Tuesday April 21 & Thursday 23rd

See the course webpage for **slides**, **video links**, and google docs **Q&A** links

Topics for this Lecture:

- *Review for final*

This is normally a two-part lecture, where we work out problems students request. Instead, you will need to make sure you practice lots of problems!
Email me and your TAs with questions.

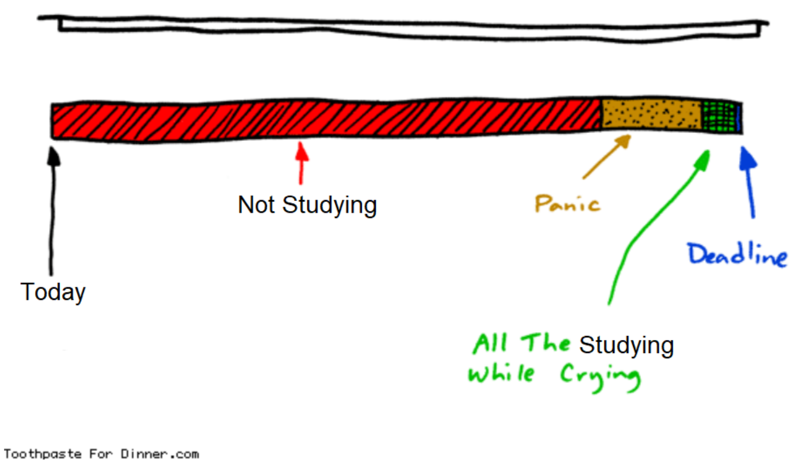
- Assignment 14 due Friday

The final exam will again be on lon-capa. You will have 2 hours to take the exam.
You can take the exam any time within the time window that will be announced via email. The time window will encompass the original final exam time, Monday April 27th 2:30-4:30pm. The full time window will be announced via email, but will likely be from Monday morning through Tuesday evening.
Please watch your email.

Study Tips:

- Look at old TopHat questions
- Try a problem before looking at the soluion
- Focus on solution **processes**, not equations

What not to do:



Class Review: Whirlwind tour of PHYS 2001

📖 In OpenStax

- Topics: (Section 1, Section 2, Section 3. Final is ~1/2 Section 3, ~1/2 Sections 1&2.)
  - Kinematics (Ex.: soccer ball trajectory, free-fall, braking time) — Ch. 2-3
  - Forces (Ex.: tension of rope holding weight, free-body diagram) — Ch. 4-5
  - Torque (Ex.: person on a bridge, weight hanging from a beam) — Ch. 9
  - Energy & Work (Ex.: speed of dropped thing just above ground) — Ch. 7
  - Momentum conservation (Ex.: collisions, bullet & block) — Ch. 8
  - Circular Motion (Ex.: linear speed of rotating object, ice skater) — Ch. 6
  - Simple Harmonic Motion (Ex.: mass & spring, pendulum) — Ch. 16
  - Fluids (Ex.: buoyancy, water speed in an expanding pipe) — Ch. 11,12
  - Thermal Physics (Ex.: expansion of rod, equilibrium temp.) — Ch. 13,14
  - Thermodynamics (Ex.: engine efficiency, cycles) — Ch. 15

*Anything covered in the lecture notes is fair game.
*TopHat questions, practice exams, homework problems, & pre-class assignments all contain the types of questions that could be on the exam.

Study Tips

***Recommended study procedure*:**

1. Review notes
2. Try typical practice problems (a couple per topic, e.g. TopHat Q's)
3. Look at lecture notes for the questions you struggled on
   & possibly consult the relevant section of the book
4. Go back to step 1 until you feel at least ok about most topics
5. Try the practice exam in a realistic setting.
6. Zero-in on the topics you're still struggling on, trying practice problems, reviewing the notes & repeating.
7. Once you've studied for a bit, create your equation sheet.

