Fluids and Pressure

Density ρ = mass/volume [kg/m^3]

-Specific gravity   SG = $\rho_{object}/ \rho_{water}$ If SG>1 sinks,   if SG <1 floats

- Specific gravity SG = fraction of floating object below the water
- ρ_{water} = 1000 kg/m^3

Pressure   P = Force/Area   [N/m^2 = Pascals]

- $P_{atm} = 1.01 \times 10^5$ Pa
- A small force can exert a huge pressure if area of contact is small (e.g. pushing tack into wall)

$$P_{absolute}=P_o + \rho gh \qquad\qquad P_{gauge}= \rho gh$$

- P_o is the pressure above the fluid, which is usually $P_{atm} = 1.01 \times 10^5$ Pa
- P_{gauge} measures the difference between the fluid pressure and atmosphereic pressure
- P_{gauge} is what you measure when you check your tires

Volume flow rate = (Area)(speed)   [m^3/sec]

$$A_1v_1=A_2v_2$$

(or **Av = constant**)

- Note: This is true for liquids, not gases, because liquids are incompressible

Buoyancy

- **Archimedes principle**: The Buoyant force equals the weight of the fluid displaced

$$F_{buoyancy} = \rho_{fluid} V_{fluid\ displaced}\, g$$

- The $V_{fluid\ displaced}$ is not always the volume of the object!   (unless it is completely submerged)
- $F_{buoyancy}$ = Weight in air – Weight in water   (for objects that don't float)

Bernoulli's Equation

$$P_1 + ½\rho v_1^2 + \rho gh_1 = P_2 + ½\rho v_2^2 + \rho gh_2$$

Note: If the height does not change significantly, Bernoulli's eqn says,

$$P_1 + ½\rho v_1^2 = P_2 + ½\rho v_2^2$$

(or   **$P + ½\rho v^2$= constant**)

- **Bernoulli's principle**: If the speed of a fluid increases, the pressure of the fluid decreases
- e.g. Blowing air over paper decreases pressure on top, and the paper rises

Thermal Physics

Thermal expansion $\Delta L = \alpha L_o \Delta T$ [m]

- Note: ΔT can be in ^oC or K, but if you have an equation with just **T** it must be in K
- Almost all objects expand when heated (note: holes in heated objects also expand)

Thermal conduction $Q/time = kA\,\Delta T/L$ [J/sec or Watts]

- Heat Q passes through a material of area A, thickness L, and thermal conductivity k
- **Conduction** is when heat flows through an object, **convection** is when currents of hot fluid flow to colder regions, and **radiation** is when energy is transferred by EM waves

$PV = nRT$ (n=moles, T in K, R = 8.31 Pa m^3 /mol K, R = 0.082 atm L /mol K)

$PV = Nk_BT$ (N = # molecules, T in K, P in Pa, V in m^3, $k_B = 1.38 \times 10^{-23}$ J/K)

$Q_{gained} = Q_{lost}$ (note: Heat is measured in Joules)

$Q = mc\,\Delta T$ (use when object is changing temperature)

$Q = mL$ (use when object is changing phase, e.g. solid to liquid or liquid to gas)

- use **heat of fusion** for (solid <-> liquid) use **heat of vaporization** for (liquid <-> gas)

$V_{rms} = [3k_BT/M_{molecule}]^{1/2}$ (root-mean-square speed of molecule in an ideal gas)

Laws of thermodynamics

First Law: $\Delta U = Q_{\text{heat flows into gas}} + W_{\text{work done on gas}}$

- Internal energy (U) increases if heat Q flows into a gas, or work W is done on a gas
- If internal energy of a gas increases, then T increases.
- For Monatomic Ideal Gas you can use the equation $\Delta U=3/2\,\Delta(PV)$

Second Law: Entropy of universe is always increasing

- heat never flows spontaneously from cold to hot
- no heat engine can have an efficiency of 1

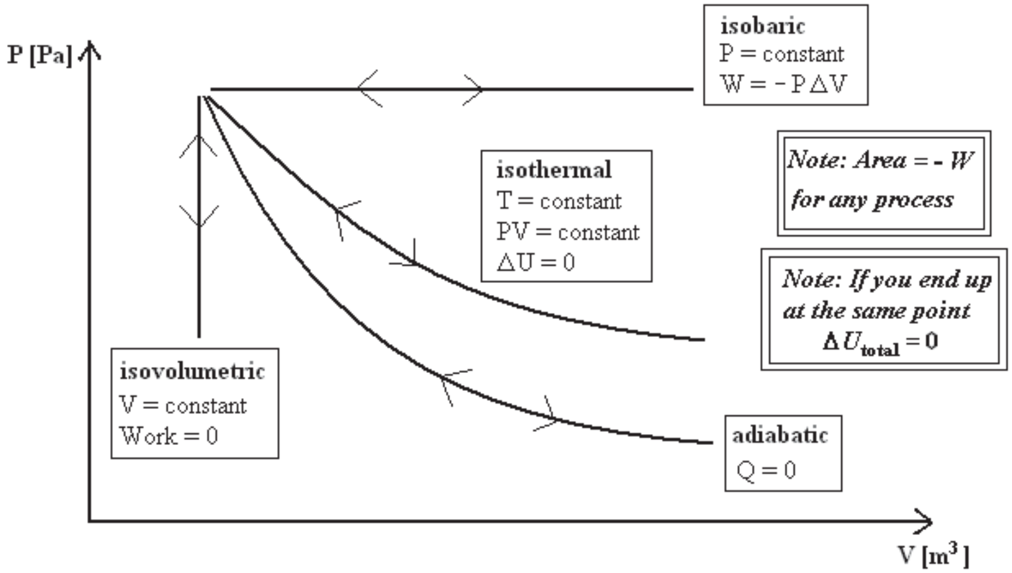
efficiency $= W/Q_H = 1 - Q_C/Q_H$ (Q_c is waste heat created by heat engine)

- The most efficient engine (Carnot engine) has efficiency of $e = 1 - T_C/T_H$

Change in entropy $\Delta S=Q/T$

- if heat flows into an object, that object's entropy increases (and vice versa)

Common thermal processes



Important things to know about PV diagrams

moving to right is expansion (- work is done on gas)

moving to left is compression (+ work is done on gas)

Work done on gas = - Work done by gas

Moving to larger PV (up and right) means ΔU is + (and since W is -, Q must be +)

Moving to lower PV (down and left) means ΔU is - (and since W is +, Q must be -)

Example 1

An ice cube at -35C is dropped into a 100g aluminum container that holds 300g of water at 50C. If the equilibirum temperature reached is 20C, what was the mass of the ice cube?

c_{water} = 4186 J/kg C
c_{ice} = 2100 J/kg C
$c_{aluminum}$ = 900 J/kg C
L_{fusion} = 330,000 J/kg

