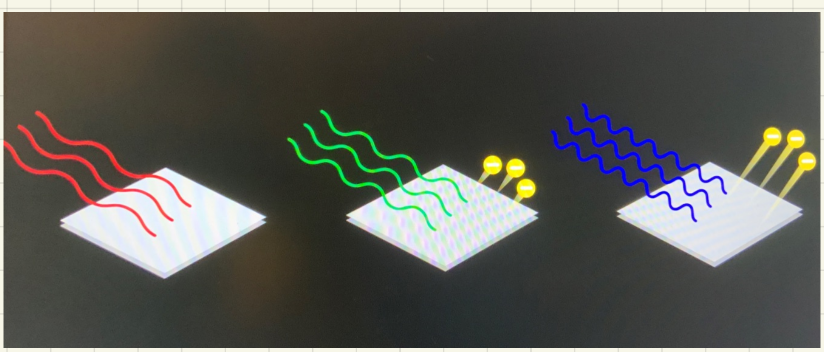
Special Relativity: $\overset{mv}{p} = \frac{h}{\lambda}$ $\quad \lambda = \frac{h}{mv}$

$E_{photon} = E_0 + KE_{photoelectron}$

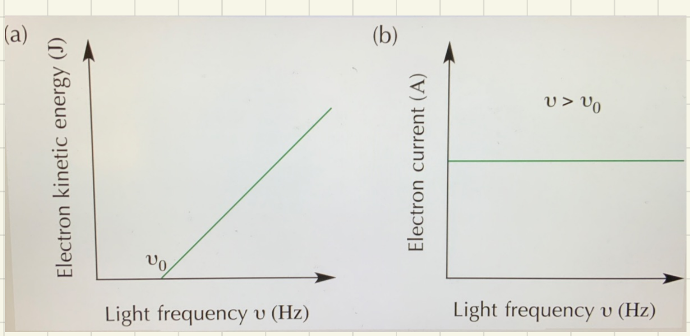
Enought = work need to free photoelectrons

$c = \lambda f$

$E_{photon} = \frac{hc}{\lambda}$



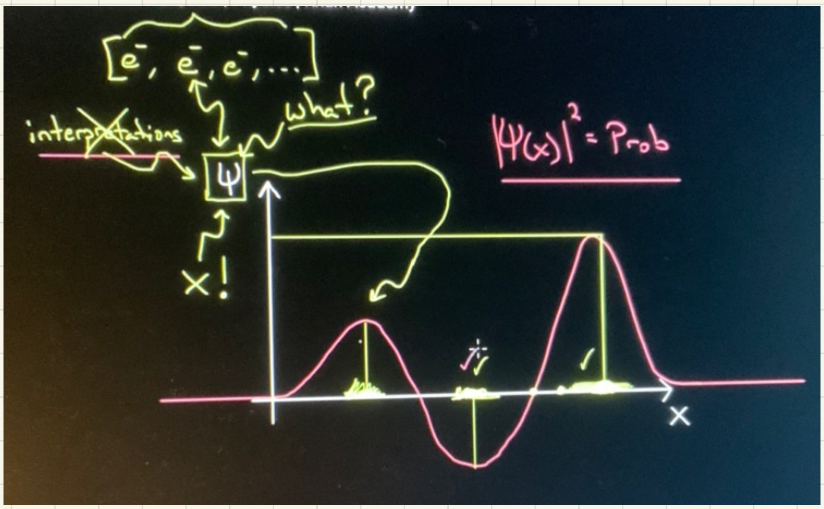
The light amplitude was kept constant as the light frequency increased.




$KE_{electron} = hf - \phi = \frac{1}{2} m_e v^2$

$m_e = 9.1094 \times 10^{-31}$ kg

## Quantum wave function:




$$|\Psi(x)|^2 = \text{Prob}$$

## Atomic Energy level:

$1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}$

first excited state ↓

Can only be at 0eV, 4eV, 6eV, 7eV

Ground state

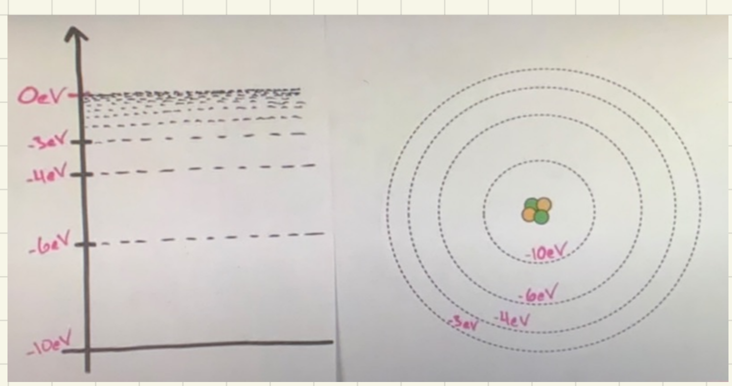

excited states (unstable)

Absorb 4 ev photons to get to first excited state.