General comments:

- At least 8 hours of studying is probably necessary to do well. Likely more.
- Making an equation sheet doesn't really count as studying.
  Just like copy-pasting isn't the same as reading & comprehending.
- Try practice problems without looking at the solutions.
  The solution will almost always look clear/obvious when reading it,
  but that won't mean you can actually reproduce it!
- <u>Focus on the relevant process for solving a class of problems.</u>

Exam Taking Tips

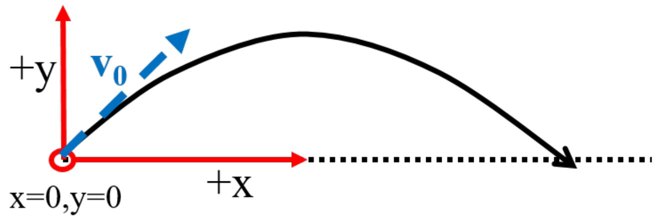
- Stay calm.
- Work on the problems that are easy for you first.
- Work your way through progressively tougher ones.
- If you get stuck on a problem, move to a different one and revisit it later.
- Read over your exam carefully once you're finished to make sure you didn't miss anything, read a problem wrong, or make a small mistake.
- Review lon-capa to make sure you have something submitted for each problem.

NOTE:

The following are general tips for major items related to a given topic, along with some example problems, but they are by no means are comprehensive.

Anything presented in class this semester is fair game.

Kinematics



- How to recognize:
  - Trajectories, motion with linear acceleration
- Tips for solving:
  1. Draw (if not drawn already)
  2. What information do you know?
  3. What do you want to know?
  4. Which of your equations will get you (2) from (1)?
  5. Work through algebra of that equation.
  6. If it doesn't work-out, go back to (4) and try another equation.
- Notes:
  - Horizontal & vertical motion in a 2D-kinematics problem can both be solved like separate 1D-kinematics problems. They are only linked in time.
  - Be sure to cancel-out irrelevant variables in your equations when you can. For example, if the initial velocity is zero.

<u>2D Projectile motion eqns.</u>

1. $v_x = v_{x,0}$
2. $x = x_0 + v_{x,0}t$
3. $v_y = v_{y,0} + a_y t$
4. $y = y_0 + v_{y,0}t + \frac{1}{2}a_y t^2$
5. $y = y_0 + \frac{1}{2}(v_{y,0} + v_y)t$
6. $v_y^2 = v_{y,0}^2 + 2a_y(y - y_0)$

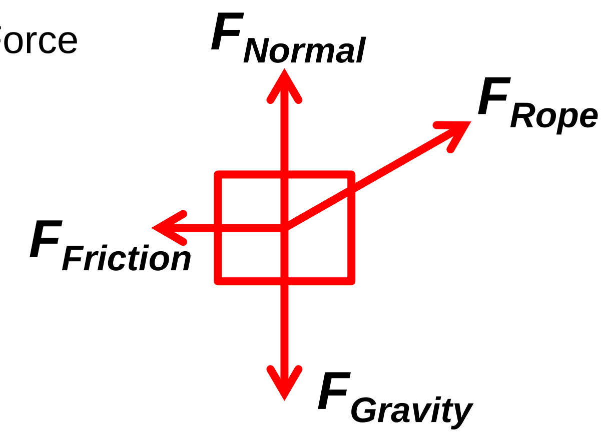
Kinematics: *Examples of typical problems*

1. An object is dropped from a pre-specified height. How fast is it going before it hits the ground? How long does it take to hit the ground?
   i. Know: "Dropped" -> v_i=0, a_y=g=9.8m/s^2. Know height.
   ii. How fast? Want to know: final speed -> $v_y^2 = v_{y,i}^2 + 2a_y(y - y_0)$
   iii. How long?: Want to know: time -> $y = y_0 + v_{y,i}t + \frac{1}{2}a_y t^2$

2. An object begins with some speed at some angle, determine the velocity at some point in time.
   i. Know: $|v_i|$, a_y=g=9.8m/s^2, know θ_i …so know initial x an y velocity components
   ii. Get initial velocity components: SOH CAH TOA
   iii. Horizontal component: x-acceleration is zero, so this is constant
   iv. Y-component: Zero at maximum height, symmetric about trajectory, $v_y = v_{y,0} + a_y t$

