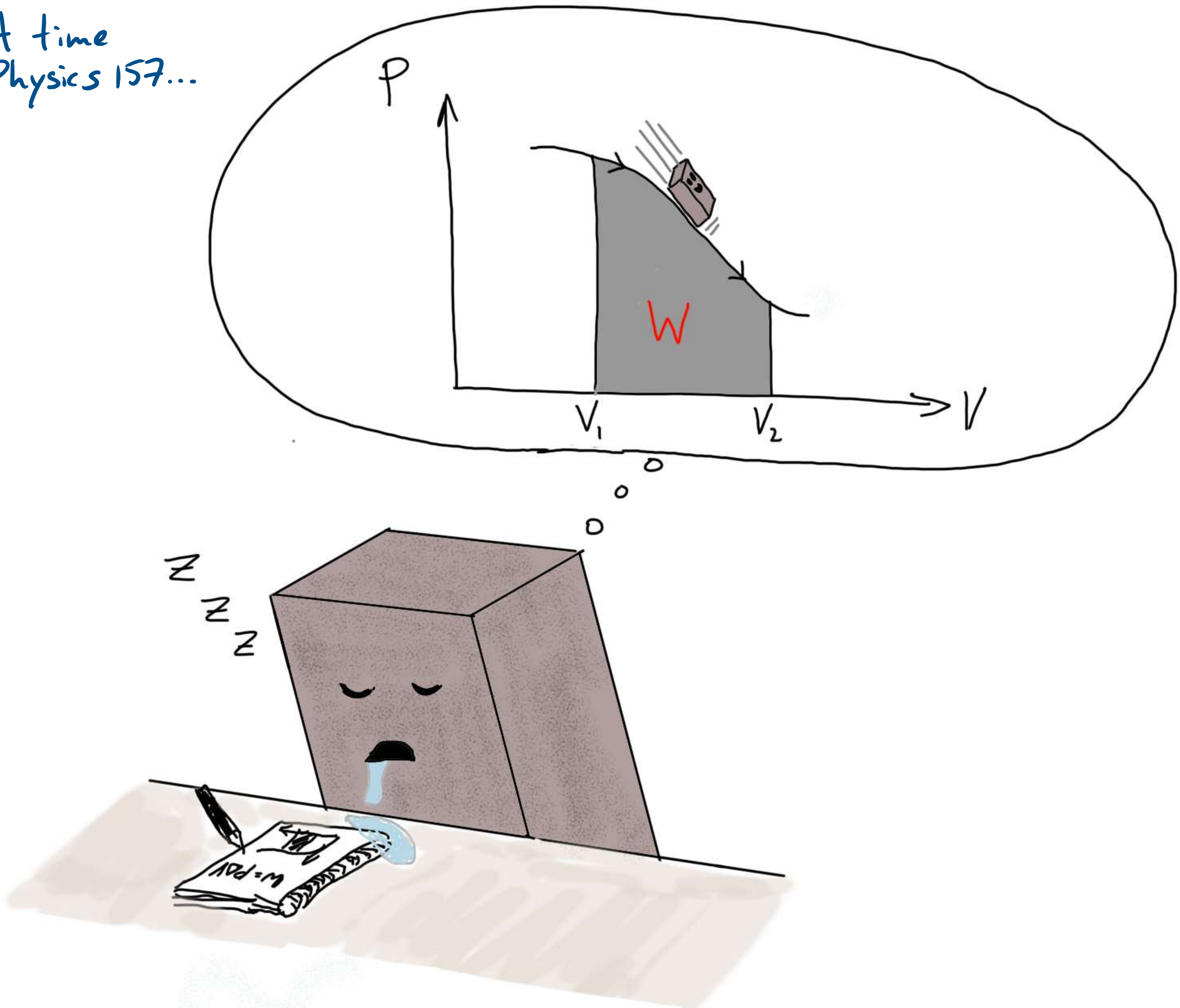
Learning goals:

