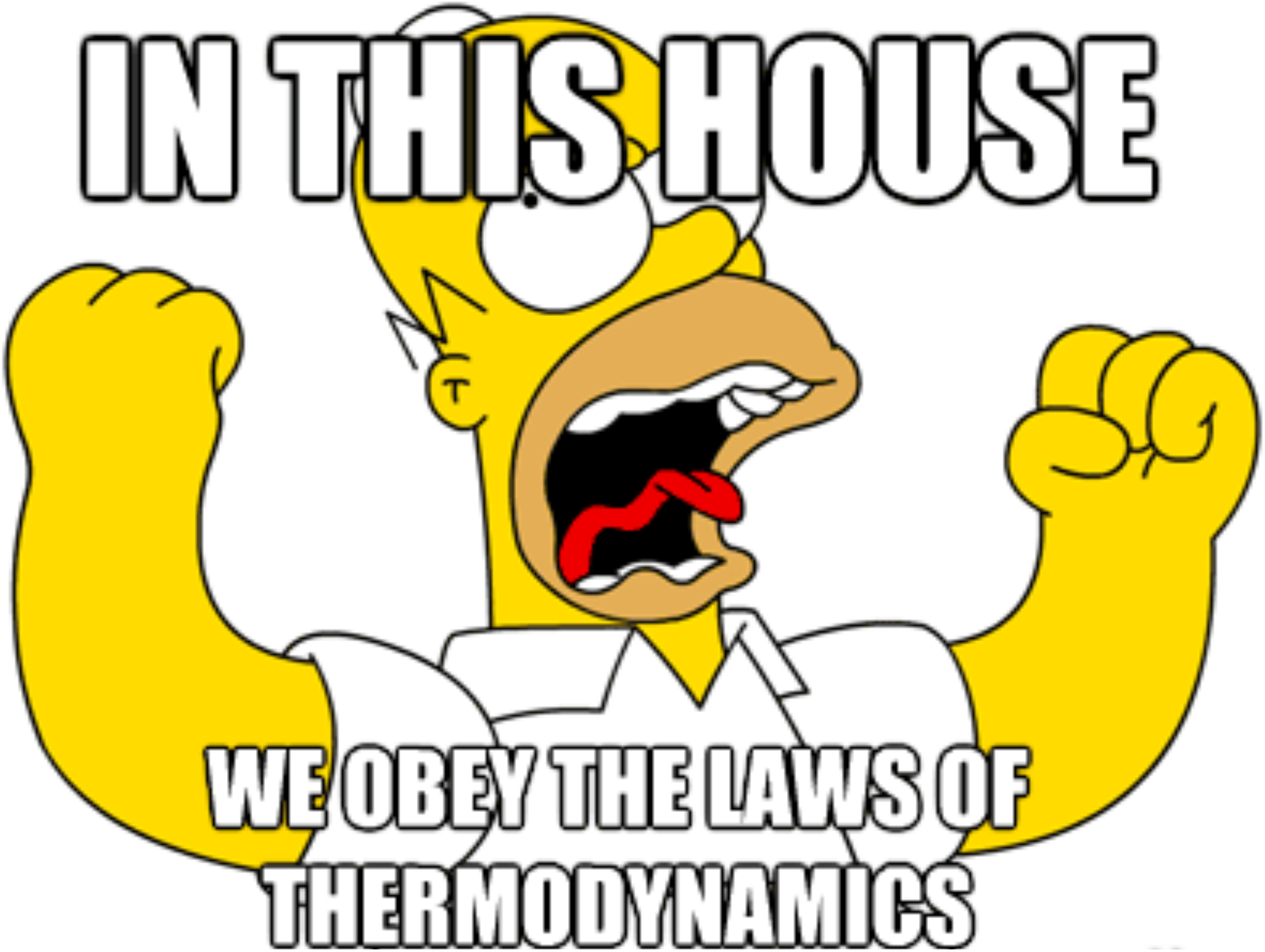
College Physics I: 1511 Mechanics & Thermodynamics

Professor Jasper Halekas
Van Allen Lecture Room 1
MWF 8:30-9:20 Lecture

Announcements

- Welcome back!
- Second to last HW due Thursday
- Last lab this week

[redacted]