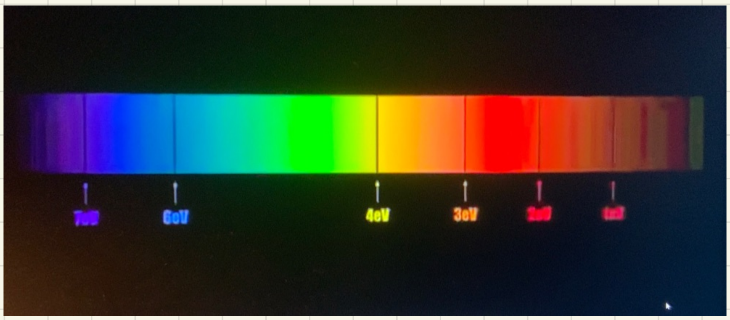
Will always want to fall back down to ground state by emitting photons.

Have to absorb all photons or none of them

higher ev level − lower ev level

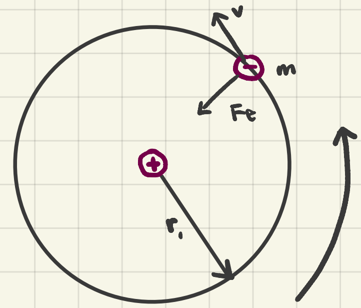


## Absorption spectrum:




## Bohr model radii

$$F = \frac{kq_1 q_2}{r^2}$$




$$\frac{ke(-e)}{r^2} = \frac{mv^2}{r}$$

$$\frac{ke^2}{r} = mv^2$$

$$\frac{ke^2}{r} = m\left(\frac{nh}{2\pi mr}\right)^2$$

$$\frac{ke^2}{r} = \cancel{m}\,\frac{n^2h^2}{4\pi^2 \cancel{m^2} r^2}$$

$$r = \frac{n^2h^2}{ke^2 4\pi^2 m}$$

$$r = n^2(5.3\times10^{-11})$$

$* \ r_1 = 5.3\times10^{-11}\ m$

$r_n = n^2 r_1$

bigger radius, less energy

$L = r \times p$ $\qquad \vec{p} = m\vec{v}$

$L = rmv\sin\theta$

$L = rmv = n\left(\frac{h}{2\pi}\right)$

$$v = \frac{nh}{2\pi mr}$$

$* \ v_1 = 2.2\times10^6\ m/s$

$$v_n = \left(\frac{1}{2}\right)^{n-1} v_1$$

$$U_E = \frac{-ke^2}{r}$$

$* \ E_1 = -2.17\times10^{-18}\ J = -13.6\ eV$

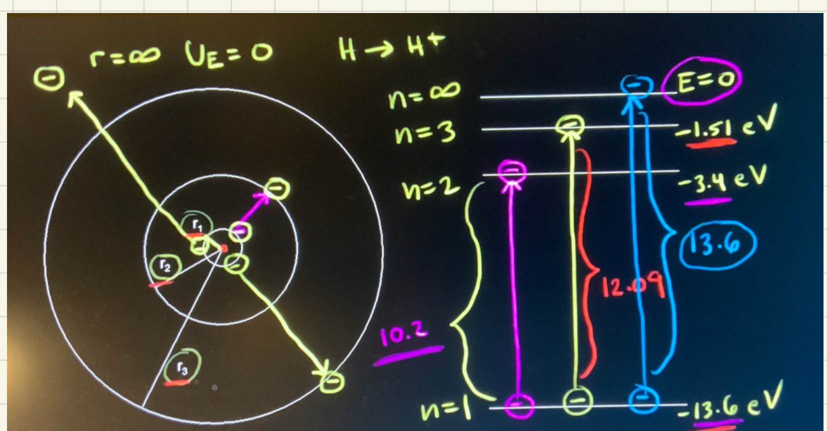
$$E_T = KE + U_E$$
$$= \frac{1}{2}\frac{ke^2}{r} - \frac{ke^2}{r}$$

$$E_T = -\frac{1}{2}\frac{ke^2}{r}$$

$$E_n = -\frac{1}{2}\frac{ke^2}{r_n}$$

$$E_n = \frac{1}{n^2}E_1$$

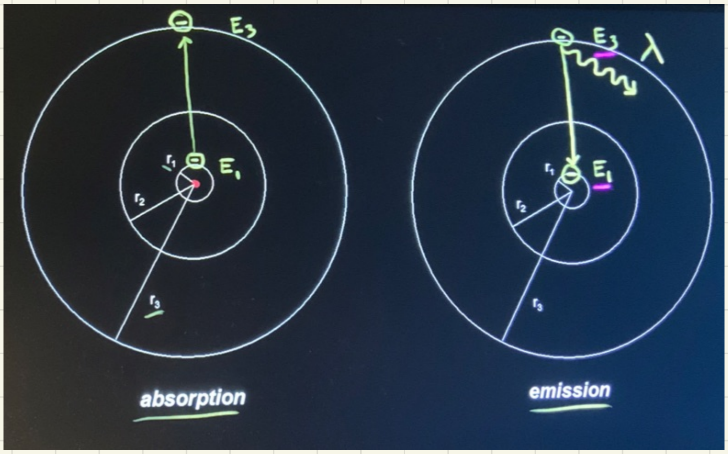
## Bohr's model of energy levels:



