* Electricity
	+ Charges on a plane - C
		- |a x b| = ab(sinϴ)
		- a • b = ab(cosϴ)
	+ Conductors v. Insulators
		- Conductors = Free electrons
		- Insulators = no free electrons, work required
	+ Point Charge = Spherical Symmetry
	+ Electric Field
		- **k = 1/4πϵ0 = 9 x 109**
		- **E = k|q| / r2**
		- **E = λ / 2πr2ε0 ; λ = q / d**
			* (for an infinite line of charge)
		- **E = σ / 2ε0 ; λ = q / A**
			* (for an infinite charged plate)
	+ Induction Effect – (+) charge induce dipole on neutral objects
	+ Dipole
		- ED (dipole) decreases rapidly
		- **p = dipole moment = qd**
		- E = 2kp/r3 (sum of E on a planar charge system)
	+ Torque
		- τ = p x E
		- **τ = pE(sinϴ)**
	+ Energy
		- **U = -pE(cosϴ)**
		- If a dipole starts at an angle, it will oscillate
	+ Gauss’s Law
		- J = Flux = j • A
		- J = jA(cosϴ) = jA
		- фE  = E • A = EA(cosϴ) = Electric Flux
			* **фE = E • dA = EA** (with surface perpendicular to E)
			* Point charge: **фE = 4πr2E**
			* **фE = qenclosed / ε0**
		- Answers (1) Charge location, (2) E
	+ Conductors
		- Conductor negates E inside (due to change separation)
	+ Electric Potential – Scalar
		- **ΔV = ΔU / q**
		- Parallel capacitor – each plate gives off **E = σ / ε­0**
		- U = -qEx (ΔU = Eq(x2 – x1))
		- From above 2 equations, V = -Ex + C
			* **ΔV = E • dL; V = kq / r**
			* **ΔVpoint charge = q / 4πrε­0**
			* Apply 3 charges on plane separated by r = d

**C**

**A**

**B**

* + - * + Potential at A: V(A) = V1­(A) + V2(B)
				+ **V(A) = [q1 + q2] / 4πε0d**
		- V = constant at any point in a conductor
		- E = 0 at any point in conductor
	+ Capacitance – F - ( || plate capacitor) – origin on the right (negative) plate
		- Parallel plate capacitor charge = equal and opposite on each side
		- **C = ε0A / d** (from V = E • dl , E|| = σ / ε0
		- **U = q22C**
	+ Circuits – Capacitance
		- **q = q1 + q2 (parallel); q = q1 = q2 (series)**
		- **V = V1 = V2­ (parallel); V = V1 + V2 (series)**
		- **C = C1 + C2 (parallel) C-1 = C1-1 + C2-1 (series)**
	+ Dielectrics
		- **E = V / d** ; gets smaller with smaller A, larger d
		- **C = KC0 = KAε0 / d**
	+ Current - Amp
		- Motion of equivalent positive charges
		- I = Δq / Δt
		- **I = V / R**
	+ Resistance - Ω
		- R = V / I
		- Higher T 🡪 Higher KE 🡪 More resistance
		- Resistance is nonconservative
		- **P = IV = V2 / R = I2R**
	+ Circuits – Resistors
		- **R-1 = R1-1 + R2-1 (parallel)**
		- **R = R­1 + R2 (series)**
	+ Equivalent Circuits
	+ RC Circuit
		- V = q / C + *i*R; *i* = current from capacitor
		- **q(t) = CV[ 1 - *e*-t / RC]**
		- ***i*(t) = V*e*-t / RC / R**
* Magnetism
	+ No point charge
	+ **ф­M = B • dA** = 0 (closed surface)
	+ Magnetic force
		- **F = qv x B = qvB(sinϴ)**
		- **F = IL x B = ILB(sinϴ)**
	+ Angular motion
		- Uses a­c = V2 / r ; F = ma; FM = qbB(sinϴ)
		- **ω = qB / m** (moving perpendicular to field)
		- **T = 2π / ω**
	+ Magnetic dipole
		- **μ0 = IA**
		- **τ = μ x B**
	+ Magnetic Current
		- Current flows induce a magnetic field
			* **μ0 = 4π(10-7)**