Forces & Equilibrium

- How to recognize:
  - Free-body diagram, pushing and/or pulling happening (not about an axis), acceleration due to pushing/pulling is being asked for.
- Tips for solving:
  1. Draw a free-body diagram (i.e. labeled arrows for each force)
  2. Apply newton's 1st law: $\Sigma F = ma$.
  3. Do the algebra to find the missing force or the acceleration.
- Notes:
  - If an object is not accelerating, the forces must be balanced.
  - Should know formulae for:
    - Gravity, Buoyancy, Friction, Normal Force, Centripetal Force

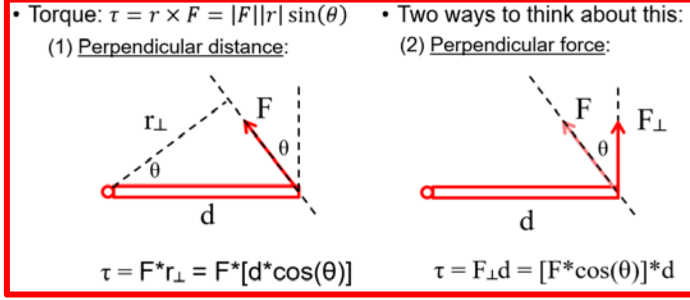


Forces & Equilibrium: *Examples of typical problems*

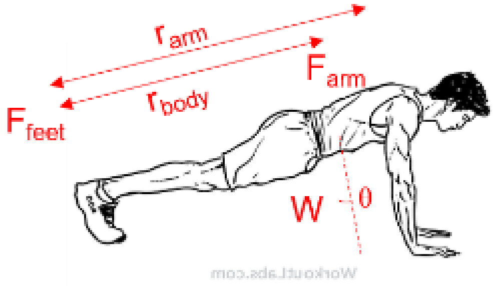
1. An object has some initial speed, a constant force is applied to it for some amount of time, what is the final speed?
   i. Know: v_i, F, Δt
   ii. Always use $\Sigma F = ma$. Recall $a = \Delta v / \Delta t$

2. Two objects are connected by a rope, which goes through a pulley. We know the masses of the blocks and the acceleration of one block. What is the acceleration of the second block and what is the rope tension?
   i. Know: M_1, M_2, a_1
   ii. Note that connected objects accelerate together
   iii. Always use $\Sigma F = ma$. Be careful about the "system definition"

Torque & Static Equilibrium



- How to recognize:
  - A force or forces are acting on an object, but aren't applied directly to the center of an object.
- Tips for solving:
  1. If it's not rotating or accelerating, use static equilibrium: $\Sigma F_x=0$ & $\Sigma F_y=0$ & $\Sigma\tau=0$.
     If it is, then you're probably just being asked for torque.
     Or for the angular acceleration due to torque: $\tau=I\alpha$.
  2. Draw a free-body diagram.
  3. Pick an axis of rotation.
     If you want to ignore a force, put the axis of rotation where it is applied.
     If you want to find a force, put the axis of rotation in a place so that the other force(s) create a net torque.
  4. Do the algebra for the static equilibrium equations.
- Notes:
  - The weight of an object pulls down from its center of gravity. For a uniform object, this is its geometric center.

