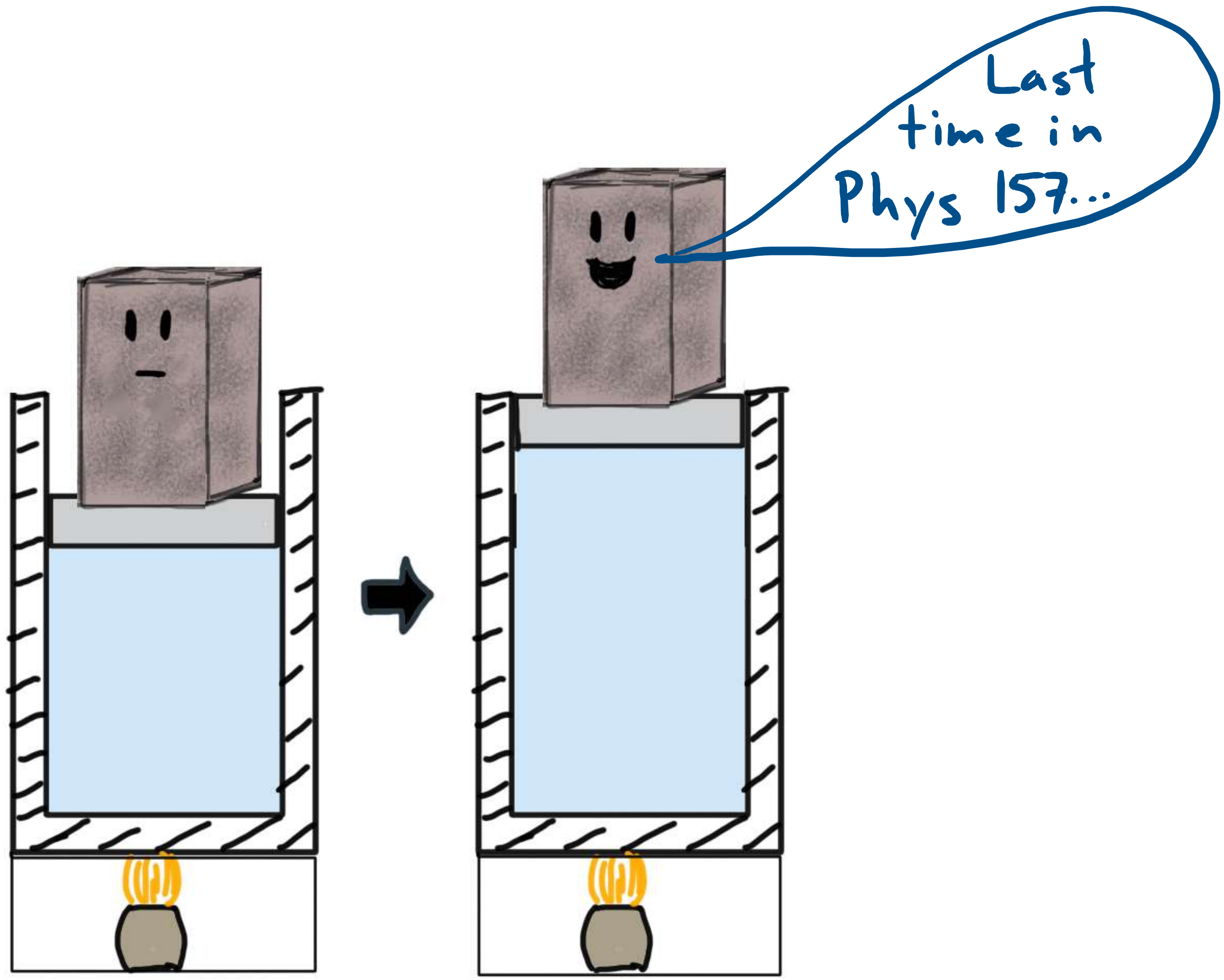
Office hours today: after class (Remo)
4-5pm, 8-9pm (Zoom)