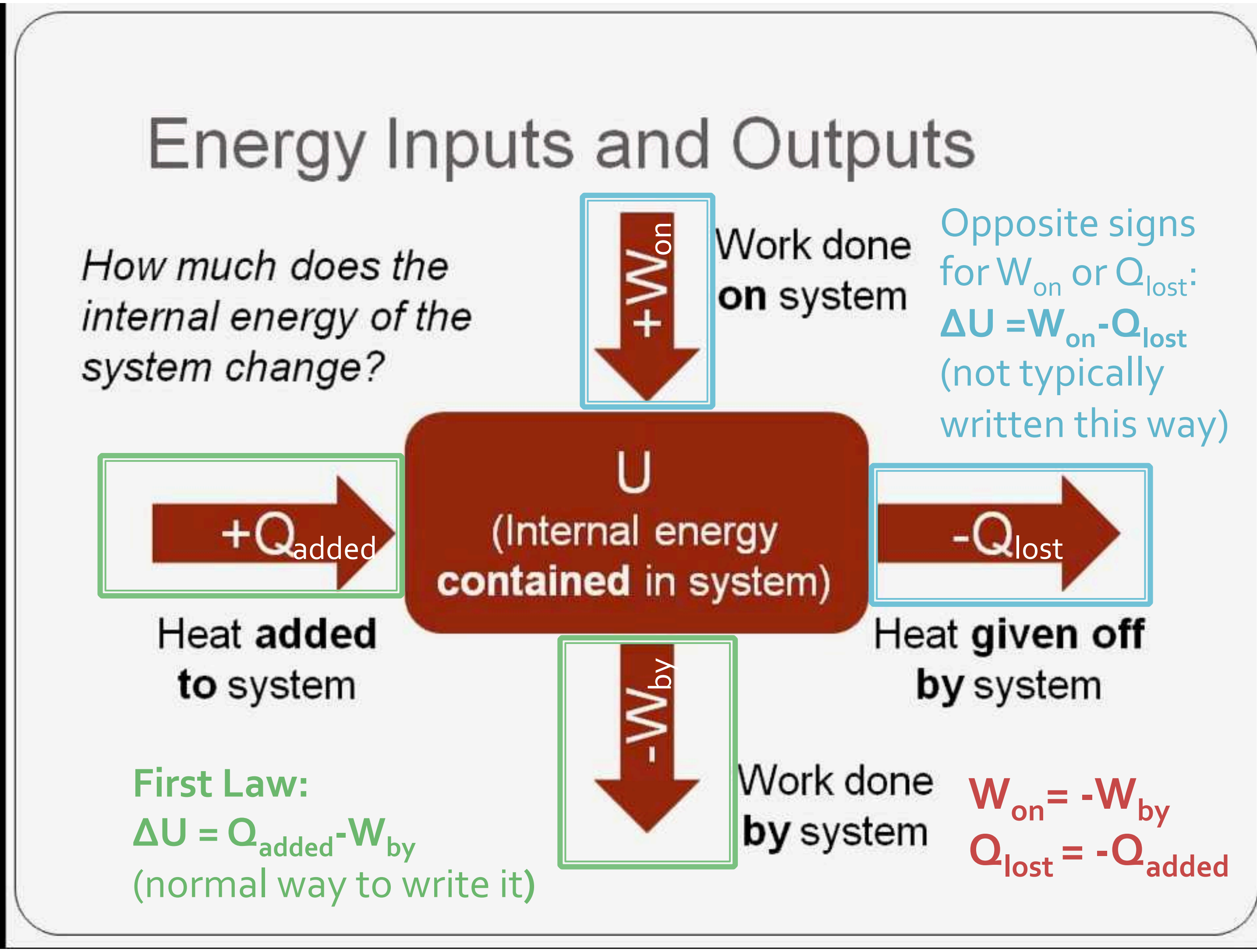
First Law of Thermodynamics

The change in internal energy of a system is equal to the heat added to the system minus the work done by the system.