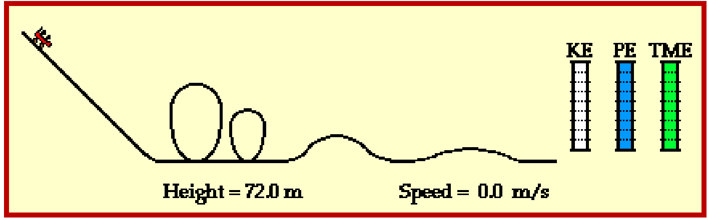


Torque & Static Equilibrium: *Examples of typical problems*

1. Multiple forces are applied some distance from the axis of rotation, what is the net torque?
   i. Know: Forces (F), distances from axis of rotation (r)
   ii. Always use $\Sigma\tau = F_i r_i$, where "i" indicate F and r for force number i.
   iii. Counterclockwise torque is positive, clockwise is negative

2. Given the net torque, how long does it take for an object to go from rotating at some initial speed to some final speed.
   i. Know (or solved above) $\Sigma\tau$, initial angular speed ω_i and final angular speed ω_f
   ii. Like $F = ma$, $\tau = I\alpha$. Recall angular acceleration $\alpha = \Delta\omega/\Delta t$

Energy & Work



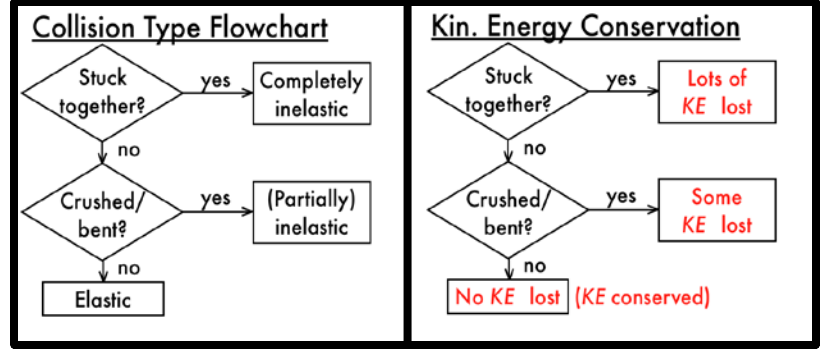
- How to recognize:
  - You're given a height of an object at one location, but asked for the speed at another (or vice versa). You know a non-conservative force and are asked for an energy change (or vice versa).
- Tips for solving:
  1. Employ energy conservation, minus energy removed by non-conserving forces.
  2. $\Sigma PE_i + \Sigma KE_i = \Sigma PE_f + \Sigma KE_f + W_{NC}$
  3. If you know the non-conserving force, $W=Fd\cos(\theta)$
  4. Work through the algebra.
- Notes:
  - Potential energy is with respect to some reference height, which you choose.
  - Typical non-conserving forces are friction or the force of an object being indented as it is impacted (e.g. a landing pad for a stunt person).
  - If you're asked for information regarding a trajectory (e.g. max height, velocity before impact), but you don't need time information, this can be easier than using 1D kinematics.

Energy & Work: *Examples of typical problems*

1. An object starts out at some height with some initial velocity, what is the velocity at some lower height?
   i. Know: Initial and final heights, initial velocity.
   ii. Energy is conserved, minus non-conservative work. No work here, so , $\Sigma PE_i + \Sigma KE_i = \Sigma PE_f + \Sigma KE_f$, where KE = (1/2)mv2 and PE = mgh, noting that h is always relative to some reference height.

2. An object of a given mass is moving at some speed on a horizontal surface, when friction, specified by some friction coefficient, slows it to rest after some distance. What was the initial speed?
   i. Know: Object mass, coefficient(s) of friction, distance until rest. "Rest" = final velocity is zero. No height change, so can ignore potential energy.
   ii. Energy is conserved, minus non-conservative work. Here there is friction (a non-conservative force) and no height change, so $\Sigma KE_i = \Sigma KE_f + W_{NC}$
   iii. Work done by a force along a distance is W=Fdcos(θ), so when a force opposes the direction of motion, W is negative.