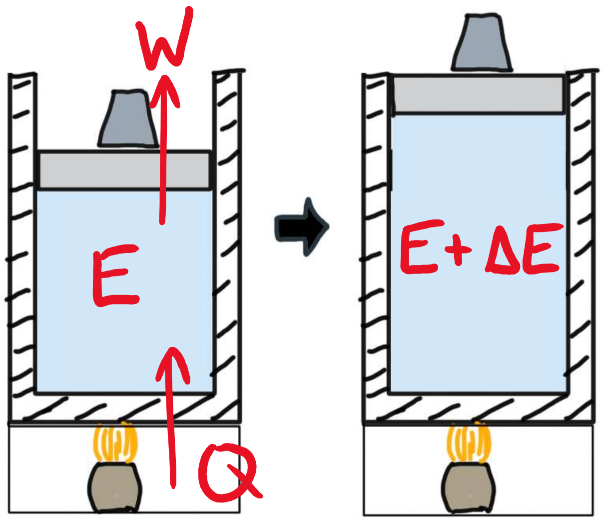
Learning Goals for today

- Decide when the work done by a gas is positive or negative
- Calculate work done by a gas in a process given how the pressure changes with volume during a process
- Relate the work done by a gas to the area under the curve describing the process on a PV diagram
- Explain why the work done by a gas plus the work done by the environment of the gas (external forces) should add to zero
- Explain what is meant by the internal energy of a gas
- Calculate the change in internal energy for a gas given the change in temperature


Last time in Phys 157...

