FINAL

Physics 101: Lecture 27
Thermodynamics

- Today's lecture will cover Textbook Chapter 15.1-15.6

Check your grades in grade book!!

First Law of Thermodynamics
Energy Conservation

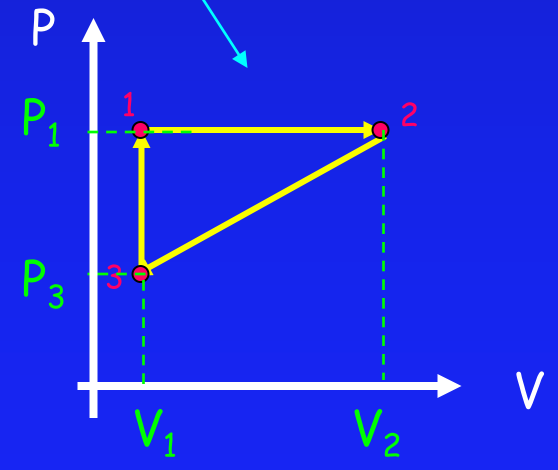
The change in internal energy of a system (ΔU) is equal to the heat flow into the system (Q) plus the work done *on* the system (W)

$$\Delta U = Q + W$$

Increase in internal energy of system

Heat flow into system

Work done on system



Equivalent ways of writing 1st Law:

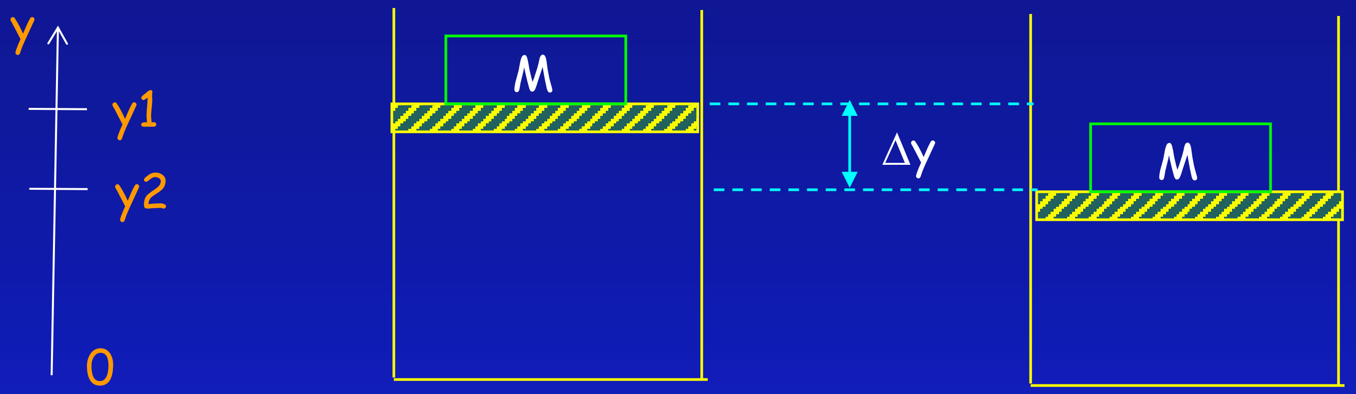
$$Q = \Delta U - W$$

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 1st law of thermodynamics to the soup. What is the sign of (A=Positive B= Zero C=Negative)

1) Q Positive, heat flows into soup
2) W Zero, is close to correct
3) ΔU Positive, Soup gets warmer

Work Done on a System ACT



The work done on the gas as it contracts is

A) Positive B) Zero C) Negative

$W =$ (work done ON system) $= F\ d\ \cos\theta$

$= P\ A\ d\ = -\ P\ A\ (y2-y1)\ = -P\ \Delta V$

$W = -p\ \Delta V$: *only for constant Pressure*

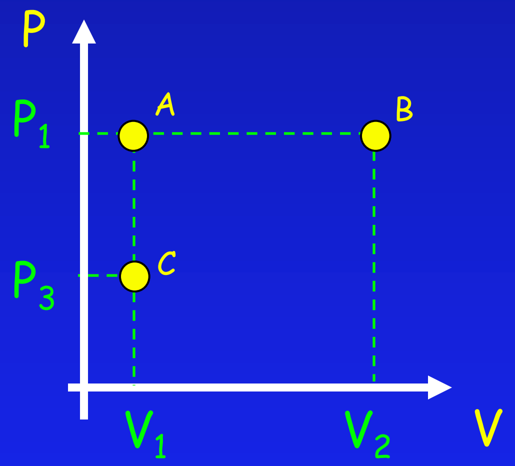
$W < 0$ if $\Delta V > 0$ negative work required to expand system

