# Physics 101: Lecture 28
# Thermodynamics

# 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
    - » $\sigma$ = Stefan-Boltzmann constant = $5.67 \times 10^{-8}$ $J/s\text{-}m^2\text{-}K^4$


  - ➔ No "medium" required

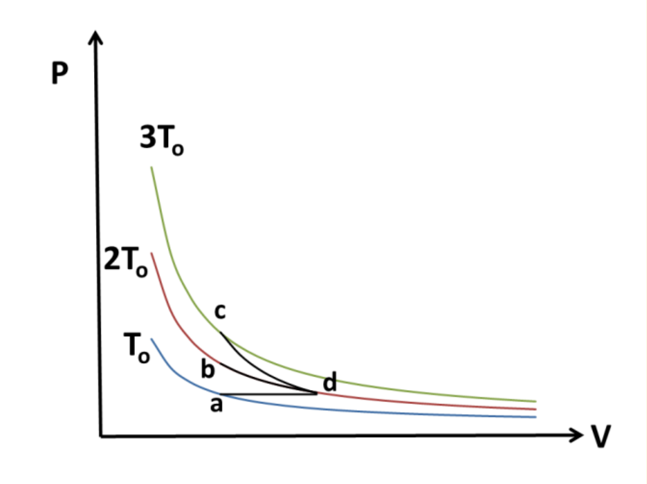
DEMO

- 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

# Checkpoint 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

# First Law of Thermodynamics = Energy Conservation

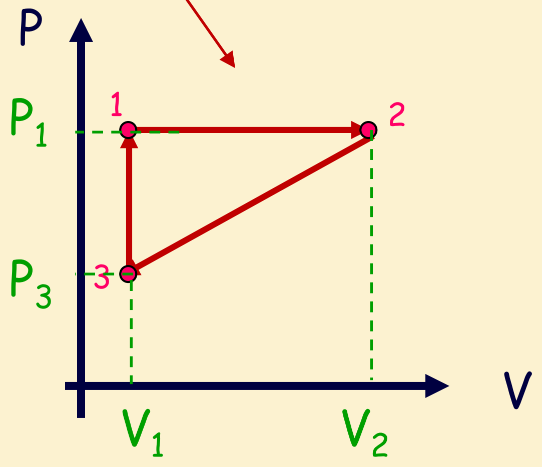
The change in internal energy of a system ($\Delta U$) is equal to the heat flow into the system ($Q$) minus the work done *by* the system ($W$)

$$\Delta U = Q - W$$

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)

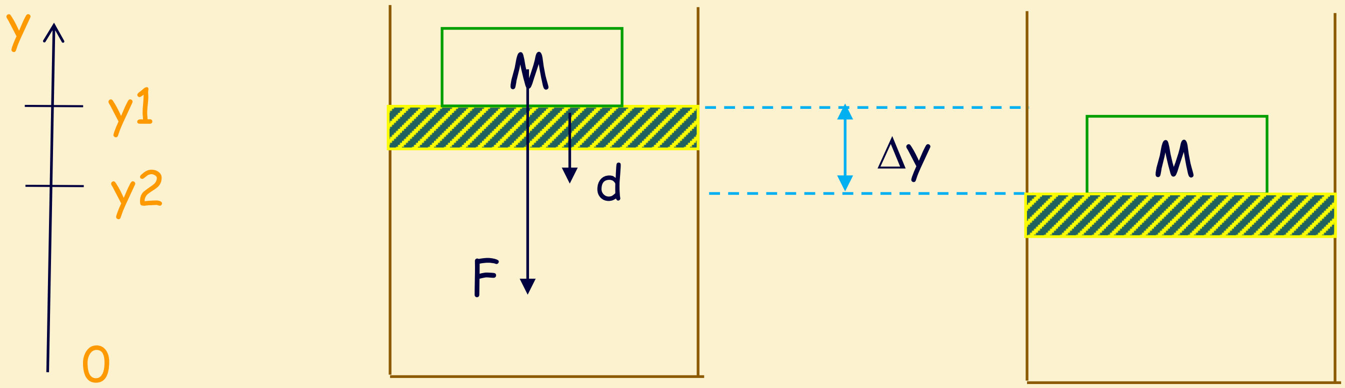


# Signs Example

- You are heating some soup in a pan on the stove. To keep it from burning, you also stir the soup. Apply the 1$^{st}$ law of thermodynamics to the soup. What is the sign of (A=Positive B= Zero C=Negative)