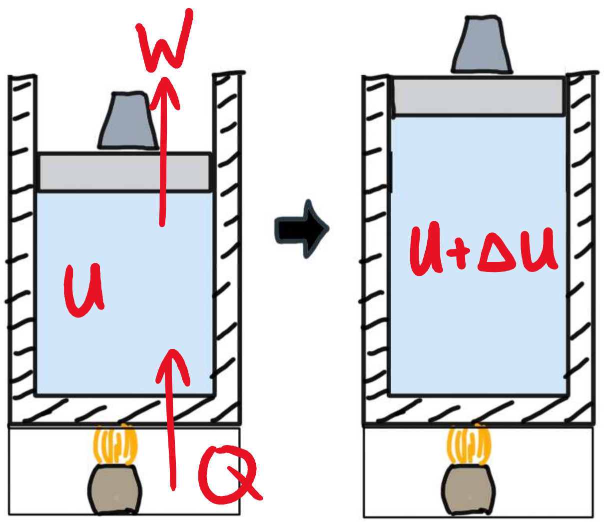
- Determine the sign of W for different parts of a system and explain why these must add to zero for a closed system
- Explain why the temperature change is zero in the free expansion of an ideal gas
- Explain why the change in internal energy for a gas depends only on the initial and final states and not the specific process
- Use the First Law of thermodynamics to calculate Q for a process depicted on a PV diagram
- For processes on a PV diagram with the same initial and final state, determine which has the largest Q and/or the largest W

Last time in Physics 157...



THE FIRST LAW OF THERMODYNAMICS

= Conservation of energy



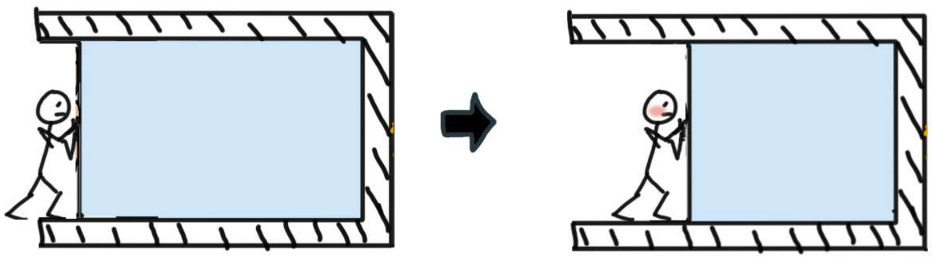
$$\Delta U = Q - W$$

- ΔU: net change in energy of gas
- Q: heat added to gas
- W: work done by gas

Work done by a gas (constant pressure):

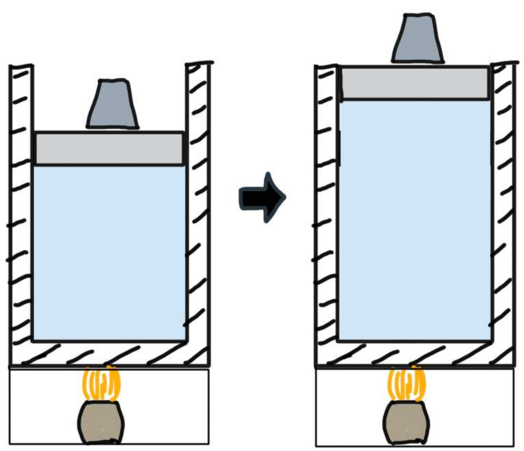
$$W_{gas} = P \Delta V$$

P ↖ F/A $\qquad$ ΔV ↖ $A \Delta x$



Compression:

