

Lecture 24 Announcements

- Another **Utah Baroque Ensemble** concert: Sunday Nov 23, 7:30 pm, LDS church at 1081 W 1060 North in Provo
- No class on Tuesday** (Friday instruction)
- All extra credit due by last day of class (Dec 11)
- Evening exam review session tonight**
a. 7 – 9 pm, room C215 (right below the TA lab)
- Exam 4 starts today!**
a. Exam ends **Tues Nov 25** (late fee after 5 pm)
b. Covers Chapters 9-12, HW 15-19 (but cumulative)
c. 3 hour time limit, –0.5 pt/min after 3:05
d. Last year's exam posted on website
i. Average time: 2.1 hours; average score: 63%
ii. I attempted to make your exam a little easier
e. At least one problem where you turn in work
f. **Note card allowed** as usual
i. 3x5 note card, front & back, handwritten only
ii. I will *not* give you most formulas on the exam
iii. I *will* give constants like
1. $\rho_{\text{water}} = 1000 \text{ kg/m}^3$
2. $k_B = 1.381 \times 10^{-23} \text{ J/K}$
3. $N_A = 6.022 \times 10^{23}$
4. $R = k_B \cdot N_A = 8.314 \text{ J/mol} \cdot \text{K} = 0.08206 \text{ liter} \cdot \text{atm/mol} \cdot \text{K}$
5. $\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$

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- Thermal conductivities/specific heat/expansion coefficients/etc as needed
- I *will* give you conversion factors like
1. $1 \text{ atm} = 1.013 \times 10^5 \text{ Pa} = 14.7 \text{ psi}$
2. $T_F = \frac{9}{5} T_C + 32$
3. $T_K = T_C + 273.15$
4. $1 \text{ cal} = 4.186 \text{ J}$
5. $1 \text{ m}^3 = 1000 \text{ L}$
- I *won't* give you standard stuff
1. metric prefixes (e.g. $1 \text{ kPa} = 1000 \text{ Pa}$)
2. area of a circle = πr^2
3. water freezes at 0° C , boils at 100° C
4. number of seconds in an hour
5. etc.
- Calculators allowed** as usual
- Things to study** as usual, very roughly in order of importance:
i. HW problems
ii. Last year's exam
iii. Conceptual stuff, especially:
1. clicker quizzes
2. Warmup questions
3. demos
iv. Worked problems from class
v. Textbook problems

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Real engines modeled by PV-diagram cycles

Example: Gasoline engines

- Piston is compressed quickly
- Heat is then added quickly by igniting fuel
- Piston then expands quickly
- Heat is then expelled quickly (by getting rid of old air)
→ Same air is not re-used; the cycle is just an approximation

The “Otto cycle”

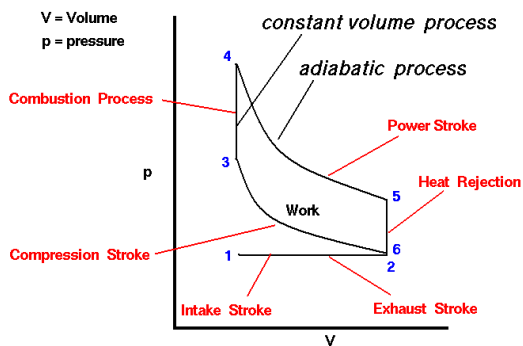


Image credit: <http://www.grc.nasa.gov/WWW/K-12/airplane/otto.html>

Difference between gas and diesel engines?

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2nd Law of thermodynamics:

Heat spontaneously flows from hot to cold, not the other way around.

Why? **Order.** From textbook: which hand is more likely?



... but which is more likely, a straight flush or a garbage hand?

→ Boltzman 3D program revisited; increasing “entropy”

Another version of the law:

In an engine, you can't convert all the heat into usable work

Why are they equivalent?

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Review of Chapter 12

$W_{on\ gas} = \text{area under curve in P-V diagram}$
 (= $-P\Delta V$ for constant pressure process)

U depends only on T; often it's strictly proportional
 (= $3/2 nRT$ for monatomic ideal gas)

Visualizing isothermal contours in P-V diagrams helps understand changes in temperature—and hence U

1st Law: $\Delta U = Q_{added} + W_{on\ system}$

Engines: transform heat to work
 2nd Law: ...but not *all* of the heat!

