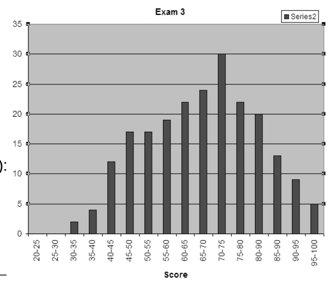
Physics 207, Lecture 26, Dec. 4

- MidTerm 3
- Exams will be returned at your next discussion section
- Regrades: Write down, on a separate sheet, what you want regraded and why.

Mean: 68
Median: 68
Std. Dev.: 15
Range: High 100
Low 32
Solution posted on
http://my.wisc.edu
Nominal curve (conservative):

88-100 A
70-87 B or A/B
41-69 C or B/C
35-41 marginal
25-34 D



Physics 207, Lecture 26, Dec. 4

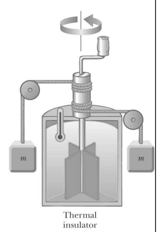
- Agenda: Ch. 20, Heat & the 1st Law of Thermodynamics
  - ❖ Heat and energy
  - ❖ Heat capacity
  - ❖ Energy transfer mechanisms: (thermal conduction, convection, radiation)
  - ❖ 1st Law of thermodynamics (i.e., You can't win)
  - ❖ Work done by an ideal gas in a piston
    - ➢ (dW = F dx = F / A A dx = P dV, Work-Energy)
    - (Looks new but it is really the <u>same</u> physics!
    - Except for the definition of displacement (i.e., volume)
  - ❖ Introduction to thermodynamic cycles (Chapter 22)

Assignments:

- Problem Set 9 due Tuesday, Dec. 5, 11:59 PM
- Problem Set 10 (Ch. 20 & 21) due Tuesday, Dec. 12, 11:59 PM
  Ch. 20: 13,<u>22</u>,38,43,50,**68** Ch.21: 2,16,29,36,70
- Wednesday, Chapter 21 (Kinetic Theory of Gasses)

Heat

- Heat: Q = C Δ T (internal energy transferred)
  - ❖ Q = amount of heat that must be supplied to raise the temperature by an amount Δ T .
  - ❖ [Q] = Joules or calories. **1 Cal = 4.186 J**
    1 kcal = 1 Cal = 4186 J
  - ❖ Energy to raise 1 g of water from 14.5 to 15.5 °C
  - (James Prescott Joule found the mechanical equivalent of heat.)
  - C ≡ Heat capacity (in J/ K)



- Q = c m Δ T
  - ❖ c: specific heat (heat capacity per units of mass)
  - ❖ amount of heat to raise T of 1 kg by 1 °C
  - ❖ [c] = J/(kg °C)

Sign convention:

+Q : heat gained
- Q : heat lost

Specific Heat : examples

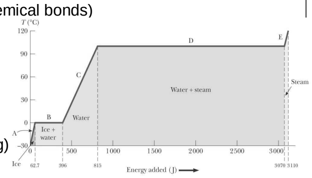
Substance	c in J/(kg-C)
aluminum	902
copper	385
iron	452
lead	128
human body	3500
water	4186
ice	2000

- You have equal masses of aluminum and copper at the same initial temperature. You add 1000 J of heat to each of them. Which one ends up at the higher final temperature (assuming no state change)?

(A) aluminum (B) copper (C) the same

Latent Heat

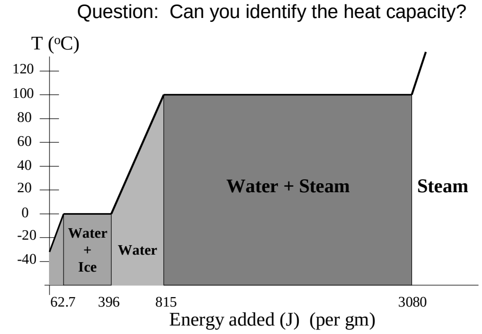
- Latent heat: amount of internal energy needed to add or to remove from a substance to change the state of that substance.
  - ❖ Phase change: T remains constant but internal energy changes
  - ❖ Heat does not result in change in T (latent = "hidden")
  - ❖ e.g. : solid ⇔ liquid or liquid ⇔ gas
    (heat goes to breaking chemical bonds)
- L = Q / m
  - ❖ Heat per unit mass
    [L] = J/kg
  - ❖ Q = ± m L
    + if heat needed (boiling)
    - if heat given up (freezing)
  - ❖ L_f : Latent heat of fusion
    solid ⇔ liquid
  - ❖ L_v : Latent heat of vaporization
    liquid ⇔ gas



