MATERIAL COVERED

• Concepts in Halliday, Resnick and Walker, **Chapters 1-15, 19-21**
  ▪ There will be 6 questions on the exam
  ▪ The approximate breakdown of the questions will be:
  – Half covering Chapters 1-12 (midterms 1 & 2)
  – Half covering Chapters 13-15 & 19-21 (after midterm 2)

• Questions will be based on material covered in:
  ▪ Lectures
  ▪ Problems in the Homework
  ▪ Sections of the Text not touched on in Lectures or Homework will not be included in the exam.

• Question Format:
  ▪ Questions will be very similar to the homework problems and to those on the midterms

WHAT TO BRING

• The exam will be closed book, but

• You will be allowed to use one 8½ x 11 note sheet
  ▪ You may use both sides of the note sheet
  ▪ The notes must be in your handwriting – No photocopies
  ▪ You may include anything you want on the note sheet
    (formulas, example problems, graphs, inspirational poetry…)
  ▪ You will be asked to had in your note sheet with your exam, so **put your name on it**
    – The note sheet will not be graded, but
    – Failure to hand in your note sheet will cost you points

• Remember to bring a **calculator**

• I will provide all necessary:
  ▪ constants
  ▪ unit conversions
  ▪ moments of inertia
GENERAL ADVICE

• Studying for the Exam
  ▪ Do all the homework problems and understand the solutions.
  ▪ Review your lecture notes.
  ▪ Have a look at the “Questions” at the end of each chapter. If you find that you have problems with groups of them you should concentrate on understanding those areas.

• Exam-Taking Strategies
  ▪ Before beginning the exam read over all the problems.
  ▪ Before doing a problem read it carefully so you don’t miss anything.
  ▪ Start with the easiest problem.
  ▪ If you get stuck – don’t waste time. Go on to another problem.
  ▪ Write legibly. If the grader can’t read your solution he/she can’t grade it.
  ▪ Show your work. No work = no partial credit.
  ▪ Draw detailed pictures - this can indicate to the grader that you understand the concept of the problem even if you don’t do the math correctly.
  ▪ Solve problems algebraically before plugging in numbers.
  ▪ Check your answers for correct units and reasonable values.
  ▪ Don’t worry if you can’t do everything. Grading will be on a curve.

• Time Budgeting
  ▪ Do not allow yourself to miss out on points by wasting all your time on a few problems.
  ▪ Make a time budget at the beginning of the exam and stick carefully to it!
  ▪ For a 3 hour exam with 6 questions a sample budget could be:
    – 10 min Read over all problems and decide the order to do them.
    – 25 min Spend this amount of time on each problem.
    When a problem's time is up, stop, and go to the next one.
    – 20 min Check over your work and revisit any parts you couldn't do.

• Partial Credit. How to make sure you get it.
  ▪ Show your work. You will not get credit if you simply write down the correct answer.
  ▪ Draw a diagram of the problem with forces and a coordinate system.
    – A well drawn diagram will be worth points.
    – No diagram will make it difficult for the grader to give partial credit.
  ▪ Show clearly the steps you have taken in attempting to solve the problem.
    – If the grader can’t follow your reasoning you won’t get much credit.
  ▪ Include units in your answers.
    – Points will be taken off for answers without units.
  ▪ Use appropriate significant digits
    – Points will be taken off for answers that have many (3-4) more significant digits than the information given.
Key Concepts

UNITS
• Always include units in answers!
• Know common units
  ▪ N = kg m/s^2, etc.
• Be able to convert back and forth between different units

VECTORS
• Drawing Coordinate Systems
• Difference between Vectors and Scalars
  ▪ Vector = magnitude and direction (at least two numbers)
  ▪ Scalar = number with sign
• Vector Representation
  ▪ Cartesian: \( \mathbf{v} = v_x \mathbf{i} + v_y \mathbf{j} + v_z \mathbf{k} \)
    – Unit vectors
  ▪ Polar: \( \mathbf{v} = \text{magnitude}(v) \text{ and angle}(\theta) \)
    ▪ Calculating components of vectors along coordinate axes
• Adding and Subtracting Vectors
• Multiplying Vectors
  ▪ Dot Product: \( \mathbf{c} = \mathbf{a} \cdot \mathbf{b} = ab \cos \theta \)
  ▪ Cross Product: \( \mathbf{c} = \mathbf{a} \times \mathbf{b} \)
    – \( c = ab \sin \theta \)
    – Direction of \( \mathbf{c} \) from Right-Hand-Rule