$W > 0$ if $\Delta V < 0$ positive work required to contract system

$W = 0$ if $\Delta V = 0$ no work needed to keep system at const V

Thermodynamic Systems and P-V Diagrams

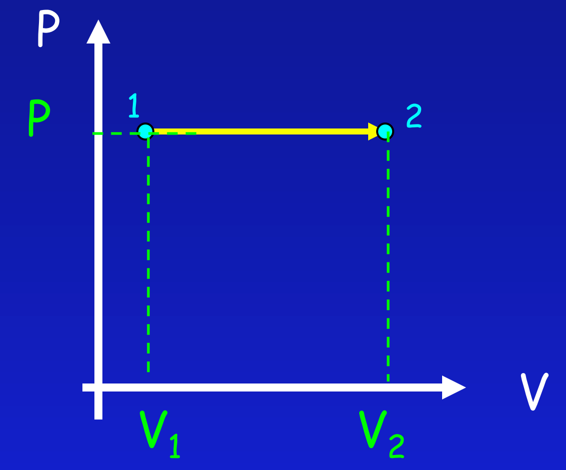
- ideal gas law: $PV = nRT$
- for n fixed, P and V determine "state" of system
  - ➔ $T = PV/nR$
  - ➔ $U = (3/2)nRT = (3/2)PV$



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

First Law of Thermodynamics
Isobaric Example

2 moles of monatomic ideal gas is taken from state 1 to state 2 at constant pressure $p=1000$ 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

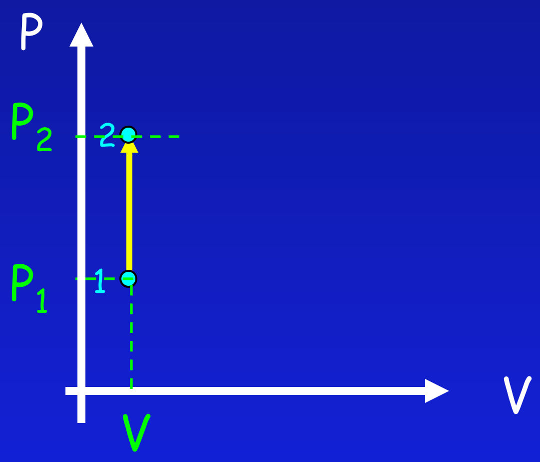
2 moles of monatomic ideal gas is taken from state 1 to state 2 at <u>constant volume</u> $V=2m^3$, where $T_1=120K$ and $T_2=180K$. Find Q.