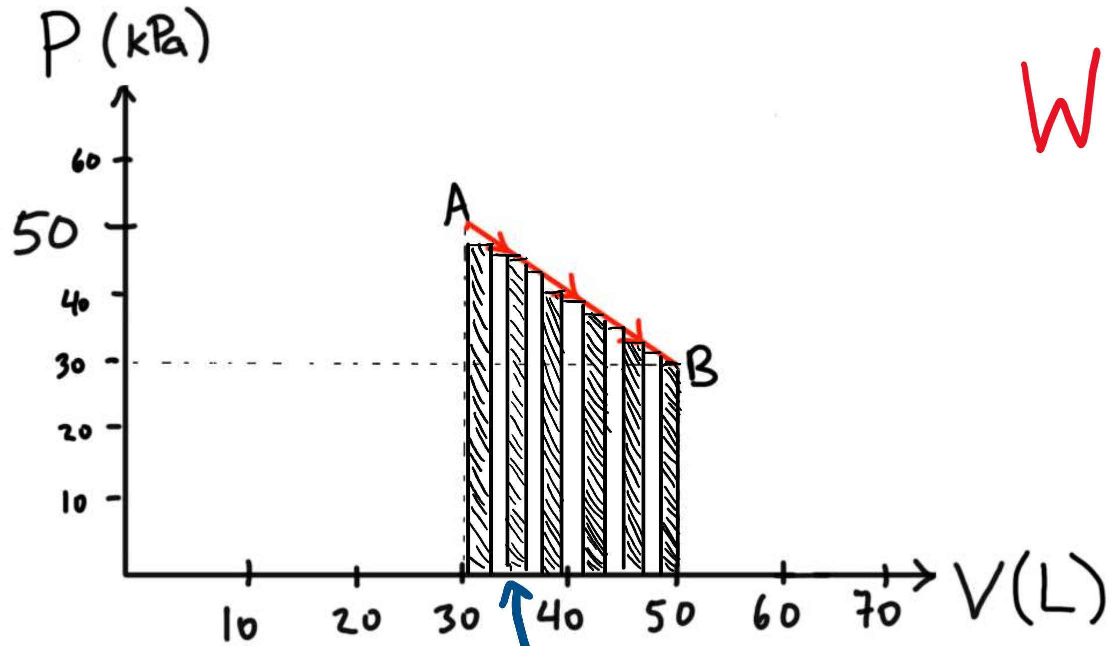
W_{gas} negative



expansion:

W_{gas} positive

Work for changing pressure:



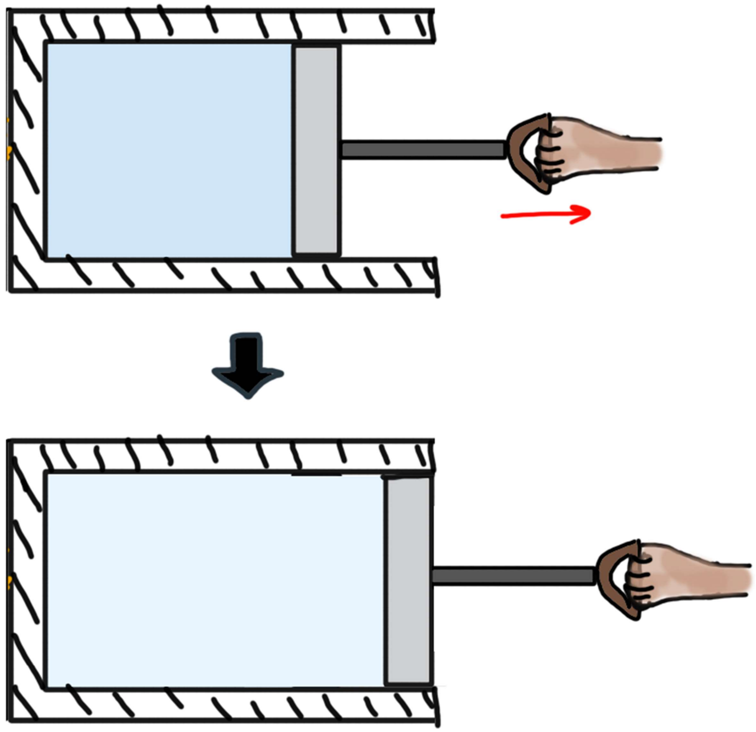
rectangle area is $P(V) \cdot dV$

$$W = \int_{V_i}^{V_f} P(V)\, dV$$

= area under the P-V graph

+ if V inceasing

- if V decreasing



A person pulls on a piston to reduce the pressure of the gas inside a cylinder. In this situation:

