* 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**