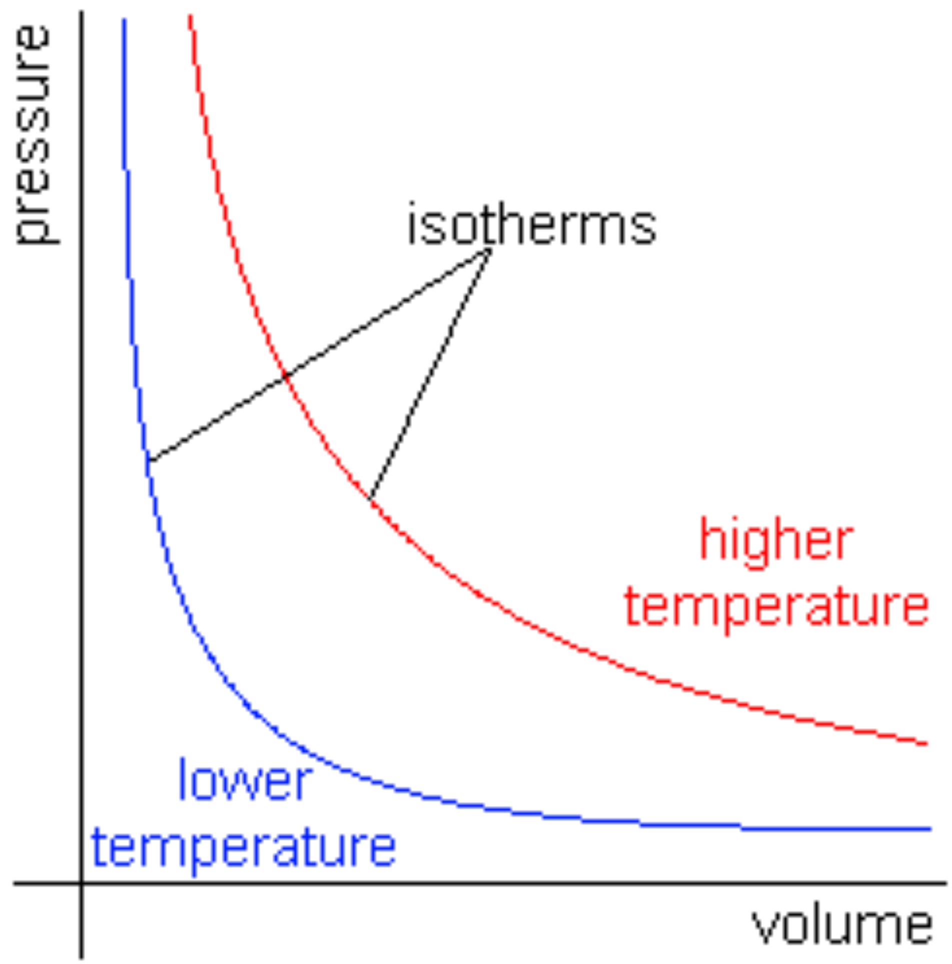
$$\Delta U = Q - W$$

- Change in internal energy
- Heat added to the system
- Work done by the system

First Law Bookkeeping



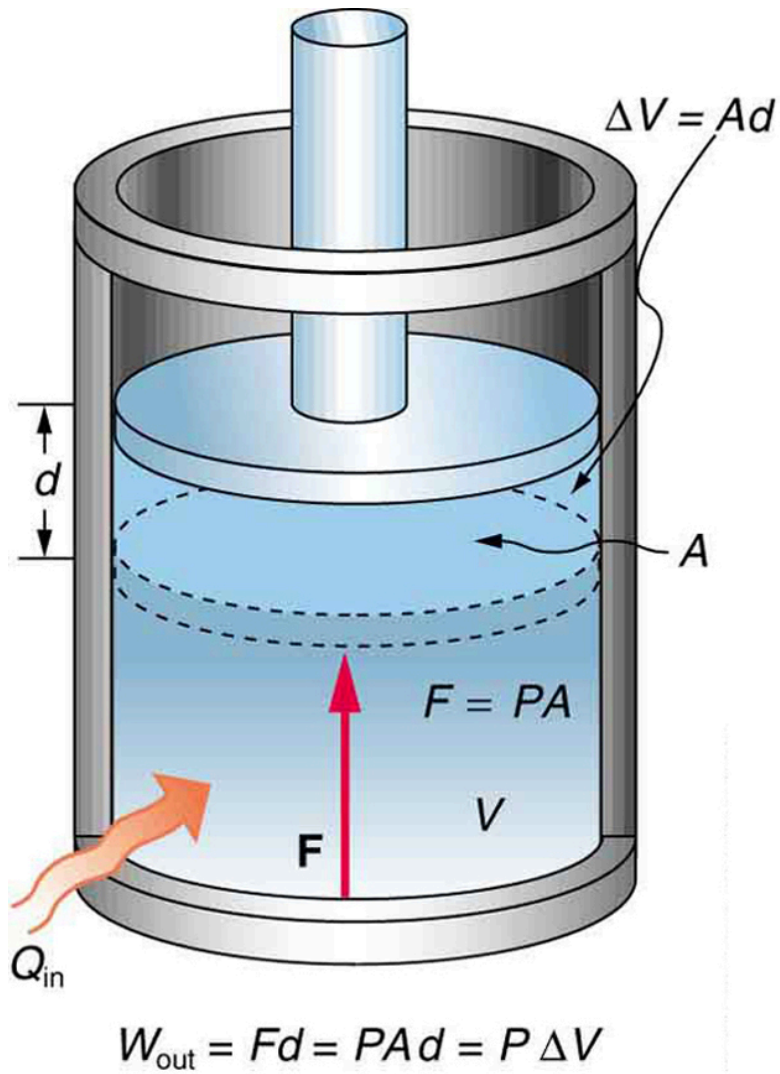
PV Diagrams

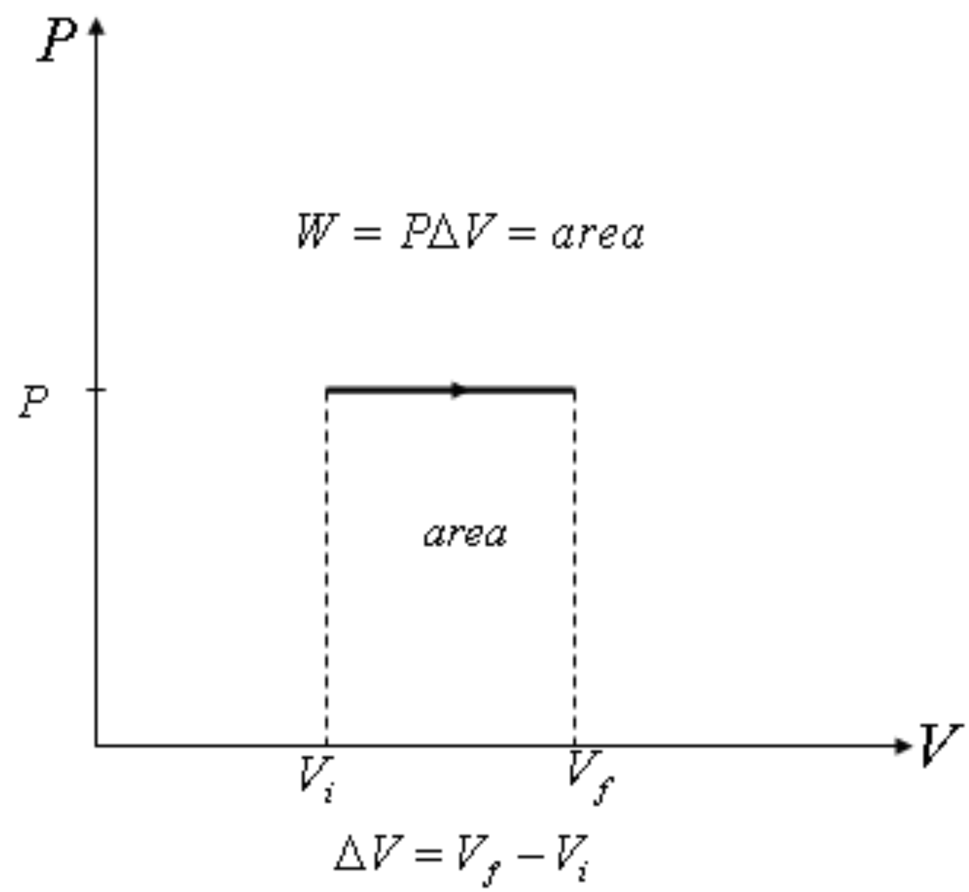


PV = NkT

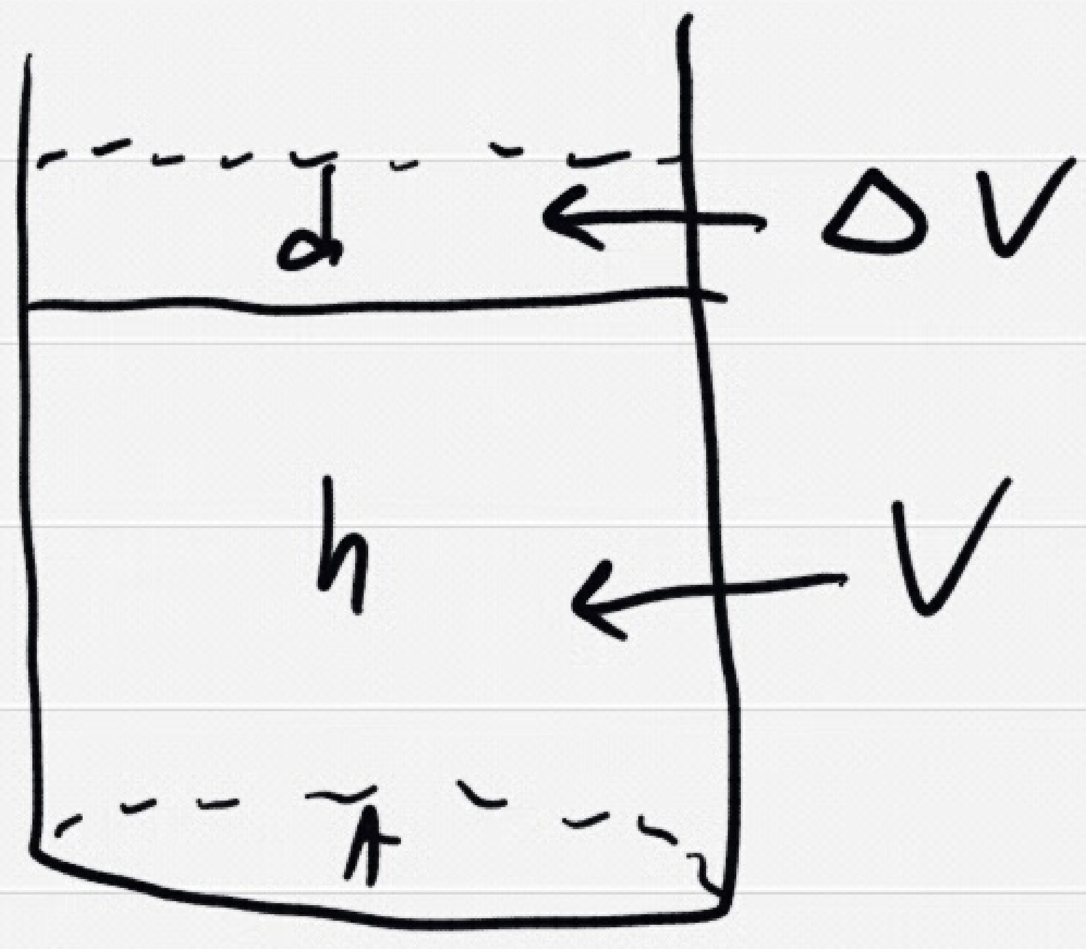
PV = nRT

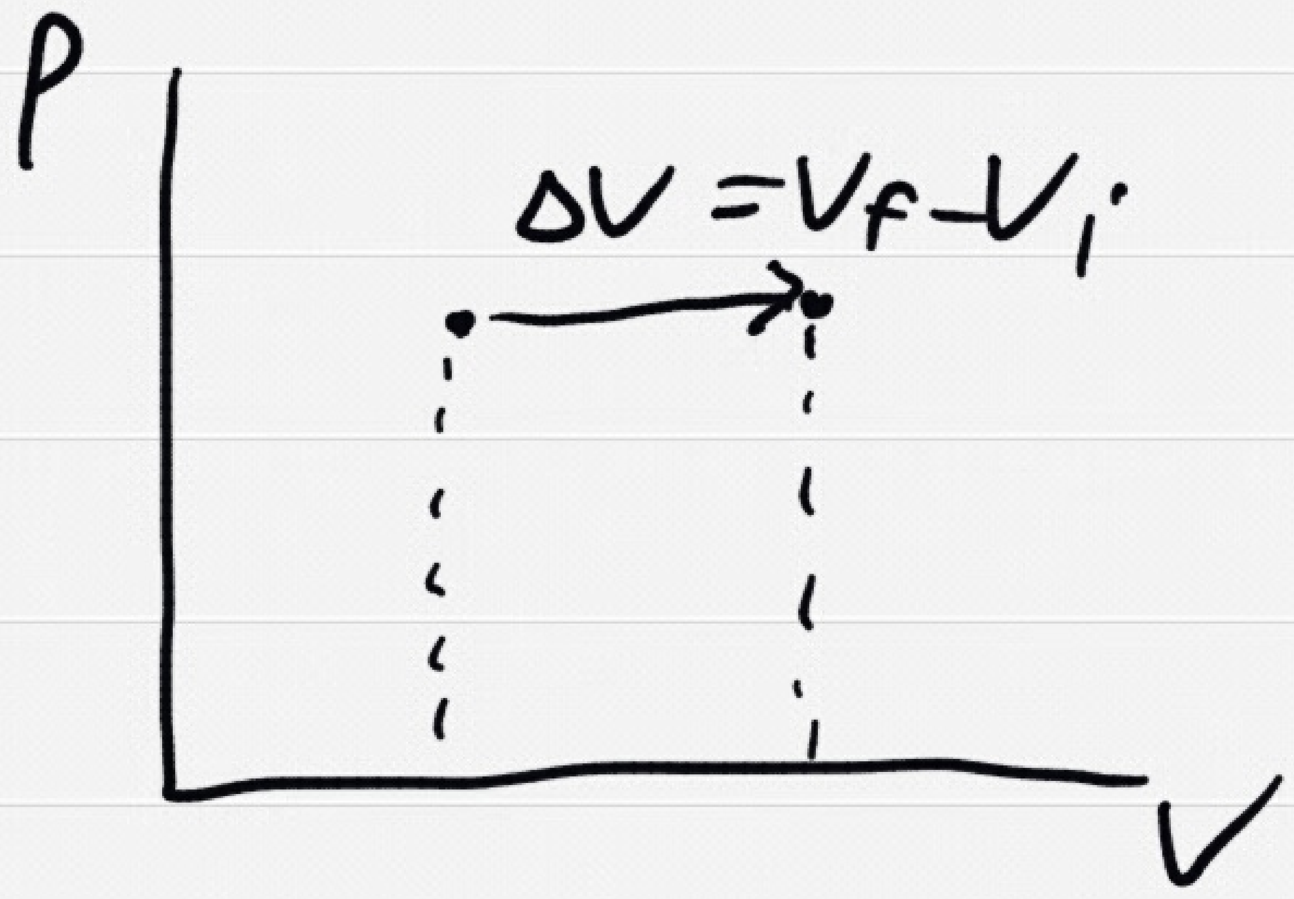