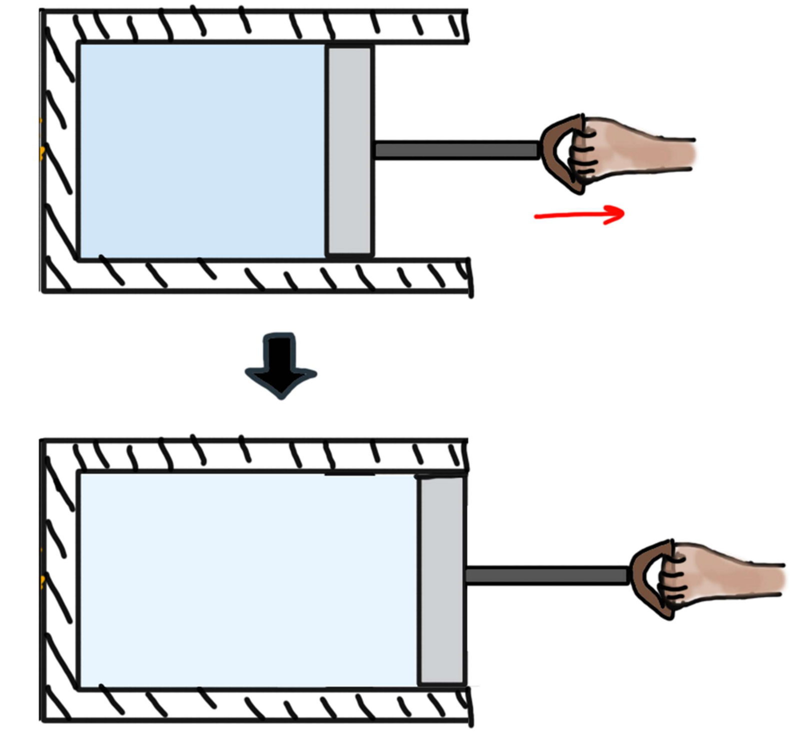
A) the work done by the gas and by the person are both negative.

B) the work done by the gas and by the person are both positive.

C) the work done by the gas is negative and the work done by the person is positive.

D) the work done by the gas is positive and the work done by the person is negative.

EXTRA: Is anything else doing work?



gas expands ⇒ +ve work
person pulls up & piston moves up ⇒ +ve work

★ outside air does −ve work on piston ★

$$W_{gas} + W_{person} + W_{air} = \Delta E_{piston} = 0$$

A person pulls on a piston to reduce the pressure of the gas inside a cylinder. In this situation:

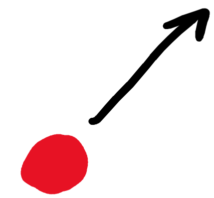
A) the work done by the gas and by the person are both negative.

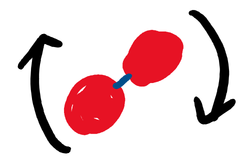
B) the work done by the gas and by the person are both positive.

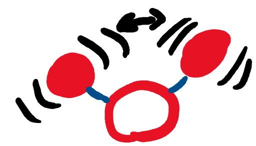
C) the work done by the gas is negative and the work done by the person is positive.

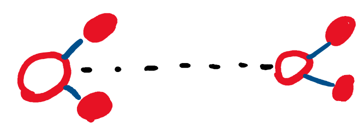
D) the work done by the gas is positive and the work done by the person is negative.