From fuel burned Heat exhausted

$$Q_h = |W_{net}| + Q_c$$

$$\text{efficiency} = |W_{net}|/Q_h$$

Carnot Theorem: ...often not even *most* of the heat!
 max eff. = " e_c " = $1 - T_c/T_h$

Song:

http://www.uky.edu/~holler/CHE107/media/first_second_law.mp3

Formulas Review

Definitions and Fundamental Laws

Final exam: you will be expected to know these

Definition of density: $\rho = \frac{m}{V}$

Definition of pressure: $P = \frac{F}{A}$

Archimedes' Principle: $F_B = W_{displaced\ fluid}$
 $= m_{displaced\ fluid} \times g = \rho_{fluid} V_{object} g$

Ideal Gas Law: $PV = nRT = Nk_B T$

First Law of Thermodynamics: $\Delta U = Q_{added} + W_{on\ system}$

Definition: isothermal = no temperature change

Definition: adiabatic = no heat exchanged

New stuff, but not quite as basic

Final exam: I will give you these (but maybe without the "tags")

stress = F/A ; strain = $\Delta L/L$; Y = stress/strain

$$P = P_0 + \rho gh$$

$$VFR = A_1 v_1 = A_2 v_2$$

$$P_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2$$

$$\Delta L = \alpha L_0 \Delta T$$

$$\Delta V = \beta V_0 \Delta T; \beta = 3\alpha$$

$$KE_{ave} = \frac{1}{2} m v_{ave}^2 = \frac{3}{2} k_B T$$

$$\text{Calorimetry: } Q = mc\Delta T; Q = mL$$

$$\text{Conduction: } \frac{\Delta Q}{\Delta T} = kA \frac{T_2 - T_1}{L}$$

$$\text{Radiation: } P = e\sigma AT^4$$

$W_{on\ gas} = -P\Delta V$ (constant pressure)
 = area under curve in P-V diagram (general)

$$U = \frac{3}{2} Nk_B T = \frac{3}{2} nRT \quad (\text{monatomic ideal gas})$$

Cycles: $Q_h = |W_{net}| + Q_c$

$$e = \frac{|W_{net}|}{Q_{added}} = 1 - \frac{Q_c}{Q_h}$$

$$\text{Carnot Theorem: } e_{max} = 1 - \frac{T_c}{T_h}$$

Things which *you* might consider to be formulas

(but I don't really, so I won't give them to you on exam)

Constant volume: $W = 0$

Isothermal: $\Delta U = 0$

Adiabatic: $Q = 0$

Cycles: $\Delta U = 0$

Exam 4 - Review of important concepts

1. Pressure (Force/area)

a. Solids

- i. Stress (like 1D pressure) & Strain
- ii. Young's modulus

b. Non-moving Liquids:

- i. Pressure increases with depth
- ii. Pascal's principle: pressure in fluid the same at same h

c. Archimedes' Principle: $F_B = \text{weight of displaced fluid}$

...

2. Fluid dynamics

a. Viscosity

b. "Garden hose equation"

- i. Why/when true

c. Bernoulli effect: motion of fluid causes P to decrease

- i. wings: combination of air deflection and Bernoulli

$$d. \text{Bernoulli eqn: } P_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2$$

3. Temperature effects

a. Thermal expansion:

- i. $\Delta L = \alpha L_0 \Delta T$

- ii. $\Delta V = \beta V_0 \Delta T$ ($\beta = 3\alpha$, for solids)

b. Ideal gas law: $PV = Nk_B T$; $PV = nRT$

c. Average kinetic energy of molecules: $\frac{1}{2} m v_{ave}^2 = \frac{3}{2} k_B T$

- i. Use to get average speed
- ii. Internal energy, $U = 3/2 nRT$ for monatomic ideal gas