Work Done by Isobaric Gas





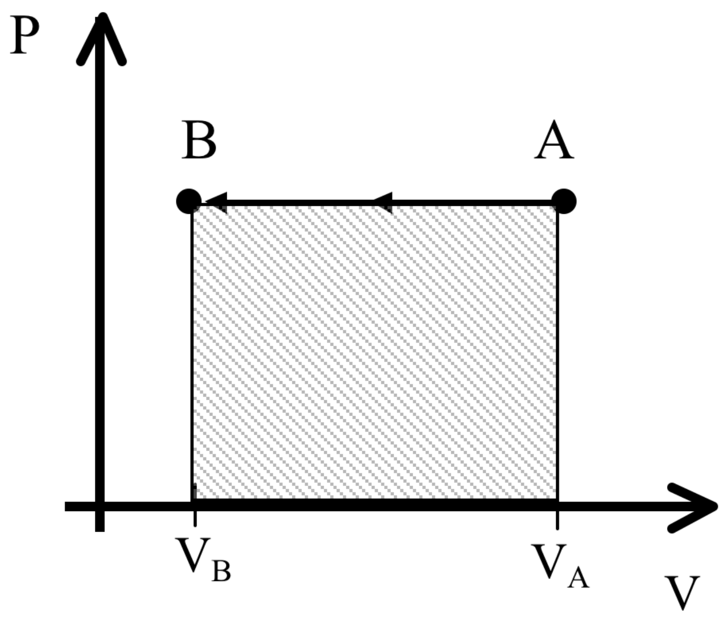
$$W = Fd = PAd$$
$$= P\Delta V$$





Concept Check

A gas is in a container with a piston lid and is taken from thermodynamic state, A, to a new thermo-dynamic state, B, shown on the P-V diagram below. The work done by the gas is:



A) the area under the P-V curve.

B) minus the area under the P-V curve.