1. $Q = \Delta U - W$

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

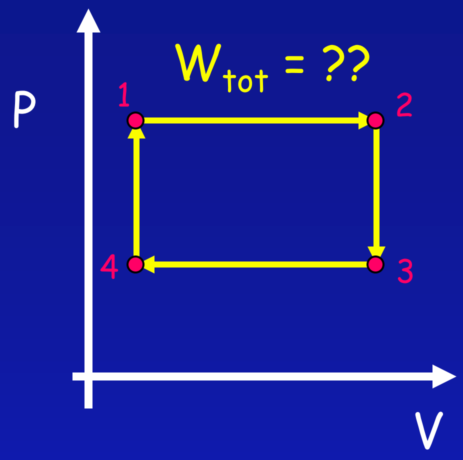
3. $W = -P\, \Delta V = 0$ J

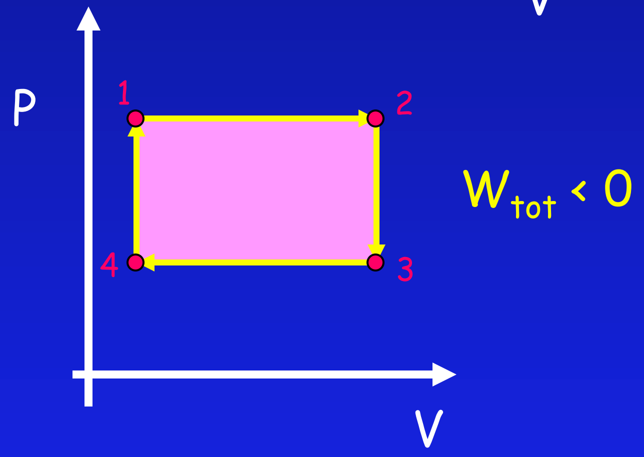
4. $Q = \Delta U - W = 1500 + 0 = 1500$ J

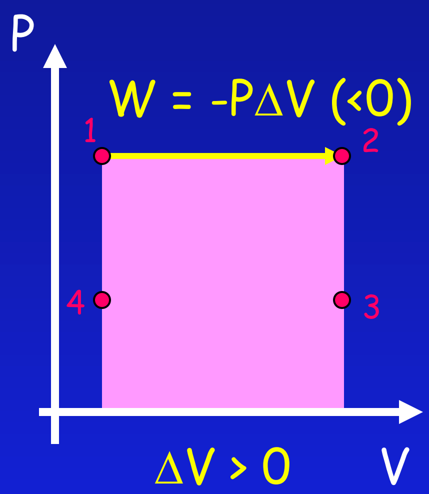


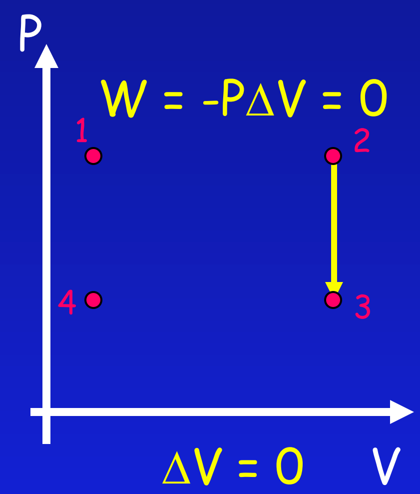
requires less heat to raise T at const. volume than at const. pressure

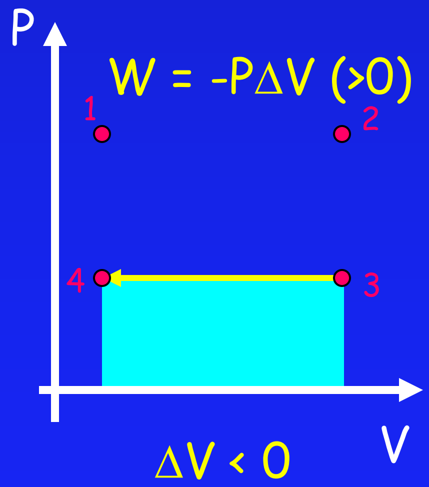
Homework Problem: Thermo I

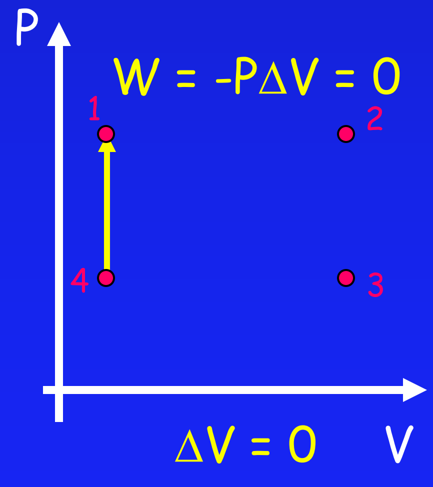










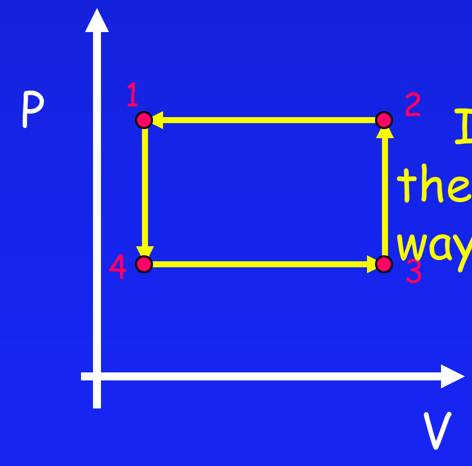


WORK ACT

If we go the opposite direction for the cycle (4,3,2,1) the net work done on the system will be

