DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS

TSOKOS OPTION B-2A THERMODYNAMICS (B2.1 THRU B2.5)

Essential Idea:

- The first law of thermodynamics relates the change in internal energy of a system to the energy transferred and the work done. The entropy of the universe tends to a maximum.

Nature Of Science:

- Variety of perspectives: With three alternative and equivalent statements of the second law of thermodynamics, this area of physics demonstrates the collaboration and testing involved in confirming abstract notions such as this.

International-Mindedness:

- The development of this topic was the subject of intense debate between scientists of many countries in the 19th century.

Understandings:

- The first law of thermodynamics
- The second law of thermodynamics
- Entropy
- Cyclic processes and pV diagrams
- Isovolumetric, isobaric, isothermal and adiabatic processes
- Carnot cycle
- Thermal efficiency

Applications And Skills:

- Describing the first law of thermodynamics as a statement of conservation of energy
- Explaining sign convention used when stating the first law of thermodynamics as $Q = \Delta U + W$
- Solving problems involving the first law of thermodynamics

$pV^{\frac{5}{3}} = constant$

Applications And Skills:

- Describing the second law of thermodynamics in Clausius form, Kelvin form and as a consequence of entropy
- Describing examples of processes in terms of entropy change
- Solving problems involving entropy changes

$pV^{5/3}$ = constant

Applications And Skills:

- Sketching and interpreting cyclic processes
- Solving problems for adiabatic processes for monatomic gases using $pV^{5/3}$ = constant
- Solving problems involving thermal efficiency

Guidance:

- If cycles other than the Carnot cycle are used quantitatively, full details will be provided
- Only graphical analysis will be required for determination of work done on a pV diagram when pressure is not constant

Data Booklet Reference:

$$Q = \Delta U + W$$

$$U = \frac{3}{2} nRT$$

$$\Delta S = \frac{\Delta Q}{T}$$

$$pV^{\frac{5}{3}} = cons\tan t$$ *(for monatomic gases)*

$$W = p\Delta V$$

$$\eta = \frac{usefulworkdone}{energyinput}$$

$$\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$$

Utilization:

- This work leads directly to the concept of the heat engines that play such a large role in modern society
- The possibility of the heat death of the universe is based on ever-increasing entropy
- Chemistry of entropy (see Chemistry sub-topic 15.2)

Aims:

- Aim 5: development of the second law demonstrates the collaboration involved in scientific pursuits
- Aim 10: the relationships and similarities between scientific disciplines are particularly apparent here

Reading Activity Questions?

Internal Energy

- The <u>total</u> kinetic energy of the molecules of the gas plus the potential energy associated with the intermolecular forces
- For an ideal gas, the intermolecular forces are assumed to be zero

Internal Energy

- Average kinetic energy of the molecules is given by

$$\overline{E}_k = \frac{1}{2} m\overline{v}^2 = \frac{3}{2} kT$$

where

$$k = R/N_A = 1.38x10^{-23}\, JK^{-1}$$

the Boltzmann constant

Internal Energy

- Internal energy, U, of an ideal gas with N molecules is given by

$$U = N\overline{E}_k = \frac{3}{2}NkT$$

and since

$$k = R/N_A$$

$$N = (n)(N_A)$$

$$PV = nRT$$

then

$$U = \frac{3}{2}nRT = \frac{3}{2}PV$$

Internal Energy

- In this equation, n is the number of moles

$$U = \frac{3}{2}nRT = \frac{3}{2}PV$$

- The change in internal energy due to a change in temperature is thus

$$\Delta U = \frac{3}{2}nR\Delta T$$

Internal Energy

- *This formula shows that the internal energy of a fixed number of moles of an ideal gas depends only on temperature and not on the nature of the gas, its volume, or any other variable*