1) Q
2) W
3) $\Delta U$

# Work Done by a System Clicker Q




$W = Fd\cos\theta$

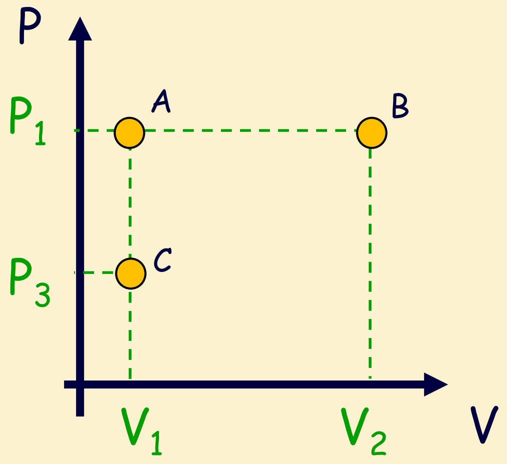
The work done by the gas as it contracts is

A) Positive B) Zero C) Negative

$W =$ (work done by system) $= F\,d = P\,A\,d = P\,\Delta V = P(V_f - V_i)$

# Thermodynamic Systems and P-V Diagrams

- ideal gas law: $PV = nRT$
- for n fixed, P and V determine "state" of system
  - ➔ $T = PV/nR$
  - ➔ $U = (3/2)nRT = (3/2)PV$




- Examples (Clicker Qs):
  - ➔ which point has highest T?
  - ➔ which point has lowest U?
  - ➔ to change the system from C to B, energy must be added to system

# Checkpoint from Last Wed.

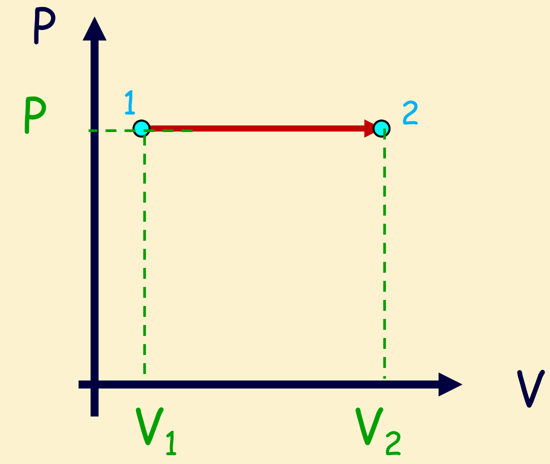
$\Delta U = Q - W$

- 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 less than W

# 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 $V_1 = 2 m^3$ and $V_2 = 3 m^3$. Find $T_1$, $T_2$, $\Delta U$, 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

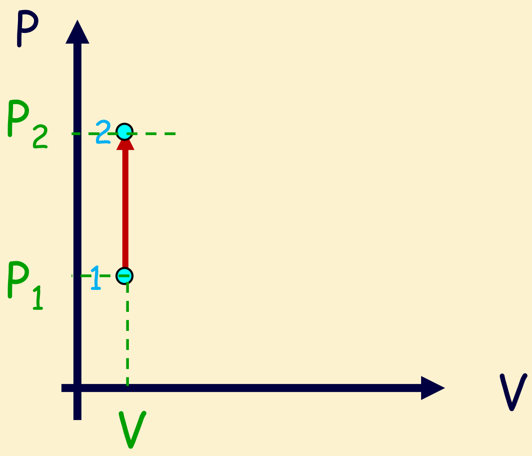
   $\Delta U = (3/2)\, p\, \Delta V = 1500$ J (has to be the same)

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 <u>constant volume</u> $V=2m^3$, 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**

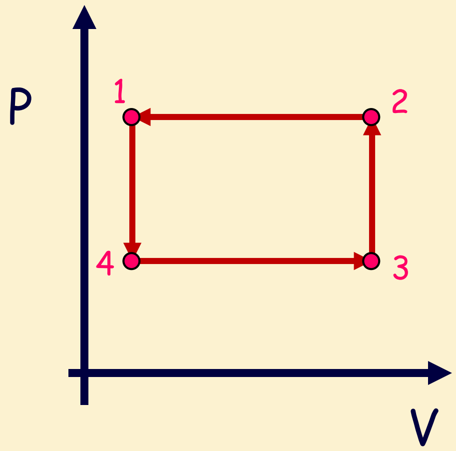
# WORK Clicker Q

If we go through the cycle (4,3,2,1,4) the net work done **on** the system will be

A) Positive

B) Negative

How would answers above change if we go in the opposite direction: 4,1,2,3,4?