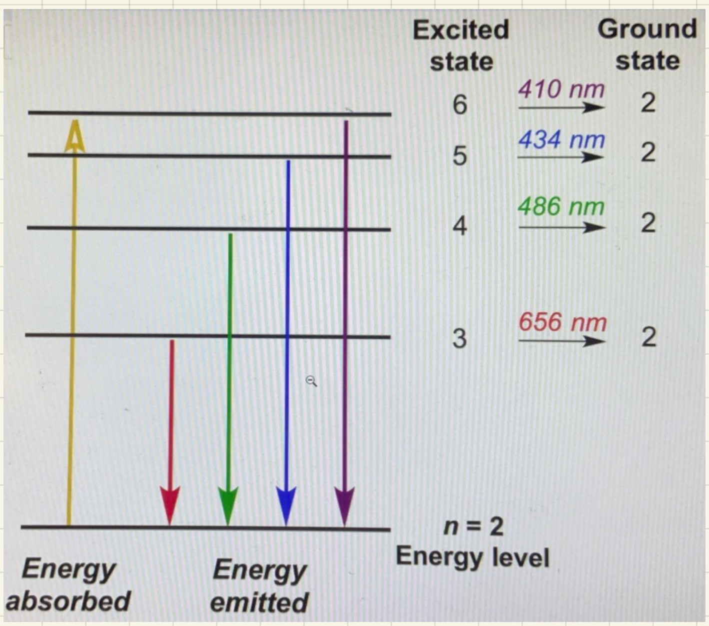

$$hf = \Delta E = \left(\frac{1}{n_i^2} - \frac{1}{n_j^2}\right)\cdot 13.6\ eV$$

**Rydberg constant:** $R = 1.097 \times 10^{7}\ \frac{1}{m}$

**Balmer-Rydberg equation:** $\frac{1}{\lambda} = R\left(\frac{1}{i^2} - \frac{1}{j^2}\right)$




**Absorption & Emission:**




The spectral lines in the visible region of hydrogen's emission spectrum.

$p^+ = 1.00727647$ amu

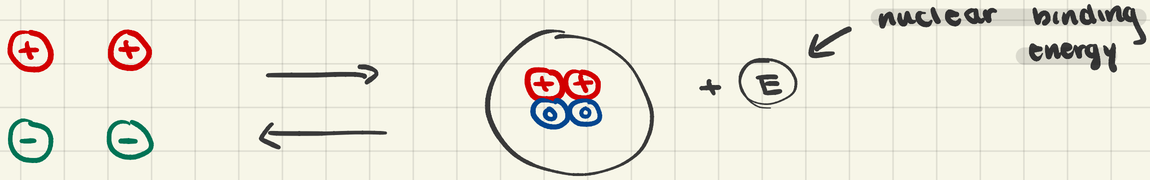
$n = 1.00866490$ amu

**mass defect:** difference between predicted mass and actual mass

**1 amu = $1.66054 \times 10^{-27}$ kg**

**$E = mc^2$**

energy released when the nucleus is formed




only short distances

strong force > electrostatic force

**stable nucleus:** ratio of $\frac{N}{Z} = 1$

**Alpha decay:** $\alpha \rightarrow$ helium

releasing 2 neutrons & 2 protons

$^{p+n}_{p}E \rightarrow ^{p+n-4}_{p-2}E + ^{4}_{2}He$

**Beta decay:**

2 types of emission

(neutron → proton) electron emission $-$ $^{p+n}_{p}E \rightarrow ^{p+n}_{p+1}E_2 + ^{0}_{-1}e$

(proton → neutron) positron emission $+$ $^{p+n}_{p}E \rightarrow ^{p+n}_{p-1}E_2 + ^{0}_{+1}e$

**Gamma decay:** doesn't change the number of protons or neutrons

- releases energy

$n > p$ $^{p+n}_{p}E \rightarrow ^{0}_{0}\gamma + ^{p+n}_{p}E_1$

excited state lower state

Half-life: $T\left(\frac{1}{2}\right)^n$

$N(t) = N_0 e^{-kt}$

$-\lambda t = \ln \frac{1}{2}$

$t_{1/2} = \frac{\ln \frac{1}{2}}{-\lambda} = \frac{0.963}{\lambda}$

$\lambda = \frac{0.693}{t_{1/2}}$

$\ln N = -\lambda t + \ln N_0$

$y = mx + b$

results in linear graph