THE FIRST LAW OF THERMODYNAMICS

= Conservation of energy



also called ΔU

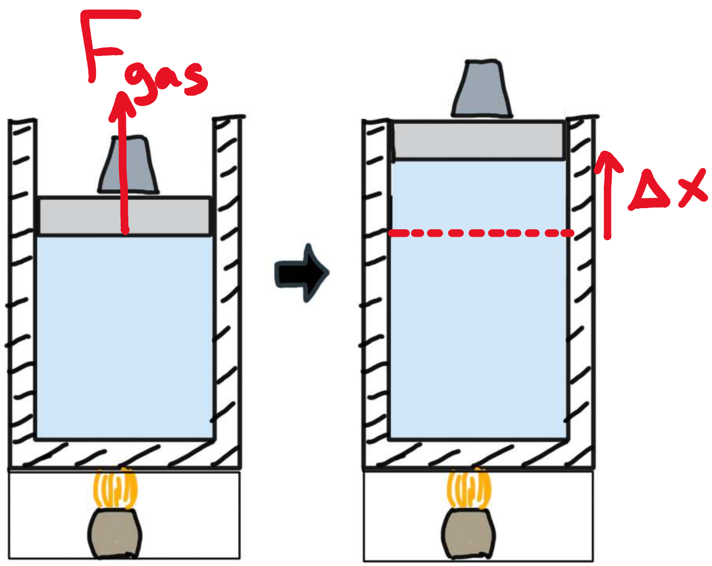
$$\Delta E_{gas} = Q - W$$

ΔE_{gas}: net change in energy of gas

Q: heat added to gas

W: work done by gas

WORK : transfer of energy via mechanical process



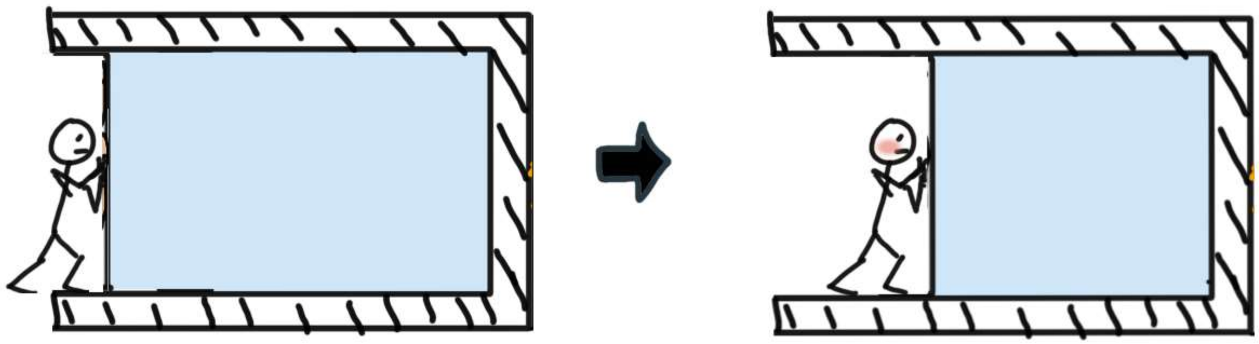
work done by system

$$W = F \cdot \Delta x_{\parallel}$$

Force exerted by system

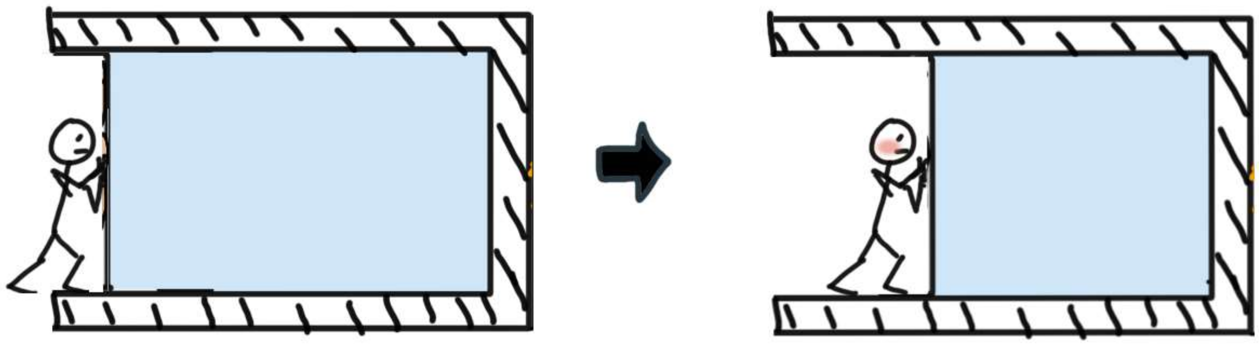
displacement in direction of force

- assumes constant force



A gas with pressure P is in a cylinder with a piston of area A. A little man pushes the piston and moves it by a small amount d. If the pressure remains approximately constant during this time, the work W done by the gas in this process is:

A) W = 0 : the little man is doing the work.
B) W is positive and equal to P A d
C) W is negative and equal to - P A d
D) Not enough information to answer.



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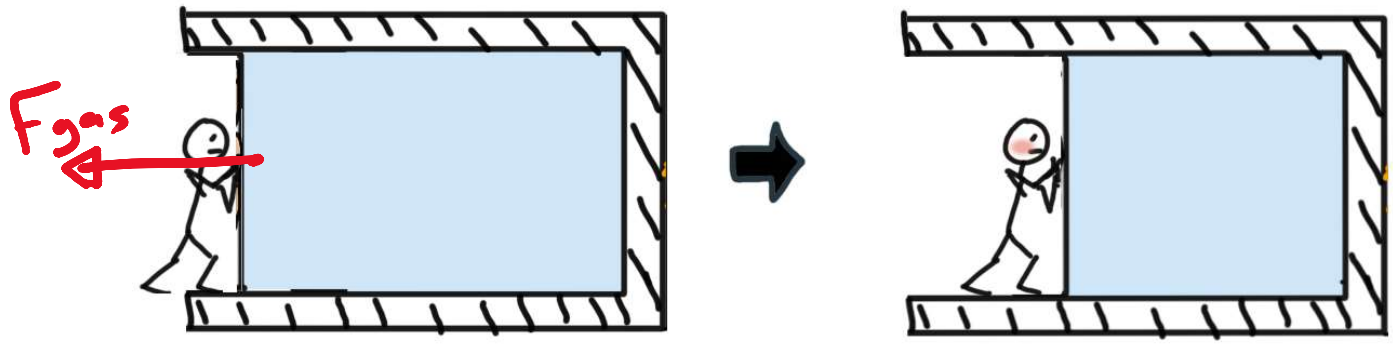