$$\Delta U = \frac{3}{2} nR\Delta T$$

System

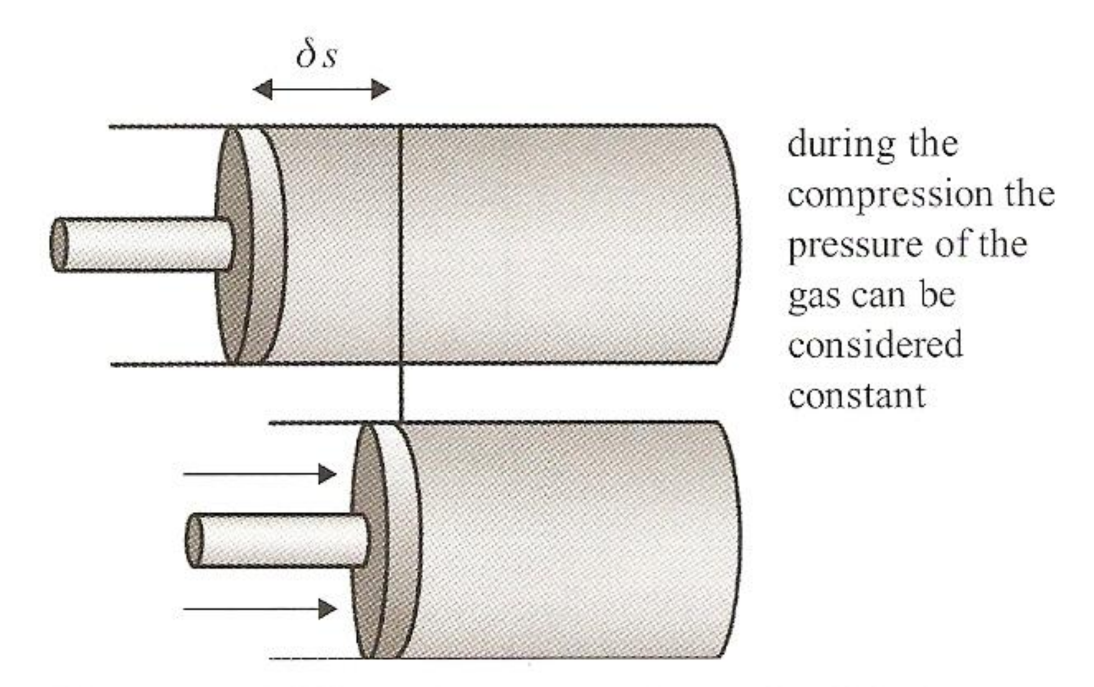
- Means the complete set of objects under consideration
- Does not include the surroundings
- ***Open system*** – mass <u>can</u> enter or leave
- ***Closed system*** – mass <u>cannot</u> enter or leave
- ***Isolated system*** – no energy in any form can enter or leave

System State

- Refers to the complete set of parameters that define the system
- Not to be confused with states of matter *(or states that matter, for that matter)*
- Any process that change the state of an ideal gas (temperature, pressure or volume) is called a thermodynamic process
- Examples are adding/subtracting heat or doing work on the system

Work Done On or By A Gas

- Compressing a gas with a piston, the (small) work done is given by:



$$W = F\Delta s$$

$$F = PA$$

$$W = PA\Delta s$$

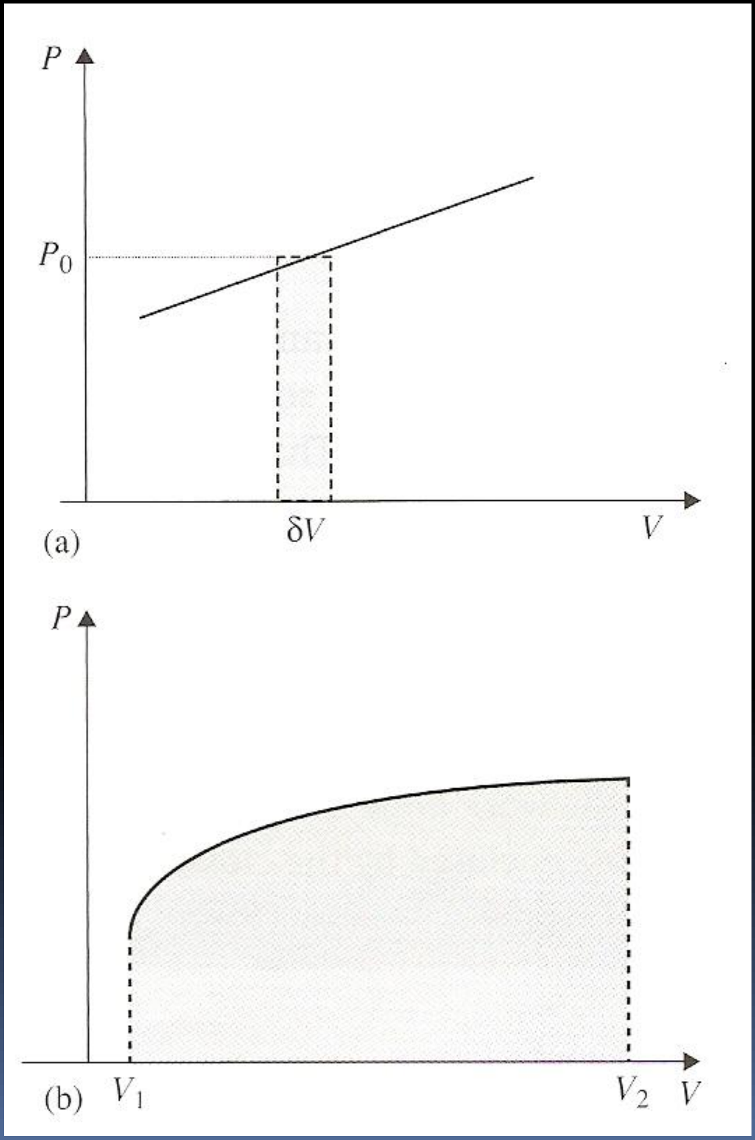
$$A\Delta s = V$$

$$W = P\Delta V$$

Work Done On or By A Gas

- For large changes in volume, the pressure will increase with each incremental change so it must be integrated