	L_f (J/kg)	L_v (J/kg)
water	33.5×10^4	22.6×10^5

Latent Heats of Fusion and Vaporization

Question: Can you identify the heat capacity?



Lecture 26: *Exercise 1*
Latent Heat

- You are heating water for cooking pasta. You notice "steam" (Q: Can you really see steam?) starting to escape between the lid and pot so you lift the lid to take a peek and both water and steam spew out.
- Equal amounts of steam and boiling water coat your hand.

  In the first case it is boiling water at 100 C.

  In the second case it is steam at 100 C.

  - Which is more dangerous?

(A) boiling water (B) steam (C) no difference

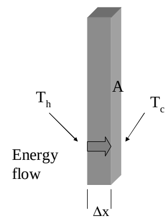
Energy transfer mechanisms

- Thermal conduction (or conduction):
  - Energy transferred by direct contact.
  - e.g.: energy enters the water through the bottom of the pan by thermal conduction.
  - Important: home insulation, etc.

- Rate of energy transfer (J / s or W)
  - Through a slab of area A and thickness Δx, with opposite faces at different temperatures, T_c and T_h

    $\mathcal{P} = Q / \Delta t = k A (T_h - T_c) / \Delta x$

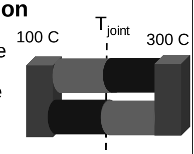
  - k :Thermal conductivity (J/s m °C)



Thermal Conductivities

	J/s m °C		J/s m °C		J/s m °C
Aluminum	238	Air	0.0234	Asbestos	0.25
Copper	397	Helium	0.138	Concrete	1.3
Gold	314	Hydrogen	0.172	Glass	0.84
Iron	79.5	Nitrogen	0.0234	Ice	1.6
Lead	34.7	Oxygen	0.0238	Water	0.60
Silver	427	Rubber	0.2	Wood	0.10

Lecture 26: *Exercise 2*
Thermal Conduction

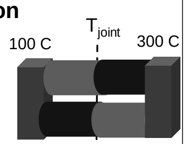


- Two identically shaped bars (one blue and one green) are placed between two different thermal reservoirs . The thermal conductivity coefficient k is twice as large for the blue as the green.
- You measure the temperature at the joint between the green and blue bars. Which of the following is true?

(A) $T_{top} > T_{bottom}$ (B) $T_{top} = T_{bottom}$ (C) $T_{top} < T_{bottom}$ (D) need to know k

Lecture 26: *Exercise 2*
Thermal Conduction

- Two identically shaped bars (one blue and one green) are placed between two different thermal reservoirs . The thermal conductivity coefficient *k* is twice as large for the blue as the green.



$\mathcal{P} = Q / \Delta t = k A (T_h - T_c) / \Delta x$

Top: $\mathcal{P}_{green} = \mathcal{P}_{blue} = Q / \Delta t = 2 k A (T_{high} - T_j) / \Delta x = k A (T_j - T_{low}) / \Delta x$

$2 (T_{high} - T_j) = (T_j - T_{low}) \rightarrow 3 T_{j(top)} = 2 T_{high} - T_{low}$

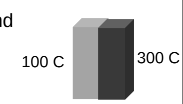
By analogy for the bottom: $3 T_{j(bottom)} = 2 T_{low} - T_{high}$

$3 (T_{j(top)} - T_{j(bottom)}) = 3 T_{high} - 3 T_{low} > 0$

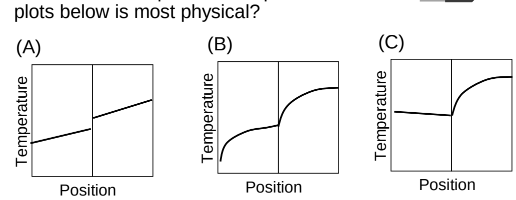
(A) $T_{top} > T_{bottom}$ (B) $T_{top} = T_{bottom}$ (C) $T_{top} < T_{bottom}$ (D) need to know k

Lecture 26: *Exercise 3*
Thermal Conduction

- Two thermal conductors (possibly inhomogeneous) are butted together and in contact with two thermal reservoirs held at the temperatures shown.