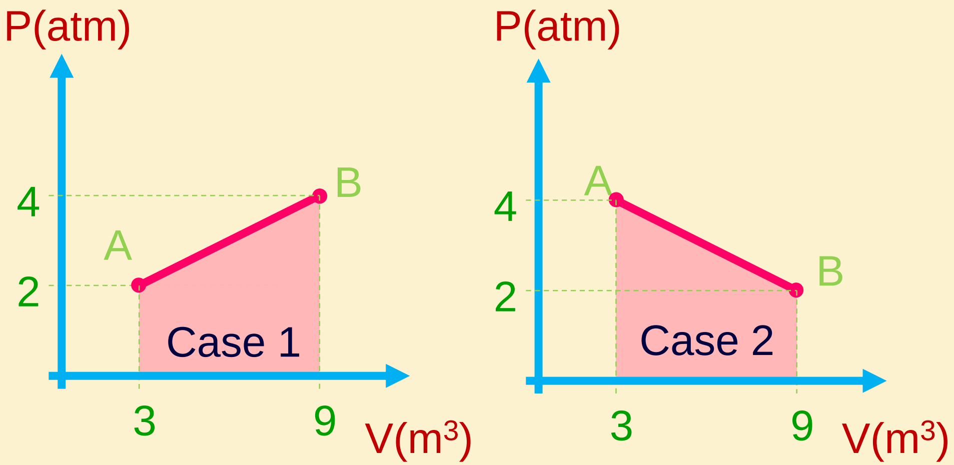
# PV Clicker Qs

Shown in the picture below are the pressure versus volume graphs for two thermal processes, in each case moving a system from state A to state B along the straight line shown. In which case is the work done by the system the biggest?

A. Case 1

B. Case 2

C. Same



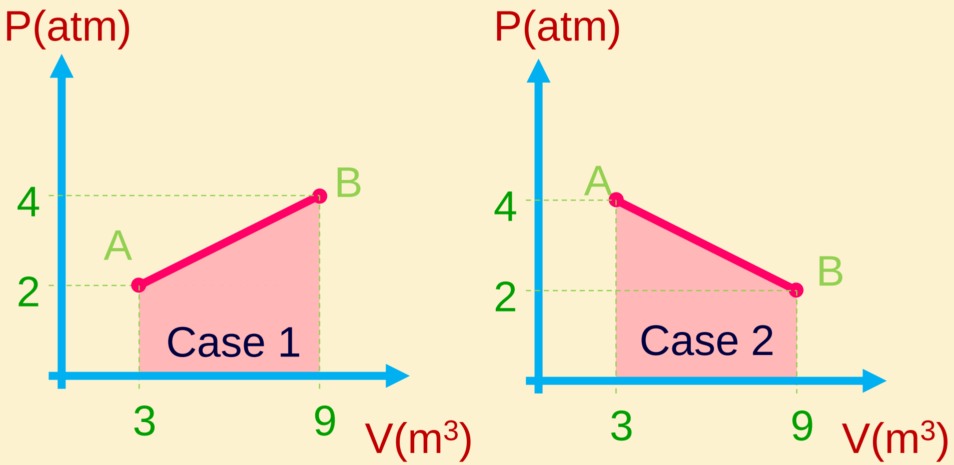
# PV Clicker 2

Shown in the picture below are the pressure versus volume graphs for two thermal processes, in each case moving a system from state A to state B along the straight line shown. In which case is the change in internal energy of the system the biggest?

