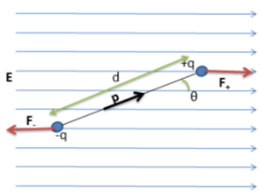
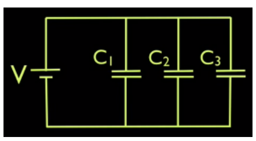
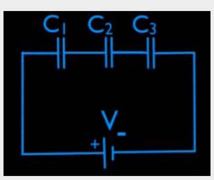
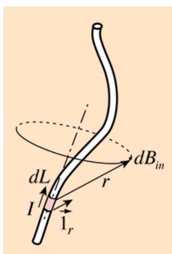
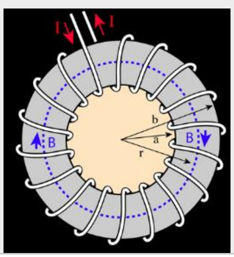
KNOAPP'S PHYSICS TOOLBOX		
Name - description	Equation	Definitions
Force of Gravity – Used to calculate the force between two objects in space.	$\mathbf{F_G} = \frac{-Gm_1m_2}{d^2}\mathbf{r} = m_2g\mathbf{r}$	$\mathbf{F_G}$ – Force between objects G – 6.674E-11 m^3 kg^-1 s^-2 m – Mass of object(s) d – Distance between objects **r** – Unit vector between objects
Coulomb's Law – Used to calculate the force between two point-charges in space.	$\mathbf{F_C} = \frac{Kq_1q_2}{d^2}\mathbf{r} = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{d^2}\mathbf{r}$	$\mathbf{F_C}$ – Force between charges K – 8.994E9 N m^2/c^2 ε_0 – 8.854E-12 1/N c^2/m^2 q – Charge(s) d – Distance between charges **r** – Unit vector between charges
Lorentz Equation – Fundamental equation connecting force to charges and fields.	$\mathbf{F} = q\mathbf{E} + q\mathbf{v} \times \mathbf{B}$	q – Charge **E** – Electric field vector **v** – Velocity relative to a source **B** – Magnetic field vector
Lorentz Conversion – An extremely helpful derivation from the previous equation to convert electric fields to forces.	$\mathbf{E} = \frac{\mathbf{F}}{q}$	**E** – Electric field vector **F** – Force vector q - Charge
Superposition – Used to calculate the result of a system of particles or charges.	$\mathbf{F} = \mathbf{F_1} + \mathbf{F_2} + \mathbf{F_3} + \cdots$ $\mathbf{E} = \mathbf{E_1} + \mathbf{E_2} + \mathbf{E_3} + \cdots$	**E** – Electric field vector(s) **F** – Force vector(s)
Coulomb's E-Field Equation – Used to calculate an electric field given a source, charge(s), and distance vector(s) to source. Derived from Coulomb's Law and Lorentz's Equation. Commonly used to solve for loops, disks, and rods.	$\mathbf{E} = \frac{Kq}{d^2}\boldsymbol{r}$ $\mathbf{dE} = \frac{Kdq}{d^2}\mathbf{r}$	**E** – Resulting electric field vector **dE** – Small electric field vector K – 8.994E9 N m^2/c^2 q – Charge dq – Small Charge d – Distance from charge **r** – Unit vector from charge
Charge Densities – Common symbols used to describe a charge over a dimension of space.	$\lambda = \frac{\text{Charge}}{\text{Length}}$ $\sigma = \frac{\text{Charge}}{\text{Area}}$ $\rho = \frac{\text{Charge}}{\text{Volume}}$	Charge – Ex. Q Length – Ex. 2πR Area – Ex. πR^2 Volume – Ex. 4/3πR^3