C) Zero

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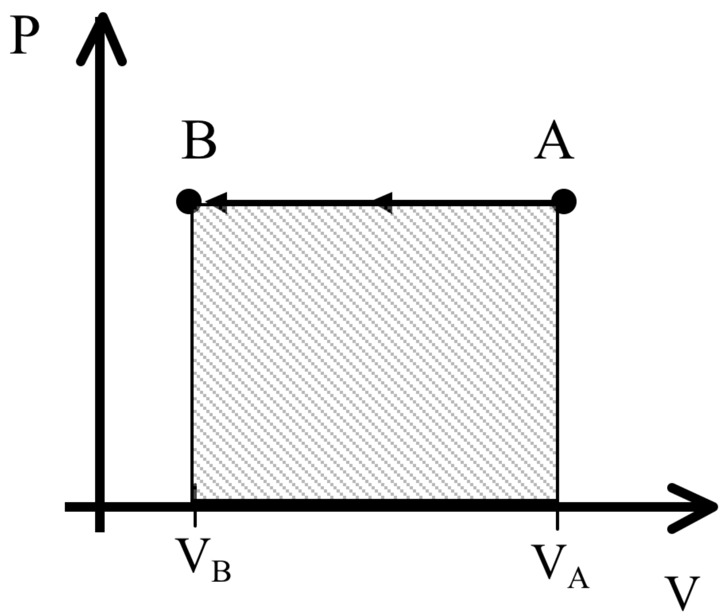


A) the area under the P-V curve.

B) minus the area under the P-V curve.

C) Zero

Heat Transferred to/from Isobaric Gas

- $\Delta U = Q - W = Q - P\Delta V \quad \Rightarrow Q = \Delta U + P\Delta V$
  - From ideal gas law $P\Delta V = \Delta(nRT)$
  - For constant n, $P\Delta V = nR\,\Delta T$

- For monatomic gas $\Delta U = \Delta(3/2\; nRT)$
  - For constant n, $\Delta U = 3/2\; nR\,\Delta T$

  - $Q = nR\,\Delta T + 3/2\; nR\,\Delta T = 5/2\; nR\,\Delta T$
    - (monatomic, constant n)

Isobaric

$$\Delta U = Q - W$$
$$= Q - P\Delta V$$

$$\Rightarrow Q = \Delta U + P\Delta V$$

$$PV = nRT$$
$$\Rightarrow P\Delta V = \Delta(nRT)$$
$$= nR\Delta T \quad \text{for const. } n$$

$$\Delta U = \Delta(3/2\, NkT)$$
$$= \Delta(3/2\, nRT)$$
for monatomic gas

$$Q = nR\Delta T + 3/2\, nR\Delta T$$

$$= \boxed{5/2\, nR\Delta T}$$

Temperature & Volume for Isobaric Gas

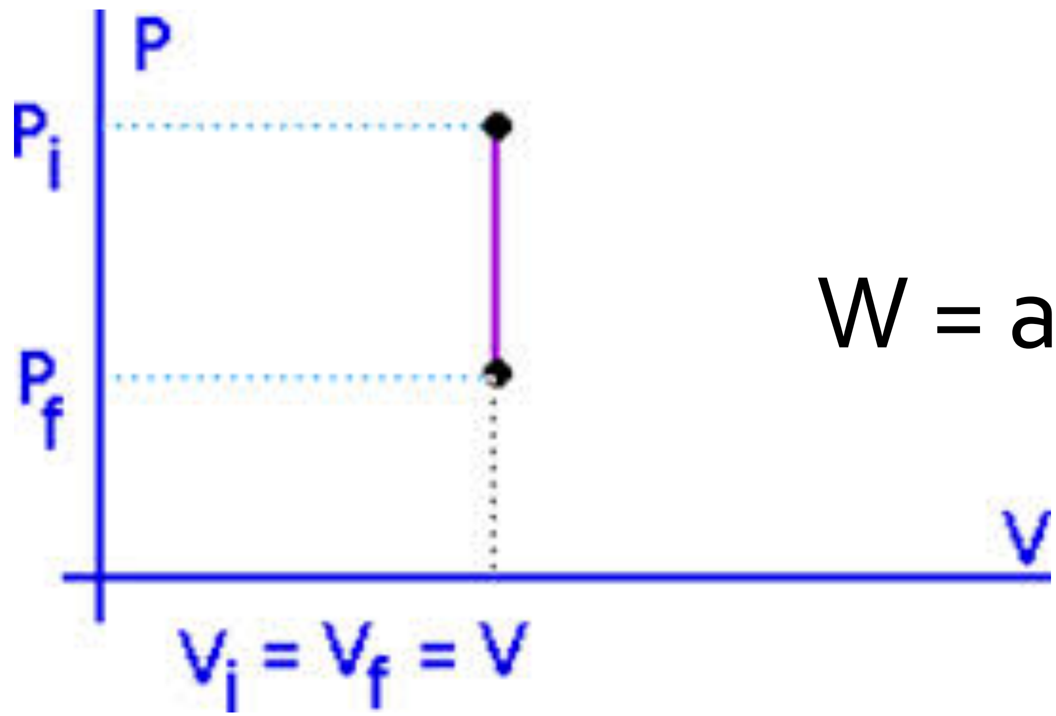
- $PV = nRT$
- $V = nRT/P$

- If heat is added, temperature goes up, volume goes up, and work is done by gas

- If heat is extracted, temperature goes down, volume goes down, and work is done on gas
  - You can produce heat by compressing the gas!

Work Done by Isochoric Gas

- Isochoric = Constant Volume
- No movement means no work.
  - (this does not mean there is no heat Q)



W = area = 0

Heat Transferred to/from Isochoric Gas

- $\Delta U = Q - W = Q$ (since $W = 0$)
- For monatomic gas $\Delta U = \Delta(3/2\ nRT)$
  - For constant n, $Q = \Delta U = 3/2\ nR\ \Delta T = 3/2\ Nk\ \Delta T$
  - This just corresponds to the total change in kinetic energy, since the average kinetic energy per atom is $3/2\ kT$

Isochoric

$$\Delta U = Q - W$$
$$= Q \qquad (W=0)$$

$$\Delta U = \Delta(3/2\, nRT)$$
for monatomic

If n constant:

$$Q = \Delta U = \boxed{3/2\, nR\Delta T}$$

Temperature & Pressure for Isochoric Gas

- PV = nRT
- P = nRT/V

- If heat is added, temperature goes up, and pressure goes up

- If heat is extracted, temperature goes down, and pressure goes down

Ideal Gas Processes

Process	ΔU	Q	W
Constant Volume (Isochoric)	$3/2\ nR\ \Delta T$ (monatomic)	$3/2\ nR\ \Delta T$ (monatomic)	0
Constant Pressure (Isobaric)	$3/2\ nR\ \Delta T$ (monatomic)	$5/2\ nR\ \Delta T$ (monatomic)	$P\Delta V = nR\ \Delta T$

Work and Heat: Isobaric vs. Isochoric

- Isobaric (constant n, P)
  - Heat added $Q = 5/2\ nR\ \Delta T$ (monatomic)
  - Work done as gas expands (volume increases)

