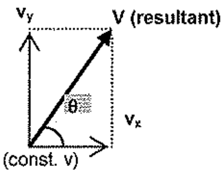
I. MECHANICS — 35%

A. Kinematics

1. Motion in one dimension
   - average $v = \Delta s / \Delta t$
   - **average $v = (v_f + v_i) / 2$ (only if a is constant)**
   - **average $a = (v_f - v_i) / \Delta t$ (or, average $a = \Delta v / \Delta t$)**
   - **$\Delta s = v_i t + 1/2 (a \Delta t^2)$ (only if a is constant)**
   - **$v_f^2 = v_i^2 + 2 a \Delta s$ (only if a is constant)**



2. Motion in two dimensions **$v_x = v \cos\theta$ $v_y = v \sin\theta$**
   Projectile motion: $a = 9.8\ m/s^2$ in y dir... $a = 0$ in x dir (const. v)
3. Uniform Circular motion $a_{centripetal} = v^2 / r$

B. Newton's laws of motion

1. Static equilibrium (first law) $a = 0$ when $\Sigma F = 0$
2. Dynamic equilibrium (Second law) **$\Sigma F = m\,a$**
3. Force pairs are equal & opposite (third law)
4. Friction **$F_{kinetic} = \mu_{kinetic} N$** acts in direction opposite velocity
5. Friction **$F_{static\ (max)} = \mu_{static} N$** acts in direction opposite potential velocity
6. Centripetal: **$F_{centripetal} = m v^2 / r$** from friction, tension, gravity, magnetic force etc.
7. Springs : Hooke's law **$F_{spring} = - k\Delta x$** (k = spring constant (N per 'extra meter'))

C. Work, energy and power

1. Work and work-energy theorem **$W = F\,d\cos\theta$** [Joules = N.m]
2. Conservative forces and potential energy **$W_{net} = \Delta KE$**
   - a) **$KE = 1/2\ m v^2$**
   - b) **$PE_{gravity} = m\,g\,h$**
   - c) **$PE_{spring} = 1/2\ \Delta x^2 k$**
3. Conservation of energy **$\Sigma E_{initial} - W_{'lost'} = \Sigma E_{final}$**
4. Power **$P = W / t = F\,v$** (v = velocity) [Watts, J/s]

D. Systems of particles, linear momentum

1. Impulse **$F\Delta t = \Delta(mv) = \Delta p$**, and **momentum $p = mv$**
2. Conservation of linear momentum, collisions
   - a) explosions: **$\Sigma p_i = 0 = \Sigma p_f$**
   - b) perfectly elastic : **$\Sigma p_i = \Sigma p_f$** and **$\Sigma KE_i = \Sigma KE_f$**
   - c) inelastic: **$\Sigma p_i = \Sigma p_f$ only**

E. Rotation

1. Centripetal accn $a_c = v^2 / r$
2. Centripetal force **$F_c = m v^2 / r$** (from $\Sigma F = ma$)
3. Torque and rotational statics
   - (a) **$T = F\,r \sin\theta$** (T=Torque, r=lever arm length, θ=angle between arm and force)
   - (b) Static Equilibrium: Both $\Sigma T = 0$ and $\Sigma F_x = 0$, $\Sigma F_Y = 0$
4. Conservation of angular momentum; think ice skater! (no numbers needed here)

F. Springs, Oscillations and gravitation

1. Hooke's Law: **$F = -k\Delta x$**, **$U_{spring} = PE_{spring} = 1/2\ (\Delta x^2 k)$**
2. Simple harmonic motion: **Frequency = 1 / T**
   - (a) Mass on a **spring $T = 2\pi\sqrt{(m / k)}$**; T = period; planet doesn't change period !
   - (b) **Pendulum** and other oscillations **$T = 2\pi\sqrt{(L / g)}$**; mass doesn't change period !
3. Newton's law of gravity **$F_g = G\,m_1 m_2 / r^2$** ($G = 6.67 \times 10^{-11}\ N.m^2/kg^2$)