MOTION
• Definitions of:
  ▪ Position and Displacement
    – \( \mathbf{r}(t) \) and \( \Delta \mathbf{r} \)
  ▪ Velocity and Speed
    – \( \mathbf{v} = \Delta \mathbf{r} / \Delta t \)
    \( \mathbf{v} = d\mathbf{r}/dt \)
  ▪ Acceleration
    – \( \mathbf{a} = \Delta \mathbf{v} / \Delta t \)
    \( \mathbf{a} = dv/dt \)
• Differences between average and instantaneous acceleration and speed
• \( a = 0 \Rightarrow v = \text{constant} \)
• Relative Motion
  ▪ Understand concept of Frames of Reference
    – Difference between Inertial and Non-inertial Frame
  ▪ Transformations of position / velocity / acceleration between inertial frames
    – \( \mathbf{x}_{o1} = \mathbf{x}_{o2} + \mathbf{x}_{21} \)
    – \( \mathbf{v}_{o1} = \mathbf{v}_{o2} + \mathbf{v}_{21} \)
    – \( \mathbf{a}_{o1} = \mathbf{a}_{o2} \) for object \( o \) in reference frames 1 and 2
MOTION WITH CONSTANT ACCELERATION

- Equations of Motion in 1D and 2D and how to use them
  - See Table 2-1 in the Text
  - Understand how to break 2D equations of motion up into components
  - Velocity Direction = Tangent to y vs. x curve
- Keep Track of Signs \((x, v, a)\) when writing equations
- Acceleration of gravity near earth
- Projectile Motion
  - Independence of \(x\) and \(y\) components
  - Range (and when to use it)

FORCE

- Newton’s Laws
  - 1st Law: No Force means No Acceleration
    - \(F=0 \Rightarrow a=0 \Rightarrow v=\text{constant}\)
  - 2nd Law: Total Force Acting on Body proportional to Acceleration of Body
    - \(\sum F = ma\)  This is a vector equation
  - 3rd Law: Action = Reaction
    - \(F_{12} = -F_{21}\)
    - The force body 1 exerts on body 2 is equal and opposite to the force body 2 exerts on body 1
- Mass
  - Difference between mass and weight
- Free-Body Diagrams
  - Always draw these – they are crucial!
  - Draw one for each object in the problem.
  - Make sure you keep straight which forces are acting on which bodies!
  - When must you include a Force
    - Gravity (at the CM)
    - Points of Contact between objects
  - Choose useful coordinate systems
    - one axis along direction of motion or acceleration
- Forces to Understand
  - Weight \(W = mg\)
  - Normal Force Perpendicular to Surface
  - Friction
    - Static
      - \(F_f^{max} = \mu_s \ N\)
      - Direction: opposite to applied force
      - Remember that at point static friction breaks down:
        - \(F_f = F_f^{max}\) and \(a = 0\)
    - Kinetic
      - \(F_f = \mu_k \ N\)
      - Direction: along surface of contact, opposite to motion
- Drag Force
  - Know general form
- Tension
  - Understand direction of tension pulling on objects
- Uniform Circular Motion
  - Definition = motion in a circle with constant speed
  - Relationship between period, speed and radius
    > \[ T = \frac{2\pi r}{v} \]
  - Force required for object to stay in uniform circular motion
    > \[ F_{\text{cent}} = ma_{\text{cent}} \text{ – pointing towards center of circle} \]
    > \[ a_{\text{cent}} = \frac{v^2}{r} \]
    > Keep in mind that a real force must be provided by something like gravity, tension, etc. if an object is to move in a circle
- Standard Force Problems to Understand
  - Blocks and Inclined Planes
  - Cords and Pulleys
  - Objects with friction
    - static: on the verge of motion
    - kinetic
  - Objects moving in circles and what causes it
  - Static situations – No motion
- Strategy for solving force problems
  1) Draw a sketch of the problem – include important forces
  2) Decide what object(s) you want to consider
  3) Draw a free body diagram(s) for each object
    - include all forces acting on the object
    - forget about the forces the object exerts on other things
  4) Choose a coordinate system and draw it on your free-body diagram(s)
  5) Write down the force equations in the x- and y-directions
    - don’t think too much here – just break the forces into components and write down the equations
    - try to be as general as possible
      - don’t make assumptions about accelerations or relationships between forces
  6) Try to find all the relationships that you can between accelerations and forces
  7) Solve the simultaneous equations