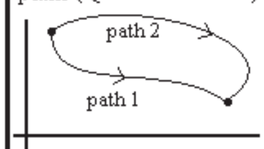
$Q_{gained} = Q_{lost}$ *(Note: ice cube gains heat, but water and aluminum lose heat)*

m(2100)[0C - (-35C)] + m(330,000) +m(4186)(20C-0) = (0.1kg)(900)(50C-20C) + (0.3kg)(4186)(50C-20C)

m(487220) = 40374

m = 0.083 kg

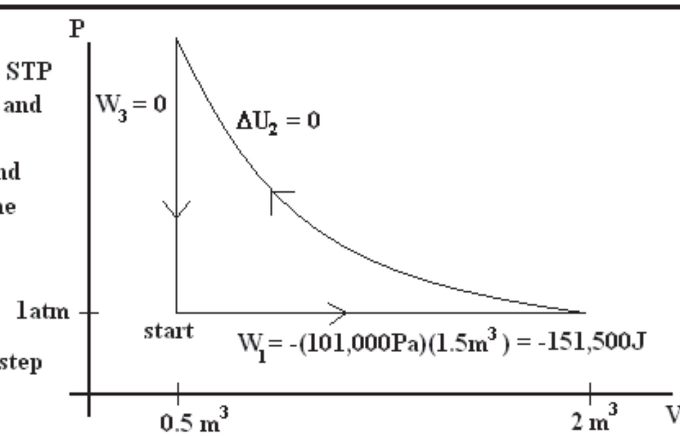
If two paths start at the same point, and end up at the same point, ΔU will be the same for both paths (Q and W will not)



Example 2

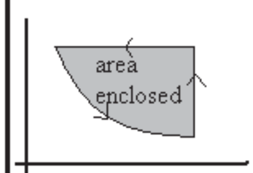
A 0.5 m^3 sample of an ideal gas starts at STP and expands to 2 m^3 at constant pressure and absorbs 200,000J of heat. Then the gas is compressed isothermally back to 0.5 m^3 and the gas does 320,000J of work. Finally the gas is cooled at constant volume back to 1atm.

Draw the process on a PV diagram and determine the ΔU, Q and W for each step and the whole process.



path 1	path 2	path 3	total path
W=-151,500 J	W= 320,000J	W=0	W= 168,500J
Q = +200,000J	Q = -320,000	Q= -48,500J	Q = -168,500J
ΔU= +48,500J	ΔU = 0	ΔU= -48,500J	ΔU = 0

The total area enclosed by a closed path will tell you the total work done (could be + or -)



For an enclosed area the total work done on gas is + if top line goes to the left (as seen in the above diagram)

Electric Forces, Fields, Energy & Voltage

F_e is **electric force** [Newtons]

+ charges feel force in same dir of the electric field (E), - charges feel force in opp. dir of electric field (E)

E is **electric field** [N/Coulomb or Volts/meter]

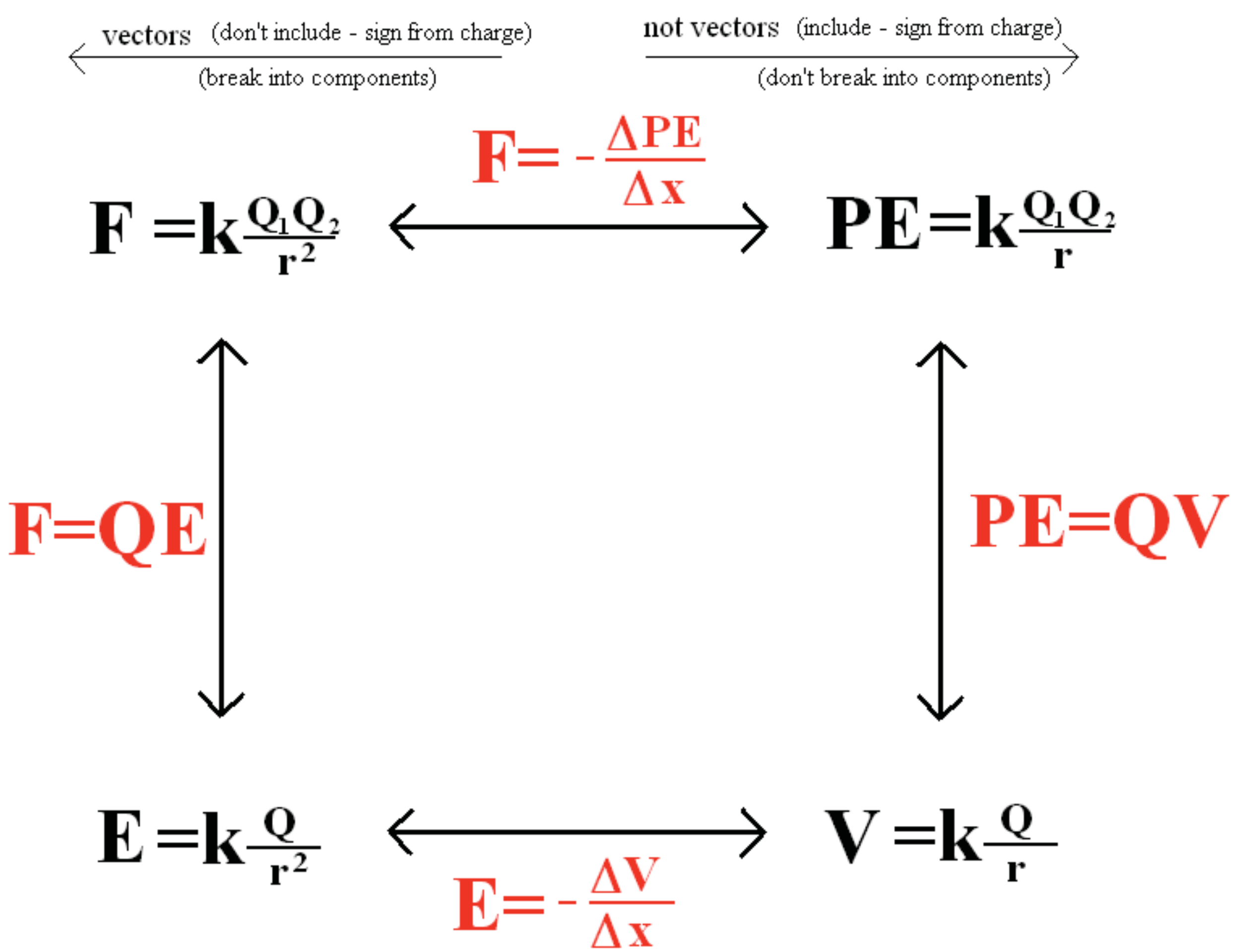
+ charges create electric fields that point radially outward from charge, - charges create E pointing inward

$PE_{electric}$ is **electric potential energy** [Joules]

Electric Poetential Energy (PE) is another form of energy that objects can have

V is **electric potential** [J/Coulomb or Volts]