II. HEAT, KINETIC THEORY AND THERMODYNAMICS — 15%

A. Fluid Mechanics

1. Hydrostatic Pressure (p) at rest
   fluids treated as incompressible; no density change due to height or depth of fluid!
   - a. Fluid exerts pressure in all directions ⊥ to surface it contacts (top, side, and bottom)
   - b. **$p = F_\perp / A = p_0 + \rho g h$** ($\rho$ = fluid density)
2. Buoyancy
   - a. Float: $\rho_{object} < \rho_{fluid}$; Object displaces its weight in fluid;
     F_{Net} upward $= F_{buoy} = \rho V g$
     Archimedes' Principle: F_{buoy} = Wt of displaced fluid
   - b. Submerged means the entire object is below the top level of the fluid. The object displaces its volume in fluid. $Wt_{apparent} = mg - F_{buoy}$
3. Fluid flow continuity **$A_1 v_1 = A_2 v_2$ (A = area, v = velocity; ↑A↓v)**
4. Bernoulli's Equation: **$p_1 + 1/2\ (\rho v_1^2) + \rho g h_1 = p_2 + 1/2\ (\rho v_2^2) + \rho g h_2$**
   If the fluid isn't moving, cancel the KE/V parts and you've got the hydrostatic p formula If no Δh, cancel the PE/V parts: the faster a fluid moves, the lower the pressure!!

B. Temperature and Heat

1. Temperature scales **$T_{kelvin} = T_{centigrade} + 273$**   1 calorie = 4.156 Joule
2. **Specific Heat (c): $Q = m\,c\,\Delta T$** (Water... $c = 4200\ J/kg\ ^0C$)
3. **Latent Heat (L): $Q = m\,L$** ($\Delta T = 0$ during phase change)
4. total Q_{loss} = total Q_{gain}
5. mixing two substances that were originally at different temperatures, finding final temperature.... Note: sign ΔT is positive here as written below
   so, $\Sigma mc(T_i - T_f)_{loss} = \Sigma mc(T_f - T_i)_{gain}$

C. Kinetic theory and thermodynamics

1. Ideal gases
   - a) Kinetic model; temperature is measure of KE in molecules
     $KE_{average} = 1/2\ m v^2 = 3/2\ k\,T$.(k: Boltzmann's constant: 1.38×10^{-23} J/K)
   - b) Molecules of an ideal gas have
     - (1) elastic collisions (no K.E. lost)
     - (2) negligible volume
     - (3) no forces between atoms
   - c) Ideal gas law **$PV = nRT$ ...**
     n: number of moles   P: Pressure (Pascal or N/m^2)
     V: volume (m^3)   T: temp (**KELVIN !!!!!**)
     ...if mass of gas doesn't change **then $P_1 V_1 / T_1 = P_2 V_2 / T_2$**
   - d) Universal Constants
     - (1) R = universal gas constant = 831 J / mol.K
     - (2) 1 mole = Avogadro's number of molecules = 6.02×10^{23} molecules
2. Laws of thermodynamics
   - a) Zeroeth Law: all objects at same temp are at thermal equilibrium.
   - b) First Law **$\Delta U = Q + W$** (U is internal energy, temp) a.k.a. Conservation of Energy
   - c) Second Law: **$\Delta S = \Delta Q / T$** (S is entropy, disorder) a.k.a. Law of Entropy
     - (1) can't get equal or more work out of system than heat put in
     - (2) can't make 100% efficient engine
     - (3) heat won't flow by itself from cold to hot
     - (4) entropy in universe will always increase
   - d) Q = positive if heat added to system, Q = negative for heat loss
   - e) W = positive if work done on system
3. Processes on PV diagram
   - a) Work **$W = P\ \Delta V$** applies to gases compressed
     - (1) work done by gas system is positive for expansion
     - (2) negative work is work done on system
     - (3) work is area under curve on PV diagram
   - b) isothermal: constant temp ($\Delta U = 0$ so $Q = W$)
   - c) isobaric: constant pressure (both Q and W are nonzero)
   - d) isochoric (isovolumetric) constant volume ($W = 0$ so $\Delta U = Q$)
   - e) adiabatic: no heat transfer during process: either free expansion or process. It must happen very quickly
4. Heat engines... Work done by engine... **$W = Q_h - Q_c$**
   - a) substance from high temp (hot reservoir) does work (at engine) and is expelled at lower temp (cold reservoir)
   - b) **Efficiency $= W/Q_h = 1 - (Q_c/Q_h)$** note that efficiency is always less than 1.
   - c) work is area enclosed by cycle in PV diagram [$W = P\Delta V$]
   - d) **Carnot Engine.... highest efficiency $= 1 - (T_c / T_h)$**