Momentum Conservation



Patrick M. Len

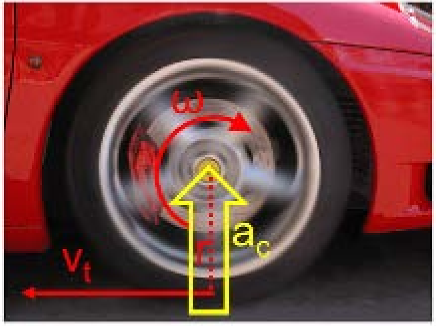
- How to recognize:
  - Objects are colliding.
- Tips for solving:
  1. Draw your initial & final situations. Label all object(s)' velocities.
  2. Employ momentum conservation.
  3. $\Sigma p_i = \Sigma p_f$
  4. Work through the algebra to find the missing information.
- Notes:
  - Impulse is equal to the change in momentum.
  - If no kinetic energy is lost, the collision is elastic.
  - If some kinetic energy is lost, the collision is inelastic.
  - If the objects stick together, a lot of kinetic energy is lost, and the collision is completely inelastic

Momentum Conservation: *Examples of typical problems*

1. Two objects that each have some mass and some initial velocity collide, resulting in a final velocity. What type of collision is it?
   i. Know: masses and initial and final velocities. Will know if they stuck together or not, based on what the problem says.
   ii. Always use momentum conservation: $\Sigma p_i = \Sigma p_f$, where we have to combine the masses of objects that are stuck together
   iii. Quicker method may be possible if they "stick together", in which case we know it is completely inelastic.

2. An average force is applied over some time to an object, what is it's change in momentum?
   i. Know: Force and time
   ii. Impulse $J = F_{avg}\Delta t = \Delta p = p_f - p_i$

Circular and Rotational Motion



- How to recognize:
  - Something is moving, but not in a straight line.
- Tips for solving:
  1. Convert linear variables to angular variables when necessary. Or convert the other way when necessary.
  2. If something is spinning, but changing its mass distribution, employ angular momentum conservation: $I_i\omega_i = I_f\omega_f$
  3. If a torque is applied, use the analogy to Newton's 1st law: $\tau = I\alpha$
- Notes:
  - Newton's law still applies for centripetal force: $F_c = ma_c = mr\omega^2$

Equations for kinematics in 1D & Newton's Laws apply to rotational motion as well, by subsituting the appropriate quantities:

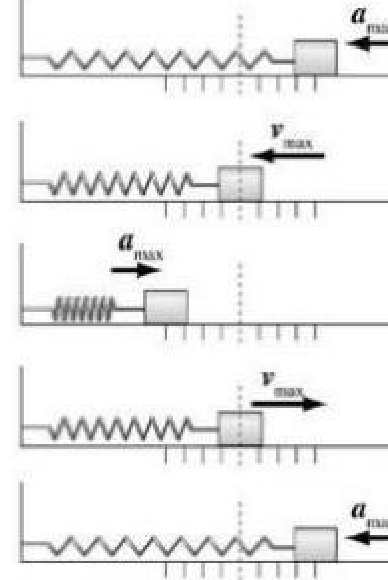
Linear Quantity			Corresponding Rotational Quantity		
Quantity	***Variable***	***SI units***	***Quantity***	***Variable***	***SI units***
length	x	m	angle	$\theta = s/r$	rad
velocity	$v = \Delta x/\Delta t$	m/s	angular velocity	$\omega = \Delta\theta/\Delta t$	rad/s
acceleration	$a = \Delta v/\Delta t$	m/s^2	angular acceleration	$\alpha = \Delta\omega/\Delta t$	rad/s^2
mass	m	kg	moment of inertia	I (formula depends on object shape)	$kg*m^2$
force	$F = ma$	N	torque	$\tau = I\alpha$	N*m
momentum	$p = mv$	kg*m/s	angular momentum	$L = I\omega$	$kg*m^2/s$

Circular and Rotational Motion: *Examples of typical problems*

1. A wheel with some radius rolls with some angular speed for some amount of time. How far has the wheel rolled? How fast is the wheel moving? What is the magnitude of the force holding an object of some mass to the rim of the wheel?
   i. Know: Wheel radius r, angular speed ω, elapsed time Δt, object mass m
   ii. Get arc length from the definition of an angle $\theta = s/r$ and recall that the angular velocity is $\omega = \Delta\theta/\Delta t$.
   iii. The transverse velocity $v = r\omega$
   iv. As always, $F = ma$, where the acceleration is the centripetal acceleration, $a = mr\omega^2 = mv_t^2/r$