			* Infinite wire = **μ0I / 2πr = B**
		- Force between 2 wires
			* **F = μ0I1I2L / 2πd**
		- Ampere’s Law
			* **B • dL = μ0I**
			* Surface can be an open surface
	+ Solenoid - store a charge
		- Magnetic current concentrated in the center
		- **B = μ0I (N/L); B = nμ0I**
* Induction
	+ Important B identities
		- Ampere’s Law: **B • d = μ0I**
		- **For a wire, d = 2πr**
	+ Causes – Change in I 🡪 E
	+ Faraday’s Law
		- **B • d = -d/dt B • dA**
		- **ℇ = dфB / dt**
		- **ℇ = v0B = IR**
		- **I = v0B / R**
		- **Ploop = B22v2 / R**
	+ ℇ only exist if Δф­B
	+ Lentz’s Law
		- Currents (Inducted) counter a B field currently being transmitted to ensure cooperation of 1st law
	+ Equations
		- Angular Speed = **ω = 2πf**
		- **vmetal = RMg / (B)2**
	+ Self-Inductance
		- **L = фB / I**
		- **ℇL = -L (d*i* / dt)**
		- Solenoid
			* **μ0n2A (d*i* / dt) = ΔV**
			* **L = μ0n2A**
			* **B = μ0n**
			* Energy Density: **uB = B2 / 2 μ0**
			* **U = uBA**
	+ Circuits
		- Current at Initial state = open circuit
		- Current at Final state = short circuit
		- Inductor current: **ℇL = - ℇ0e-Rt/L**
			* **I = ℇL + ℇL  / R = (ℇ0 / R)(1 – e-Rt/L)**
			* Loop Rule: **0 = ℇ0­ – IR – L (di / dt)**
		- Energy and Power
			* **U = ½ LI2**
			* **P = LI (di/dt) = I2R**
	+ Magnetic Force
		- **F = qv X B**
		- **F = I X B**
	+ Magnetic and Electric fields
	+ = Δ
	+ **E • dr = -d/dt B • dA**
* Maxwell’s Equation
	+ The 4 Equations
		- [Gauss E] **E • dA = q / ϵ0**
		- [Gauss B] **B • dA = 0**
		- [Amperé] **B • dr = μ0I + μ0 ϵ0 (dфE / dt)**
		- [Faraday] **E • dr = - (dфB / dt)**
	+ When in vacuum, **q / ϵ0 = 0** and **μ0I = 0**
	+ and
		- [Faraday] **δE / δx = - (δB / δt)**
		- [Amperé] **δB / δx = - μ0 ϵ0 (δE / δt)**
* Properties of Light
	+ and
		- **kEp = ωBp**
		- **kBp = μ0 ϵ0­ωEp**
		- **E = cB**
	+ Equations
		- Wave
			* **E(x,t) = Epsin(kx – ωt) (^j)**
			* **B(x,t) = Bpsin(kx – ωt) (^k)**
		- Angular Velocity
			* **ω = 2π / T**
			* **ω = 2πf**
		- Period
			* **T = 2π / ω**
		- Propagation Velocity
			* Wave speed **c = (ω / k) = (1 / ) = 3 x 108**
			* **c = λf, k = 2π / λ**
		- Average Energy
			* **uEM = ½E2ϵ0 + ½B2µ0 = E2ϵ0 ­= (B2 / μ0)**
			* **<UEM> = ½E2ϵ0**
			* **uE = ½E2ϵ0**
			* **uB = B2 / 2μ0**
	+ Poynting Vector
		- Average Poynting Vector (Light Intensity)
			* **<S> = (EpBp) / 2 = (UEM)c**
		- Expanding in Spheres
			* **S = P / 4πr2**
		- Radiation Pressure
			* [Absorb] **Prad = <S> / c**
			* [Reflect] **Prad = 2<S>/ c**
			* **F = -eE = -ecB**
	+ Polarization
		- Relationship to
		- Intensity relationship
			* [Malus] Intensity: **S = S0cos2ϴ**
* Reflection and Refraction
	+ Law of Reflection
		- **ϴ = ϴ’**
	+ Speed of light in different mediums
		- **n = c/v**
	+ Snell’s Law
		- **n1sinϴ1 = n2sinϴ2**
	+ Brewster (Polarizing) Angle
		- Perpendicular “reflected” wave to the refracted one
		- **tanϴp = n­2 / n1**
	+ Critical Angle
		- The angle at which refraction 🡪 reflection
		- **sinϴc = n­2 / n1**
	+ Change in wavelength through a prism