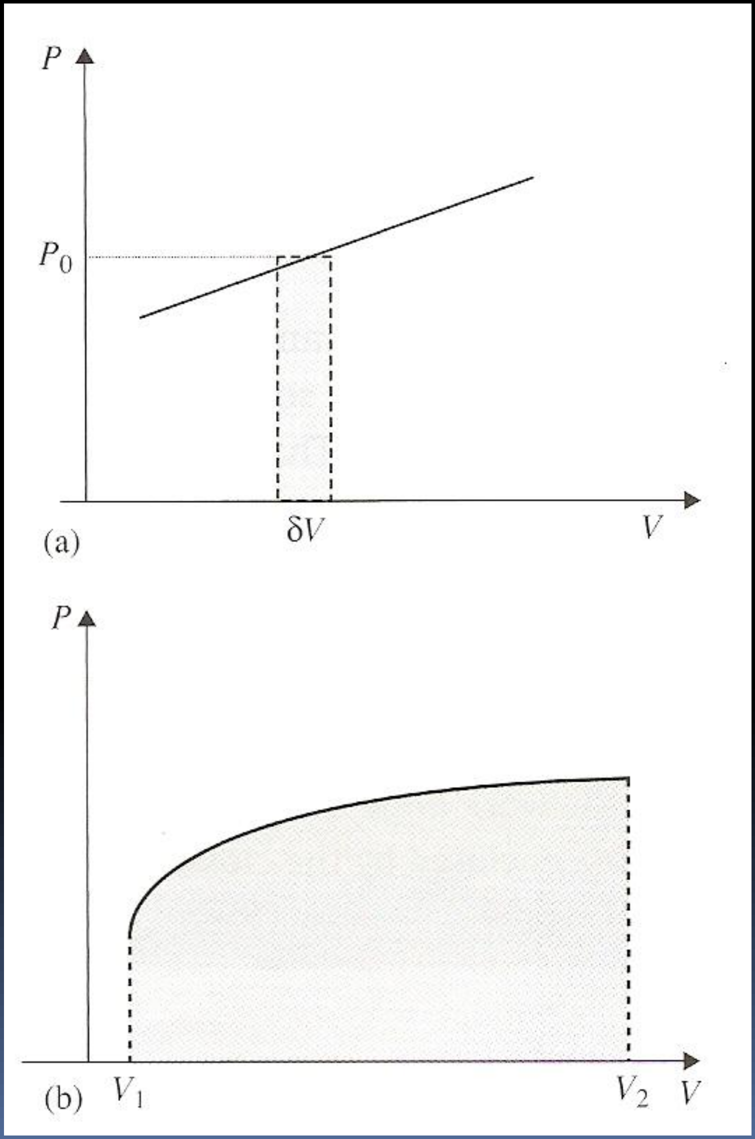
$$\delta W = P\delta V$$



Work Done On or By A Gas

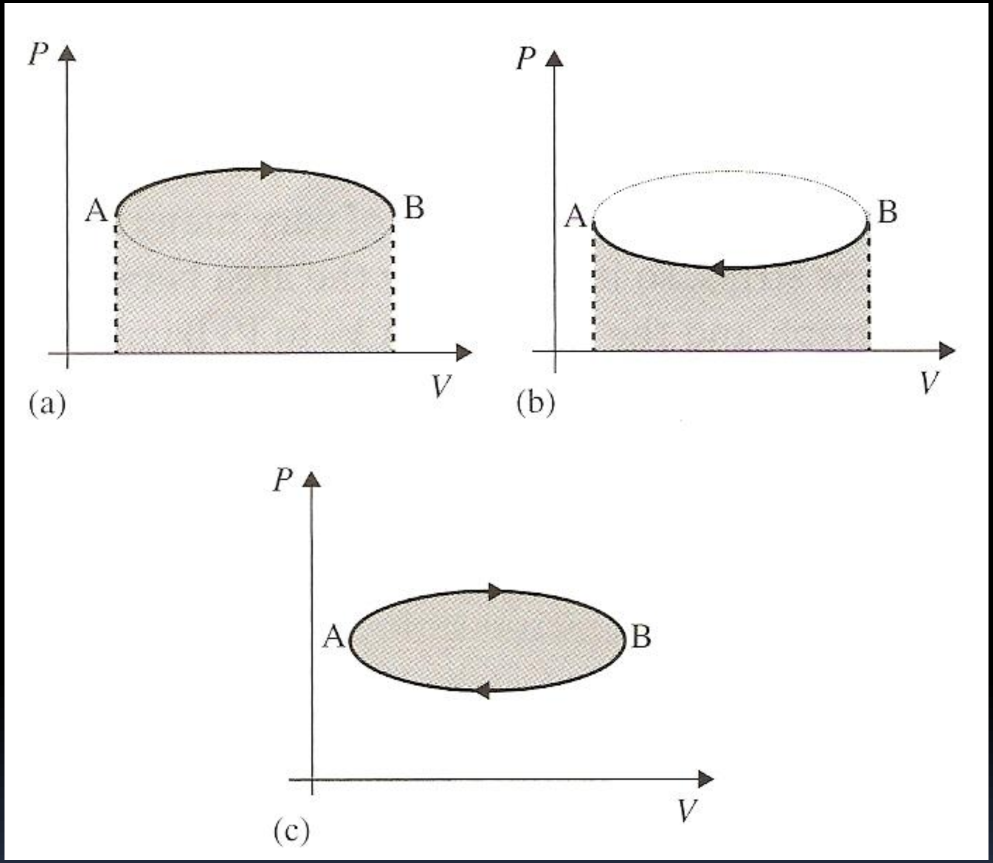
- The ***total work*** done when a gas expands by an arbitrary amount is the area under the graph of a pressure-volume diagram.

$$\delta W = P\delta V$$



Work Done On or By A Gas

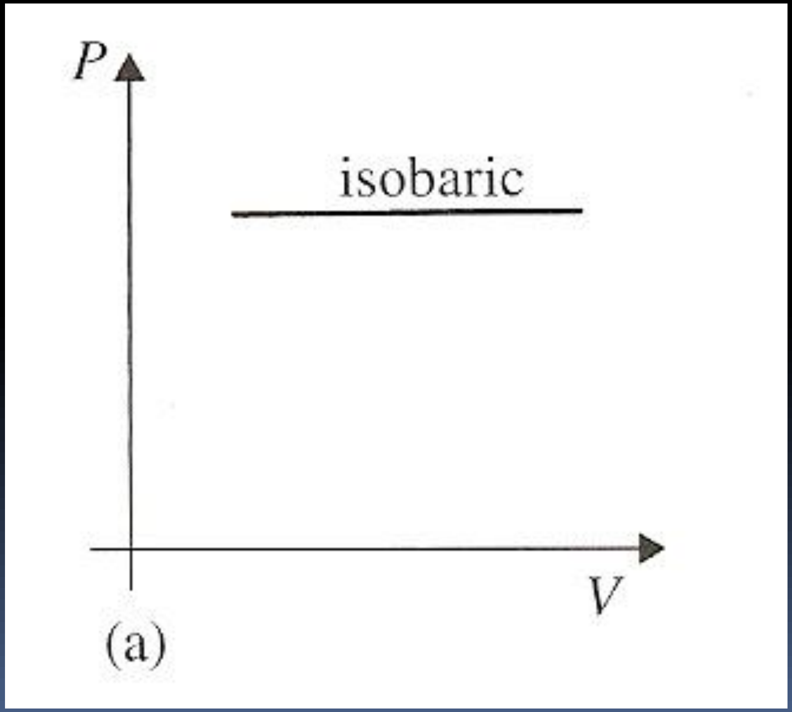
- The ***net work*** done is the work done by the gas minus the work done on the gas.
- It equals the area enclosed by the closed loop (i.e., the area between the upper and lower curves)