U : The energy of a gas

Sum of : kinetic energy 

rotational energy 

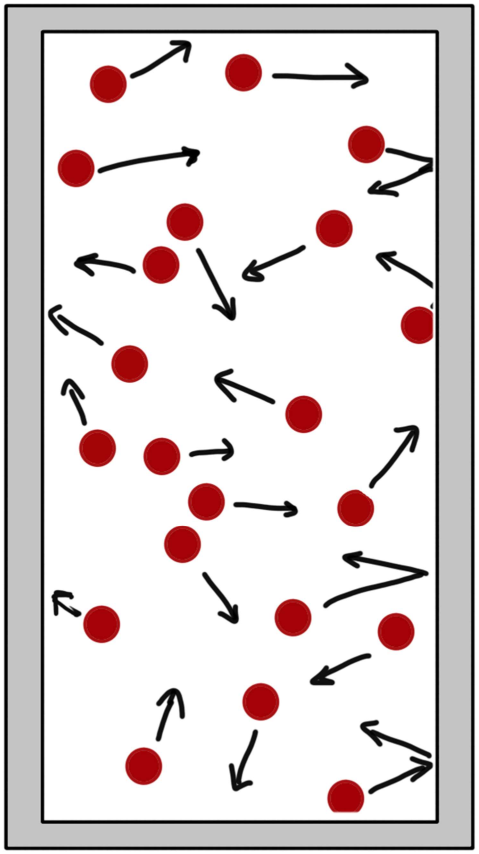
vibrational energy 

electrostatic potential energy 

Main equation : $\Delta U = nC_v \Delta T$

molar specific heat: larger for more complex molecules

Example: Energy of a monatomic ideal gas



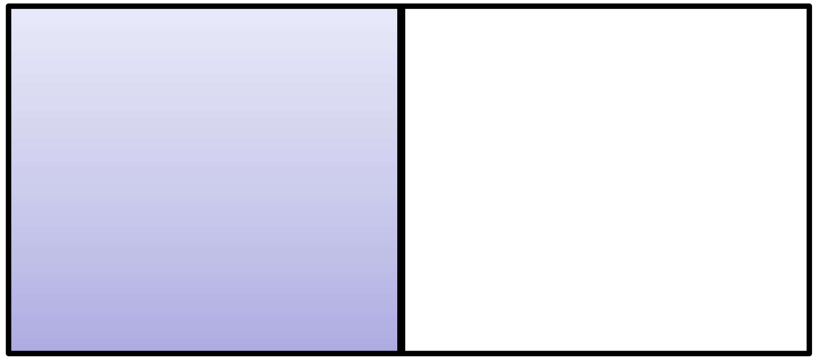
U = total kinetic energy of molecules

$= N \cdot E_{kin}^{avg}$

$= \text{const} \times n \times T$

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

$\Delta U = nC_v \Delta T$ so $C_v = \frac{3}{2} R$

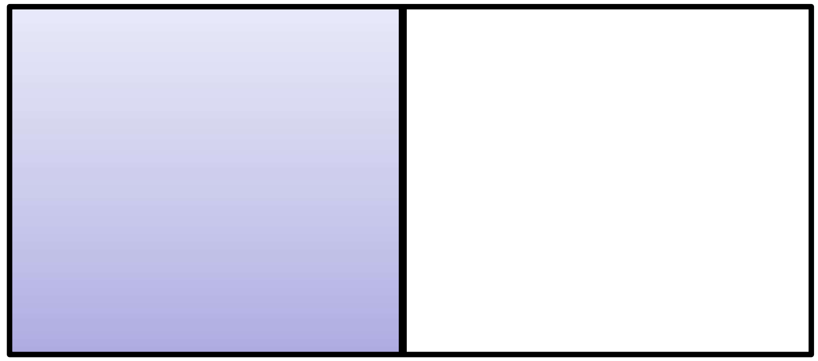


A container with a partition in the middle is filled halfway with an ideal monatomic gas. If the partition is removed instantaneously so that the gas is allowed to fill the box, the final temperature of the gas will be

A) lower than the original temperature.
B) the same as the original temperature.
C) higher than the original temperature.
D) I have no idea how to think about this.

Hint: what is the microscopic meaning of temperature?

EXTRA: What if it is a real gas with attractive interactions between molecules?