A. Case 1

B. Case 2

C. Same



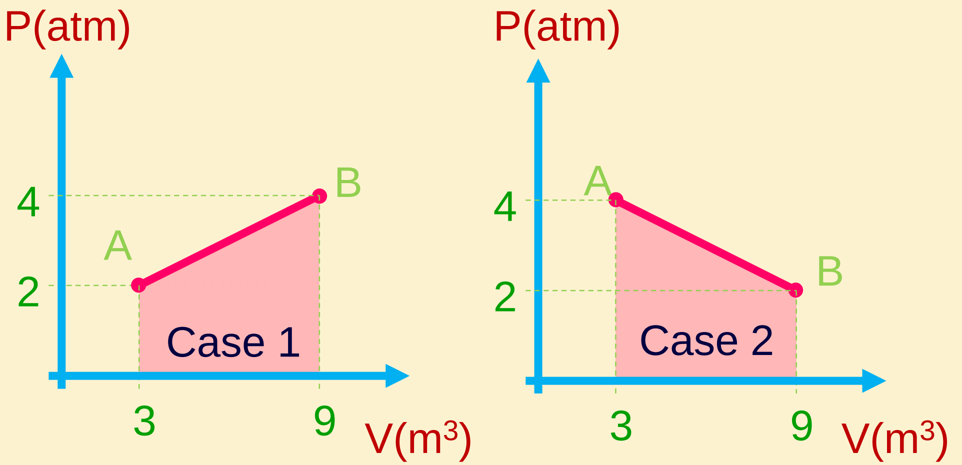
# PV Clicker 3

Shown in the picture below are the pressure versus volume graphs for two thermal processes, in each case moving a system from state A to state B along the straight line shown. In which case is the heat added to the system the biggest?

A. Case 1

B. Case 2

C. Same



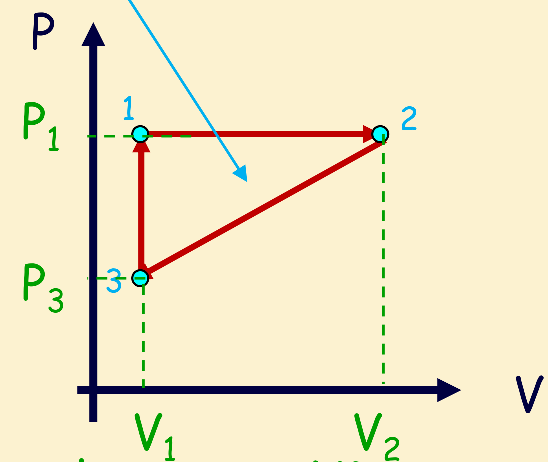
# First Law Questions

$\Delta U = Q - W$

Change in internal energy of system

Heat flow into system

Work done by system




## Some questions:

- Which part of cycle has largest magnitude change in internal energy, $\Delta U$?

  $2 \rightarrow 3$ (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?

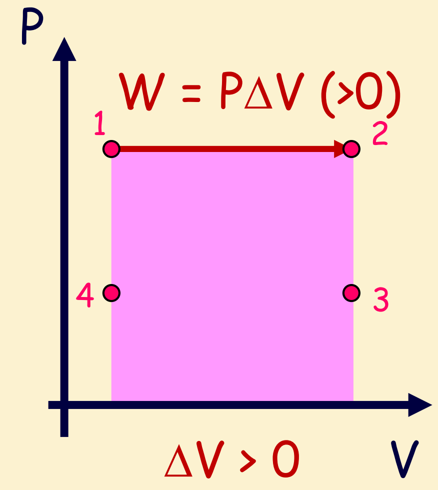
  $\Delta U = 0$ for closed cycle (since both p & V [and T] are back where they started)

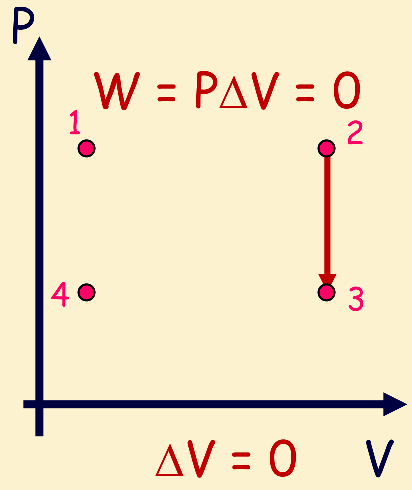
- What is net heat into system for full cycle (positive or negative)?

  $\Delta U = 0 \Rightarrow Q = W =$ 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:

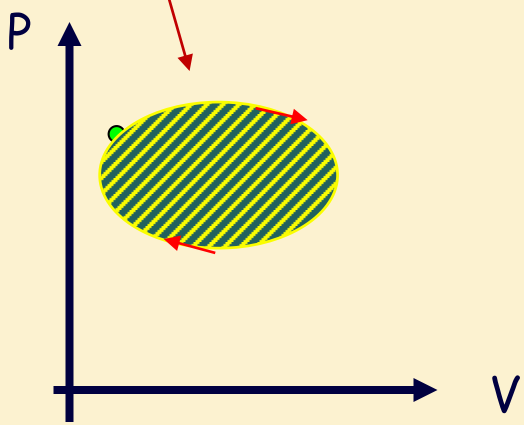
➔1st Law of Thermodynamics: Energy Conservation

$$\Delta U = Q - W$$

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 $\Delta U=0 \Rightarrow Q=W$