WORK & ENERGY (non-rotational)
- Work
  - \[ W = \int F \cdot ds \] General Definition
  - \[ W = F \cdot d \] Constant Force, Linear Displacement
  - \( W \) is independent of path (depends only on endpoints of integral) for conservative forces
  - Be able to calculate for simple situations (no complicated integration)
- Kinetic Energy
- \( K = \frac{1}{2} mv^2 \)

- **Potential Energy**
  - \( \Delta U = - \int F \cdot ds = -W(i\to f) \) P.E. Difference between two points
  - Only sensible to define P.E. for conservative forces
    - Integral is path independent
  - Concept of Reference Point \( \Rightarrow \) Allows to Define \( U(r) \)
    - Always make clear what your reference point is!
  - Be able to calculate for simple situations (no complicated integration)

- **Total Mechanical Energy**
  - \( E = K + U \)
  - \( E \) is constant for conservative forces (conservation of energy)

- **Power**
  - \( \langle P \rangle = W / t \)
  - \( P_{\text{inst}} = dW/dt = dE/dt = F \cdot v \)

- **Conservative Forces**
  - Which forces are conservative
    - Gravity
    - Spring Force
  - And which aren’t
    - Friction

- **Conservation of Energy**
  - \( K_1 + U_1 = K_2 + U_2 \) Mechanical Energy Cons. for Isolated Systems
  - \( \Delta K = -\Delta U \) Alternate formulation
    - Applicable when all forces are conservative
      - No friction or other energy dissipation
    - Understand what is meant by a system
      - Isolated = no external forces
    - Remember to define a reference point for the P.E.

- **Dissipation of Energy**
  - Define clearly what is the “System” and what is “External”
    - what belongs to each category will depend on the problem
  - \( W_{\text{ext}} = \Delta E_{\text{tot syst}} = \Delta K + \Delta U + \Delta E_{\text{int}} \)
    - Don’t worry too much about the details of \( \Delta E_{\text{int}} \)
      - how it is distributed among the objects in a system
    - Do understand its source
      - for example, energy dissipated by friction causes increase in \( E_{\text{int}} \)
    - Be able to calculate \( \Delta E_{\text{int}} \) for simple cases involving friction

- **Specific Applications to Understand**
  - Be thoroughly comfortable with using energy conservation in problems involving combinations of these.
  - Be careful of signs
    - Use your physical intuition to tell you what they should be for work and potential energy
  - Work - Kinetic Energy Theorem
This is most often useful in situations where an object starts and ends at rest
> $\Delta K = 0 \Rightarrow W_{\text{tot}} = 0$

**Gravity**
- $F = mg$
- $\Delta U = mg \Delta y$
- Make sure you understand conservation of energy applied to falling bodies or bodies sliding down ramps.

**Springs**
- Concept of relaxed position
- $F = -k\Delta x$
- $\Delta U = \frac{1}{2} k\Delta x^2$
- Be able to calculate things like:
  > position of turning points
  > speed as a function of $\Delta x$

**Pendulums**
- Calculate speed, height of swing, etc.
- Relationship between speed and tension in cord

**Friction**
- Calculate Energy loss due to presence of friction for simple situations

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**MOMENTUM & CENTER-OF-MASS**

- Calculate position of center of mass for simple systems
  - $r_{\text{CM}} = \sum m_i r_i / M_{\text{tot}}$
  - $r_{\text{CM}} = \int r \, dm / M_{\text{tot}}$ (no complicated integrals)
  - Understand how to use symmetry to simplify the calculations

- Motion of the CM
  - $\Sigma F_{\text{ext}} = M_{\text{tot}} a_{\text{CM}}$
  - Pay special attention to the case when $\Sigma F_{\text{ext}} = 0$
  - Calculate motions of parts of the system based on knowledge of CM
  - Remember to always clearly define your system
  - Understand problems involving positions of objects in a system as they change locations