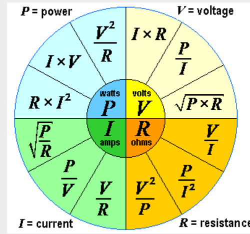
Infinite Parallel Plates – As R (distance) of the plates goes to infinity, the electric field inside the plates converges to the following equation.	$\mathrm{E} = 2\dfrac{\sigma}{2\varepsilon_0} = \dfrac{\sigma}{\varepsilon_0}$	E – Resulting electric field σ – Charge Density ε_0 – 8.854E-12 1/N c^2/m^2
Torque on Dipole – Finding the resulting torque on a system of charges within an electric field. 	$\tau = \mathbf{d}\,\mathrm{q}\mathbf{E}\sin\theta$ $\mathbf{p} = \mathrm{q}\mathbf{d}$ $\lvert\boldsymbol{\tau}\rvert = \lvert\mathbf{p}\ \mathrm{x}\ \mathbf{E}\rvert = \mathrm{pE}\sin\theta$	τ – Resulting torque on Dipole **d** – Distance between charges q – Charge(s) **E –** Constant electric field vector **p** – Dipole moment vector θ – Angle formed by **d** or **p**
Flux – The quantity of something that passes through an area. Example: air flowing through a fan.	$\phi_\mathrm{E} = \lvert\mathbf{E}\cdot\mathbf{A}\rvert = \mathrm{EA}\cos\theta$	ϕ_E – Electric flux **E** – Electric field vector **A** – Area orientation vector θ – Angle between vectors
Gauss' Law for E – One of Maxwell's equations. The area integral of the electric field over any closed surface is equal to the net charge enclosed in the surface divided by the permittivity of space.	$\phi_\mathrm{E} = \oint_S \mathbf{E}\cdot\mathbf{da} = \dfrac{\mathrm{q_{in}}}{\varepsilon_0}$	ϕ_E – Flux for electric field **E** – Electric field vector **da** – Small area orientation vector $\mathrm{q_{in}}$ – Charge enclosed in G-sphere ε_0 – 8.854E-12 1/N c^2/m^2
Conductor – Transfers electrons easily **Insulator** – Prohibits electron transfer	$\mathrm{E_c} = 0$	$\mathrm{E_c}$ – Electric field inside conductor
Potential Energy – The energy possessed by an object relative to others.	$\Delta\mathrm{U} = -\mathrm{W_C} = -\int \mathrm{Fdx}$	ΔU – Change in potential energy $\mathrm{W_C}$ – Work conservative F – Force dx – Small distance
Point Charge Potential – The potential energy of a system of charges relative to one another.	$\mathbf{U_E} = \dfrac{\mathrm{Kq_1q_2}}{\mathrm{d}}\mathbf{r} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{\mathrm{q_1q_2}}{\mathrm{d}}\mathbf{r}$	$\mathbf{U_E}$ – Force between charges K – 8.994E9 N m^2/c^2 ε_0 – 8.854E-12 1/N c^2/m^2 q – Charge(s) d – Distance between charges **r** – Unit vector between charges
Point Charge Voltage – The electric potential of a system of charges.	$\mathrm{V} = \dfrac{-\mathrm{U}}{\mathrm{q}} = \dfrac{\mathrm{q}}{4\pi\varepsilon_0}\dfrac{1}{\mathrm{r}}$	V – Voltage U – Potential energy q – Charge ε_0 – 8.854E-12 1/N c^2/m^2 r – Distance from charge

Voltage and Electric Field – The following equations relate V and E. If you've got one, you can get the other.	$\mathbf{E} = -\nabla \mathbf{V}$ $V_{(x)} = -\int E_{(x)} dx$ $E_{(x)} = \frac{-dV_{(x)}}{dx}$	**E** – Electric field vector **V** – Voltage vector *Note dimensions x, y, z exist though only x has been recorded.
Capacitance – The ability of a component or circuit to collect and store energy in the form of an electrical charge.	$C = \frac{Q}{V}$	C – Capacitance Q – Charge V – Voltage
Capacitance Potential – The potential energy a capacitor can store within itself.	$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$ $C = \frac{A\varepsilon_0}{a}$ $U = \frac{1}{2}E^2(Aa)\varepsilon_0$ $E = (\frac{Q}{A\varepsilon_0})^2$	U – Potential of capacitor Q – Charge C – Capacitance V – Voltage ε_0 – 8.854E-12 1/N c^2/m^2 A – Area of capacitor plate(s) a – Distance between plates E – Constant
Parallel Capacitors 	$Q_T = Q_1 + Q_2 + Q_3$ $V_B = V_1 = V_2 = V_3$ $C_{Eq} = C_1 + C_2 + C_3$	Q_T – Total charge V_B – Voltage of the battery C_{Eq} – Equivalent capacitance
Series Capacitors 	$Q_T = Q_1 = Q_2 = Q_3$ $V_B = V_1 + V_2 + V_3$ $\frac{1}{C_{Eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	Q_T – Total charge V_B – Voltage of the battery C_{Eq} – Equivalent capacitance
Current Density – The amount of current that passes through an area in a given time. Current density is denoted by J.	$J = \frac{\text{Total Current}}{\text{Total Area}}$ $I = \mathbf{J} \cdot \mathbf{A}$	**J** – Current density vector, A/m^2 **A** – Area orientation vector I – Current
Ohm's Law - The electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it, and inversely proportional to the resistance.	$\mathbf{J} = \frac{\mathbf{E}}{\rho}$ $\mathbf{E} = \frac{\mathbf{V}}{L}$ $\rho = \frac{RA}{L}$ $V = IR$	**J** – Current density vector, A/m^2 ρ – Electrical conductivity **E** – Electric field vector V – Voltage I – Current R – Resistivity