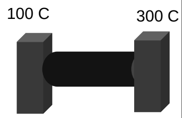


- Which of the temperature vs. position plots below is most physical?



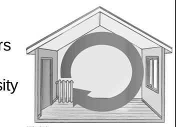
Lecture 26: *Exercise* Thermal Conduction and Expansion

- A single Al bar, nominally 1.0 m long and 0.100 m in diameter at 200 C, is anchored between two different thermal reservoirs held exactly a distance 1.0 m apart.
- What is the tension in the bar?
- Now the reservoirs are said to be 0 C and 200 C. What is tension in the aluminum rod?



Energy transfer mechanisms

- Convection:
  - ❖ Energy is transferred by flow of substance
    1. Heating a room (air convection)
    2. Warming of North Altantic by warm waters from the equatorial regions
  - ❖ Natural convection: from differences in density
  - ❖ Forced convection: from pump of fan



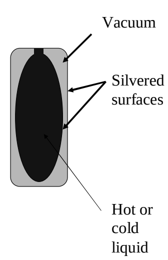
- Radiation:
  - ❖ Energy is transferred by photons
    e.g.: infrared lamps
  - ❖ Stefan's Law

$\mathscr{P} = \sigma A e\, T^4$ (power radiated)

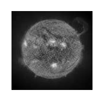
- ❖ $\sigma = 5.7\times10^{-8}$ W/m^2 K^4 , T is in Kelvin, and A is the surface area
- ❖ *e* is a constant called the emissivity

Minimizing Energy Transfer

- The Thermos bottle, also called a Dewar flask is designed to minimize energy transfer by conduction, convection, and radiation. The standard flask is a double-walled Pyrex glass with silvered walls and the space between the walls is evacuated.



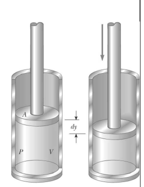
Anti-global warming or the nuclear winter scenario



- Assume I = 1340 W/m^2 from the sun is incident on a thick dust cloud above the Earth and this energy is absorbed, equilibrated and then reradiated towards space where the Earth's surface is in thermal equilibrium with cloud. Let e (the emissivity) be unity for all wavelengths of light.
- What is the Earth's temperature?
  - ❖ $P = \sigma A\, T^4 = \sigma (4\pi r^2)\, T^4 = I\, \pi r^2 \rightarrow T = [I / (4 \times \sigma)]^{1/4}$
  - ❖ $\sigma = 5.7\times10^{-8}$ W/m^2 K^4
  - ❖ T = 277 K (A little on the chilly side.)

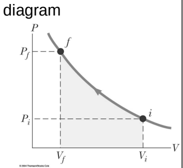
1st Law: Work & Heat

- Two types of variables
  - ❖ State variables: describe the system (e.g. T, P, V, U).
  - ❖ Transfer variables: describe the process (e.g. Q, W).
    = 0 unless a process occurs
    ⇒ involve change in state variables.