- Momentum
  - $p = mv$ particle
  - $\Sigma F = dp/dt$
  - $p_{\text{CM}} = M_{\text{tot}} v_{\text{CM}}$ system
  - $\Sigma F_{\text{ext}} = dP_{\text{CM}}/dt$
  - Conservation of Momentum
  - $\Sigma F = 0 \Rightarrow p = \text{constant} \Rightarrow p_i = p_f$
  - Calculate motion of components of system under momentum conservation
  - Be careful of Relative Motion
    > e.g. people walking on boats with speeds given with respect to the boat
    > Gallilean Transforms: $v_{\text{ao}} = v_{\text{ab}} + v_{\text{bo}}$

- Collisions
- Impulse
  > \( \Delta p = \int F \, dt = \langle F \rangle \Delta t \)
- Series of Collisions
  > calculate average force
- Elastic Collisions:
  > \( P_i = P_f \)  \quad \text{Momentum Conserved}
  > \( K_i = K_f \)  \quad \text{Kinetic Energy Conserved}
- Inelastic Collisions:
  > \( P_i = P_f \)  \quad \text{Only Momentum Conserved}
- Totally Inelastic Collisions:
  > Objects stick together after collision
- Be able to set up momentum and K.E. conservation equations for collisions in 1D and 2D
  > Algebra will be kept to a Minimum
- Understand motion of CM for collisions (remains unchanged)

**ROTATIONAL MOTION**

- See Table below for important formulas
- Definitions of Angular: Displacement, Velocity, Acceleration
- Understand relationships between rotational and translational quantities
  - radial and tangential components of motion
  - calculate angular velocity from period of rotation
    > \( \omega = \frac{2\pi}{T} \)
    > Remember that if an object is travelling in a circle some force must be acting on it
      - pointing toward the center of circle
      - magnitude of force = \( \frac{mv^2}{r} \)
- Be comfortable with Angular Equations of Motion (kinematics) for constant angular acceleration
- Rotational Inertia
  - \( I = \sum m_i r_i^2 = \int r^2 \, dm \)
  - Be able to calculate for simple objects or collections of objects
    - No complicated calculations
    - remember: \( I \) is an additive quantity (like mass)
  - Understand the Parallel Axis Theorem
- Torque:
  - \( \tau = r \times F \)
  - be able to calculate its magnitude and direction from force and displacement vector
- Newton’s 2nd Law (Angular Form): \( \Sigma \tau = I\alpha \)
  - Use this to solve rotational dynamics problems
  - Important problems to understand
    - Weights and Massive Pulleys
    - Cords winding or unwinding on of Spools
• Work & Energy
  - Be able to solve energy conservation problems involving linear and rotational motion
• Rolling without slipping
  - $v_{CM} = \omega r$
  - $K = \frac{1}{2} m v_{CM}^2 + \frac{1}{2} I_{CM} \omega_{CM}^2$
  - Use energy conservation to calculate motion of bodies rolling down inclines
    - understand problems for bodies with several parts (like bicycles)
• Angular Momentum
  - Calculate from:
    - $L = \mathbf{r} \times \mathbf{p}$
    - $L = I \omega$
  - $\sum \tau = dL/dt$
  - Conservation of Angular Momentum of a System
    - $\sum \tau_{ext} = 0 \Rightarrow L_{syst} = \text{constant} \Rightarrow L_i = L_f$
    - Solve problems for motion of components of a system
      > Change in $L$ of one component
      > Change in $I$

STATIC EQUILIBRIUM
• This is just a special case of Force and Torque problems where all objects are stationary.
• Understand how to write down force and torque equations for all components $(x,y,z)$
  - $\sum \mathbf{F}_{ext} = 0$ acting through the CM
  - $\sum \tau_{ext} = 0$ acting about a point that you choose cleverly
    - Choose origin for torque calculations such that some of the torques are zero