Superconductors – The resistivity of a conductor increases with temperature. At absolute zero, resistivity reaches its minimum.	$\rho_{(T)} = \rho_0[1 + \alpha(T - T_0)]$ $\rho_{(T)_{wire}} = \frac{L\rho_0}{A}[1 + \alpha(T - T_0)]$	$\rho_{(T)}$ – Electrical conductivity at T ρ_0 – Resistivity minimum α – Temperature co-efficient T – Temperature T_0 – Reference temperature L – Length of wire A – Area of wire end
Power – The rate at which work is done or the amount of energy transferred per unit of time.	$P = VI = I^2R = \frac{V^2}{R}$	P – Power V – Voltage I – Current R – Resistivity
Charging/Discharging a Capacitor – A Capacitor is a passive device that stores energy in its Electric Field and returns energy to the circuit whenever required. It may be charged or discharged.	$Q_{(t)_{charge}} = Q_{max}(1 - e^{-\frac{t}{RC}})$ $Q_{(t)_{discharge}} = Q_{max}e^{-\frac{t}{RC}}$	Q – Charge of capacitor Q_{max} – Max charge of capacitor t – Time R – Resistivity C – Capacitance
Gauss' Law for B – One of Maxwell's equations. The net magnetic flux of any closed surface is zero.	$\phi_B = \oint_S \mathbf{B} \cdot \mathbf{da} = 0$	ϕ_B – Flux for magnetic field **B** – Magnetic field vector **da** – Small area orientation vector
Important Conversions – Units and their conversions.	$1 \text{ gauss} = 10^{-4} \text{ Tesla}$ $\mu_0 = 4\pi \text{ x } 10^{-7} \text{ Hm}^{-1}$	(none) *Note Lorentz Equation is super helpful getting from E to B to F.
Force on Wire – The following equation can be used to calculate the force on a wire in a magnetic field.	$\mathbf{F}_{\boldsymbol{\ell}} = I\ell \text{ x } \mathbf{B}$ $\mathbf{dF}_{\boldsymbol{\ell}} = I\mathbf{d}\ell \text{ x } \mathbf{B}$	$\mathbf{F}_{\boldsymbol{\ell}}$ – Force on wire line I – Current ℓ – Length and direction of wire **B** – Magnetic field vector
Torque on Disk – The following equations can be used to calculate the torque on a disk in a magnetic field.	$\boldsymbol{\tau} = I\mathbf{A} \text{ x } \mathbf{B} = \boldsymbol{\mu} \text{ x } \mathbf{B}$ $U = -\boldsymbol{\mu} \cdot \mathbf{B}$	$\boldsymbol{\tau}$ – Torque on disk I – Current **A** – Area orientation vector **B** – Magnetic field vector U – Potential energy $\boldsymbol{\mu}$ – I**A**
Electron in B Field – The following sets of equations apply to an electron traversing through a magnetic field. Derived from F=ma and Lorentz equation.	$\sum F_r = qvB = m\frac{v^2}{r}$ $r = \frac{mv}{qB}$ $v = \frac{qrB}{m}$	F_r – Force radial q – Charge B – Magnetic field m – Mass v – Velocity r – Radius
Torque on Plank - The following equations can be used to calculate the torque on a plank in a magnetic field.	$\sum \tau = Ia^2B\sin\theta$	$\boldsymbol{\tau}$ – Torque on plank I – Current **A** – Area orientation vector **B** – Magnetic field vector θ – Angle formed by **A**

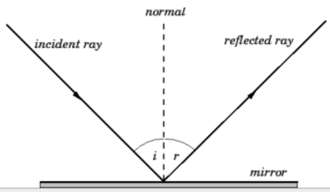
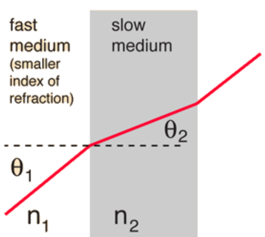
Hall Effect – What happens when charge is run through both a magnetic field and an electric field?	$V = \frac{E}{B}$	V – Velocity of charge E – Electric field B – Magnetic field
Biot-Savart's Law – A description of a magnetic field given a stationary electric current.  	$\mathbf{dB} = \frac{\mu_0}{4\pi} I \frac{\mathbf{d\ell} \times \mathbf{r}}{r^2}$	**dB** – Small magnetic field vector $\mathbf{d\ell}$ – Small length vector of wire μ_0 – 4πE-7 Hm^-1 **r –** Unit vector distance to **dB** r – Distance to **dB**
B of a Directional Wire – The following equation is derived from Biot-Savart's Law. This only applies to straight wires that carry current.	$B = \frac{\mu_0 I}{2\pi x} \frac{a}{\sqrt{x^2 + a^2}}$	B – Magnetic field μ_0 – 4πE-7 Hm^-1 I – Current x – Distance from wire a – Half of wire length
B of a Ring – The following equation is derived from Biot-Savart's Law. This only applies to rings that carry current.	$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{\frac{3}{2}}}$	B – Magnetic field μ_0 – 4πE-7 Hm^-1 I – Current R – Radius of ring x – Distance from wire
Ampere's Law – For any closed loop path, the sum of the length elements times the magnetic field in the direction of the length element is equal to the permeability times the electric current enclosed in the loop.	$\oint_C \mathbf{B} \cdot \mathbf{d\ell} = \mu_0 I + \varepsilon_0 \mu_0 \frac{d\phi_B}{dt}$	**B** – Magnetic field vector $\mathbf{d\ell}$ – Small length vector μ_0 – 4πE-7 Hm^-1 I – Current ε_0 – 8.854E-12 1/N c^2/m^2 $d\phi_B$ – Change in magnetic flux dt – Change in time
B for an Infinite Wire – Derived from B of a Directional wire as a >> x. Can also be derived directly from Ampere's Law.	$B = \frac{\mu_0 I}{2\pi} \frac{1}{r}$	B – Magnetic field μ_0 - 4πE-7 Hm^-1 I – Current r – Distance from wire