III ELECTRICITY AND MAGNETISM — 25%

A. Electrostatics:

1. Charge (q), Electric field (E) and potential (V)
   - a) e= charge of electron = -1.6×10^{-19} C. Electron mass = 9.11×10^{-31}kg
   - b) **$F_{electric} = Eq$**   E field lines starts at "+" and goes to "-" charge
     - **E** **$= \Delta V / d$ (if field is uniform)**
     - **V** **$= W / q$**   (1V = 1 J/C)
     - **V** $= k\,q / r$ (if q is a spherical or point charge)
     - **W** $= - \Delta V\,q = \Delta PE_{electric}$
     - **E** **$= kq/r^2$**
   - c) 1 eV = 1.6×10^{-19} Joules (1 eV is the energy needed to move an electron across 1V)
2. Coulomb's law and field and potential of point charges
   $F_{electric} = k\,q_1 q_2 / r^2$ (if q is a spherical or point charge)
   k = Coulomb's constant = $9.0 \times 10^9\ Nm^2/C^2$ F is attractive for "+", repulsive for "-"
3. V and E inside a conductor
   V is constant on surface, and inside has the same value as surface of conductor
   E field is zero inside conductor

B. Conductors, capacitors

1. Electrostatics with conductors
   Charging conductors by contact and by induction (review these processes)
2. **Parallel plate capacitors $Q = C\,V$**
   (C is capacitance... the charge stored for each volt)
   $C = Q / V$;
   C α area of plate / separation of plates

C. Electric Circuits

1. Current (I), resistance (R) , and power (P)
   - a) **R α Length / Area**
   - b) **Ohm's Law $V = I\,R$**
   - c) **$P = I\,V = I^2 R = V^2/R$**   [Watts: 1W = I J/s]
2. Steady-state direct current circuits with batteries and resistors only
   - a) **Resistors in series....** share same current:
     - (i) **$R_T = R_1 + R_2 + R_3 + ...$**
     - (ii) current the same at every point
     - (iii) sum of the ΔV's in entire circuit is zero
   - b) **Resistors in parallel..** share same V:
     - (i) **$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + ...$**
     - (ii) **Σ I into a junction = Σ I out of the junction**
     - (iii) **$V_T = V_1 = V_2 = V_3 = ...$**
3. Capacitors in steady-state circuits
   - a) **Capacitors in parallel** - share same V:
     - (i) **$C_T = C_1 + C_2 + C_3 + ...$**
     - (ii) **$Q_T = Q_1 + Q_2 + Q_3 + ...$**
     - (iii) **$V_T = V_1 = V_2 = V_3 = ...$**
   - b) **Capacitors in series** - share same Q :
     - (i) **$1/C_T = 1/C_1 + 1/C_2 + 1/C_3 + ...$**
     - (ii) **$Q_T = Q_1 = Q_2 = Q_3 = ...$**
     - (iii) sum of the ΔV's in entire circuit loop is zero

D. Magnetism

1. Forces on moving (v) charges (q) in magnetic fields (B): $F_{magnetic} = B\ q\ v \sin\theta$
   a) **Left** Hand Rule: FirstFinger=Field seCond=Current Fum=Force
   b) current is opposite to flow of negative charge, same as flow of positive charge
   c) has circular motion in B field: $F_{CENTRIPETAL} = F_{MAGNETIC}$ $(mv^2/r = B\ q\ v)$
2. Forces on **current-carrying wire** in magnetic fields
   a) Wire in magnetic field: $F = B\ I\ L \sin\theta$
   b) **Left** Hand Rule: FirstFinger=Field seCond=Current Fum=force
   c) Torque on wire loop in B field: **Torque** $= B\ I\ A \sin\theta$ (A= area of loop)
   d) Magnetic Force between two very long current carrying wires, dist **d** apart:
   Force on one meter of each wire $= \mu_o I_1 I_2 / 2\pi r$

3: Fields at distance **r** from long current-carrying wires.... $B = \mu_o I / 2\pi r$
Right Hand rule: current flows in Right thumb direction, B field curls with fingers

4: $B = \phi / A$ (ϕ: no. of flux lines A: area they pass through)

5: An emf (ε) is created when a wire cuts magnetic flux: **emf** $= B\ L\ v \sin\theta$

or when flux changes through a loop of wire: **emf** $= -\Delta\phi/\Delta t$
Right Hand Rule: FirstFinger=Field seCond=Current Vum=Vel of wire
Lenz's Law: induced emf produces a current whose B field opposes the change in magnetic flux through a current loop thus creating a repulsive force (no free lunch)