$$\delta W = P\delta V$$

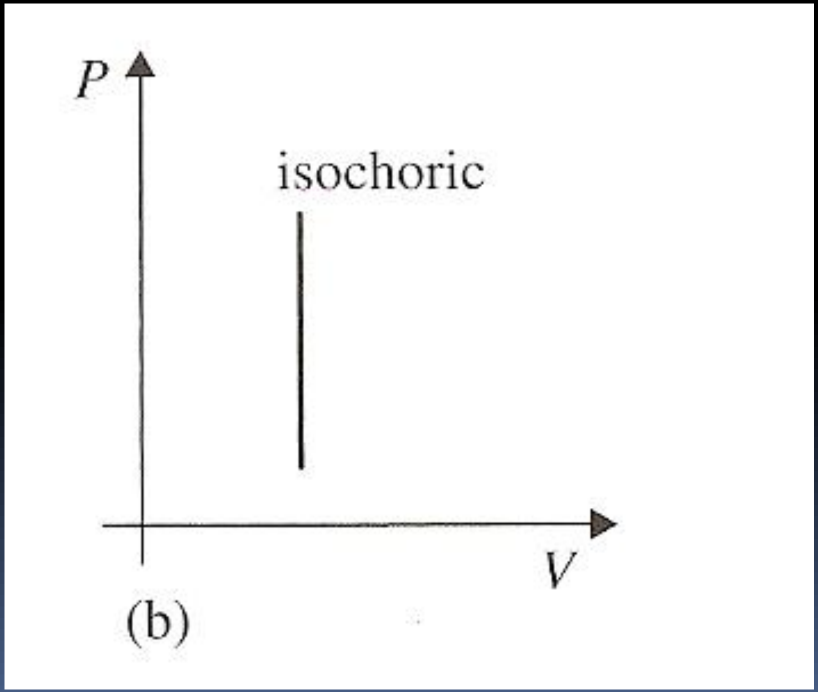
Thermodynamic Processes

- ***Isobaric*** – The gas expands or contracts under constant pressure



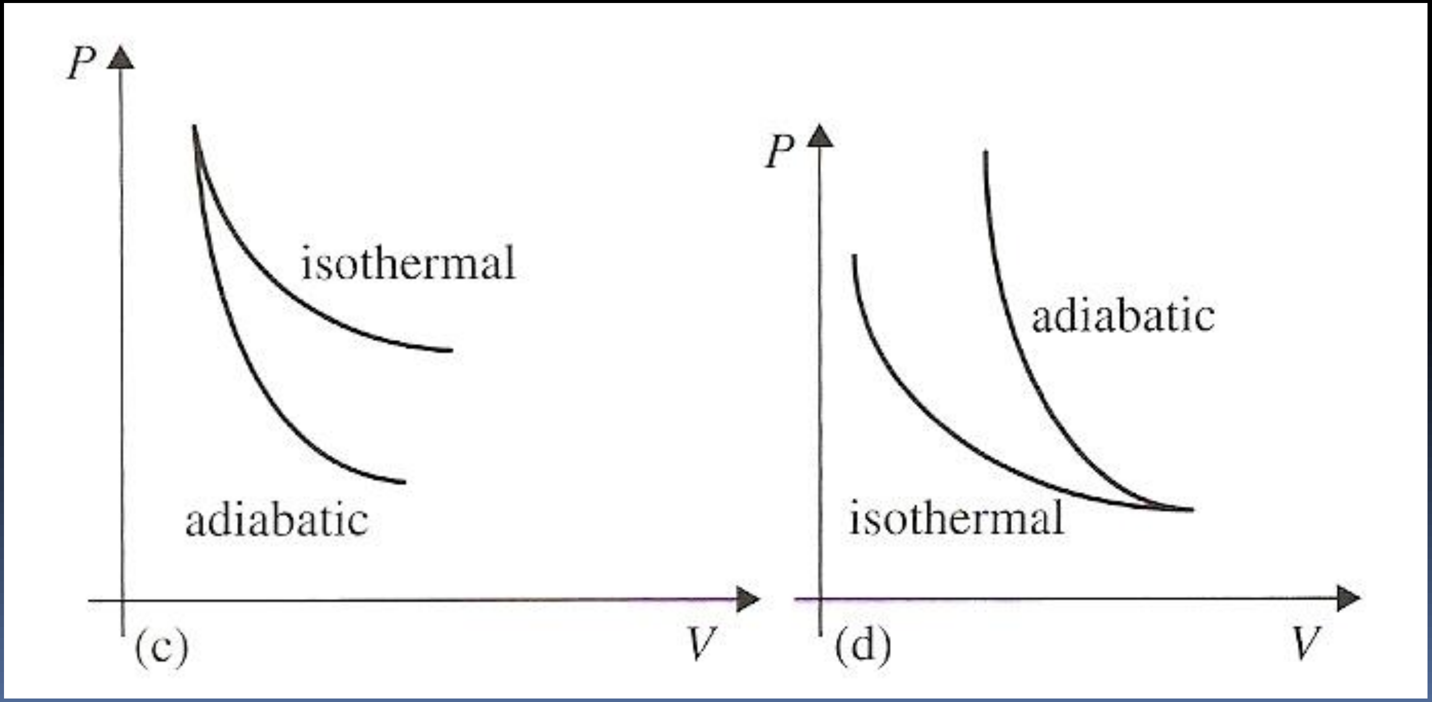
Thermodynamic Processes

- ***Isovolumetric (Isochoric)*** – The volume of the gas remains the same as pressure increases or decreases