Electric Potential (V) at a point is the Electric Potential Energy (PE) 1C of charge would have at that point



Note: + and - charges both feel a force **toward lower $PE_{electric}$** , also **Electric fields E** point toward **lower V**

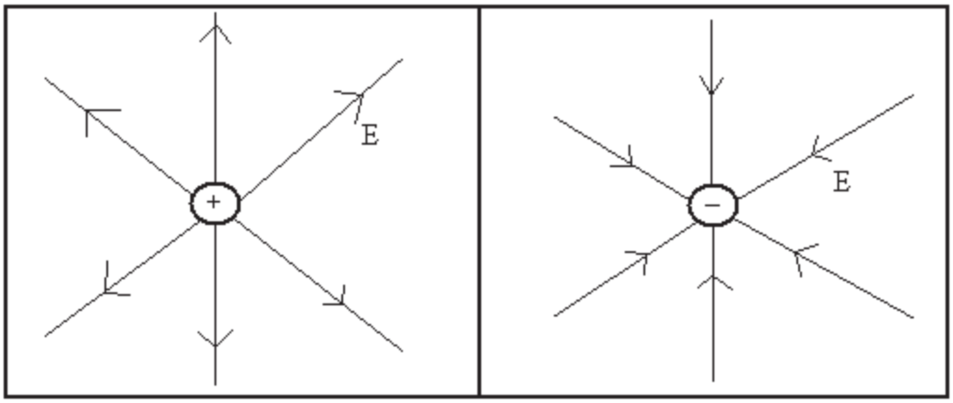
Electric Field Lines and Equipotential Lines

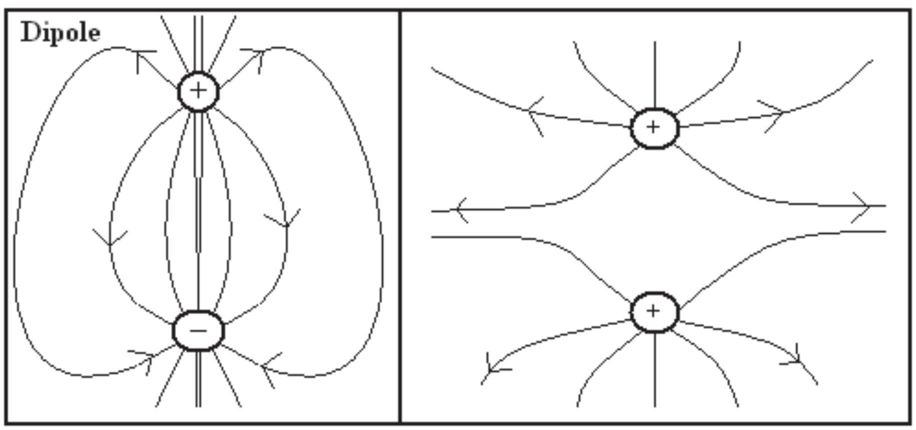
Electric Field Lines show the direction of the electric field (E) at points in space.

Field lines point radially outward from "+" charges, and radially inward toward "-" charges.

The Electric field E is greatest where field lines are closest together.

Larger charges get more field lines to start/end on them.



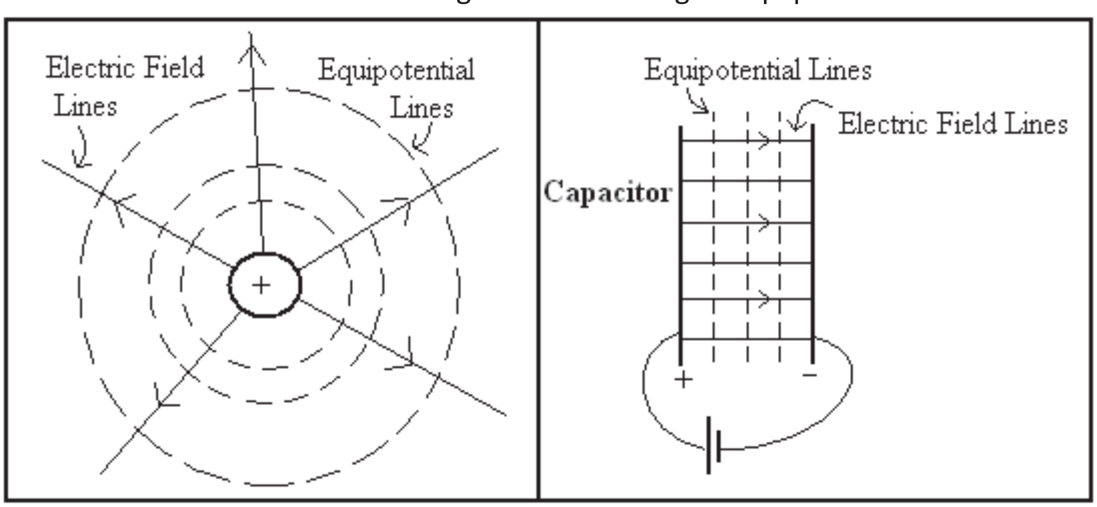


Equipotential Lines show lines of constant electric potential (V).

Equipotential Lines are always perpendicular to the Electric Field Lines.

The Electric Field E is greatest where Equipotential Lines are closest together, $\mathbf{E=-\Delta V/\Delta x}$

There is no work done when a charge is moved along an Equipotential Line.



Circuits

Current

$I = Q/t$ [C/sec = Amperes]

- defined to be in the direction of positive charge flow (or opposite direction of e^-)
- is directed out of the + terminal of a battery, and into the - terminal

Resistance

The resistance of a length **L** of cylinder made with resistivity **ρ**, and cross sectional area **A** is,

$R=\rho\ L/A$ [Ohms]

Ohm's Law

$V = IR$ (V is voltage drop across resistor, I is current through the resistor, R is resistance)

- V is not necessarily the voltage of the battery!
- **Ohmic materials** have constant resistance (slope on V vs. I), regardless of what the current is
- **Non-Ohmic materials** change their "resistance" depending on what the current/voltage is

Electrical Power

$P = IV$ [Watts]

$P = I^2R$

$P = V^2/R$

Capacitors

$C = Q/V$ (C is capacitance, Q is charge on + plate, V is voltage across capacitor)

- Capacitance tells you how well a capacitor can store charge
- Inserting a **Dielectric** between a capacitor always **increases capacitance** by a factor of **k**
- Capacitors store energy as well, which is given by

$E_{capacitor} = \frac{1}{2} QV = \frac{1}{2} CV^2$

- For a parallel plate capacitor with plates of area A separated by a distance d, capacitance is,

$C = \varepsilon_o A/d$

Combining Resistors

Resistors in Series

$$R_{eq} = R_1 + R_2$$

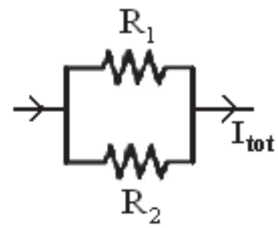
Note: Resistors in Series always have same current