- Isochoric (constant n, V)
  - Heat added $Q = 3/2\ nR\ \Delta T$ (monatomic)
  - No work done (volume constant)

- More heat required to change temperature of isobaric gas since some of the heat goes to work

Isobaric $Q_p = \frac{5}{2} nR\,\Delta T$
Isocharic $Q_v = \frac{3}{2} nR\,\Delta T$

specific heat

$$Q = mc\,\Delta T$$

rewrite $Q = nC\,\Delta T$

C = molar heat capacity

= J/(mole °C)

$$C_p = Q_p/(n\Delta T)$$

$$= \frac{5}{2} R$$

$$C_v = Q_v/(n\Delta T)$$

$$= \frac{3}{2} R$$

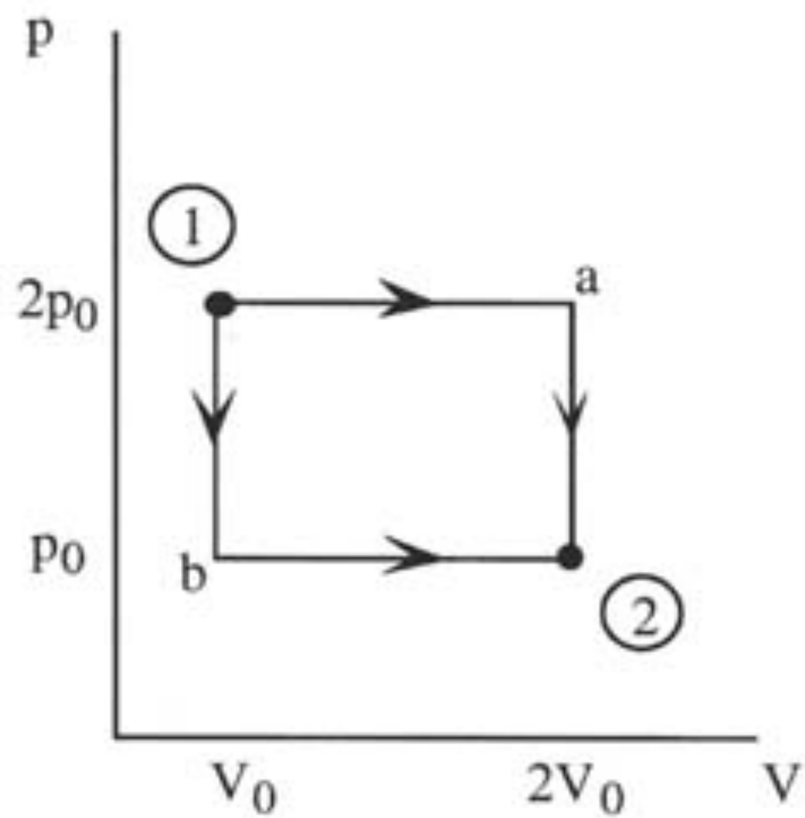
Specific Heat Capacity

- For a solid $Q = mc\,\Delta T$
- For an ideal gas we can write $Q = nC\,\Delta T$ in terms of a molar heat capacity
  - $C = Q/(n\,\Delta T)$
  - Units of C = [J]/([mole][°C])
- For a monatomic gas, these are:
  - $C_P = Q_{isobaric}/(n\,\Delta T) = 5/2\,R$
  - $C_V = Q_{isochoric}/(n\,\Delta T) = 3/2\,R$

Concept Check

- What is the total work done along paths a and b?

A. $W_a = p_o V_o$, $W_b = p_o V_o$
B. $W_a = 2p_o V_o$, $W_b = 2p_o V_o$
C. $W_a = 2p_o V_o$, $W_b = p_o V_o$
D. $W_a = p_o V_o$, $W_b = 2p_o V_o$