2. An object is rotating at some rate with some mass distribution, when suddenly the mass distribution changes. What is the new angular speed for rotation?
   i. Know: Mass of objects in the distribution, their distance from the axis of rotation, the initial angular speed.
   ii. Angular momentum is conserved: $L = I_i\omega_i = I_f\omega_f$. Typical moments of inertia are those for a point mass $I_{point} = mr^2$ and a disk $I_{disk} = (1/2)mr^2$.

Simple Harmonic Motion



- How to recognize:
  - Something is repeating, e.g. in circles or moving back & forth.
- Tips for solving:
  1. What do you know?
  2. What do you want to know?
  3. Look at your list of relevant equations to figure out how to get to (1) from (2).
- Notes:
  - Newton's laws still apply, i.e. F=ma.
  - A cycle is anything that repeats: oscillations, circles, …
  - Position, velocity, and acceleration are related as they are in 1D kinematics.

Spring:

$$F_{applied} = kx \qquad \omega_{spring} = \sqrt{\frac{k_{spring}}{m_{weight}}} = \sqrt{\frac{k}{m}}$$

Note: T, f, ω are ***independent of amplitude!***

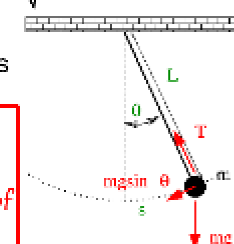
$$x = A\cos(\omega t) \qquad x_{max} = A$$
$$v = -A\omega\sin(\omega t) \qquad v_{max} = A\omega$$
$$a = -A\omega^2\cos(\omega t) \qquad a_{max} = A\omega^2$$

Note: $f = 1/T$
$\omega = 2\pi f$
T, f, ω independent of oscillation amplitude.

Pendulum:

$$\omega_{pendulum} = \sqrt{\frac{g}{l_{pendulum}}} = \sqrt{\frac{g}{l}}$$

F ≈ -mg θ
F ≈ -(mg/L)s

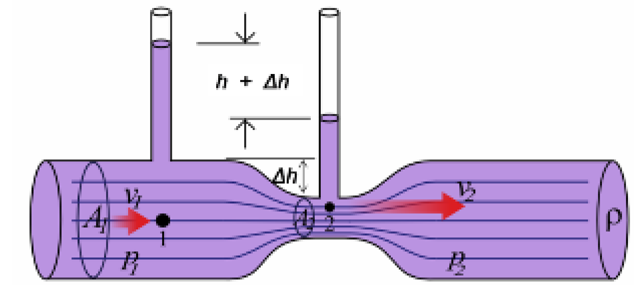


Simple Harmonic Motion: *Examples of typical problems*

1. An object oscillates with some frequency, what is the spring constant or pendulum length?
   i. Know: oscillation frequency
   ii. Be careful! The oscillation frequency f is not the angular frequency, ω, which is the formula we usually use to relate spring+mass or pendulum properties to oscillation details.
   iii. For a mass+spring, $\omega = \sqrt{k/m}$, for a pendulum $\omega = \sqrt{g/l}$

2. An oscillation is shown graphically, either by the position, velocity, or acceleration. You are asked about one of the other properties not graphed (position, velocity, acceleration, or force)
   i. Know: Force must be maximum at the amplitude, minimum at zero-displacement. Velocity is maximum at zero displacement, minimum at the amplitude. F = ma = kx relates the force and the acceleration

Fluids



- How to recognize:
  - Something is floating or flowing.
- Tips for solving:

  ~~1. If floating, draw a free-body diagram including the buoyancy force:~~
  ~~$F_{buoyancy}=\rho_{fluid}V_{displaced}g$.~~ Struck-out text not on final

  ~~2. Solve for the missing piece of information with algebra.~~

  3. If flowing, use Bernoulli's equation ($P_i + \rho g h_i + \frac{1}{2}\rho v_i^2 = P_f + \rho g h_f + \frac{1}{2}\rho v_f^2$) and the continuity equation (ρ*A*v = constant) to relate things you know at one point in the system to things you know at a later point.

