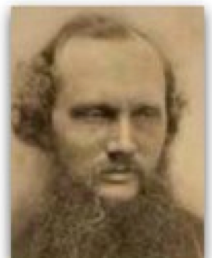
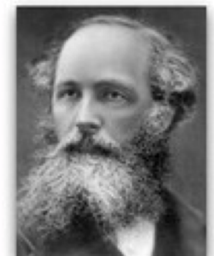
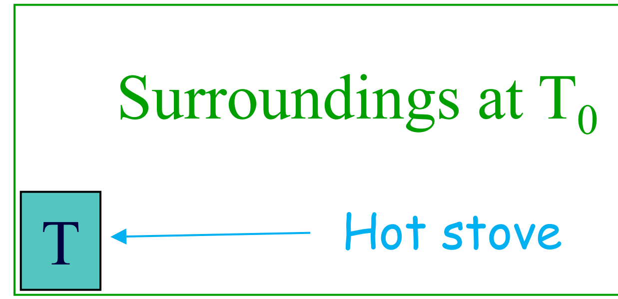
Physics 101: Lecture 28
Thermodynamics

École Polytechnique	Glasgow school	Berlin school	Edinburgh school
 Sadi Carnot (1796-1832)	 William Thomson (1824-1907)	 Rudolf Clausius (1822-1888)	 James Maxwell (1831-1879)
Vienna school	Gibbsian school	Dresden school	Dutch school
 Ludwig Boltzmann (1844-1906)	 Willard Gibbs (1839-1903)	 Gustav Zeuner (1828-1907)	 Johannes der Waals (1837-1923)

Heat Transfer: Radiation

- All things radiate electromagnetic energy
  - $H_{emit} = Q/t = eA\sigma T^4$
    - » e = emissivity (between 0 and 1)
      - perfect "black body" has e=1
    - » T is temperature of object in Kelvin
    - » σ = Stefan-Boltzmann constant = 5.67×10^{-8} J/s-m^2-K^4
  - No "medium" required

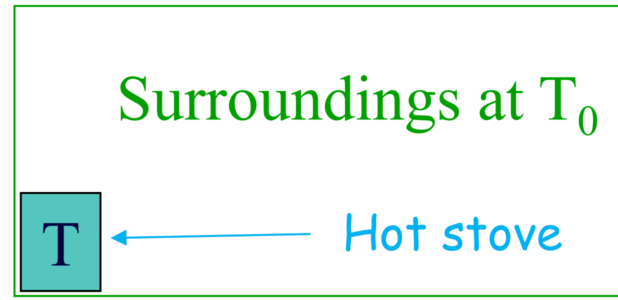


DEMO

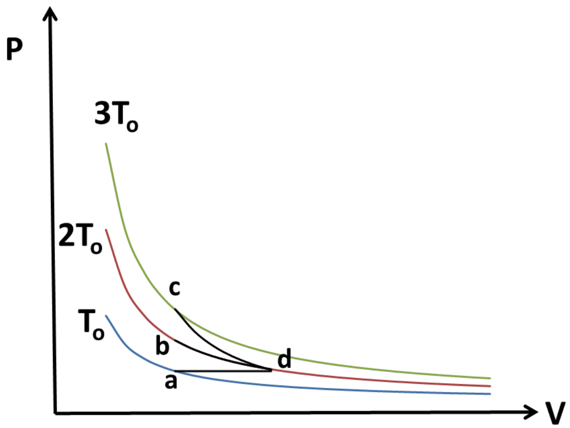
- All things absorb energy from surroundings
  - $H_{absorb} = eA\sigma T_0^4$
    - » T_0 is temperature of surroundings in Kelvin
    - » good emitters (e close to 1) are also good absorbers

Heat Transfer: Radiation

- All things radiate and absorb electromagnetic energy
  - $H_{emit} = eA\sigma T^4$
  - $H_{absorb} = eA\sigma T_0^4$
  - $H_{net} = H_{emit} - H_{absorb} = eA\sigma(T^4 - T_0^4)$
    - » if $T > T_0$, object cools down
    - » if $T < T_0$, object heats up



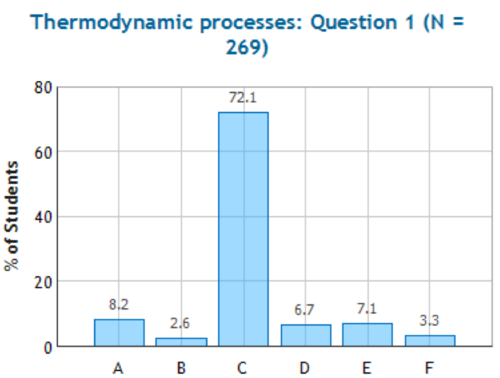
Bridge Set from Last Wed



A volume of N_2 is compressed through three processes as shown. Which process has the greatest decrease in the average kinetic energy of the molecules?

A. a to d B. b to d C. c to d

Only process where T goes down is c to d and average KE depends only on Temp.