Force between Wires – Given two current carrying wires of a constant distance apart carrying current the same direction, what force is generated between them?	$\mathbf{F} = \frac{\mu_0 \ell}{2\pi} \frac{I' I}{r} \mathbf{i}$	**F** – Force between wires μ_0 – 4πE-7 Hm^-1 ℓ – Length of wire I' – First wire I – Second wire r – Distance between them **i** – Unit vector
Ideal Solenoid – A cylinder with current wrapped around it tightly. Generates a magnetic field in the direction of the cylinder faces.	$B = \mu_0 \frac{N}{\ell} I$	B – Magnetic field μ_0 – 4πE-7 Hm^-1 N – Number of turns on wire ℓ – Length of wire I – Current
Toroid – A ring with current wrapped around it tightly. Generates a magnetic field in the direction of the ring. 	$B = \mu_0 \frac{N}{2\pi r} I$	B – Magnetic field μ_0 – 4πE-7 Hm^-1 N – Number of turns on ring r – Radius of ring I – Current
B Inside Wire – Given the current density of a wire, area of its face and radius, the magnetic field can be calculated inside the wire.	$B = \mu_0 I \frac{r}{2\pi R^2}$	B – Magnetic field μ_0 – 4πE-7 Hm^-1 I – Current r – Radius being checked R – Radius of wire
Special Relativity – Want to calculate the speed of light? Its super simple! ™	$t' = t \frac{1}{\sqrt{1 - \frac{v^2}{C^2}}}$ $C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$	t' – Time passed (dilation) t – Time passed for observer v – Velocity C – 299 792 458 m / s μ_0 – 4πE-7 Hm^-1 ε_0 – 8.854E-12 1/N c^2/m^2
Faraday's Law - Any change in the magnetic environment of a coil of wire will cause a voltage (emf) to be "induced" in the coil. No matter how the change is produced, the voltage will be generated.	$\mathcal{E} = \oint_C \mathbf{E} \cdot \mathbf{d\ell} = \frac{-d\phi_B}{dt}$ $d\mathcal{E} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{d\ell}$	$\mathcal{E}$ – Electro-magnetic force (EMF) **E** – Electric field vector $\mathbf{d\ell}$ – Small length vector $d\phi_B$ – Change in magnetic flux dt – Change in time $d\mathcal{E}$ – Change in EMF **v** – Velocity vector **B** – Magnetic field vector

Useful Information – Anything useful that doesn't exactly fit in just once place in this toolbox.		P – Power V – Voltage I – Current R – Resistance
Mutual Inductance – A change in the current of one coil affecting the current and voltage in a second coil. Derived from Ampere's Law.	$\mathcal{E}_2 = -N_2\frac{d\phi_{B2}}{dt} = -M\frac{di_1}{dt}$ $M = \frac{\mu_0 N_2 N_1 A_1}{L_1} = \frac{N_2\phi_{B2}}{i_1}$	$\mathcal{E}$ – Electro-magnetic force (EMF) N – Number of turns in coil $d\phi_B$ – Change in magnetic flux dt – Change in time M – Mutual inductance di – Change in current dt – Change in time A – Area of coil face L – Length of coil i - Current 1 – Inner coil 2 – Outer coil
Self Inductance – The induction of a voltage in a current-carrying wire when the current in the wire itself is changing.	$\mathcal{E} = N\frac{d\phi_B}{dt} = L\frac{di}{dt} = -L\frac{d^2q}{dt^2}$ $L = \mu_0\frac{N^2}{\ell}A$	$\mathcal{E}$ – Induced EMF N – Number of turns in coil $d\phi_B$ – Change in magnetic flux dt – Change in time dq – Change in charge L – Inductance μ_0 – 4πE-7 Hm^-1 A – Area of coil face
Power of Inductor – The rate at which work is done by an inductor.	$P = i\mathcal{E} = iL\frac{di}{dt}$	P – Power i – Current $\mathcal{E}$ – EMF L – Inductance di – Change in current dt – Change in time
Potential Energy of Inductor – The amount of energy a inductor can store within itself.	$dU = Pdt = Li(di)$ $U = L\int i\,di = \frac{1}{2}Li^2$	dU – Change in potential energy P – Power dt – Change in time L – Inductance i – Current di – Change in current U – Potential energy
Charging/Discharging an RL Circuit – An RL circuit contains an battery (EMF) with a switch to charge the inductor and a resistor to reduce current. Derived from sum of the voltages equals zero.	$I_{(t)_{charge}} = I_{max}(1 - e^{-\frac{R}{L}t})$ $I_{(t)_{discharge}} = I_{max}e^{-\frac{R}{L}t}$	I – Current R – Resistance L – Inductance t - Time