Thermodynamic Processes

- ***Isothermal*** – The temperature of the gas remains the same as pressure and volume change
- ***Adiabatic*** – the gas does not absorb or release any thermal energy (Q = 0)



Thermodynamic Processes

- ***Isothermal*** – The temperature of the gas remains the same as pressure and volume change
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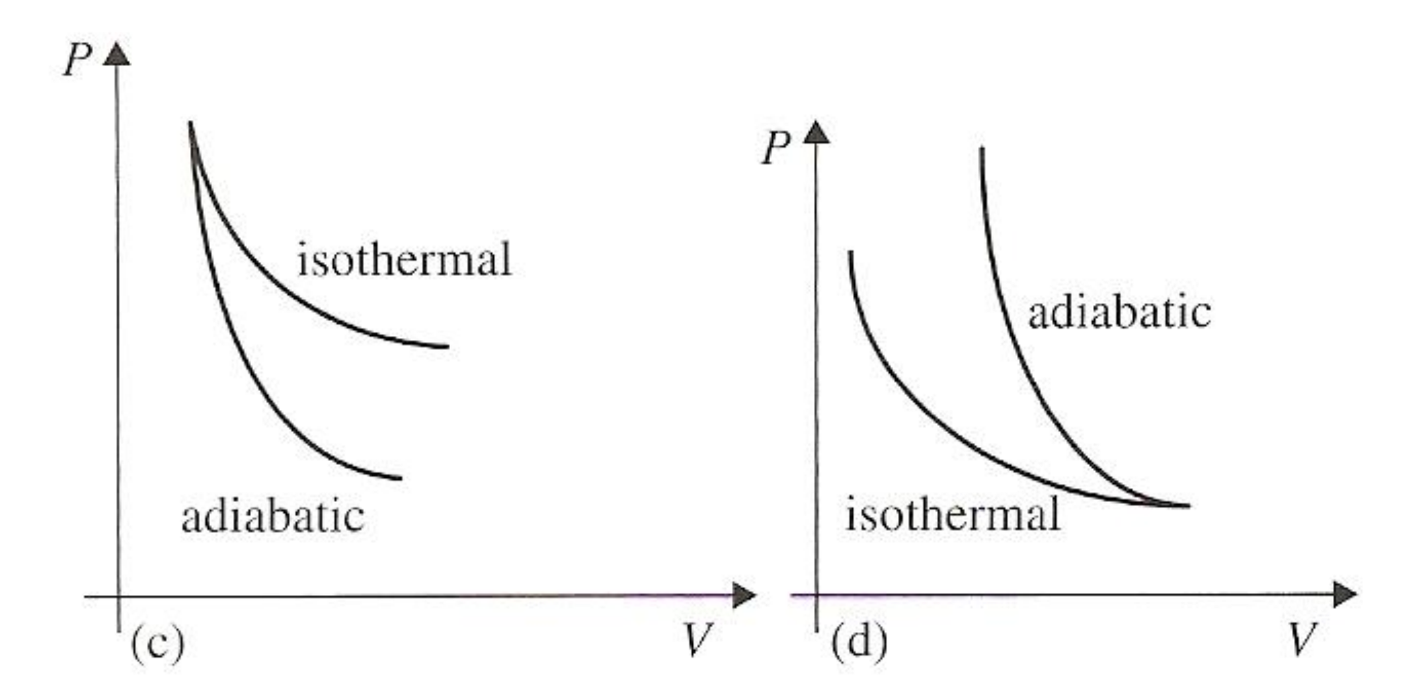
Key is to observe the steepness of the slope – adiabatic steep, isothermal not so steep