If circuit has only 1 battery,

Choose resistors, two at a time, and reduce to a single resistor to determine the current through the battery. Then determine how current breaks up at junctions using these rules ↗

Resistors in Parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



Note: Resistors in Parallel always have same voltage

If one resistor is 3 times larger than the other, smaller resistor gets 3/4 of the total current $I_{R_1} = \frac{3}{4} I_{tot}$

If one resistor is 5 times larger than the other, smaller resistor gets 5/6 the total current $I_{R_1} = \frac{5}{6} I_{tot}$

or, if resistors are not a nice ratio use this formula

$$I_{R_1} = I_{tot} \frac{R_2}{(R_1 + R_2)}$$

Combining Capacitors

Capacitors in Series

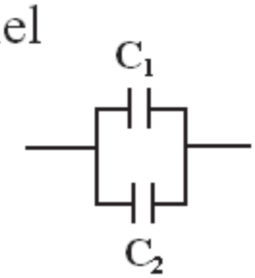
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

Note: Capacitors in series all have same charge

When you reduce all capacitors to a single C, you can find Q (=CV). Then work backwards to find Q on each capacitor.

Capacitors in Parallel

$$C_{eq} = C_1 + C_2$$



Note: Capacitors in parallel all have same voltage

For capacitors in parallel, if one capacitor has **3** times more capacitance than the other, it gets **3/4** of the total charge.

Or, if not a nice ratio use,

$$Q_1 = Q_{tot} \frac{C_1}{C_1 + C_2}$$

Note: After a short time, current will no longer flow through a C, and any segment of a circuit with a C will have no current.

Kirchoff's Rules

Junction Rule: $I_{in} = I_{out}$

- Total current flowing into junction equals total current flowing out of junction

Loop Rule: $\Sigma\Delta V = 0$

- The sum of the changes in voltage around any closed loop always equals zero

$\Delta V = -IR$ (if you **pass through** resistor in the **same direction as current**)

$\Delta V = IR$ (if you **pass through** resistor in the **opp. direction as current**)

$\Delta V = +\varepsilon_{battery}$ (if you **pass through** the battery from **– terminal to + terminal**)

$\Delta V = -\varepsilon_{battery}$ (if you **pass through** the battery from **+ terminal to - terminal**)

Terminal Voltage

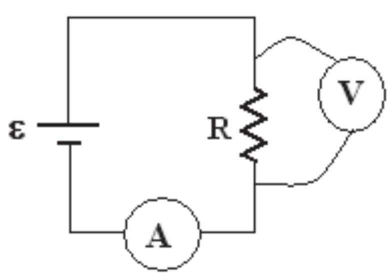
$V_{ab} = \varepsilon - Ir$ (**V_{ab}** is the terminal voltage, **ε** is the emf of battery, **r** is internal resistance)

-Every battery has an internal resistance **r** which will lower the terminal voltage when current flows
- A 9V battery will not necessarily have a measured terminal voltage of 9V, unless no current flows
- The **ε** of a 9V battery is 9V even when no current flows, but the measured terminal voltage will be less
- **Slope** of Vab vs. I graph is negative the **internal resistance**. The **y intercept** is the **emf ε**.

Electrical Meters

Voltmeter

- Measures voltage change across circuit element (resistor, battery, etc.)
- Ideally has **infinite resistance** so it does not draw any current away from circuit
- Needs to be hooked up in **parallel** with circuit element



Ammeter

- Measures current through a circuit element (resistor, battery, etc.)
- Ideally has **no resistance** so it does not change the current
- Needs to be hooked up in **series** with circuit element

Magnetism

Magnetic forces

$F_B = qvB\sin\theta_{vB}$ (**q** is charge, v is speed, **B** is magnetic field, θ is angle between v and B)

- The direction of force on + charge is given by the **Right hand rule** (**V**ery-**B**ad-**F**inger)
- If the charge is negative the force is in the opposite direction
- Magnetic forces **never do Work** (since F_B is always **perpendicular** to motion W=Fdcos**90**=0)
- Magnetic forces often make charges (**q**) of mass **m** travel in circles of radius **r** given by,

$r = mv/qB$

Note: If you want a charged particle to travel in a **straight line ("velocity selector")**, create an electric field E so that the forces cancel, i.e. speed is ratio of E to B

$v=E/B$ (since $F_B = F_E$ or $qvB = qE$)

Note: The forces have to be of equal size, not the fields! (i.e. $\mathbf{F_B = F_E}$, but **E** does not equal **B**)

Magnetic force on wire

$F_B = ILB$ (I is current that feels force, L is length of wire, B is mag. field from other sources)

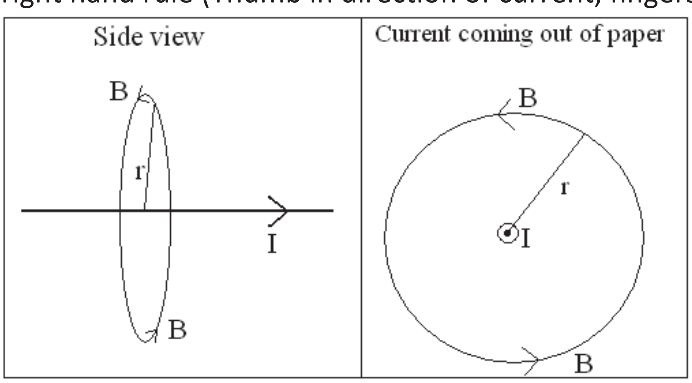
-to find direction of F_B use the same right hand rule (except **v** is now direction of **I**)

Magnetic fields

The magnetic field a distance **r** from a long straight current (**I**) carrying wire is given by,

$B = \mu_o I/2\pi r$ [Tesla] $\mu_o = 4\pi \times 10^{-7}$ T m/A

- The magnetic field from a long straight wire is directed along a circle centered at wire with direction given by right hand rule (Thumb in direction of current, fingers curl in direction of B)



- Note: Wires with I in same direction will attract, Wires with I in opp. Direction will repel

Induced voltage ε

$\varepsilon = -\Delta\Phi_M/\Delta t$ (magnetic flux $\Phi_M = BA\cos\theta$ A is the area of the loop of wire)

$\varepsilon = \Delta(BA\cos\theta)/\Delta t$

- You will induce a voltage in a loop of wire if you change **B, A, or θ**

For a piece of wire or a conducting bar of length L the induced voltage will be

$\varepsilon = LvB$ (remember there is **v**oltage on **L**as **V**egas **B**oulevard)