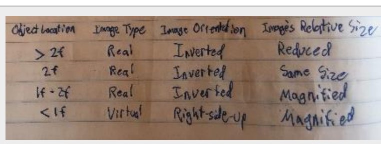
CL Circuit – An oscillating circuit in which a capacitor and inductor trade charge.	$Q_{(t)} = Q_{max}\sin(\omega t + \varphi)$ $\omega = \sqrt{\frac{1}{CL}}$ $f = \frac{\omega}{2\pi}$	Q – Charge ω – Angular frequency t – Time φ – Angular offset C – Capacitance L – Inductance f – Frequency
RCL Circuit – An oscillating circuit in which a capacitor and inductor trade charge with resistance from a resistor.	$Q_{(t)} = Q_{max}e^{-\frac{R}{2L}}\cos(\omega t + \varphi)$ $\omega = \sqrt{\frac{1}{CL} - \left(\frac{R}{2L}\right)^2}$	Q – Charge R – Resistance L - Inductance ω – Angular frequency t – Time φ – Angular offset C – Capacitance
Resistors in AC – Derived using Kirchoff's Laws. The following are important equations when dealing with resistors in alternating current.	$I = I_{max}\cos(\omega t)$ $V_R = I_{max}R\cos(\omega t)$ $I_{rms} = \frac{I}{\sqrt{2}}$ $P_{ave} = I_{rms}^2 R$	I – Current ω – Angular frequency t – Time V_R – Voltage of resistor R – Resistance I_{rms} – Current root mean squared P_{ave} – Power average *Note I and V_R are in phase
Capacitors in AC – Derived using Kirchoff's Laws. The following are important equations when dealing with capacitors in alternating current.	$I_{max} = \omega CV = \frac{V}{X_C}$ $I = I_{max}\cos(\omega t + \frac{\pi}{2})$ $V_C = I_{max}X_C\cos(\omega t)$ $X_C = \frac{1}{\omega C}$ $V = IR = IX_C$	I – Current ω – Angular frequency C – Capacitance V – Voltage t - Time V_C – Voltage of capacitor X_C – Capacitive reactance R - Resistance *Note V_C lags I by $\frac{\pi}{2}$
Inductors in AC – Derived using Kirchoff's Laws. The following are important equations when dealing with inductors in alternating current.	$I_{max} = \frac{V}{\omega L} = \frac{V}{X_L}$ $I = I_{max}\cos\left(\omega t - \frac{\pi}{2}\right)$ $V_L = I_{max}X_L\cos(\omega t)$ $X_L = \omega L$	I – Current V – Voltage ω – Angular frequency L – Inductance X_L – Inductance reactance t – Time V_L – Voltage of inductor *Note V_C leads I by $\frac{\pi}{2}$

LRC Circuit in AC - Derived using Kirchoff's Laws. The following are important equations when dealing with LRC circuits in alternating current.	$V_S = V_L + V_R + V_C = V\cos(\omega t)$ $I = \frac{V}{Z}\cos(\omega t - \varphi)$ $\varphi = \tan^{-1}(\frac{X_L - X_C}{R})$ $Z = \sqrt{R^2 + (X_L - X_C)^2}$ $I = \frac{V}{Z}$ $I_{rms} = \frac{V_{rms}}{Z}$	V_S – Voltage of the system V_L – Voltage of inductor V_R – Voltage of resistor V_C – Voltage of capacitor I – Current V – Voltage Z – Impedance ω – Angular frequency t – Time φ – Angular offset X_L – Inductance reactance X_C – Capacitive reactance R – Resistance I_{rms} – Current root mean squared V_{rms} – Voltage root mean squared
Power in AC – The rate at which work in completed when using AC circuits.	$P_{ave} = \frac{1}{2}IV\cos\varphi$	P_{ave} – Power average I – Current V – Voltage φ – Angular offset
Reduced Voltage and Alignment – Useful equations for reduced voltage and alignment.	$\frac{V_1}{N_1} = \frac{V_2}{N_2}$ $R_1 = \frac{R_2}{\left(\frac{N_2}{N_1}\right)^2}$	V – Voltage N – Number of turns R – Resonance
Resonance – When impedance is at its lowest.	$Z = \sqrt{R^2 + (X_L - X_C)^2}$ $X_L = \omega L$ $X_C = \frac{1}{\omega C}$ $\omega_0 = \sqrt{\frac{1}{LC}}$	Z – Impedance R – Resistance X_L – Inductance reactance ω – Angular frequency X_C – Capacitive reactance L – Inductance C - Capacitance
Solar Sailing – How to use light as a means of acceleration.	$a = \frac{\lvert s\rvert}{mc}$	a – Acceleration |s| – Power provided m – Mass c – speed of light
Energy Density of Light - The oscillating electric and magnetic fields of light carry energy.	$U = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0}B^2 = \varepsilon_0 E^2$	U – Energy density of light ε_0 – 8.854E-12 1/N c^2/m^2 E – Electric field μ_0 – 4πE-7 Hm^-1 B – Magnetic field

<table>
<tr><td>Law of Reflection – A description of how light reflects off a mirror-like surface.