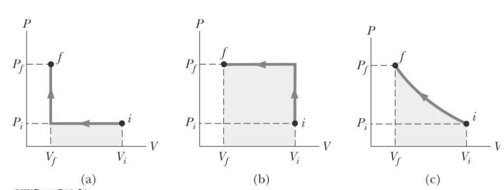
- Work done on gas (minus sign because system volume)
  - ❖ W = F d cosθ = -F Δy
    = - PA Δy = - P ΔV
  - ❖ Valid only for isobaric processes (P constant)
  - ❖ If not, use average force or calculus: W = area under PV curve

PV diagram



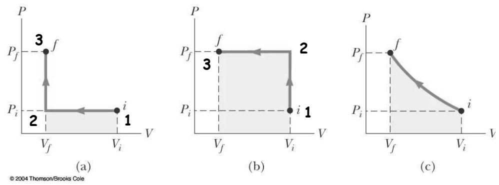
1st Law: Work & Heat

- Work:
  - ❖ Depends on the path taken in the PV-diagram
    (It is not just the destination but the path…)
  - ❖ Same for Q (heat)



1st Law: Work (Area under the curve)

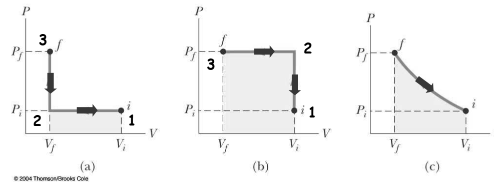
- Work depends on the path taken in the PV-diagram :



(a) $W_a = W_{1\ to\ 2} + W_{2\ to\ 3}$ (here either P or V constant)
❖ $W_a = - P_i\,(V_f - V_i) + 0 > 0$ (work done on system)
(b) $W_b = W_{1\ to\ 2} + W_{2\ to\ 3}$ (here either P or V constant)
❖ $W_b = 0 - P_f\,(V_f - V_i) > W_a > 0$ (work done on system)
(c) Need explicit form of P versus V but $W_c > 0$

Reversing the path (3→ 2 → 1)

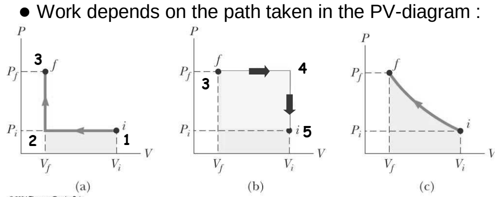
- Work depends on the path taken in the PV-diagram :



(a) $W'_a = W_{1\ to\ 2} + W_{2\ to\ 3}$ (here either P or V constant)
❖ $W'_a = 0 - P_i\,(V_i - V_f) < 0$ (work done on system)
(b) $W'_b = W_{1\ to\ 2} + W_{2\ to\ 3}$ (here either P or V constant)
❖ $W'_b = - P_f\,(V_i - V_f) + 0 < W_a < 0$ (work done on system)
(c) Need explicit form of P versus V

1st Law: Work (going full cycle)

- Work depends on the path taken in the PV-diagram :



(a) $W_a = W_{1\ to\ 2} + W_{2\ to\ 3}$ (here either P or V constant)
❖ $W_a = - P_i\,(V_f - V_i) > 0$ (work done <u>on</u> system)
(b) $W'_b = W_{3\ to\ 4} + W_{4\ to\ 5}$ (here either P or V constant)
❖ $W'_b = - P_f\,(V_i - V_f) < 0$ (work done <u>on</u> system)
(a) & (b) $W_a + W'_b = -P_i(V_f - V_i) - P_f(V_i - V_f) = (P_f - P_i) \times (V_f - V_i)$ **< 0**
but work done **<u>by</u>** system … (what I get to use)… is positive.

First Law of Thermodynamics with heat (Q) and/or work (W)

- First Law of Thermodynamics

$\Delta U = Q + W$ → work done "on" the system
→ heat flow "in" (+) or "out" (-)
→ variation of internal energy

❖ Independent of path in PV-diagram
❖ Depends only on state of the system (P,V,T, …)
❖ Energy conservation statement ⇒ only U changes

- Isolated system
  - ❖ No interaction with surroundings
  - ❖ $Q = W = 0 \Rightarrow \Delta U = 0$.
  - ❖ $U_f = U_i$: internal energy remains constant.

Recap, Lecture 26

- Agenda: Chapter 20, Heat & the 1st Law of Thermodynamics
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  - ❖ Heat capacity
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  - ❖ Work done by an ideal gas in a piston
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      (Looks new but it is really the <u>same</u> physics!
      Except the reference frame for displacement (i.e., volume)
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