GRAVITATION
• Gravitational Force
  - $\mathbf{F} = -G \frac{m_1 m_2}{r^2} \hat{r}$ \hspace{1cm} $(G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)$
  - Superposition (calculating the total force on a body)
    - $\mathbf{F}_i = \sum \mathbf{F}_{1i}$ \hspace{0.5cm} discrete bodies
    - $\mathbf{F} = \int \mathbf{dF}$ \hspace{0.5cm} continuous body
    - Remember: these are vector sums
  - Relationship between $G$ and $g$ (acceleration due to gravity) near surface of a planet
    - $g = GM/r^2$
• Gravitational Potential
  - $U = -G \frac{m_1 m_2}{r}$
  - Reference point: $U = 0$ at $r = \infty$
  - Potential energy of a system of bodies
• Gravitation of Spherical Shells
  ▪ Know behavior of Force and Potential
    – inside and outside of shell
    – as a function of position inside uniform spherical body
• Conservation of Energy in Gravitational systems
  ▪ Escape Velocity
• Kepler’s Laws
  ▪ 1) Law of Orbits: The orbit of each planet is an ellipse with the sun at one focus
  ▪ 2) Law of Areas: The speed of a planet in its orbit varies in such a manner that the
    radius vector joining the planet with the sun sweeps over equal areas in equal times.
  ▪ 3) Law of Periods: For planets $(\text{Period})^2 \propto (\text{semi-major axis})^3$
  ▪ Know the basic consequences of these for planetary motion

**FLUIDS**
• Density $\rho = M/V$
• Pressure $P = F/A$
  ▪ Know that 1atm = $1.01 \times 10^5$ Pa
• Definition of a Fluid (understand consequences):
  ▪ Cannot sustain a transverse force (only normal forces)
    – $\rightarrow$ takes shape of container
    – $\rightarrow$ Pressure acts normal to the surface of the fluid/container
  ▪ Gas: compressible
  ▪ Liquid: basically incompressible
• Pascal’s Principle
  ▪ pressure transmitted undiminished to all portion of fluid and walls of container
  ▪ understand what this means for forces applied to any point in the fluid
    – the Hydraulic Lever
• Fluid Statics
  ▪ Pressure vs depth:
    – $P_1 = P_2 + \rho g(y_1 - y_2)$ two arbitrary depths
    – $P = P_0 + \rho gh$ difference between surface and depth $h$
    – understand signs
  ▪ Buoyancy / Archimedes’ Principle
    – $F_b = \text{weight of fluid displaced by object}$
    – be able to solve force equations using buoyant force
• Fluid Dynamics
  ▪ Understand difference between laminar and turbulent flows
    – calculations will all be for laminar
  ▪ Flow rate:
    – $R = A_1 v_1 = A_2 v_2$ conservation of mass
  ▪ Bernoulli’s Equation:
    – $P_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2$ conservation of energy
    > be careful with signs
• Be able to apply flow rate and Bernoulli’s equation to get information about flow of liquids

THERMODYNAMICS

• Counting in Thermodynamics
  ▪ Avogadro’s Number: \( N_A = 6.02 \times 10^{23} \)
  ▪ 1 mole (mol) = \( N_A \) objects

• 0th Law of Thermodynamics: Temperature Definition
  ▪ If 2 bodies are in thermal equilibrium with a third then they are in thermal equilibrium with each other
    – not much that you can say about this – but I include it for completeness
  ▪ Know how to convert between temperature scales (especially Celsius and Kelvin)
  ▪ Only Kelvin can be used for equations involving absolute temperatures
  ▪ Kelvin or Celsius can be used for equations involving temperature changes

• Thermal Expansion
  ▪ Linear Expansion: \( \Delta L = L \alpha \Delta T \)
  ▪ Volume Expansion: \( \Delta V = V \beta \Delta T \)
    – \( \beta = 3\alpha \)

• Heat
  ▪ Definition: Heat = Energy transferred due to a temperature difference between two systems
  ▪ Signs
    – Object Absorbs Heat \( \rightarrow Q>0 \)
    – Object Gives Up Heat \( \rightarrow Q<0 \)
  ▪ Heat Capacity
    – \( Q = C (T_f - T_i) = C \Delta T \)
  ▪ Specific Heat = Heat capacity / mass
    – \( Q = mC_m (T_f - T_i) \)
  ▪ Molar Specific Heat
    – \( Q = nC_m (T_f - T_i) \)
  ▪ Heats of Transformation
    – Phase Change \( \Rightarrow \) Heat absorbed (given off) by object but no temp. change
      > Solid\( \Rightarrow \)Liquid & Liquid\( \Rightarrow \)Gas: Heat Absorbed
      > Gas\( \Rightarrow \)Liquid & Liquid\( \Rightarrow \)Solid: Heat Emitted
    – \( Q = Lm \)
  ▪ Be able to calculate multi-step phase changes and heating for two systems coming to thermal equilibrium