First Law of Thermodynamics = Energy Conservation

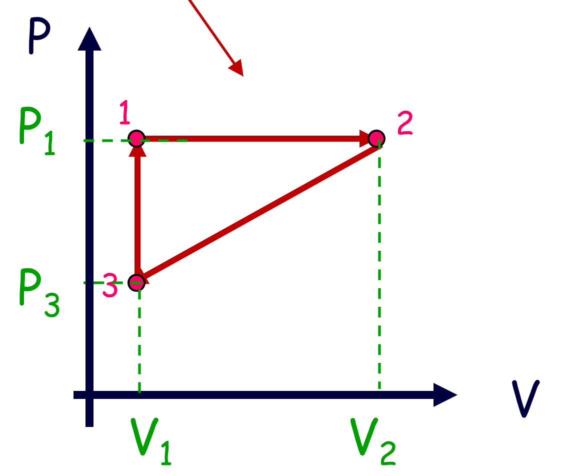
The change in internal energy of a system (ΔU) is equal to the heat flow into the system (Q) minus the work done *by* the system (W)

$$\Delta U = Q - W$$

Change in internal energy of system (depends on its Temperature)

Heat flow into system

Work done by system (Negative of work done on the gas)

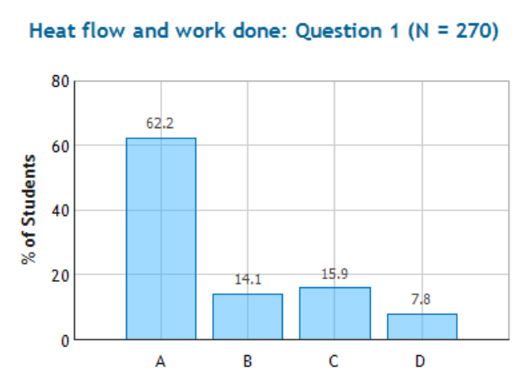


Bridge Set from Last Wed.

$\Delta U = Q - W$

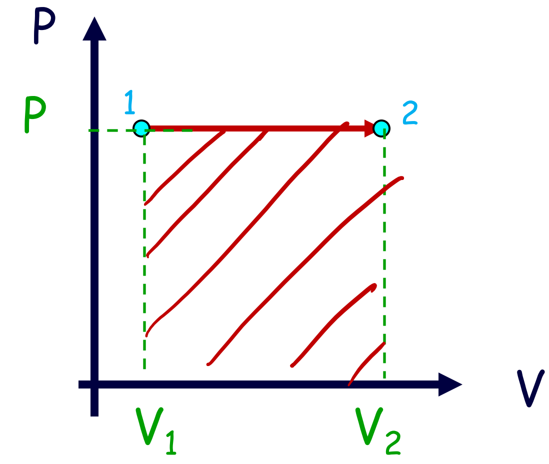
- A cylinder that has a piston contains one mole of H_2 and undergoes an expansion that doubles the initial volume of the gas. How much heat is transferred to or from the gas? (assume constant P)

1) Heat flows into gas by amount greater than W
2) Heat flows into gas by amount less than W
3) Heat flows out of gas by amount greater than W
4) Heat flows out of gas by amount le



First Law of Thermodynamics
Isobaric Example

2 moles of monatomic ideal gas is taken from state 1 to state 2 at <u>constant pressure</u> p=1000 Pa, where $V_1 = 2m^3$ and $V_2 = 3m^3$ Find T_1, T_2, ΔU, W, Q. (R=8.31 J/k mole)



1. $PV_1 = nRT_1 \Rightarrow T_1 = PV_1/nR = 120K$

2. $PV_2 = nRT_2 \Rightarrow T_2 = PV_2/nR = 180K$

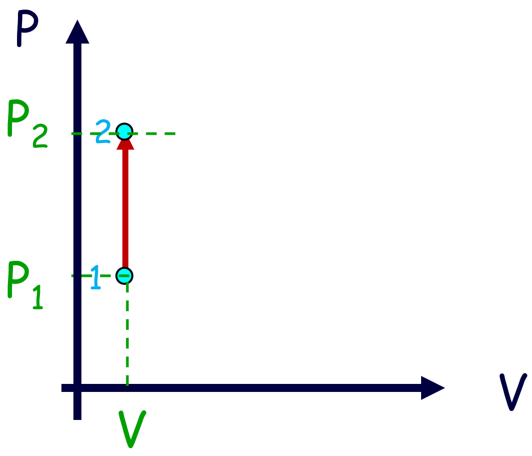
3. $\Delta U = (3/2)\, nR\, \Delta T = 1500$ J
   $\Delta U = (3/2)\, p\, \Delta V = 1500$ J (has to be the same)

4. $W = p\, \Delta V = 1000$ J

5. $Q = \Delta U + W = 1500 + 1000 = 2500$ J

First Law of Thermodynamics Isochoric Example

2 moles of monatomic ideal gas is taken from state 1 to state 2 at constant volume $V=2m^3$, where $T_1=120K$ and $T_2=180K$ Find Q.