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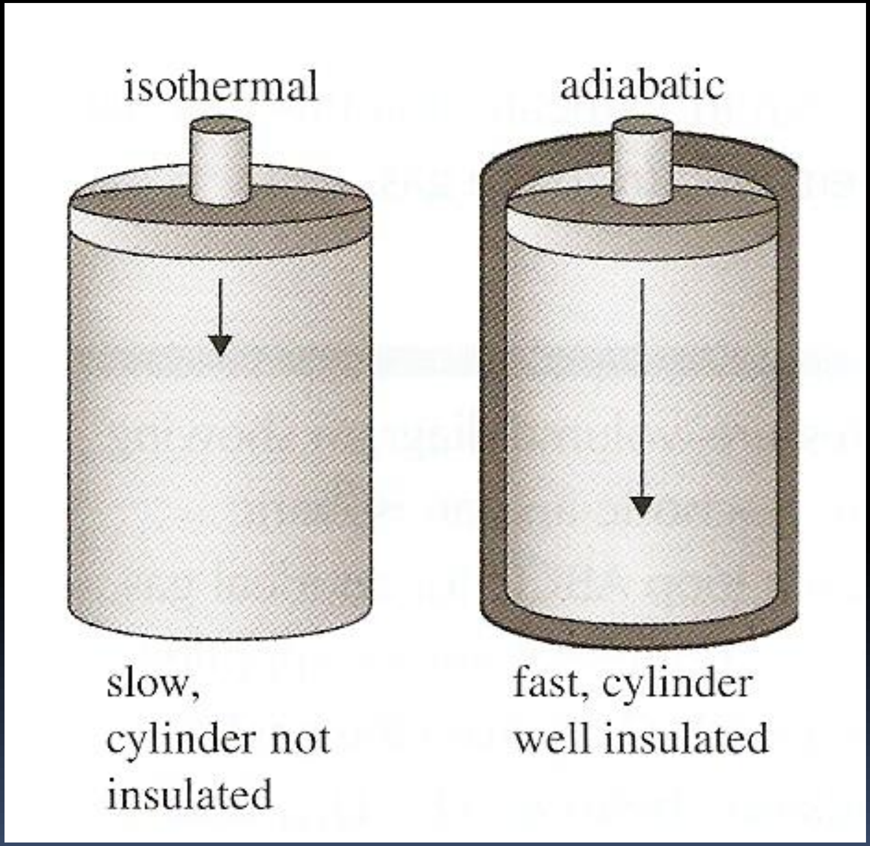

Thermodynamic Processes

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

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

First Law of Thermodynamics

- When a small amount of thermal energy Q is given to a gas, the gas will absorb that energy and use it to increase its internal energy and/or do work by expanding.
- Conservation of energy demands that