• Heat Transfer
  – 1) Conduction:
    > \( \frac{Q}{t} = kA (T_H - T_C) / L \)
    > Apply this to simple situations
  – 2) Convection
  – 3) Radiation
  – Know what Convection and Radiation are, but no explicit calculations
• Work in Thermodynamic Systems
  ▪  \[ W = \int P \, dV \]
• 1st Law of Thermodynamics: Energy Conservation / Definition of Heat
  ▪  \[ \Delta E_{\text{int}} = Q - W \]
  ▪  This is the starting point for most thermodynamics calculations
    –  in general think of this first when doing a problem
• P–V Diagrams
  ▪  Draw thermodynamic processes on them
  ▪  Calculate Work geometrically
  ▪  Use them to show graphically thermodynamic processes
• State Variables / Equations of State
  ▪  Changes in state variables do not depend on path
  ▪  Some State Variables: \( P, V, T, m, E_{\text{int}}, S \) path independent
  ▪  Not State Variables: \( W, Q \) path dependent
  ▪  Understand the consequences of something being a state variable or not
• Thermodynamic Processes
  ▪  Isometric (constant volume)
  ▪  Isothermal (constant temperature)
  ▪  Isobaric (constant pressure)
  ▪  Adiabatic (no heat)
  ▪  Free Expansion
  ▪  Cyclical (begins and ends at same thermodynamic point)
  ▪  For each of these processes you should know (see table below):
    –  what is constant
    –  general relationships between \( \Delta E_{\text{int}}, Q, W, S \)
    –  Be able to draw them approximately on a P-V diagram
      >  (except for Free Expansion)
• Ideal Gases
  ▪  Definition:
    –  1) molecules are point masses
    –  2) no interactions between molecules except for elastic collisions
    –  \( \Rightarrow E_{\text{int}} = K_{\text{int}} \) (no potential energy)
  ▪  Equation of State: \( PV = nRT \)
    –  This is another crucial formula with applications in most problems
  ▪  Know expressions for \( \Delta E_{\text{int}}, Q, W, S \) for ideal gas for all of thermodynamic processes above (see table)
  ▪  Know constant quantities for various processes (see table)
    –  Adiabatic
    –  Free Expansion
• Kinetic Theory of Ideal Gases
  ▪  Know definition of RMS: \( a_{\text{rms}} = (\langle a^2 \rangle)^{1/2} \)
  ▪  \( P = nMAV_{\text{rms}}^2 / 3V \)
  ▪  \( v_{\text{rms}} = (3RT/MA)^{1/2} \)
  ▪  \( \langle K \rangle / \text{molecule} = \frac{1}{2} kT \) for each degree of freedom
    –  \( k = R / N_A \)
- Understand what is meant by “degree of freedom”
- Monatomic Gas $\rightarrow$ 3 Translation
- Diatomic Gas $\rightarrow$ 3 Translation + 2 Rotation (+vibrational at high T)
- Polyatomic Gas $\rightarrow$ 3 Translation + 3 Rotation (+vibrational at high T)

- Internal Energy of Ideal Gas depends only on temperature:
  - $E_{\text{int}} = \frac{3}{2} nRT$ (monatomic ideal gas)
  - $\Delta E_{\text{int}} = nC_V \Delta T$ (always true)
    > this is useful in many calculations

- Molar Specific Heats of Ideal Gases
  - $C_p = C_V + R$ (generally true for any ideal gas)
  - $C_V = \frac{3}{2} R$ (monatomic ideal gas)
  - $C_V = \frac{5}{2} R$ (diatomic ideal gas)

- Solving Ideal Gas Problems
  - The three most generally applicable are formulas are:
    - 1) $PV = nRT$
    - 2) $\Delta E_{\text{int}} = Q - W$ (1st Law)
    - 3) $\Delta E_{\text{int}} = nC_V \Delta T$
  - The solution to most Ideal Gas problems will involve at least one of these three