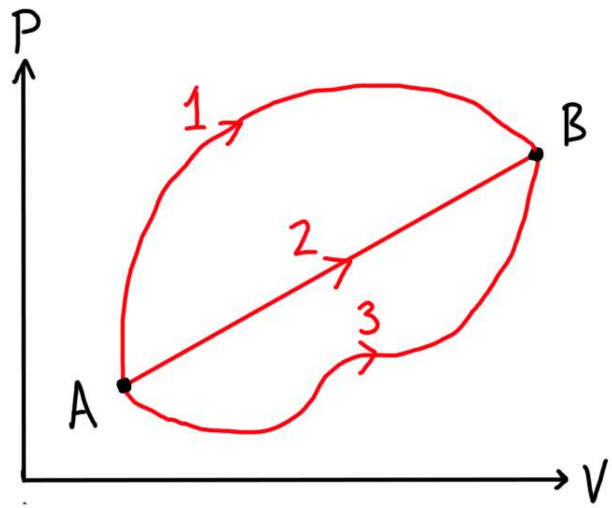
A container with a partition in the middle is filled halfway with an ideal monatomic gas. If the partition is removed instantaneously so that the gas is allowed to fill the box, the final temperature of the gas will be

A) Lower than the original temperature
B) The same as the original temperature
C) Higher than the original temperature

- Energy conserved.
- Kinetic energy per molecule doesn't change.

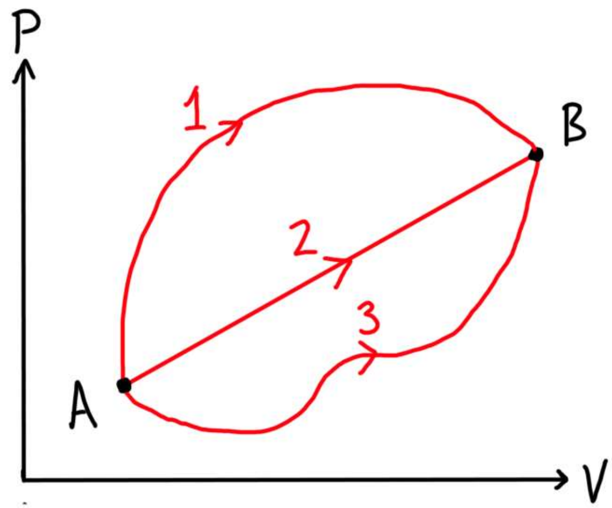
$\Rightarrow$ Temperature doesn't change

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



The graph shows three possible processes for an ideal gas going from A to B. For which path is the change ΔU largest?

A) Path 1
B) Path 2
C) Path 3
D) They are all the same.
E) We don't have enough information to answer.



The graph shows three possible processes for an ideal gas going from A to B. For which path is the change ΔU largest?

$\Delta U = n C_v \Delta T$

T is determined by P, V via $PV = nRT$

Same change in P, V ⇒ same change in T

so ΔU is the same.

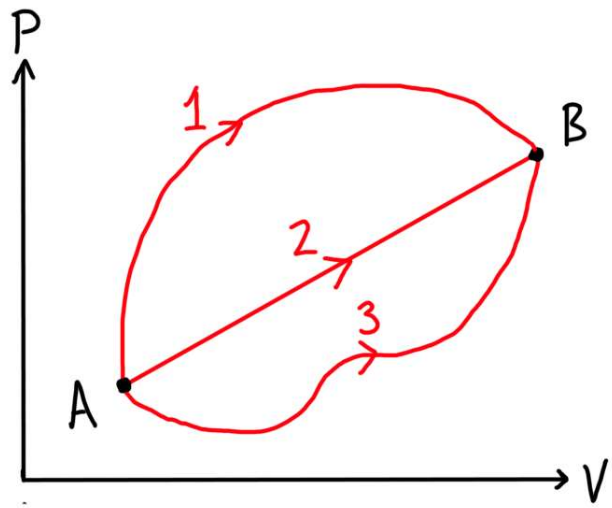
A) Path 1
B) Path 2
C) Path 3
D) They are all the same.
E) We don't have enough information to answer.