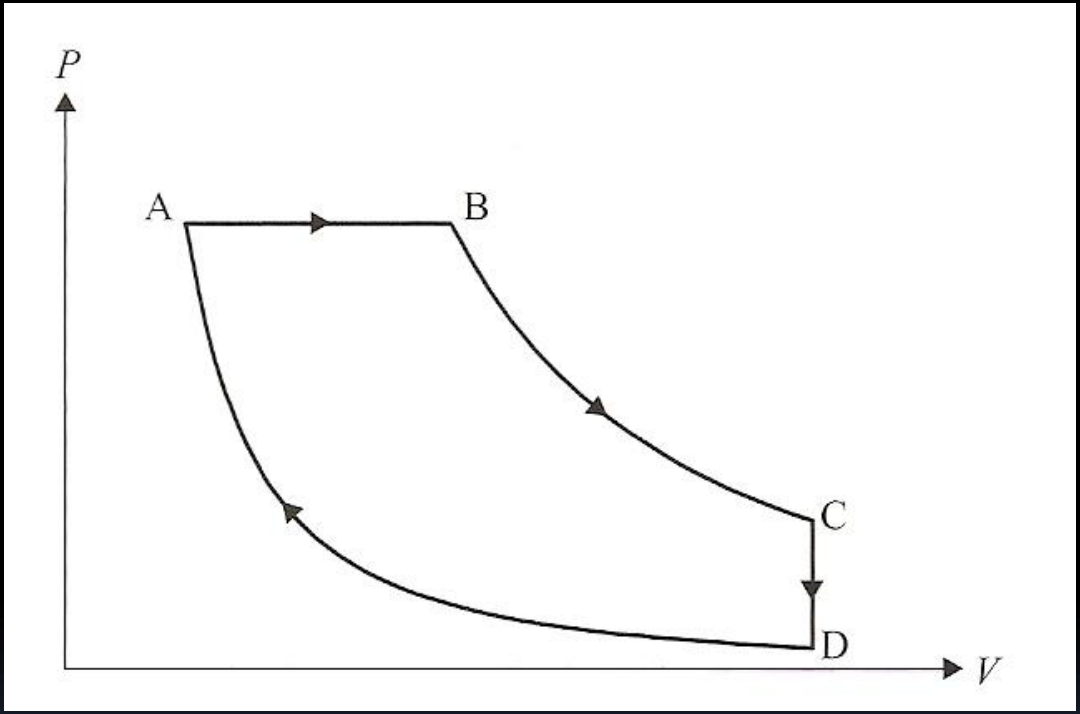
$$Q = \Delta U + W$$

First Law of Thermodynamics

$$Q = \Delta U + W$$

- + Q = thermal energy ***absorbed*** by the gas (Q_{in})
- - Q = thermal energy ***lost*** by the gas (Q_{out})
- + W = work done ***by*** the gas (W_{out}) as it expands
- - W = work done ***on*** the gas (W_{in}) to compress it
- + U = increase in internal energy/temperature
- - U = decrease in internal energy/temperature

What is going on here?



$$Q = \Delta U + W$$

$$PV = nRT$$

What is going on here?

$T_A = 400K$

$U_{A-B} = 7.2\ kJ$

$U_{C-A} = 2.2kJ$

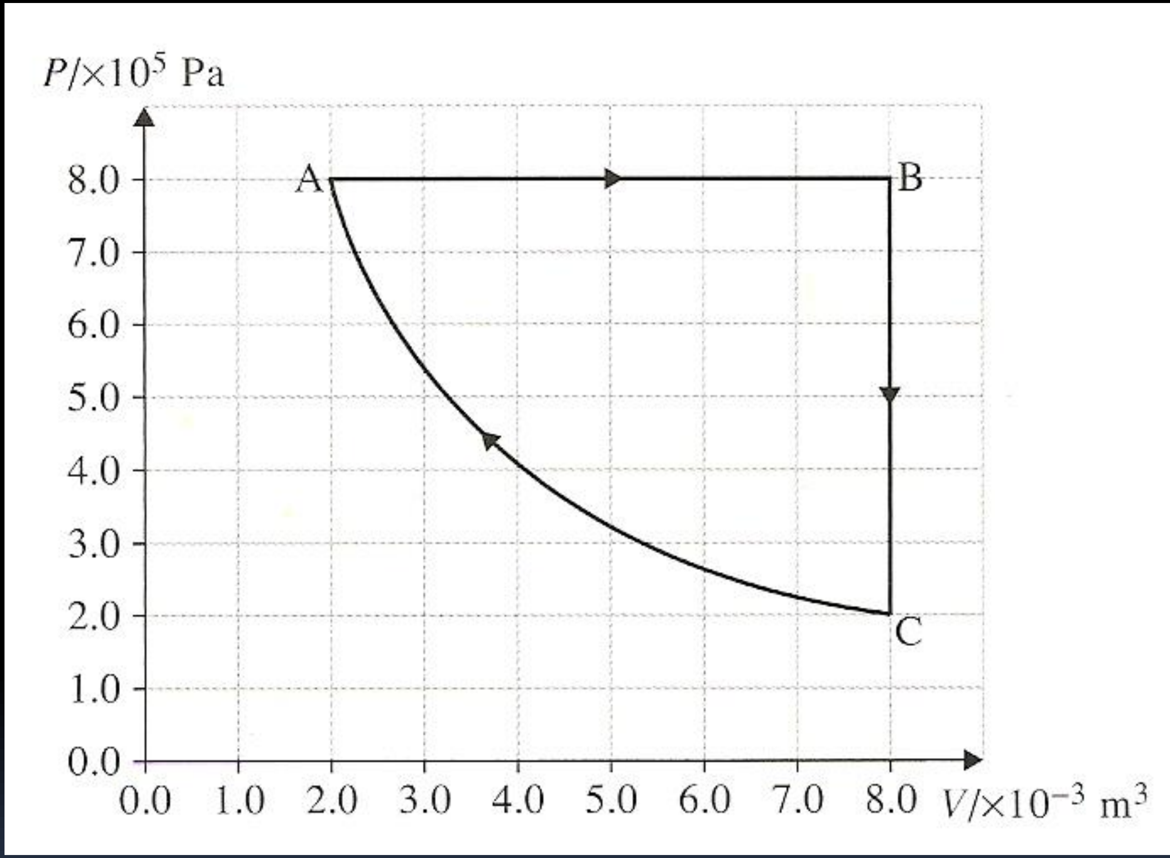
Find:

T_B

Q_{A-B}

Q_{B-C}

Net Work



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Essential Idea:

- The first law of thermodynamics relates the change in internal energy of a system to the energy transferred and the work done. The entropy of the universe tends to a maximum.

QUESTIONS?

Homework

#18-28

We Stopped Here on 2/8