IV. Waves and Optics 15%

A. Wave motion

1. **Properties of traveling waves**
   a) $V = f\lambda$ [Hz = cycle / second = wave / second] period (T) =1/frequency
   b) displacement: $x = A\cos(\omega t)$; $\omega = 2\pi f$ [ω is angular velocity]
   c) wave is inverted when reflected from fixed end. Reflects from free end upright.
2. **Doppler effect**. frequency shift with relative motion
   $f_r = f\ (v \pm v_o) / (v \pm v_s)$ (s: source, o: observer) choose signs so that frequency shifts higher for converging object and source, shifts lower for diverging.
3. **Superposition** add individual waves point by point
   a) constructive interference (increased amplitude - may be. bright)
   b) destructive interference (decreased amplitude. may be node)
   c) $f_{beat} = |f_1 - f_2|$ beats (beat frequency gives difference in f between two tones)
4. **Properties of standing waves;**
   resonance [two identical waves passing through each other]
   a) natural frequencies of vibration: f_{fun}, 1st overtone, 2nd overtone, 3rd overtone
   b) **string**: $v = \sqrt{T / [m / L]}$ T: Tension m: mass of string L: Length of string. Node at fixed end; Antinode at loose end.
   c) **pipes**; Antinode at open end, node at closed end.

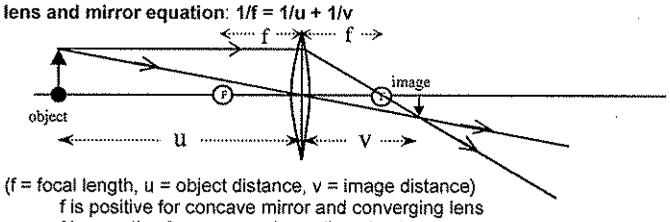
B. Physical Optics

1. **Interference and diffraction**
   single slit interference : $n\lambda = a \sin\theta$ ($n\lambda$ is path difference)
   max at n = 0, 1.5, 2.5, 3.5, 4.5 min at n = 1, 2, 3
   smooth transition between max and min.
   W-i-d-e central max. a is width of single slit.
   double slit interference : $n\lambda = a \sin\theta$ ($n\lambda$ is path difference)
   max at n = 0, 1, 2, 3, 4 min at n =0.5, 1.5, 2.5, 3.5
   smooth transition between max and min.
   a = distance between centers of slits.
   multiple slit interference(diffraction grating): $n\lambda = a \sin\theta$
   same as double slit , a is distance between adjacent slits
   min is everywhere except at exactly at max.
2. **Thin film interference**
   (a) 180° phase change (flip) when reflect off higher refractive index (out of phase)
   (b) no phase change when reflects off lower refractive index (in phase)
   (c) don't forget λ changes within medium.
3. **Dispersion of light and the electromagnetic spectrum.**
   (a) EM radiation = transverse wave (of E field and B fields at right angles)
   (b) low frequencies (long wavelengths ~ red end of spectrum) diffract and refract (bend) less than high frequencies (short wavelengths ~ blue end of spectrum)
   (c) EM spectrum: (from short to long wavelengths): cosmic. gamma, x ray, ultraviolet. Visible (blue to red), infrared, microwave. radiowaves

C. Geometric optics

1. **Reflection and refraction**
   a) **law of reflection: angle of incidence = angle of reflection** (easy!)
   a) Snells law: $n_i \sin i = n_r \sin r$ $(n = c/v)$
   b) If $n_i > n_r$ light bends away from normal
   c) If $n_i < n_r$ light bends toward normal
   e) $\sin C = n_2/n_1$ light can only be totally internally reflected if the light is passing from more dense to less dense ($n_1 > n_2$)
   f) Light decreases wavelength, **but keeps the same frequency**, when passing from less dense to more dense.
   g) Angles always measured against normal.
2. **Mirrors and Lenses**
   a) **Ray Diagrams** (location of object found by any 2 principal rays)
   (1) Light passing through center of lens always passes through without bending
   (2) Convex lens: Ray parallel to principal axis bent by lens to Principal focus.
   (3) Concave lens: Ray parallel to principal axis bent by lens so it diverges from principal focus.
   (4) All ray diagrams are 'reversible'.
   (5) Mirrors: Ray through center of curvature (2f) reflects back along same path, ray through principal axis reflects according to law of reflection ($\theta_i = \theta_r$)
   b) **Magnification:** $M = -ht_{image}/ht_{object} = -u/v$ (negative means inverted)

   c) **lens and mirror equation**: $1/f = 1/u + 1/v$



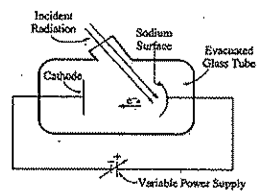
(f = focal length, u = object distance, v = image distance)
f is positive for concave mirror and converging lens
f is negative for convex mirror, diverging lens
If image distance (u) is positive then image is real, inverted
If image distance (v) is negative then image is virtual, erect.
If magnification (M) > 1 then image is magnified
If magnification (M) < 1 then image is diminished

   d) mirror $f = R/2$ (R: radius of curvature)