A) Positive

B) Negative



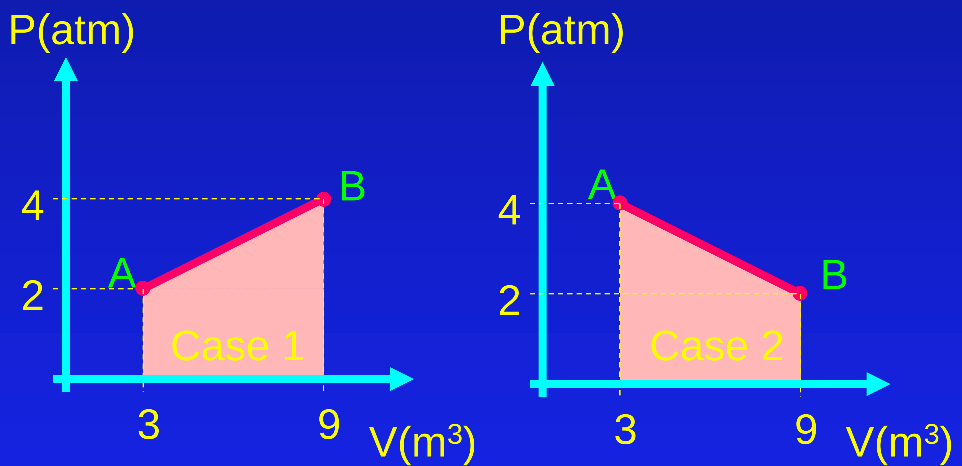
PV ACTs

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 on the system the biggest?

A. Case 1

B. Case 2

C. Same ← correct



Net Work = area under P-V curve

Area the same in both cases!