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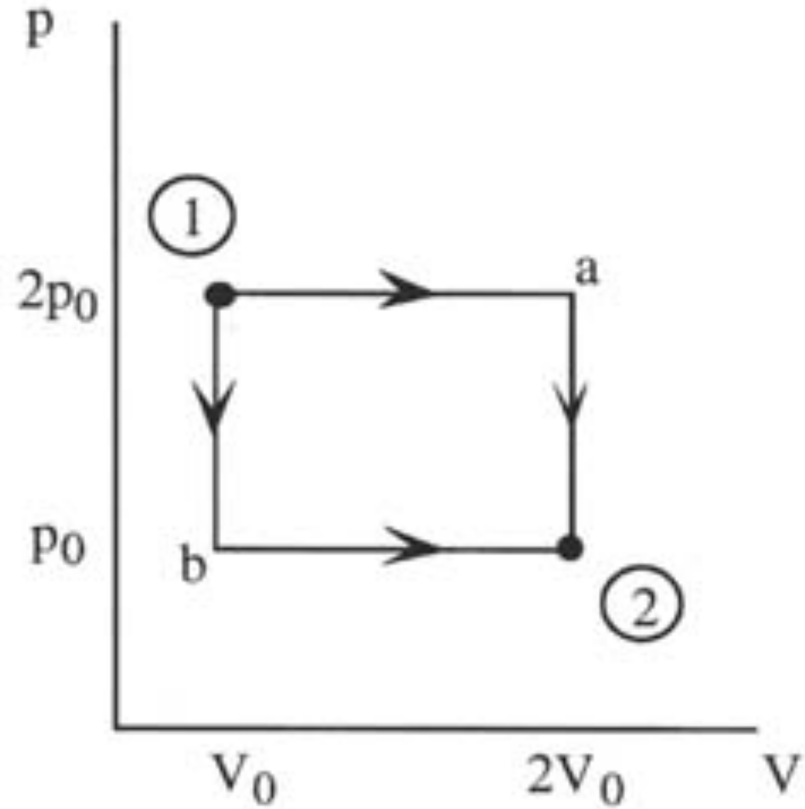
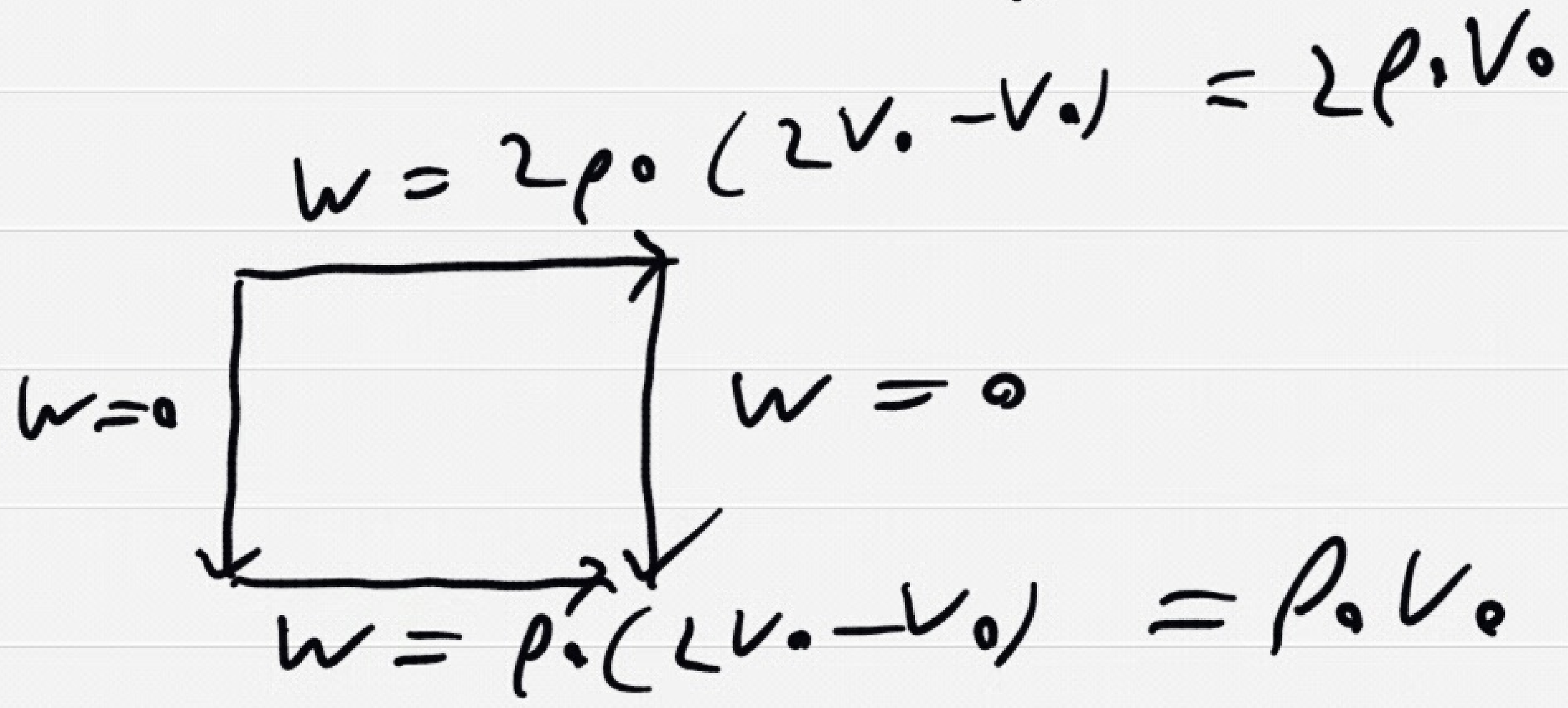
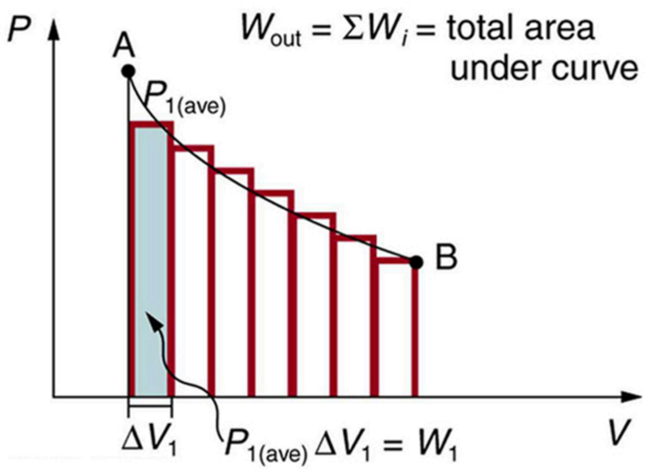


- Work only along horizontal legs

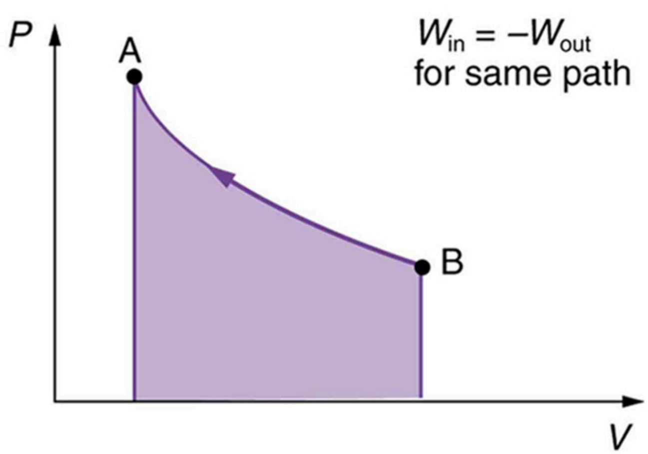


General Rule for Work Done by a Gas: Compute Area on P-V Diagram



(a)

Increase in volume => positive work done by gas



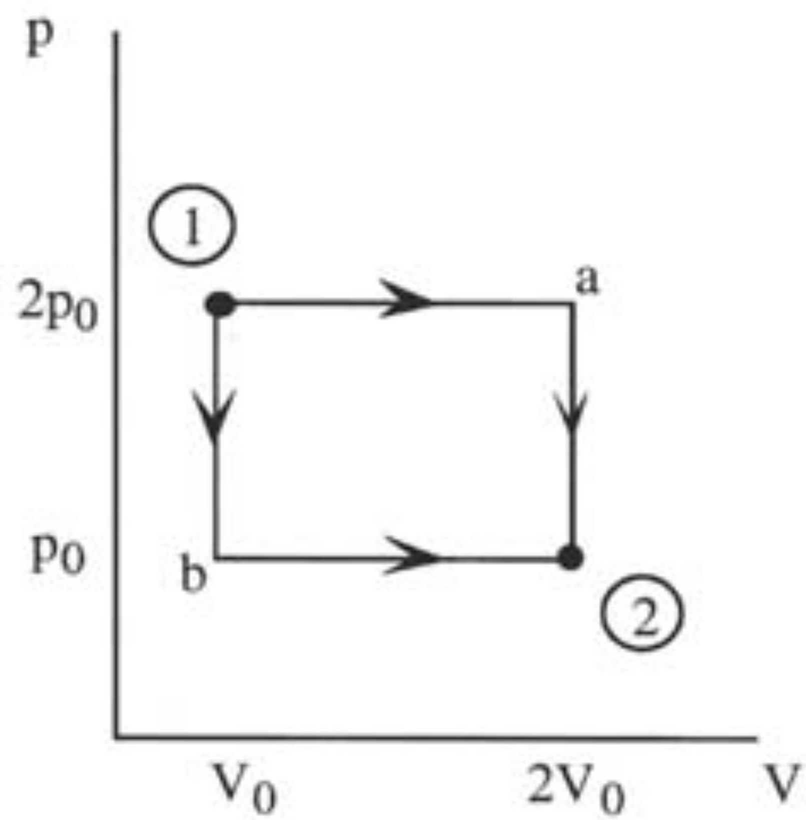
(b)