  4. If looking for pressure with depth: P=ρgh
- Notes:
  - Continuity says that if you squeeze a flowing fluid into a smaller diameter pipe, it will speed up. Bernoulli says that if you slow-down a fluid, the pressure will increase.
  - Pressure in a fluid is height-dependent.
  - The pressure above atmospheric pressure is the gauge pressure. The pressure including the atmospheric pressure is the absolute pressure.

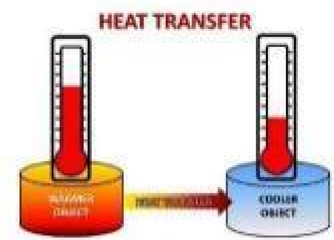
Fluids: ***Examples of typical problems***

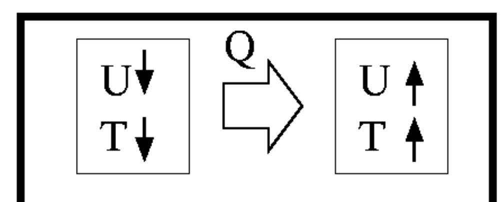
1. A fluid is flowing at some velocity in a section of pipe with some radius. Later in the pipe, something changes (pipe height and/or radius). What is the change in pressure?
   i. Know: initial radius R (so initial **area of the pipe $\boldsymbol{A = \pi R^2}$**), initial velocity v_i, and new properties (relative height h, and/or radius [so new area])
   ii. Use continuity equation for changes in velocity: $\rho_i A_i v_i = \rho_f A_f v_f$.
   iii. Use Bernoulli's equation for changes in pressure (may have had to use continuity equation first to figure out the change in velocity): $P_i + \rho g h_i + \frac{1}{2}\rho v_i^2 = P_f + \rho g h_f + \frac{1}{2}\rho v_f^2$

2. An object is located at some depth below sea level (P=1.01×10^5 Pa), where the density of water 1000 kg/m3. What is the pressure at the specified depth?
   i. Know: Pressure at sea level (reference height h_i=0) and density of water.
   ii. P=$\rho g h$, where *h* is the depth below sea level

Thermal Physics

- How to recognize:
  - Some object is responding to being heated/cooled by some other object or heat source.
- Tips for solving:
  1. Convert temperature information into favorable units (if it isn't already). These will be the units that match whatever constants you're provided.
  2. If heat is being transferred, use the heat-transfer equation: $Q=mc\Delta T$.
  3. If a hot object is touching a cold object, note that the cold object will gain some heat and the hot object will lose some heat. $Q_{gained}=Q_{lost}$.
  4. If a phase transition is occurring, take into account the heat required: $Q=mL$.
  5. If an object is expanding, are you asked for a linear or volumetric quantity? Be sure to use the correct formula.
- Notes:
  - Stick to Kelvin (or Celcius), but make sure all the units are consistent.
  - An object with a higher heat capacity takes more heat-input raise its temperature



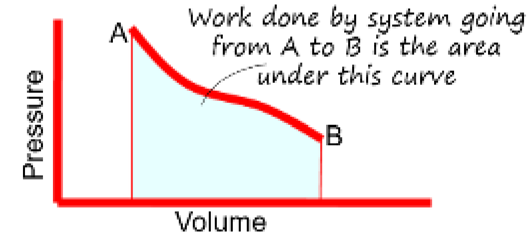


Thermal Physics: *Examples of typical problems*

1. An object of some length at some temperature is heated up to another temperature. Given the linear expansion coefficient, what is the new length of the object?
   i. Know: Initial length L_i, linear expansion coefficient α, initial and final temperature T_i T_f
   ii. $L_f = L_i + \Delta L$, where $\Delta L/L_i = \alpha\Delta T = \alpha(T_f - T_i)$
   iii. Be careful that temperatures are in C or K!