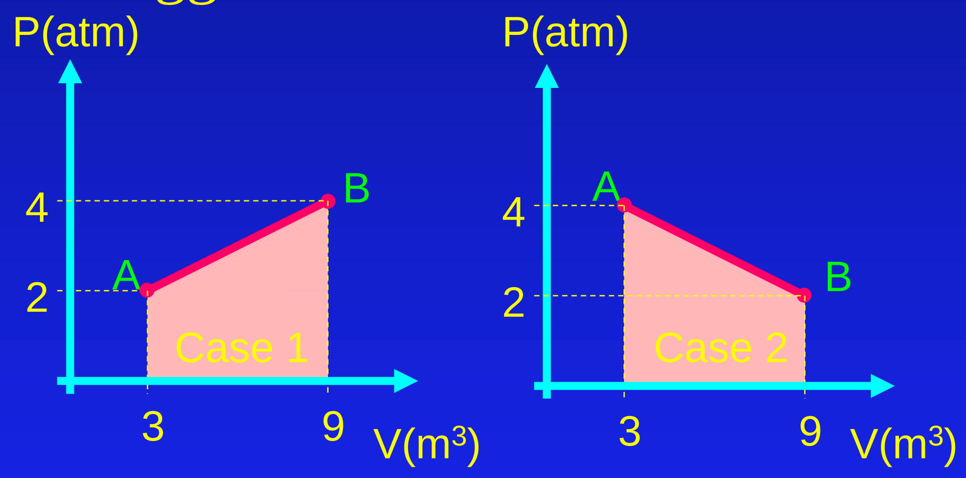
PV ACT 2

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 ← correct

B. Case 2

C. Same



$$\Delta U = 3/2\,(p_f V_f - p_i V_i)$$

Case 1: $\Delta U = 3/2(4\times9-2\times3)=45$ atm-m^3

Case 2: $\Delta U = 3/2(2\times9-4\times3)= 9$ atm-m^3

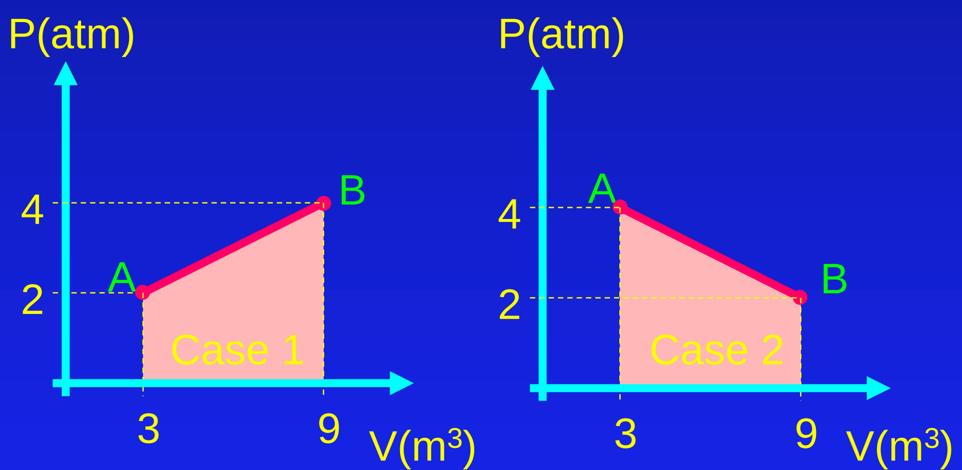
PV ACT3

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 ← correct

B. Case 2

C. Same



$Q = \Delta U - W$

W is same for both

ΔU is larger for Case 1

Therefore, Q is larger for Case 1

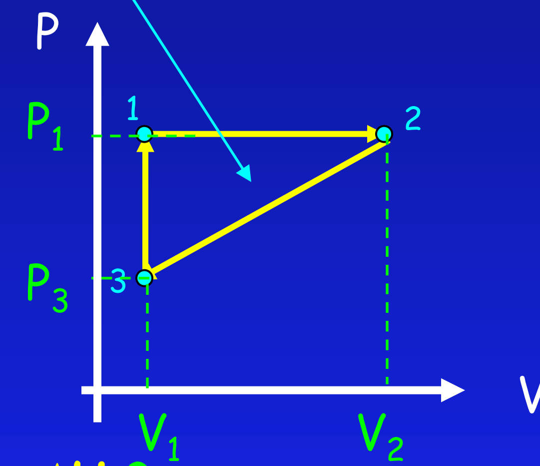
First Law Questions

$$Q = \Delta U - W$$

Work done <u>on</u> system

<u>Increase</u> in internal energy of system

Heat flow <u>into</u> system



Some questions:

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

  $2 \rightarrow 3$ (since $U = 3/2\ pV$)
- Which part of cycle involves the least work **W** ?

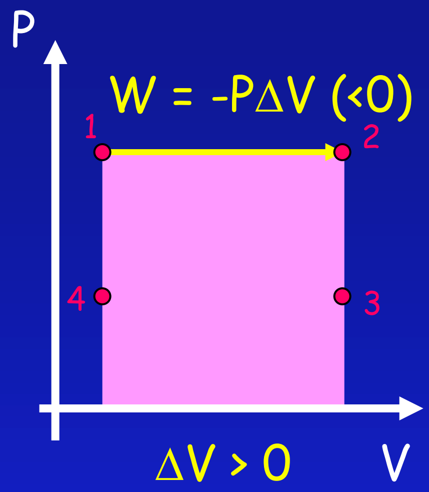
  $3 \rightarrow 1$ (since $W = -p\Delta V$)
- What is change in internal energy for full cycle?