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$F_{gas} = P \cdot A$

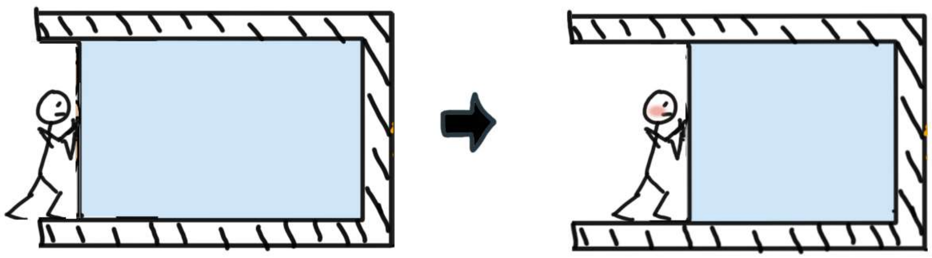
displacement in direction of force is

$\Delta x_{\parallel} = -d$

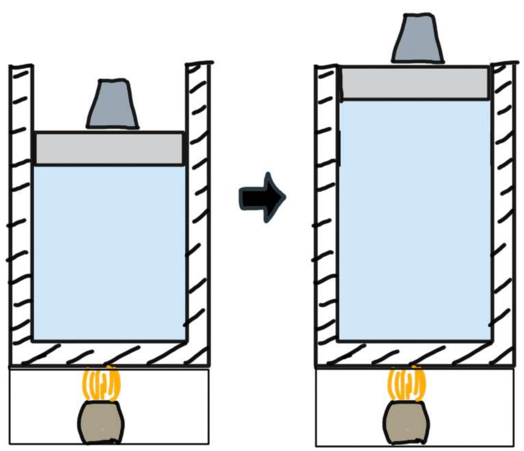
$$W = F_{gas} \cdot \Delta x_{\parallel} = -P \cdot A \cdot d$$
$$= P \Delta V$$

Work done by a gas (constant pressure):

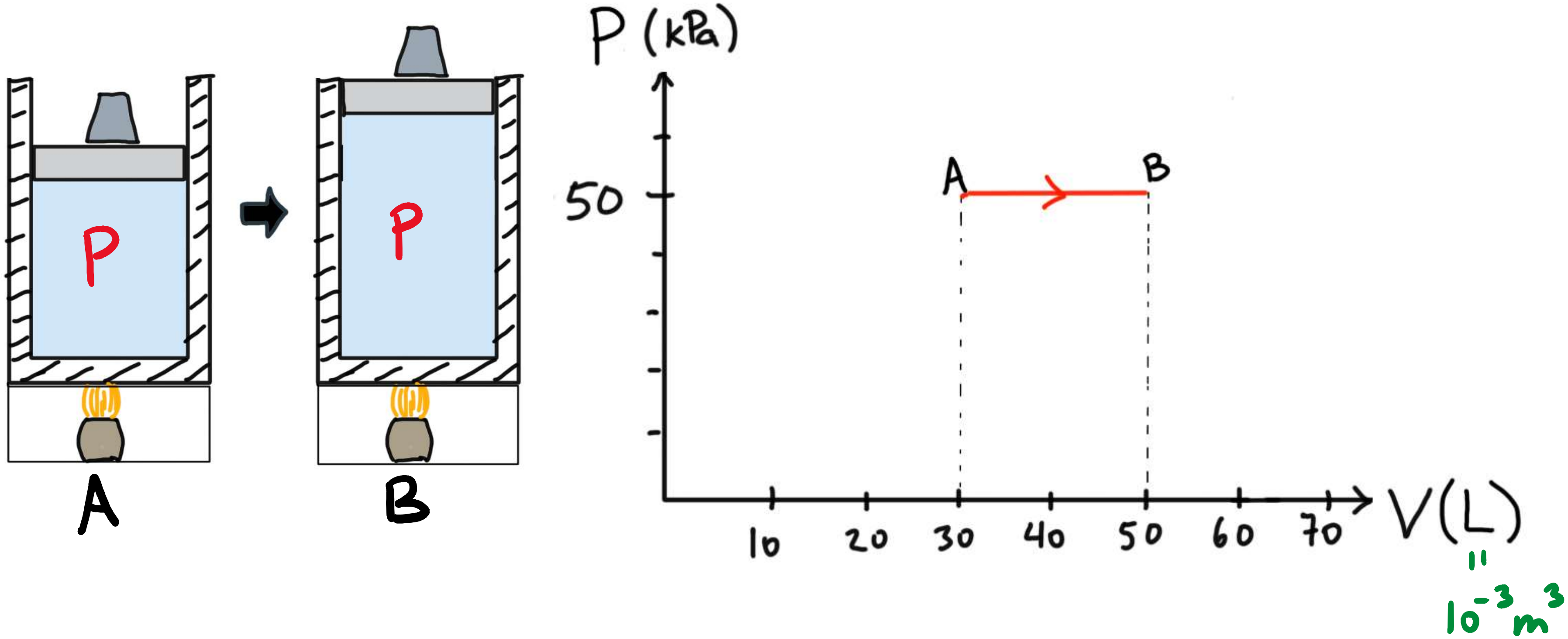
$$W_{gas} = \underset{\uparrow F/A}{P}\ \underset{\uparrow A\,\Delta x}{\Delta V}$$