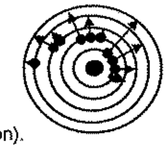
V. Modern Physics 10%

A. Atomic physics and quantum effects

1. **Photons and the Photoelectric Effect (PEE)**
   a) line spectrum light emitted by highly charged gas (excited electrons) is of distinct f frequencies only (for instance....Balmer, Lyman, Paschen series for hydrogen gas)
   b) Max Planck found that **accelerating charges emit EM radiation.** vibrating molecules that emit EM radiation can only have certain amounts of energy molecules emit energy in **lumps of energy called quanta (a.k.a. photons)** by jumping from one 'quantum state' to another.
   Energy of quanta (photon) is $E_{photon} = h\ f = h\ c / \lambda$
   (E: energy, **h= Planck's constant** = 6.63×10^{-34} Js, f = frequency, λ= wavelength)
   c) **PEE** Einstein found that hitting the surface of metals with **light of certain wavelengths can cause electrons to be ejected from the metals surface.** He used a simple circuit to prove this effect (the **effect is called the Photo Electric Effect** (PEE))
   Increasing intensity of light (the number of photons hitting each second), increases the number of electrons emitted, which increases the current flow in Einstein's circuit, but does not increase the speed of electrons.
   - # of photons hitting surface each second $\propto$ # of electrons kicked off surface
   - Speed of electrons $\propto$ frequency ↑ frequency, ↑ speed of electrons
   - $KE_{max} = hf - \phi$ [ϕ = work function, the min energy needed for an electron to get from ground state to the outside of the atom.]



   - $\phi = h f_{threshold}$; $f_{threshold}$ is the threshold ('cut-off') frequency; no electrons **leave atom** when f is below $f_{threshold}$
   - As with all waves, **high f (short λ) wave has high energy; low f (long λ) wave has low energy**
   d) **Each photon comes from a single jump of an electron** from a higher energy level to a lower energy level.
   e) **Photons have momentum**!! Even though they don't have mass. $p = hf/c = E_{photon}/c$
   f) **Compton Effect**: (kinda proves that photons have momentum). When an electron is hit by a photon, the photon loses momentum (so its wavelength increases) and the electron gains the same amount of momentum (so it moves faster) $\Delta\lambda = h / m\ c$ $\Delta\lambda = \lambda_{before\ hit} - \lambda_{after\ hit}$ m = mass of e/ c = speed of light
2. **Energy levels**



   a) Electrons can only exist in specific orbits, each at a certain energy state
   b) If an electron stays in the same orbit, it isn't radiating or absorbing. EM Radiation (photon) emitted only when electrons jump down orbits towards nucleus. The only way for electron to jump up orbits is to absorb EM radiation (photon). Photon energy still (always) obeys $E_{photon} = hf$
   $E_{photon} = E_{electron\ in\ one\ orbit} - E_{same\ electron\ in\ another\ orbit}$
3. **Wave-particle duality**
   a) de Broglie wavelengths: all moving particles (including electrons) vibrate as standing waves $\lambda_{deBroglie} = h / p = h / m\ v$
   b) small particles (electrons, protons, etc) display wave properties (!!!) like diffraction and interference : electrons diffract through regular spacing of crystals (diffraction grating). This is how we know the structure of many materials (example: x-ray crystallography).

B. Nuclear physics

1. **Nuclear reactions** (demonstrate conservation of mass # and charge).
   a) **α decay** $^{238}_{92}U \Rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$ (α particle)
   b) **β decay** $^{210}_{83}Bi \Rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e$ (β particle, electron) + ν_e (neutrino)
   c) **Fission:** bombardment of target with subatomic particles to induce radioactivity
   a. Neutron production $^{9}_{4}Be + {}^{4}_{2}He \Rightarrow {}^{12}_{6}C + {}^{1}_{0}n$ (neutron)
   d) **Fusion:** of small nuclei at high temp releasing energy
   e) **Other particles:** $^{1}_{1}H$ or $^{1}_{1}p$ (proton); $^{0}_{0}\gamma$ (gamma ray photon); $^{0}_{+1}e$ (positron)
2. **Binding Energy** (Mass-Energy Equivalence) $E = \Delta mc^2$
   E: 'Binding energy' (J) Δm: mass defect (kg) **c**: speed of light
   mass defect: mass of nucleus is less than the mass of its nucleons
   Energy associated with mass defect is released when nucleons combine and absorbed when they are released