</td><td>$\theta_i = \theta_r$</td><td>θ_i – Angle of incidence
θ_r – Angle of reflection</td></tr>
<tr><td>Index of Refraction - The bending of a wave when it enters a medium where its speed is different. The refraction of light when it passes from a fast medium to a slow medium bends the light ray toward the normal to the boundary between the two media.</td><td>$n = \frac{c}{c_m}$</td><td>n – Index of refraction
c – 299 792 458 m / s
c_m – Speed of light in medium</td></tr>
<tr><td>Snell's Law – How to find the angle at which light refracts through a medium.

</td><td>$n_1 \sin\theta_1 = n_2 \sin\theta_2$</td><td>n – Index of refraction
θ – Angle of refraction

1 – Fast medium (can be flipped)
2 – Slow medium (can be flipped)</td></tr>
<tr><td>Critical Angle – The angle at which light completely escapes a medium without reflecting.</td><td>$\theta_c = \sin^{-1}(\frac{n_2}{n_1})$</td><td>$\theta_c$ – Critical angle
n – Index of refraction

1 – Initial medium
2 – Final medium</td></tr>
<tr><td>Brewster Angle – The special angle of incidence that produces a 90 degree angle between the reflected and refracted ray.</td><td>$\theta_B = \tan^{-1}(\frac{n_2}{n_1})$</td><td>$\theta_B$ – Brewster angle
n – Index of refraction

1 – Initial medium
2 – Final medium</td></tr>
<tr><td>Lenses and Images – What image does a converging lense create?</td><td>
<table><tr><th>Object Location</th><th>Image Type</th><th>Image Orientation</th><th>Image's Relative Size</th></tr><tr><td>> 2f</td><td>Real</td><td>Inverted</td><td>Reduced</td></tr><tr><td>2f</td><td>Real</td><td>Inverted</td><td>Same Size</td></tr><tr><td>1f - 2f</td><td>Real</td><td>Inverted</td><td>Magnified</td></tr><tr><td>< 1f</td><td>Virtual</td><td>Right-side-up</td><td>Magnified</td></tr></table></td><td>f – Focal point</td></tr>
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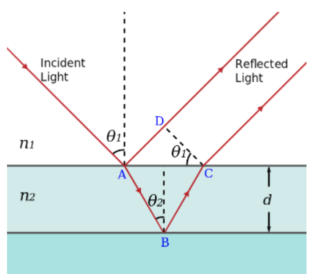
Refraction Equations – How does light interact with lenses?	$\frac{n_1}{s}+\frac{n_2}{s'}=\frac{n_2-n_1}{R}$ $f=(n-1)(\frac{1}{R_1}-\frac{1}{R_2})$ $m=\frac{-n_1 s'}{n_2 s}=\frac{-s'}{s}=\frac{y'}{y}$ **Thin lens** $\frac{1}{s}+\frac{1}{s'}=\frac{1}{f_{cm}}$ **Spherical mirror** $\frac{1}{s}+\frac{1}{s'}=\frac{2}{R}$	n – Index of refraction s – Distance to lens from object s′ – Distance to lens from image R – Radius of lens R_1 – Radius of outer lens R_2 – Radius of inner lens f – Focal point f_{cm} – Focal point in cm m - Magnification y – Height of image
Infinite Focus – When a system forms an image of an object infinitly away.	If $s=\infty$ then $s'=f$	s – Distance to lens from object s′ – Distance to lens from image f – Focal point
Power of Lens – One over the focal length in meters.	$P=\frac{1}{f}$	P – Power f – Focal length in meters
Negations – When to negate variables in optics.	(none)	s>0 – Object on incoming side s<0 – Object on outgoing side s′>0 – Image on outgoing side s′<0 – Image on incoming side m>0 – Image is upright m<0 – Image in inverted R>0 – Center on outgoing side R<0 – Center on incoming side f>0 – Converges f<0 – Diverges
Poynting Intensity - The directional energy flux (the energy transfer per unit area per unit time) of an electromagnetic field.	$\mathbf{I}=\frac{1}{2}\varepsilon_0 c\mathbf{E}^2$	**I** – Poynting intensity vector ε_0 – 8.854E-12 1/N c^2/m^2 c – 299 792 458 m / s **E** – Electric field vector
Double Slit – Equations relating to the double slit experiment in which light is shot through two slits and appears on a far surface as a series of bright spots.	$\Delta r=m\lambda$ $y_b=\frac{\lambda L}{d}m$ $y_d=\frac{\lambda L}{d}(m+\frac{1}{2})$ $I=I_{max}\cos^2(\frac{\pi d}{\lambda L}y)$	Δr – Change in small radius m – 1, 2, 3, … λ – Wavelength of light (nm) y_b – Distance to a bright spot L – Length between slits and wall d – Distance between slits y_d – Distance to a dark spot I – Intensity y – Vertical distance from origin
Single Slit – Equations relating to the single slit experiment in which light is shot through one slit and appears on a far surface as a series of bright spots.	$y_d=\frac{\lambda L}{a}m$ $\Delta y=\frac{2\lambda L}{a}$ $I=I_{max}\left[\frac{\sin\left(\frac{\pi a}{L\lambda}y\right)}{\left(\frac{\pi a}{L\lambda}y\right)}\right]^2$	y_d – Minimum intensity location λ – Wavelength of light (nm) L – Length between slits and wall a – Slit width m – 1, 2, 3, … Δy – Distance between minimums I – Intensity y – Vertical distance from origin