Lenz's Law

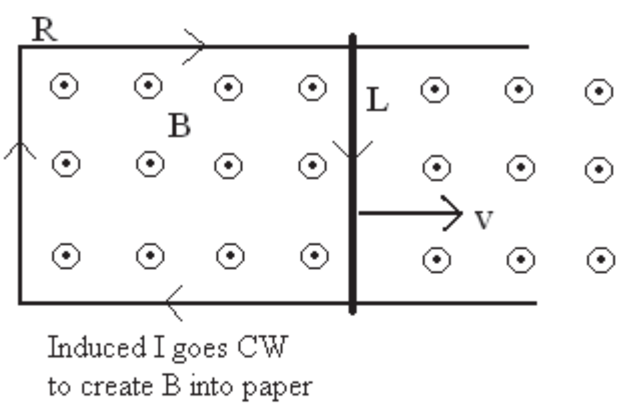
- Induced current always opposes the change in flux

If flux increases, induced current creates a magnetic field B in opp direction of existing B

If flux decreases, induced current creates a magnetic field B in same direction of existing B

Ex 1:

flux increases so induced magnetic field goes in opposite direction of existing B field (put thumb into paper to get CW current)



$F = ILB$

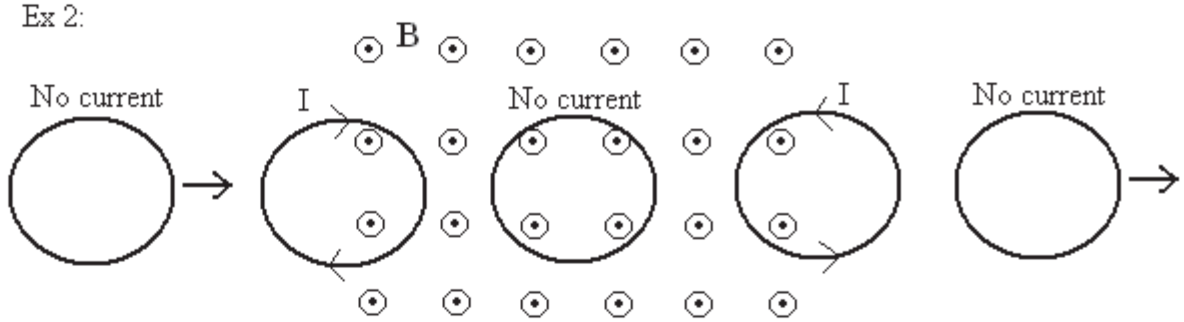
$F = (\varepsilon/R)\,L\,B$

$F = (LvB/R)\,L\,B$

$F = L^2B^2v/R$

$P = Fv$ or IV

Ex 2:



Optics

Reflection $\theta_{in} = \theta_{out}$ Note: always measure θ from the normal line

Refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$ $\mathbf{n} = \mathbf{c}/\mathbf{v} = (3 \times 10^8 \text{ m/s})/\mathbf{v}$

Index of refraction **n** is always greater than or equal to 1

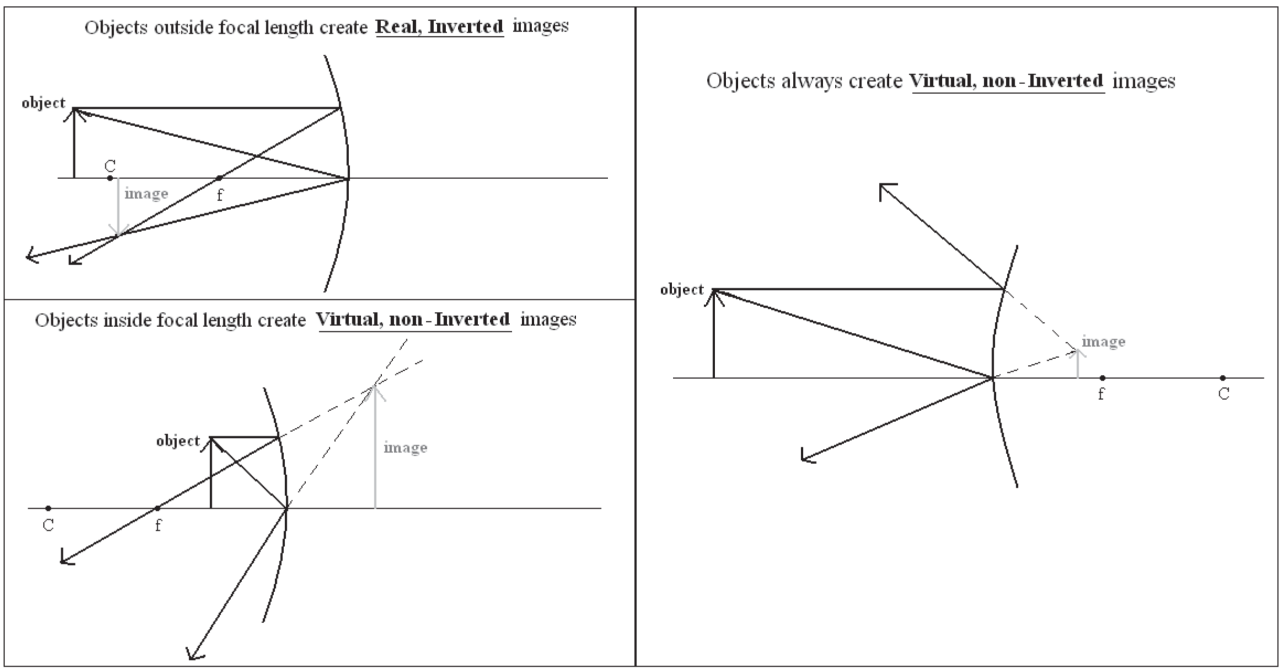
When a wave passes from a **fast medium to a slow medium** it bends **"toward the normal"**

When a wave passes from a **slow medium to a fast medium** it bends **"away from the normal"**

Total internal reflection: $\sin\theta_{critical} = n_2/n_1$ (Note: TIR only occurs if reflected off of "fast" medium)