4. Heat

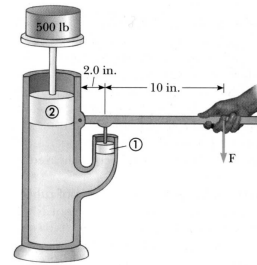
- a. Calorimetry: $Q_{\text{gained by 1}} = Q_{\text{lost by 2}}$ (Blueprint eqn)
 - i. $Q = mc\Delta T$; $Q = mL$
 - ii. Make sure each term is positive
- b. Radiation: $P = \text{heat/time} = \epsilon\sigma AT^4$
 - i. Describes heat emitted and heat absorbed
- c. Conduction: $P = \frac{\text{heat}}{\text{time}} = kA \frac{T_2 - T_1}{L}$
- d. Convection: qualitative only

5. Thermodynamics

- a. P-V diagrams
 - i. Isothermal contours
 - ii. Types of state changes: constant P, constant V, constant T ($\Delta U=0$), adiabatic ($Q=0$), cycle ($\Delta U=0$)
- b. Work done on/by a gas: area under curve on P-V
 - i. Positive vs. negative
- c. First Law: $\Delta U = Q_{\text{added}} + W_{\text{on system}}$
- d. Engines: general picture
 - i. $Q_h = |W_{\text{net}}| + Q_c$
 - ii. Efficiency: $e = \frac{|W_{\text{net}}|}{Q_{\text{added}}} = 1 - \frac{Q_c}{Q_h}$; $e_{\text{max}} = 1 - \frac{T_c}{T_h}$
- e. Second Law: ...

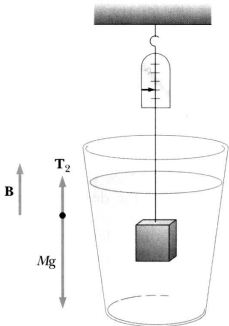
Some HW problems (missed by many):

Piston 1 in the figure has a diameter of 0.58 in.; piston 2 has a diameter of 1.5 in. In the absence of friction, determine the force F necessary to support the 500-lb weight.



Answer: 12.5 lbs

A 10.0-kg block of metal is suspended from a scale and immersed in water as in the figure. The dimensions of the block are 12.0 cm \times 10.0 cm \times 7.0 cm. The 12.0-cm dimension is vertical, and the top of the block is 5.00 cm below the surface of the water. What are the forces exerted by the water on (a) the top and (b) the bottom of the block? (c) What is the buoyant force? (d) What is the reading of the spring scale?



Answers: 712.5 N, 720.8 N, 8.2 N, 89.8 N

An underground gasoline tank at 54° F can hold 930 gallons of gasoline. If the driver of a tanker truck fills the underground tank on a day when the temperature is 90° F, how many gallons, according to his measure on the truck, can he pour in? Assume that the temperature of the gasoline cools to 54° F upon entering the tank. Use the coefficient of **volume** expansion for gasoline given in the textbook, $\beta = 9.6 \times 10^{-4} / ^\circ\text{C}$

Answer: 948 gallons

What mass of steam that is initially at 121.6° C is needed to warm 340 g of water and its 286-g aluminum container from 22.5° C to 48.5° C?

Answer: 17.4 g

Some clicker quizzes

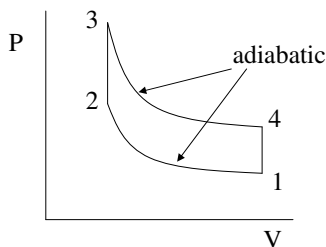
Clicker quiz 1: Where fluid moves faster the pressure is...
 a. greater
 b. smaller
 c. neither; pressure doesn't depend on speed.

Clicker quiz 2: When a spinning "curve ball" is thrown, it will tend to curve because of:
 a. the Bernoulli effect
 b. conservation of angular momentum
 c. inertia
 d. Newton's 3rd law
 e. the torque applied

Clicker quiz 3: An ideal (Carnot) heat engine takes heat from water always at 100°C in a natural hot spring under the ground (geothermal energy), and generates useful work (electricity). It exhausts the waste heat to the air above the ground. The engine will be the most efficient in:
 a. Summer
 b. Winter
 c. neither; always the same

Clicker quiz 1: The *second* law of thermodynamics says for a heat engine:

- a. you get more work energy out than you put in as heat
- b. you get the same work energy out as you put in as heat
- c. you get less work energy out than you put in as heat

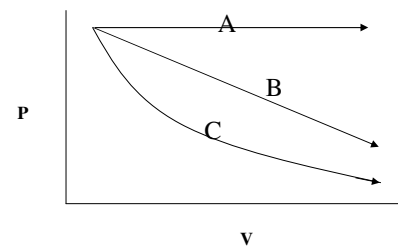


Clicker quiz 2: In this cycle, where is the lowest temperature?