Diffration Grating - Equations relating to the several slit experiments in which light is shot through many slits and appears on a far surface as a series of sharp bright spots.	$\text{mins} = n - 1$ $\varphi = \frac{\Delta r}{\lambda}(2\pi)$ $\varphi n = 2\pi$ $y_b = \frac{\lambda L}{d} m$ $\Delta r = d \sin\theta = m\lambda$	mins – Minimas between maxima n – Number of slits φ – Angle of phasor(s) Δr – Change in small radius λ – Wavelength of light (nm) L – Length between slits and wall d – Distance between slits m – 1, 2, 3, … θ – Angle of interference
Thin Film Interference – As light strikes the surface of a film it is either transmitted or reflected at the upper surface. Light that is transmitted reaches the bottom surface and may once again be transmitted or reflected. 	If $n_i < n_r$ then Relative Flip! $2d = \left(m - \frac{1}{2}\right)\frac{\lambda}{n_f}$ Flip? Then constructive Otherwise destructive $2d = \frac{m\lambda}{n_f}$ Flip? Then destructive Otherwise constructive	n_i – Incident index of refraction n_r – Reflection index of refraction d – Thickness of film m – 1, 2, 3, … λ – Wavelength of light (nm) n_f – Film index of refraction
Pressure – Force per unit area.	$P = \frac{F}{A}$	P – Pressure F – Force A – Area
Thermal Expansion – In general, when a material heats up, it expands.	$\Delta L = \alpha L \Delta T$ $\Delta V = \beta V \Delta T$ $3\alpha = \beta$	ΔL – Change in length α – Numerical constant L – Beginning length ΔT – Change in temperature ΔV – Change in volume β – Numerical constant V – Beginning volume
Conduction – Heat transferred directly through a substance.	$H = \frac{dQ}{dt} = kA\frac{dT}{dx}$	H – Heat transferred dQ – Change in heat dt – Change in time k – Thermal conductivity A – Area of the cross-section dT – Change in temperature dx – Small unit length path
Convection – Heat transferred by convection where convection occurs as warm liquid rises and cooler liquid sinks to be once again heated.	$H = \frac{dQ}{dt} = kAdT$	H – Heat transferred dQ – Change in heat dt – Change in time k – Thermal conductivity A – Area of convection dT – Change in temperature

Stefan-Boltzman's Equation – Heat transferred by radiation.	$\mathrm{H} = \frac{\mathrm{dQ}}{\mathrm{dt}} = A\epsilon\sigma T^4$	H – Heat transferred dQ – Change in heat dt – Change in time A – Area of emitting body ϵ – Emissivity σ – 5.67E-8 w/m^2k
Absorption – How much heat does an environment absorb from a material? The name is kinda screwy; better to call this radiation.	$\mathrm{H_{net}} = \mathrm{A\epsilon\sigma(T^4 - T_s^4)}$	$\mathrm{H_{net}}$ – Net heat transferred A – Area of emitting body ϵ – Emissivity σ – 5.67E-8 w/m^2k T – Temperature of material $\mathrm{T_s}$ – Temperature of surroundings
Calorimetry – Used to measure amounts of heat transferred to or from a substance.	Before or after state change $\Delta\mathrm{Q} = \mathrm{mc}\Delta\mathrm{T}$ During state change $\Delta\mathrm{Q} = \mathrm{mL_f}$ or $\Delta\mathrm{Q} = \mathrm{mL_v}$	ΔQ – Change in heat m – Mass c – Substance-specific constant ΔT – Change in temperature $\mathrm{L_f}$ – Ice and liquid constant $\mathrm{L_v}$ – Liquid and gas constant *Note negations may apply if a substance is cooling in a system.
Ideal Gas Equations – An approximation for the behaviour of most gasses with some limitations.	$\mathrm{PV} = \mathrm{nRT}$ $\frac{\mathrm{n}}{\mathrm{N_A}}\mathrm{RT} = \mathrm{nK_B T}$	P – Pressure V – Volume n – Moles R – 0.08205 (atm) or 8.314 (J) T – Temperature $\mathrm{N_A}$ – 6.022E23 $\mathrm{K_B}$ – 1.3807E-23 JK^-1 STP – 0C, 273.15K, 1 atm, 1Pa
Ideal Solid Equation – An approximation for the behaviour of most solids with some limitations.	$\mathrm{V} = \mathrm{V_0[(T - T_0)\beta - (P - P_0)K]}$	V – Volume T – Temperature β – Contant P – Pressure K - Constant
Internal Kinetic Energy – The internal energy of a system at an atomic level.	$\mathrm{KE_{system}} = \frac{3}{2}\mathrm{nRT}$	$\mathrm{KE_{system}}$- Energy of system n – Moles R – 0.08205 (atm) or 8.314 (J) T – Temperature
Monotomic Ideal Gas Kinetic Energy – The kinetic energy for a single particle of an ideal gas.	$\mathrm{KE_{particle}} = \frac{3}{2}\mathrm{K_B T}$	$\mathrm{KE_{particle}}$- Energy of particle $\mathrm{K_B}$ – 1.3807E-23 JK^-1 T – Temperature