U is a "state variable": determined from P, V, T, n

Ideal gas: U determined from T and n only

ΔU only depends on initial & final state

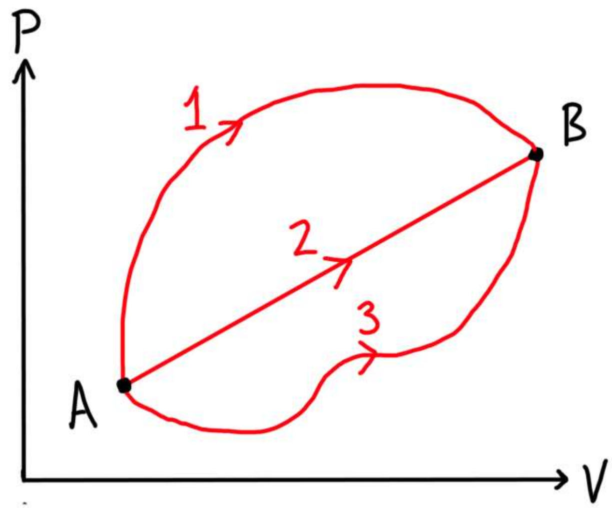
(not on the path)



The graph shows three possible processes for an ideal gas going from A to B. For which path is Q (the heat added) the largest?

Hint: Use the First Law of Thermodynamics.

A) Path 1
B) Path 2
C) Path 3
D) They are all the same.
E) We don't have enough information to answer.



The graph shows three possible processes for an ideal gas going from A to B. For which path is Q (the heat added) the largest?

Hint: Use the First Law of Thermodynamics.

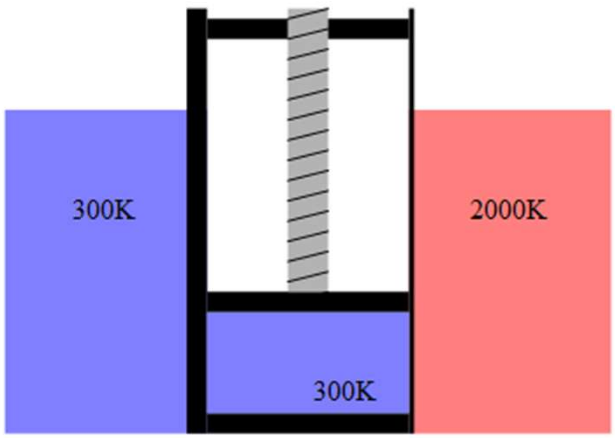
→ $Q = \Delta U + W$

A) Path 1
B) Path 2
C) Path 3
D) They are all the same.
E) We don't have enough information to answer.

ΔU is the same (last question)
W largest for path 1 (largest area under the graph)

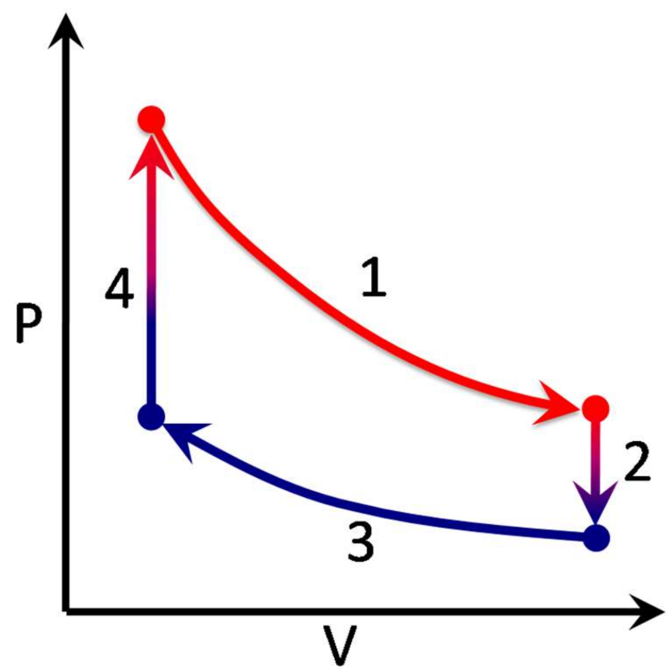
∴ Q largest for path 1

Analyzing thermodynamic processes:



Want to:

- calculate temperature, pressure, volume — IDEAL GAS LAW
- calculate work done — $P\Delta V$
- calculate heat added — $Q = \Delta U + W$



We'll understand these for

isochoric: V const.
isobaric: P const.
isothermal: T const.
adiabatic: $Q = 0$