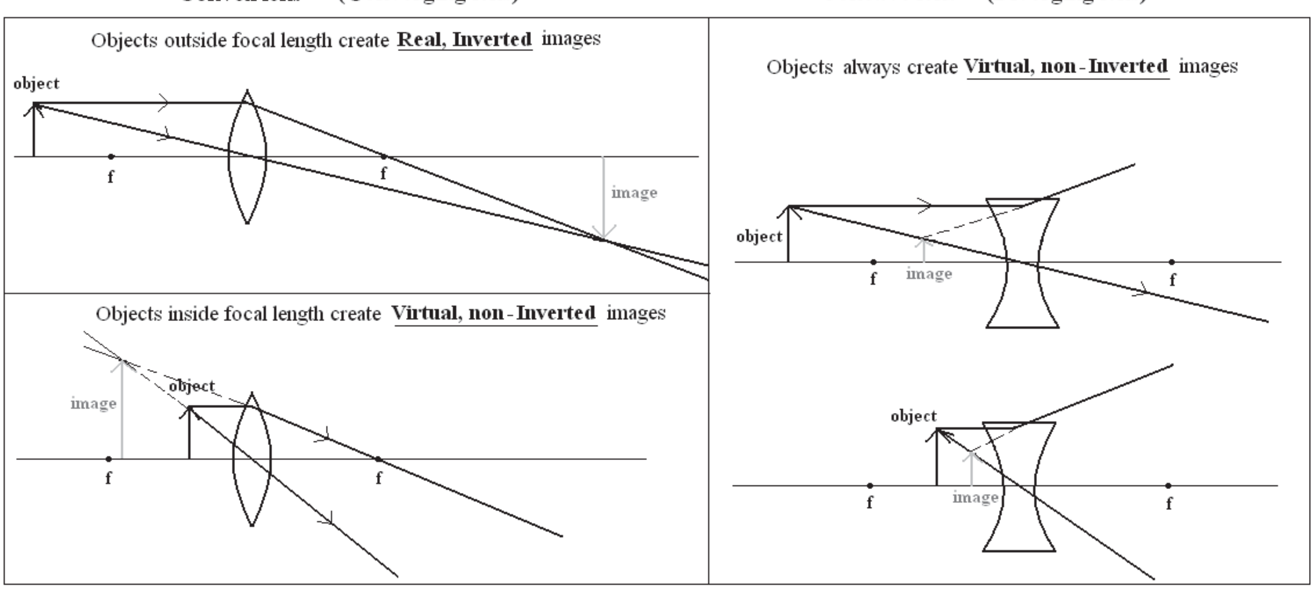
Ray tracing for Mirrors (one ray parallel, and one ray into the center)

Concave Mirror Convex Mirror



Ray tracing for Lenses (one ray parallel, and one ray into the center)

Convex lens (Converging lens) **Concave lens (Diverging lens)**



Mirror or Lens Equation

$$1/f = 1/d_o + 1/d_i$$

Magnification equation

$$M = h_i/h_o = - d_i/d_o$$

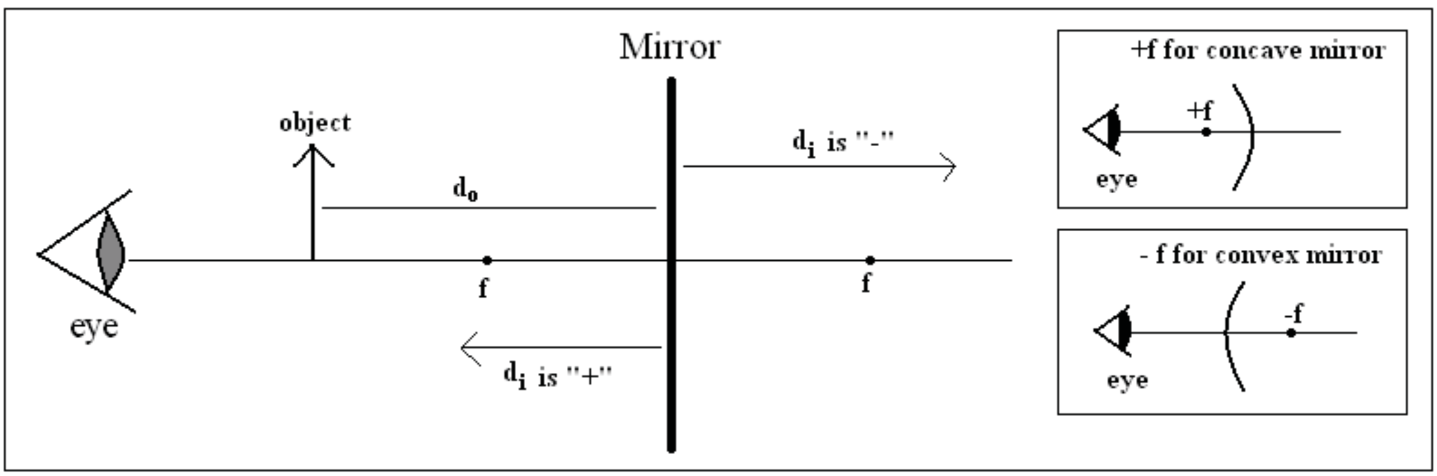
Things that are true for all mirrors/lenses

d_i is + if image is closer to you than mirror/lens

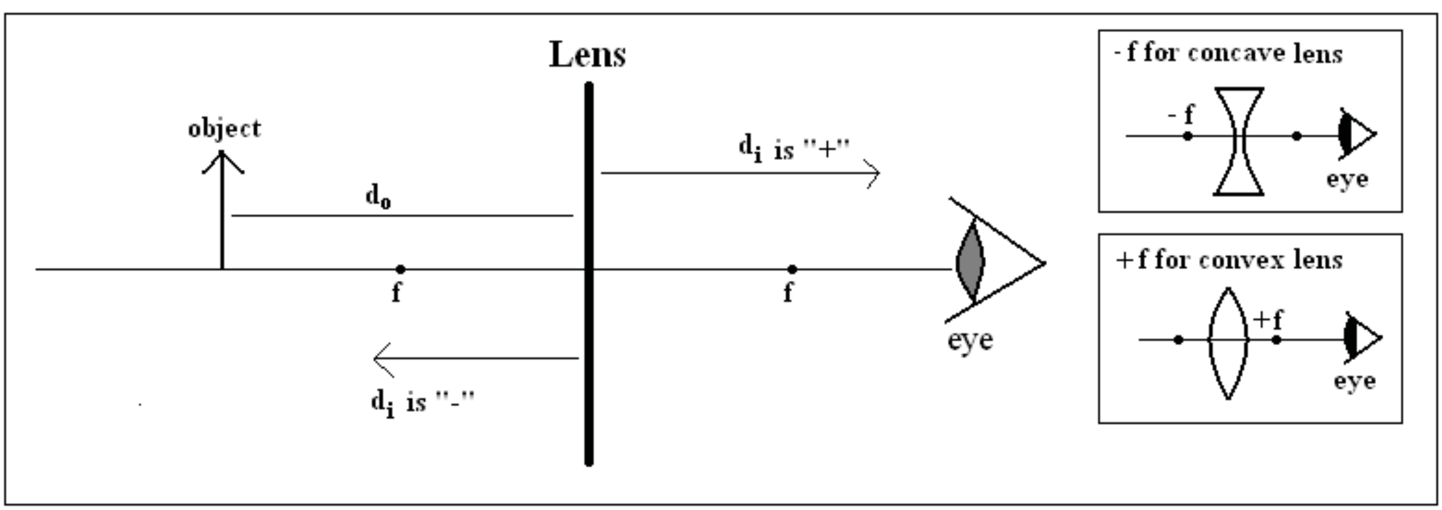
d_i is - if image is farther from you than mirror/lens

Virtual Image	These always go together	Real Image
d_i is "-"	⟵ ⟶	d_i is "+"
Right side up	(if one is true, the others are true)	Upside down

For Mirrors



For Lenses



Wave phenomenon

Reflection $\theta_{in} = \theta_{out}$ Note: always measure θ from the normal line

Refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$ $\quad n = c/v = (3 \times 10^8 \text{ m/s})/v$

Index of refraction **n** is always greater than 1

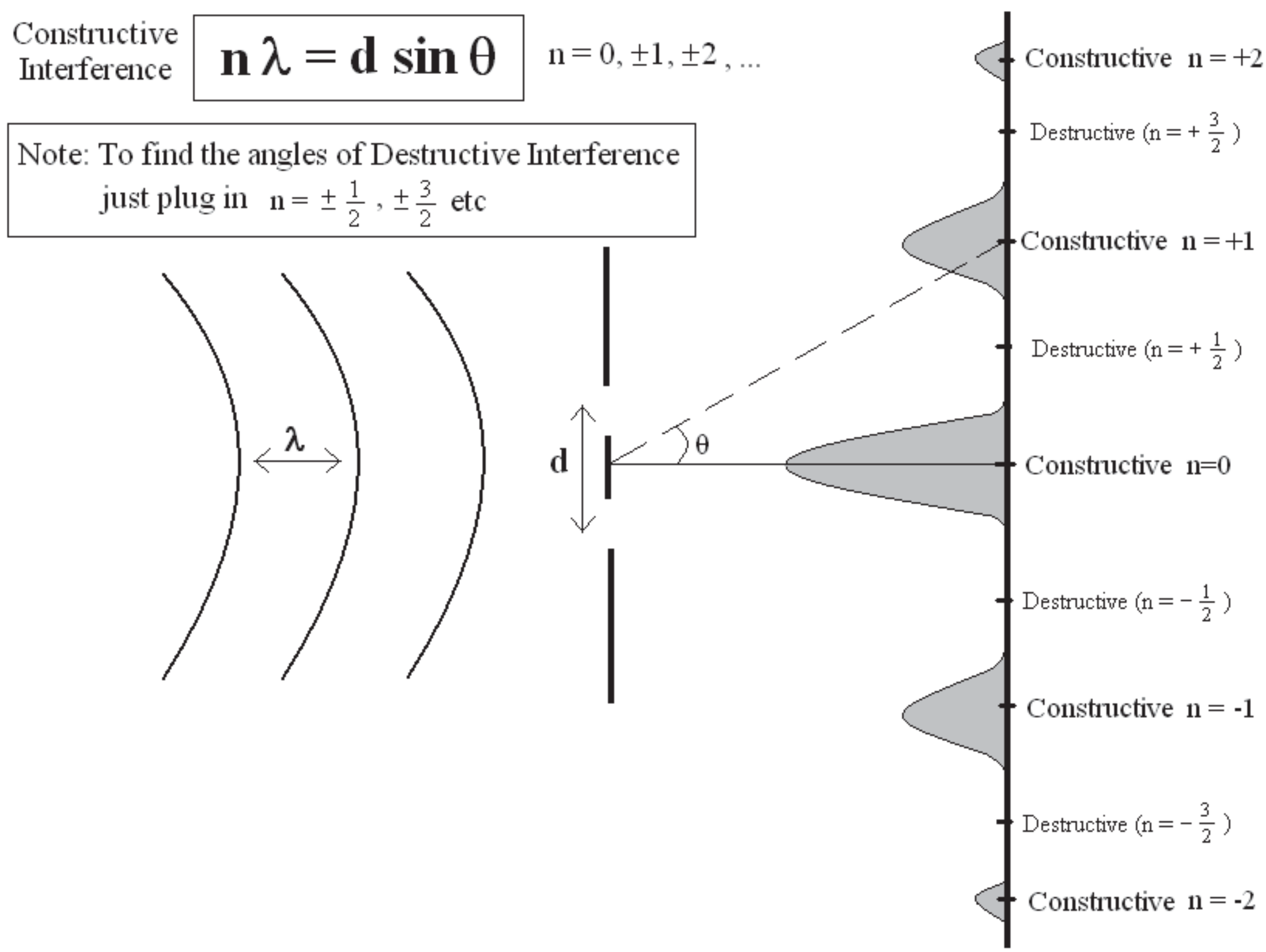
When a wave passes from a **fast medium to a slow medium** it bends **"toward the normal"**

When a wave passes from a **slow medium to a fast medium** it bends **"away from the normal"**

Total internal reflection: $\sin\theta_{critical} = n_2/n_1$ (Note: TIR only occurs if reflected off of "fast" medium)

Diffraction: The spreading out of waves when they encounter a hole or corner

Double Slit Diffraction



For Single Slit Diffraction, it is the opposite,

i.e. **Destructive** happens for $n\lambda = d\sin\theta$ $\quad n = \pm 1, \pm 2, \pm 3$ (don't use n=0 here!)

Thin film interference

For **Fast -> Slow -> Fast** interference (e.g. a soap bubble, or a thin piece of plastic)

Fast → Slow → Fast

Constructive Interference → $2t = (m + \frac{1}{2})\frac{\lambda}{n}$

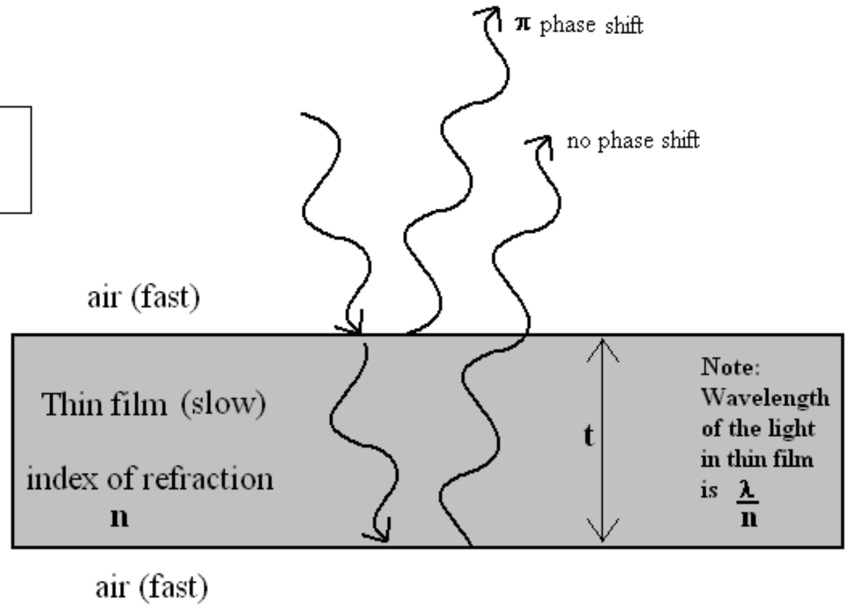
Dest. Interference → $2t = m\frac{\lambda}{n}$

t is the thickness of the Thin film

n is the index of refraction of the Thin film

λ is the wavelength of the light in the air

m = 0, 1, 2, ...