- a. 1
- b. 2
- c. 3
- d. 4

Clicker quiz 3: Where is the highest temperature?

- a. 1
- b. 2
- c. 3
- d. 4



Clicker quiz 1: The process that does the **most work** (magnitude) is _____

Clicker quiz 2: The process that is at **constant temperature** is _____

Clicker quiz 3: The process that leaves the system at the **highest T** is: _____

Clicker quiz 4: The process in which the **magnitudes** of W and Q are the **same** is: _____

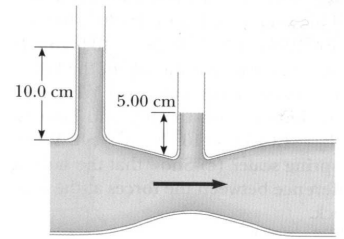
More worked problems

A container is filled to a depth of 20.0 cm with water. On top of the water floats a 44.1-cm-thick layer of oil with specific gravity 0.700. What is the absolute pressure at the bottom of the container? Assume that the atmospheric pressure is 1.00 atm.

Answer: 106285 Pa

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The inside diameters of the large portions of the horizontal pipe in the figure are 2.50 cm. Water flows to the right at a rate of $1.83\text{E-}04 \text{ m}^3/\text{s}$. Determine the inside diameter of the constriction.



Answer: 0.0148 m

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A pair of eyeglass frames are made of epoxy plastic (coefficient of linear expansion $=134 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$). At room temperature ($21.9 \text{ }^\circ\text{C}$) the frames have circular lens holes 2.232 cm in radius. To what temperature must the frames be heated in order to insert lenses 2.252 cm in radius?

Answer: 88.8°C

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You are at the bottom of a lake in a submarine. The air pressure at the surface of the lake is 1 atm. The absolute pressure at the bottom is 6 atmospheres. What is the depth of the lake? What is the force of the water on a submarine porthole of radius 4 cm?

Answers: 51.68 m, 3055 N

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A car engine operating between temperatures of 30°C and 200°C has an efficiency of 25%. If 2000 J of heat energy is supplied by the fuel every cycle, how much heat is exhausted to the air (per cycle)? How much would be if the car had the maximum possible efficiency for those two temperatures?

Answers: 1500 J, 1281 J

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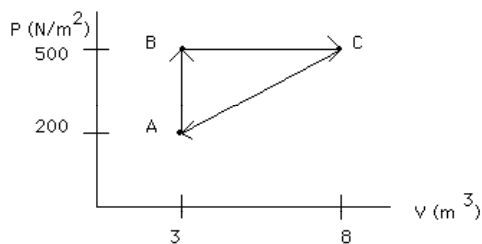
Cooled helium gas in a closed tank of volume 12 m^3 is at -100°C , at one atm pressure. How many molecules are in the gas? What is the average kinetic energy of a molecule?

If the tank is cooled further to -200°C , what will the pressure in the tank be? (in atm)

Answers: $5.087\text{E}26$, $3.584\text{E}-21\text{ J}$, 0.422 atm

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One mole of a monatomic ideal gas is taken around the cycle shown.



In the process $B \rightarrow C$, the change in the internal energy was _____ J, and it was _____ 1) positive 2) negative 3) zero. The heat exchanged was _____ J, and it was going _____ 1) into 2) out of 3) neither the gas.

For the whole cycle, the net work done on the gas was _____ J, and was _____ 1) positive 2) negative 3) zero. The heat exchanged for the cycle was _____ J, and it was going _____ 1) into 2) out of 3) neither the gas.

Answers: 3750 J, positive, 6250 J, into; -750 J, negative, 750 J, into

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