- Entropy
  - Reversible Processes
    - 1) No Dissipative Effects
    - 2) Quasi-Static: always in thermodynamic equilibrium
      > variables can be defined
  - Irreversible Processes
    - 1) or 2) do not hold
  - Entropy Defined
    - $\Delta S = \int dQ/T$ for quasi-static process
  - Entropy is a State Variable
  - Calculate Entropy Change for simple processes
  - Understand Entropy Change for an Ideal Gas
    - $\Delta S = nR \ln(V_f/V_i) + nC_V \ln(T_f/T_i)$

- 2nd Law of Thermodynamics:
  - For an Isolated System:
    - $\Delta S = 0$ reversible process
    - $\Delta S > 0$ irreversible process
  - For a non-Isolated System
    - $\Delta S = \int dQ/T$
  - Be able to say whether a process is possible based on entropy change

- Entropy for Irreversible Processes
  - Calculate $\Delta S$ for irreversible processes in a closed system by connecting initial and final states by reversible processes
  - be able to do this for very simple systems:
    > for example, 2 objects, initially at different temperatures coming to thermal equilibrium
• **Heat Engines / Refrigerators**
  - Understand how to draw the engine’s cycle on a P–V diagram
  - Understand why it’s impossible to convert heat only into work
  - Understand necessary conditions for an ideal engine
  - **Efficiency of Heat Engine:**
    \[ \varepsilon = \frac{|W|}{|Q_H|} = 1 - \frac{Q_C}{Q_H} \]
    (Carnot Engine)
  - **Coeff of Performance of Refrig:**
    \[ K = \frac{Q_C}{W} = \frac{Q_C}{(Q_H - Q_C)} \]
    (Carnot Refrigerator)
  - Be able to calculate \( \Delta E_{int}, W, Q, \Delta S \) for all steps in heat engine/refrig cycle

• **Statistical Mechanics**
  - Section 21-7 will **not** be included in the exam

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**TRANSLATIONS AND ROTATIONS**

<table>
<thead>
<tr>
<th>Translation</th>
<th>Rotation</th>
<th>Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kinematics</strong></td>
<td></td>
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<tr>
<td>( \mathbf{r} )</td>
<td>( \theta )</td>
<td>( s = r\theta )</td>
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<td>( \mathbf{v} = \frac{d\mathbf{r}}{dt} )</td>
<td>( \omega = \frac{d\theta}{dt} )</td>
<td>( v_r = \omega r )</td>
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<td>( \mathbf{a} = \frac{d\mathbf{v}}{dt} )</td>
<td>( \alpha = \frac{d\omega}{dt} )</td>
<td>( a_r = \alpha r )</td>
</tr>
<tr>
<td>( \mathbf{r}(t) = \mathbf{r}_o + \mathbf{v}_o t + \frac{1}{2}a t^2 )</td>
<td>( \theta(t) = \theta_o + \omega_o t + \frac{1}{2}\alpha t^2 )</td>
<td></td>
</tr>
<tr>
<td>( \mathbf{v} = \mathbf{v}_o + \mathbf{a} t )</td>
<td>( \omega = \omega_o + \alpha t )</td>
<td></td>
</tr>
<tr>
<td>( v^2 = v_o^2 + 2a x )</td>
<td>( \omega^2 = \omega_o^2 + 2\alpha \theta )</td>
<td></td>
</tr>
<tr>
<td><strong>Mass &amp; Inertia</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( m )</td>
<td>( I )</td>
<td>( I = \sum r_i^2 m_i = \int r^2 , dm )</td>
</tr>
<tr>
<td><strong>Force &amp; Torque</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \mathbf{F} = m \mathbf{a} = \frac{d\mathbf{p}}{dt} )</td>
<td>( \tau = I\alpha ); ( \tau = \frac{d\mathbf{L}}{dt} )</td>
<td>( \tau = \mathbf{r} \times \mathbf{F} )</td>
</tr>
<tr>
<td><strong>Momentum &amp; Angular Momentum</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \mathbf{p} = m \mathbf{v} )</td>
<td>( \mathbf{L} = I_\omega )</td>
<td>( \mathbf{L} = \mathbf{r} \times \mathbf{p} )</td>
</tr>
<tr>
<td>( \mathbf{F}_{ext} = 0 \Rightarrow \mathbf{p} = \text{const} )</td>
<td>( \tau_{ext} = 0 \Rightarrow \mathbf{L} = \text{const} )</td>
<td></td>
</tr>
<tr>
<td><strong>Work &amp; Kinetic Energy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( W = \int \mathbf{F} \cdot d\mathbf{s} )</td>
<td>( W = \int \tau , d\theta )</td>
<td></td>
</tr>
<tr>
<td>( K = \frac{1}{2}mv^2 )</td>
<td>( K = \frac{1}{2}I_\omega^2 )</td>
<td>( W = \Delta K )</td>
</tr>
<tr>
<td>( K_{\text{rolling}} = \frac{1}{2}mv_{cm}^2 + \frac{1}{2}I_{cm} \omega^2 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( P = \mathbf{F} \cdot \mathbf{v} )</td>
<td>( P = \tau \omega )</td>
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</tbody>
</table>
# Thermodynamic Processes (Ideal Gases)