1. $Q = \Delta U + W$

2. $\Delta U = (3/2)\, nR\, \Delta T = 1500\ J$

3. $W = P\, \Delta V = 0\ J$

4. $Q = \Delta U + W = 1500 + 0 = 1500\ J$

Comparing it to last slide where we had a constant pressure process (and same T_1 & T_2): **Less heat is required to raise T at const. volume than at const. pressure**

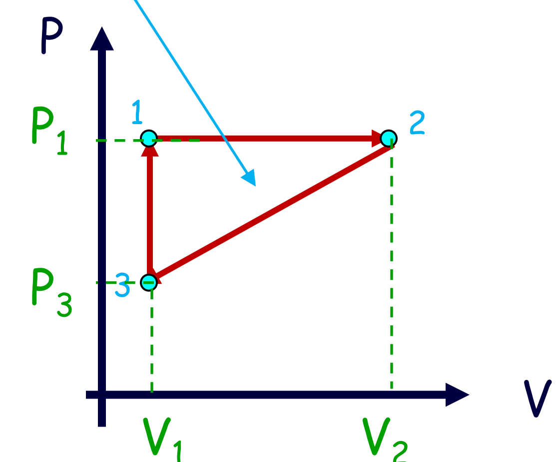
First Law Questions

$$\Delta U = Q - W$$

Change in internal energy of system

Heat flow <u>into</u> system

Work done <u>by</u> system



Some questions:

- Which part of cycle has largest magnitude change in internal energy, ΔU?

  $2 \rightarrow 3$ (since $\Delta U = 3/2\,(p_3V_3 - p_2V_2) = 3/2\, nR\,\Delta T$)
- Which part of cycle involves the most work **done by system**?

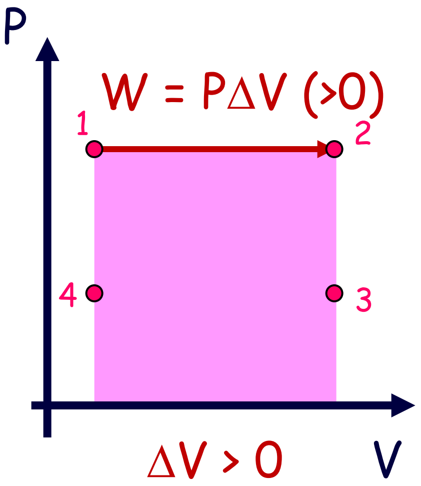
  $1 \rightarrow 2$ is most (positive), $3 \rightarrow 1$ is 0, $2 \rightarrow 3$ is negative. Net W is POSITIVE
- What is change in internal energy for full cycle?

  $\Delta U = 0$ for closed cycle (since both p & V [and T] are back where they started)
- What is net heat into system for full cycle (positive or negative)?

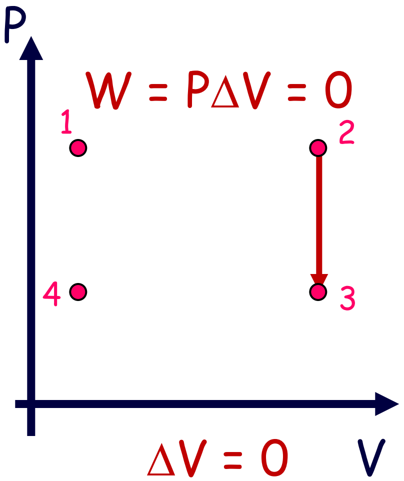
  $\Delta U = 0 \Rightarrow Q = W =$ area of triangle (>0)

Special PV Cases

- Constant Pressure (isobaric)



- Constant Volume (isochoric)



- Constant Temp $\Delta U = 0$ (isothermal)

- Adiabatic $Q=0$

Reversible?

- Most “physics” processes are reversible: you could play movie backwards and still looks fine. (drop ball vs throw ball up)

- Exceptions:
  - Non-conservative forces (friction)
  - Heat Flow:
    - » Heat never flows spontaneously from cold to hot

Summary:

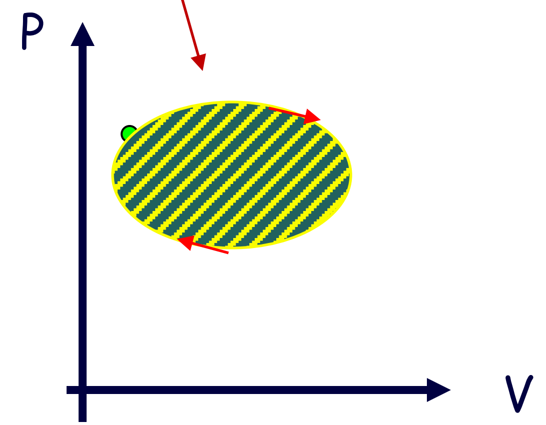
➡ 1st Law of Thermodynamics: Energy Conservation

$$\Delta U = Q - W$$

Change in internal energy of system (Depends only on Temperature)

Heat flow into system

Work done by system (Negative of work done on the gas)



- point on p-V plot completely specifies state of system ($pV = nRT$)
- work done is area under curve
- U depends only on T ($U = 3nRT/2 = 3pV/2$)
- for a complete cycle $\Delta U=0 \Rightarrow Q=W$