		- Different λ have different n values in a prism
* Lens and Mirror
	+ Virtual vs Real Image:
		- Virtual is inferred by the brain, while real is projected light
	+ Mirrors vs Lenses
		- Convex : Diverging Lens :: Concave : Converging Lens, in terms of function and ray tracing\
		- Focal point: convergence of light, **½R = f**
		- Spherical Abberation – minimized by making mirror a tiny fraction of a sphere (spherical vs parabolic)
	+ Ray Tracing
		- See figures
	+ s, s’, and f relationship
		- **1/s + 1/s’ = 1/f**
	+ Magnification
		- **M = h’/h = -(s’/s)**
	+ Lensmaker Equation (Thick Lenses)
		- **1/f = ((nlens/nmedium) – 1)(1/R1 – 1/R2)**
	+ Refraction in a lens
		- **n1/s + n2/s’ = (n­2 – n1) / R**
		- n1 = medium of object, n2 = medium of other boundary, R = radius of lens/cylinder/sphere
	+ Optical instruments
		- Eyes
			* Divergent lenses –nearsightedness
			* Convergent lenses – farsightedness
			* Diopters = 1/f, [f] = meters
			* Angular Magnification (ratio of magnification due to correction)
				+ **m = 25(centimeters)/f**
			* Compound Microscope
				+ **M0me = -(L/f0) (25centimeters/fe)**
			* Telescopes
* Constructive and Destructive Interference
	+ Interference derives from wave incoherence
	+ Paraxial approximation
		- When λ << d, trigϴ = ϴ
	+ Wave Mutation Equation
		- If Φ = π, cos = 0, Destructive interference; If Φ = 2π or 0, Constructive interference
		- **ET = 2Esin(kx – ωt + Φ/2)cos(-(Φ/2)**
		- **BT = 2Bsin(kx – ωt + Φ/2)cos(-(Φ/2)**
	+ Double Slit Interference
		- Bright fringes: **dsinϴ = mλ**, (m = 0 (center),1,2,3…)
		- Dark fringes: **dsinϴ = (m + ½)λ**, (m = 0,1,2…)
		- **ybright ­= (mLλ)/d; y­dark= ((m+ ½)Lλ)/d**
	+ Intensity Equation (double slit)
		- **<S> = (4E02/2μ0c)cos2(dπy/λL)**
	+ Multiple slit interference
		- N-1 minima between each pair of primary maxima
		- **dsinϴ = (m/N)λ**
		- Spectrometer
			* **d = 1/N**; N = number of slits
			* **dsinϴ = mλ** (bright, separation)
	+ X ray Diffraction
		- **2dsinϴ = mλ**
	+ Resolving power
		- **λ/Δλ = mN**
* Diffraction
	+ Thin Film Optics
		- Speed of light in a medium: **v = c/n**
		- Frequency is constant
		- Phase shift of π when reflected off material with nbarrier > current medium
		- No phase shift when nbarrier < current medium
		- **2dn =(m + ½)λ**
	+ Hugyen’s Principle
		- Circles – all points on a waveform act as point sources
		- Diffraction only truly happens when slit size is comparable to wavelength
		- **asinϴ = mλ** [destructive int, single-slit diffraction, (m = 1,2,3)]
	+ Intensity Equation (single slit)
		- **<S> = (E02/2μ0c) (sin(Φ/2)/(Φ/2))2; Φ = 2πa(sinϴ)/λ**
	+ Resolution
		- **1.22 (λ / d) = sin(ϴd)**
* Special Relativity
	+ **γ = 1 /**
	+ Time dilation & Length Contraction
		- **Δt = γΔt0**
		- **L = L0 / γ**
		- As a general rule, the isolated variable is smaller than the original variable
	+ Invariant Spacetime Interval
		- **(Δs)2 = c2(Δt)2 – [(Δx)2+(Δy)2+(Δz)2]**
	+ Invariant particle mass
		- **(mc2)2 = E2 – p2c2**