For **Fast -> Slow -> Slower** interference (e.g. water on glass)

Fast → Slow → Slower

Constructive Interference → $2t = m\frac{\lambda}{n}$

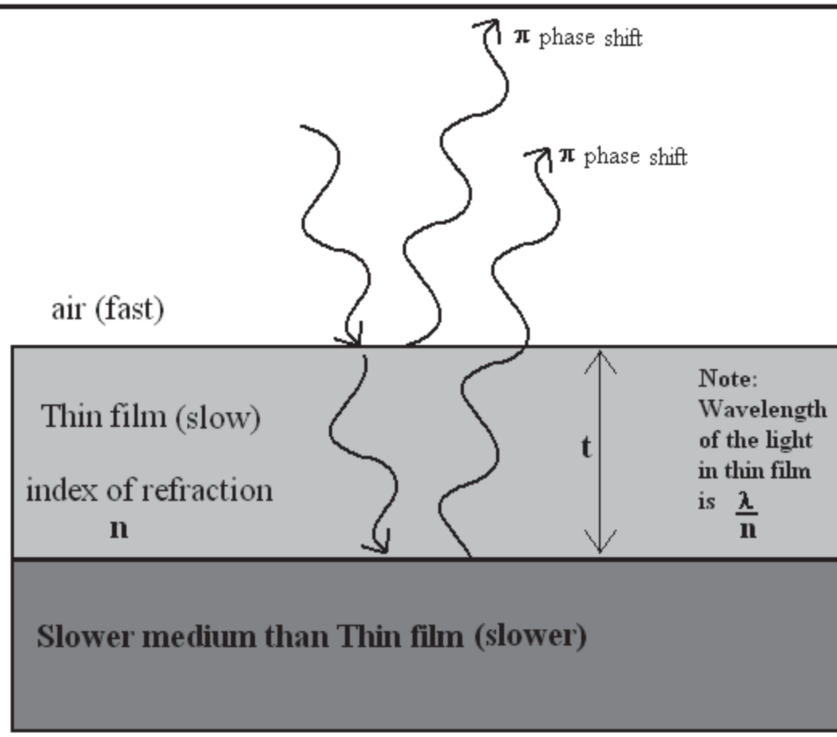
Dest. Interference → $2t = (m + \frac{1}{2})\frac{\lambda}{n}$

t is the thickness of the Thin film

n is the index of refraction of the Thin film

λ is the wavelength of the light in the air

m = 0, 1, 2, ...



Modern Physics

Photons

$E = hf$ (**f** is frequency, **h** is Plank's constant **$h = 6.626 \times 10^{-34}$ J sec**)

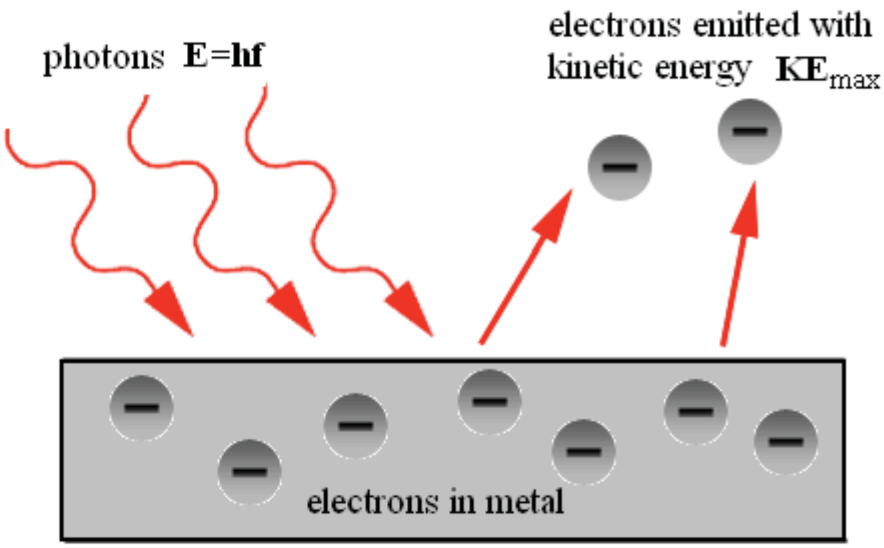
$\lambda = h/p$ (**p** is momentum, λ is wavelength)

- Higher frequency (lower wavelength) light has more energy per photon
- **1 eV** (electron Volt) = **1.6×10^{-19} Joules**
- Note: λ = **h/p** = **h/mv** works for electrons and other particles too. (DeBroglie Wavelength)

Photoelectric Effect

- Provided evidence that light behaves like a particle (photon)

$KE_{max} = hf - \phi$ (ϕ is the work function. Energy needed to free electron from metal.)



-**Increasing Intensity** of light (number of photons) **increases number of electrons**
-**Increasing frequency** of light (energy of photons) **increases KE_{max}** of electrons

Stopping potential: $\Delta V = KE_{max}/e$

- Stopping potential is the minimum voltage needed to stop the outgoing electrons

Compton Scattering

- Photons collide and scatter off other particles (typically electrons)
- Provided more evidence that light behaves like a particle, since photons collide like particles
- Wavelength of scattered light always increases by an amount,

$$\lambda - \lambda_o = h/m_e c\,(1-\cos\theta)$$ (θ is the angle between scattered and incident photons)

- The photon always decreases in energy, decreases in frequency, and increases in wavelength

Nuclear processes

$^{A}_{Z}X$

X is the element name (H for Hydrogen or Pb for Lead)

mass number A is the total # of nucleons (protons + neutrons)

atomic number Z is the # of protons

neutron number N is A - Z (number of neutrons)

Alpha Decay e.g. $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}HE$

- An alpha particle, i.e. a Helium nucleus (2 protons +2 neutrons), is emitted by a larger nucleus
-mass number **A decreases by 4** and atomic number **Z decreases by 2**

Beta Decay e.g. $^{14}_{6}C \rightarrow {}^{14}_{7}N + e^{-}$ + antineutrino

- Typically a neutron decays into a proton, electron and antineutrino
-mass number **A always stays the same**
-atomic number **Z typically increases by 1** (if neutron decays into proton)
-Occasionally a proton can absorb an electron and turn into a neutron. In this case Z decreases by 1

Gamma Decay e.g. $^{12}_{6}C^{*} \rightarrow {}^{12}_{6}C + \gamma$ (X* denotes an excited nucleus)

- A high energy photon (Gamma ray) is emitted by an excited nucleus
- Mass number **A and atomic number Z remain the same**
- Gamma decay typically occurs after an alpha or beta decay

Mass Defect (The total mass often changes in nuclear reactions like fission and fusion)

$E_{rest\ energy} = mc^2$ or $\Delta E = \Delta mc^2$

- Mass can be converted into energy ($e^{-} + e^{+} \rightarrow \gamma$'s), and energy can be converted into mass

Atomic energy levels (e^{-} emit photons if drop E levels, absorb photons if rise E levels)

electron energy levels in an atom