<table>
<thead>
<tr>
<th>Process</th>
<th>Def.</th>
<th>General (revers for S)</th>
<th>Ideal Gas</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td>$\Delta E_{\text{int}} = Q - W$</td>
<td>$\Delta E_{\text{int}} = nC_v\Delta T$</td>
<td>Heat a gas in a closed, rigid container</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta S = \int \frac{dQ}{T}$</td>
<td>$PV = nRT$</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$\Delta S = nR\ln(V_f/V_i)$</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$+ nC_v\ln(T_f/T_i)$</td>
<td></td>
</tr>
<tr>
<td>Isometric</td>
<td>$\Delta V = 0$</td>
<td>$\Delta E_{\text{int}} = Q; W = 0$</td>
<td>$\Delta E_{\text{int}} = Q$</td>
<td>Heat air in limp paper bag ➔ bag blows up</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$W = 0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\Delta S = nC_v\ln(T_f/T_i)$</td>
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</tr>
<tr>
<td>Isobaric</td>
<td>$\Delta P = 0$</td>
<td>$W = P \Delta V$</td>
<td>$Q = nC_p\Delta T$</td>
<td>Need Equilibrium System in contact w/ Thermal Reservoir:</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$W = P \Delta V$</td>
<td>- slowly pulling on a piston (syringe)</td>
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<tr>
<td>Isothermal</td>
<td>$\Delta T = 0$</td>
<td>$\Delta E_{\text{int}} = 0; Q = W$</td>
<td>$W = Q = nRT \ln(V_f/V_i)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\Delta S = nR\ln(V_f/V_i)$</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$\Delta S = Q/T$</td>
<td></td>
</tr>
<tr>
<td>Adiabatic</td>
<td>$Q = 0$</td>
<td>$\Delta E_{\text{int}} = - W$</td>
<td>$PV^\gamma = \text{const}$</td>
<td>Fast Expansion/Compression:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta S = 0$</td>
<td>$TV^{\gamma-1} = \text{const}$</td>
<td>- Sound Waves</td>
</tr>
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<td></td>
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<td></td>
<td>Well Isolated Systems:</td>
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<td></td>
<td></td>
<td>- Ice Water in a Thermos</td>
</tr>
<tr>
<td>Free Expansion</td>
<td>$Q = 0$</td>
<td>$\Delta E_{\text{int}} = 0$</td>
<td>$Q = nRT\ln(V_f/V_i)$</td>
<td>Air rushing into an evacuated chamber</td>
</tr>
<tr>
<td></td>
<td>$W = 0$</td>
<td></td>
<td>$\Delta S = nR\ln(V_f/V_i)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Delta T = 0$</td>
<td></td>
<td>$PV = \text{const}$</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$T = \text{const}$</td>
<td></td>
</tr>
<tr>
<td>Cyclical</td>
<td>$\Delta E_{\text{int}} = 0$</td>
<td>$Q = W$</td>
<td>$\Delta S = 0$</td>
<td>Heat Engines &amp; Refrigerators</td>
</tr>
</tbody>
</table>