	+ Energy and Momentum
		- **p = γmu**
		- **E = γmc2 = K + mc2 =**
	+ Relativity and Velocity
		- **u = (u’ + v) / (1 + u’v / c2)**
		- u = object velocity relative to frame S; u’ = object velocity relative to frame S’; v = relative velocity between S and S’
* Particles and Waves
	+ Identities
		- h = 6.63 x 10 -34
		- **ħ = h / 2π =** 1.05 x 10-34
	+ Equations
		- de Broglie Waves
			* **λ = h / p**
			* **vphase = ω/k**
		- **E = hf = p2/2m = ħω**
	+ Blackbody Radiation
		- Peak radiance = λT = 2.898 mm • K
		- **R(λ,T) = 2πhc2 / λ5(ehc/λkT – 1);** k = 1.38 x 10-23 J/K, R = radiance
	+ Photoelectric Effect
		- Ejection of electrons from a surface
		- Direct relationship: cutoff frequency and Work function (W)
		- Inverse relationship: frequency and Work function
		- If metal not illuminated with light with Wlight > Wmetal, then no release.
	+ Compton Scattering
		- Photons interact w/ free electrons like colliding particles. There is a shift in wavelength of the photon after collision.
		- **Etot = mc2 + pc**
		- **λ' – λ = h(1 – cos Φ) / mc**; Φ = angle between vectors
	+ Atomic Spectra
		- **1 / λ = RH (1/n22 – 1/n12)**
			* RH = 1.097 x 107
		- **E = -13.6 (1/n12 – 1/n22)**
		- Atomic radius
			* **rn = a0n2/Z;** Z = atomic number, a0 = 5.29 x 10-11 m
	+ Heisenberg’s Uncertainty Principle
		- The more known about the position of a particle, the less known about p.
		- **ΔxΔp h**
		- **p = kħ; k = 2π/λ**
* Quantum Mechanics
	+ Time-Independent Schrödinger equation
		- **- (ħ/2m)(d2ψ/dx2) + U(x)ψ = Eψ**
		- Probability Density: The probability of finding a particle in one dimension
			* **P(x) = ψ2dx**
			* Take the integral along Δx in order to find P
		- Normalization: particle must be somewhere
	+ Harmonic Oscillator
		- **En = (n + ½ ) ħω**
	+ Square Well
		- Infinite
			* **ψn = ()sin(nxπ/L)**
			* **En = n2h2/8mL2**
			* 3D Well: **E = (h2/8mL2)(nx2 + ny2 + nz2)**
			* U0 = min escape energy
			* **λn = 4mL2c / (2n+1)ℏπ**; wavelength of photon absorbed to move electron up one level
		- Finite: Discrete bound states
	+ Review: Angular kinetics
		- **ω = 2πf = ; k = spring constant**
		- **L = Iω; ω = v/r**
		- **I = mr2**
* Atomic Physics
	+ Quantum numbers
		- **n** = [energy level] integers 1+
		- = [orbital quantum number] (n-1) 🡪 0
		- **ml**= [orbital magnetic quantum number] - 🡪 +
		- **ms**= (spin) -½, +½
	+ Potential energy of an electron
		- **U(r) = ke2/r**; k = 9 x 109
	+ Bohr Radius
		- **a0 = 0.0529 nm**
	+ Radial probability Density
		- **P(r) = 4πr2ψ2**
	+ Hydrogen energy levels
		- **En = -(13.6 eV) / n2**
	+ Quantum number & Angular Momentum
		- **L = = ml­ħ;** ml = orbital magnetic quantum number
	+ Electron Spin
		- Magnitude: **S =**
		- **Sz = msħ** (space quantization)
	+ Bosons and Fermions
		- Fermions are spin particles – electrons
		- Bohr Magneton: **μB = eħ/2m = 9.27 x 10-24 A • m2** (Dipole moment)
		- Bosons don’t follow exclusion principle
	+ me = 9.11 x 10-31 kg
	+ Potential energy of e-: **U = *e*mlB/ 2m**