2. An object with some heat capacity and some temperature is added to a cup of water, which stars at some initial temperature and has some heat capacity. What is the final average temperature of the object+water once they have cooled to equilibrium?
   i. Know: Temperature of object To, temperature of water To, and their heat capacities c
   ii. $Q_{lost} = Q_{gained}$. $Q=mc\Delta T$. For the initially hotter object $\Delta T=T_i-T_{avg}$ and for the initially cooler object. $\Delta T=T_{avg} - T_i$
   iii. If a phase change is involved for one object, $Q=mL$. On a temperature vs heat graph, the phase change would be a flat line, since adding/removing heat doesn't change the object's temperature during the phase change.

Thermodynamics



- How to recognize:
  - An ideal gas is undergoing some change or a heat engine/heat pump/refrigerator is being discussed.
- Tips for solving:
  1. For an ideal gas: PV=nRT.
  2. For cycles of transitions: There is no net internal energy change: $\Delta U=0$.
  3. Apply the first law of thermodynamics if need be: $\Delta U = Q-W$. Type of transition may offer a short-cut.
  4. If a heat engine, or pump, or refrigerator, the amount of work put-in or generated depends on the difference between the heat transfer to/from the hot reservoir and the heat transfer to/from the cold reservoir: $Q_H-Q_C = W$.
  5. Efficiency/performance is how much stuff you get-out over how much stuff you get in: Engine: $e=W/Q_H$, Pump: $COP=Q_H/W$, Refrigerator: $COP =Q_C/W$.
- Notes:
  - The Carnot efficiency is the maximum theoretically possible efficiency.
  - The direction of the transition on the PV-diagram matters.

Thermodynamics: *Examples of typical problems*

1. Heat is added to a system with a fixed pressure, causing the volume to increase. What is the change in internal energy?
   i. Know: change in volume ΔV, amount of added heat
   ii. Always use: $\Delta U_{System} = Q_{ToSystem} - W_{BySystem}$. If the pressure is fixed, then $W=P\Delta V$. Adding/subtracting heat, will also change the temperature, so you could figure out the temperature change ($PV=nRT$)

2. A heat engine or refrigerator or heat pump has some amount of heat flow to/from the hot and cold reservoirs and some work put in or extracted. You are asked to find the missing piece of information and/or the efficiency.
   i. Heat engines operate in a cycle: $\Delta U = 0$, so $Q_{cycle}=W_{cycle}$
   ii. The high-T reservoir is adding heat for the cycle, whereas the low-T reservoir is removing heat, so $Q_{cycle} = Q_H - Q_C$
   iii. Energy is conserved: what goes in, must come out.
   iv. For efficiencies, use the table

Device	Basic Concept	What it provides	What we pay for/put in	How well the device is doing its job
Heat Engine	A natural flow of heat (hot to cold) is used to do work on surroundings.	Net Work: W_{net}	Heat from high-T reservoir: Q_H	$0 < e = W_{net}/Q_H < 1$ ($e_{Carnot} = 1 - T_C/T_H$)
Heat Pump	An un-natural flow of heat (cold to hot) is created by work from surroundings.	Adds heat: Q_H	Work from surroundings : W_{net}	$COP_H = Q_H/W_{net}$ ($COP_{H,Carnot} = 1/(1-T_C/T_H)$)
Refrigerator	An un-natural flow of heat (cold to hot) is created by work from surroundings.	Removes heat: Q_C	Work from surroundings : W_{net}	$COP_R = Q_C/W_{net}$ ($COP_{R,Carnot} = 1/(T_H/T_C - 1)$)

Thanks for a solid semester. Sorry it had to be finished online; hopefully this approximated what we would have gotten out of in-person meetings.

Best of luck on the exam. Take your time to study and you will be fine.

Feel free to contact me in the future with any physics/astrophysics questions that may cross your mind.