Decrease in volume => negative work done by gas (positive work done on gas)

Concept Check

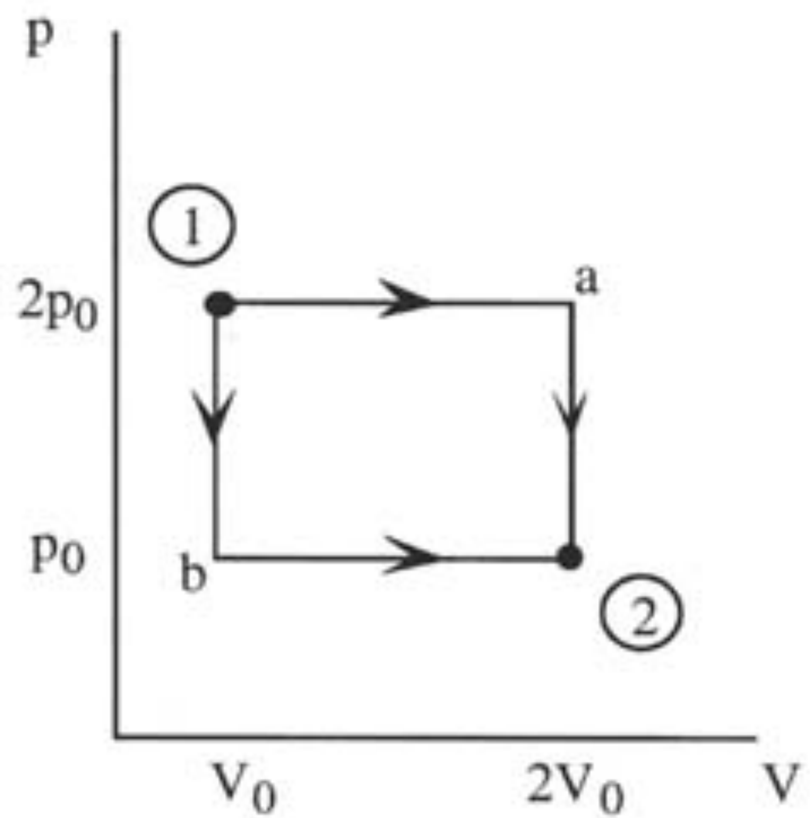
- What is the change in total internal energy along paths a and b?

A. $\Delta U_a = -p_o V_o$, $\Delta U_b = -p_o V_o$
B. $\Delta U_a = -2p_o V_o$, $\Delta U_b = -p_o V_o$
C. $\Delta U_a = 0$, $\Delta U_b = 0$
D. $\Delta U_a = 2p_o V_o$, $\Delta U_b = p_o V_o$



Concept Check

- What is the change in total internal energy along paths a and b?



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C. $\Delta U_a = 0$, $\Delta U_b = 0$
D. $\Delta U_a = 2p_oV_o$, $\Delta U_b = p_oV_o$

U proportional to T

but $T = PV/nR$

$$T_1 = 2P_0V_0/(nR)$$

$$T_2 = P_0 \cdot 2V_0/(nR) = T_1$$

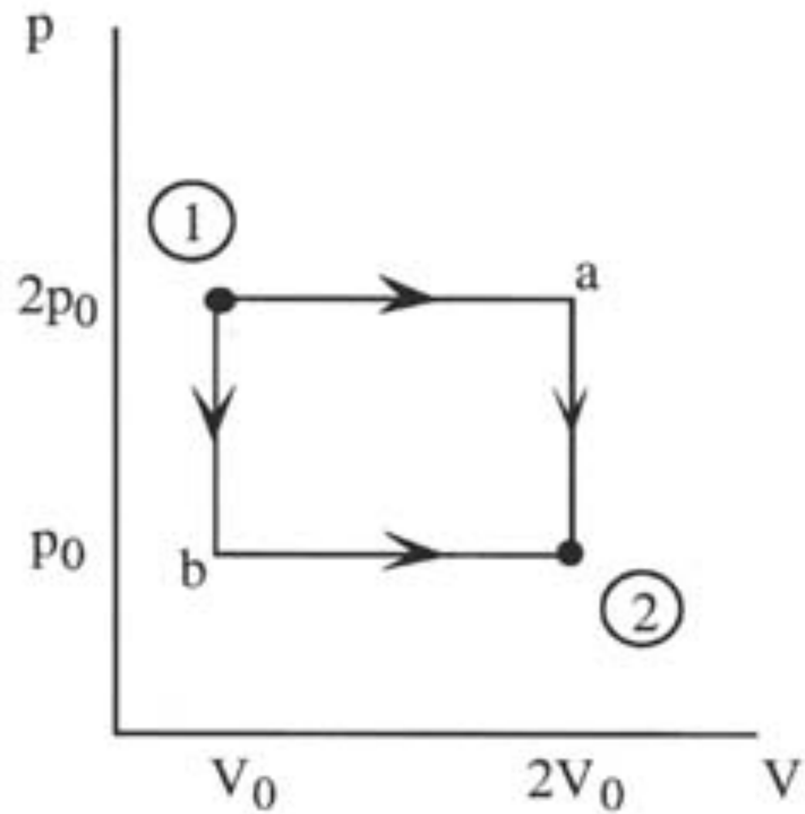
so $\Delta U_a = 0$

$\Delta U_b = 0$

Internal Energy and State Variables

- U proportional to temperature for ideal gas
  - For monatomic gas $U = 3/2\ nRT$
- But, by the ideal gas law, $PV = nRT$
  - So, for constant n, U is proportional to PV
  - For monatomic gas, $U = 3/2\ PV$
- The change in internal energy does **not** depend on path (unlike W and Q)

First Law in Action



- $W_a = 2p_oV_o$, $W_b = p_oV_o$
- $\Delta U_a = 0$, $\Delta U_b = 0$
- $\Delta U = Q - W$
- $Q_a = 2p_oV_o$, $Q_b = p_oV_o$
- To get more work out of path a, we had to add more heat to the system