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

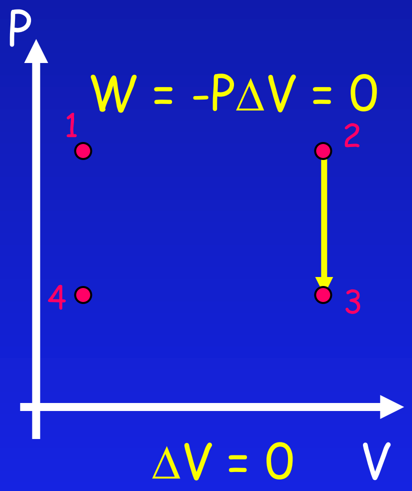
  $\Delta U = 0 \Rightarrow Q = -W =$ area of triangle (>0)

Special PV Cases

- Constant Pressure (isobaric)



- Constant Volume



- Constant Temp $\Delta U = 0$
- Adiabatic $Q=0$

Checkpoints 1-3

Consider a hypothetical device that takes 1000 J of heat from a hot reservoir at 300K, ejects 200 J of heat to a cold reservoir at 100K, and produces 800 J of work.

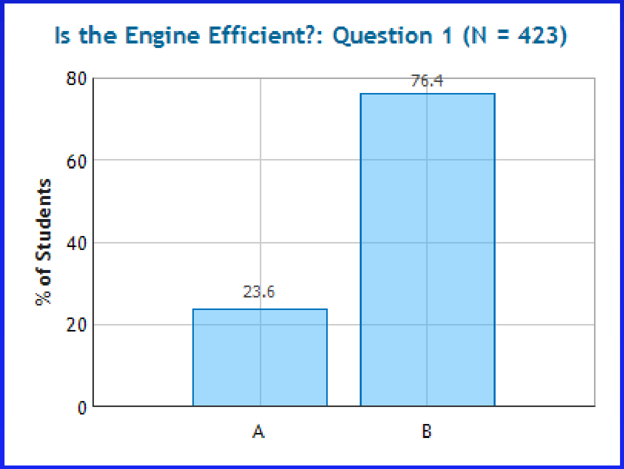
Does this device violate the first law of thermodynamics ?

1. Yes

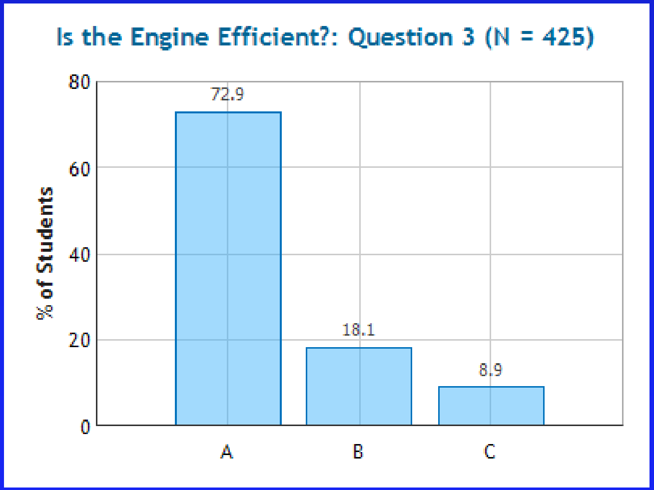
"the change in U=Q+W "

2. No ← correct

- -W (800) = Q_{hot} (1000) - Q_{cold} (200)
- Efficiency = -W/Q_{hot} = 800/1000 = 80%



80% efficient
20% efficient
25% efficient



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:

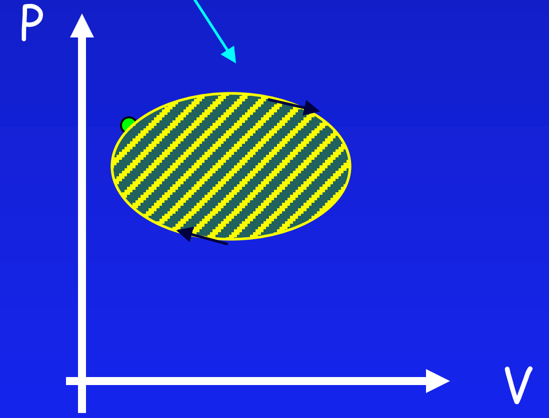
➔ 1st Law of Thermodynamics: Energy Conservation

$$Q = \Delta U - W$$

Heat flow into system

Increase in internal energy of system

Work done on system



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