Degrees of Freedom – The number of independent ways in which a system may possess translational, vibrational, or rotational motion	$C_V = \ell(\frac{1}{2}R)$	C_V – Heat to raise 1 mol 1 C ℓ - Degrees of freedom R – 8.314 J/(mol K)
Maxwell-Bolzman Distribution – From this distribution function, the most probable speed, the average speed, and the root-mean-square speed can be derived.	$f(v) = \left(\frac{m}{2\pi K_B T}\right)^{\frac{3}{2}} 4\pi v^2 e^{(-\frac{mv^2}{2K_B T})}$ $N_A K_B = R$ $v_{mp} = \sqrt{\frac{2K_B T}{m}}$	f(v) – Probability to find velocity v – Velocity m – Mass K_B – 1.3807E-23 JK^-1 T – Temperature N_A – 6.022E23 R – 8.314 J/(mol K) v_{mp} – Most probable velocity
First Law of Thermodynamics – The change in potential energy of a system is equal to the change in heat minus the work done.	$dU = dQ - dW$	dU – Change in potential energy dQ – Change in heat dW – Work done
Work Done in System – If you're lucky enough to have a PV chart, work is just the area under the curve between Vi and Vf.	$W = P(V_f - V_i)$	W – Work P – Pressure V – Volume
Isochoric – A thermodynamic process in which the volume stays constant.	$\Delta V = 0$ $\Delta U = \Delta Q$	ΔV – Change in volume ΔU – Change in potential energy ΔQ – Change in heat
Isobaric – A thermodynamic process in which the pressure stays constant.	$\Delta P = 0$ $\Delta U = \Delta Q - P(V_f - V_i)$	ΔP – Change in pressure P – Pressure V – Volume
Isothermic – A thermodynamic process in which the temperature stays constant.	$\Delta T = 0$ $U = \frac{3}{2}nRT = nC_V T$ $\Delta U = 0$ $P_1V_1 = P_2V_2$ $\Delta Q = \Delta W$ $\Delta W = nRT \ln\frac{V_f}{V_i} = PV \ln\frac{V_f}{V_i}$	ΔT – Change in temperature U – Potential energy n – Moles R – 0.08205 (atm) or 8.314 (J) T – Temperature C_V – Heat to raise 1 mol 1 C P – Pressure V – Volume ΔQ – Change in heat ΔW – Work done
Adiabatic – A thermodynamic process in which heat does not enter nor leave the system.	$\Delta Q = 0$ $\Delta U = -\Delta W$ $\frac{T_2}{T_1} = \frac{P_2V_2}{P_1V_1}$ $\Delta S = 0$	ΔQ – Change in heat ΔU – Change in potential energy ΔW – Work done T – Temperature P – Pressure V – Volume ΔS – Change in entropy

Heat Capacity Concentration – The relationship between specific heat capacity concentration and refractive index concentration.	$C_p = C_V + R$ $\gamma = \frac{C_p}{C_V} = \frac{C_V + R}{C_V} = 1 + \frac{R}{C_V}$	C_p – Heat capacity concentration C_V – Heat to raise 1 mol 1 C R – 8.314 J/(mol K) γ – Rate of molar-specific heat
Adiabatic Ideal Gas – A thermodynamic process in which heat does not enter nor leave an ideal gas system.	$T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1}$ $P_i V_i^{\gamma} = P_f V_f^{\gamma}$	T – Temperature V – Volume γ – Rate of molar-specific heat P – Pressure
Otto Cycle – An idealized thermodynamic cycle that describes the functioning of a typical spark ignition piston engine.	$e = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{\lvert Q_C \rvert}{\lvert Q_H \rvert}$ $e = 1 - \left(\frac{T_4 - T_1}{T_3 - T_2}\right) = \frac{1}{R^{\gamma-1}}$	e – Efficiency of cycle W – Work Q_H – Released “hot” heat Q_C – Released “cool” heat T – Temperature γ – Rate of molar-specific heat R – 8.314 J/(mol K)
Carnot Cycle – The maximum efficiency possible for an engine.	$e = 1 - \frac{\lvert Q_C \rvert}{\lvert Q_H \rvert} = 1 - \frac{T_C}{T_H}$	Q_H – Released “hot” heat Q_C – Released “cool” heat T – Temperature
Entropy – A quantity representing the unavailability of a system's thermal energy for conversion into mechanical work, often interpreted as the degree of freedom in a system.	$dS = \frac{dQ}{T}$ **Isothermal Ideal Gas** $dS = nRT\frac{dV}{V}$	dS – Change in entropy dQ – Change in heat T – Temperature n – Moles R – 8.314 J/(mol K) dV – Change in volume V - Volume