Compression:
W_{gas} negative



expansion:
W_{gas} positive



The graph shows how the pressure and volume of the gas in the cylinder change during the process A -> B. How much work does the gas do in this process?

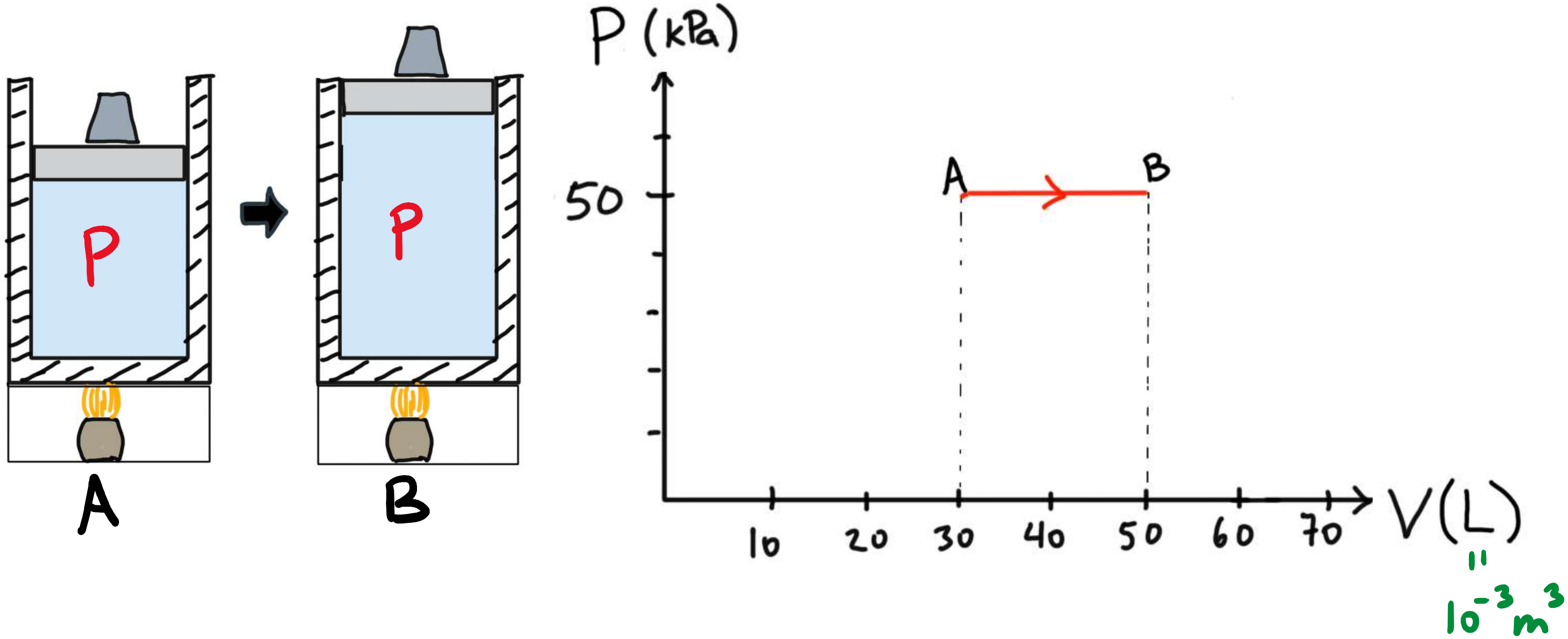
A) -100,000J

B) 100J

C) 1000J

D) -1000J

E)100,000J



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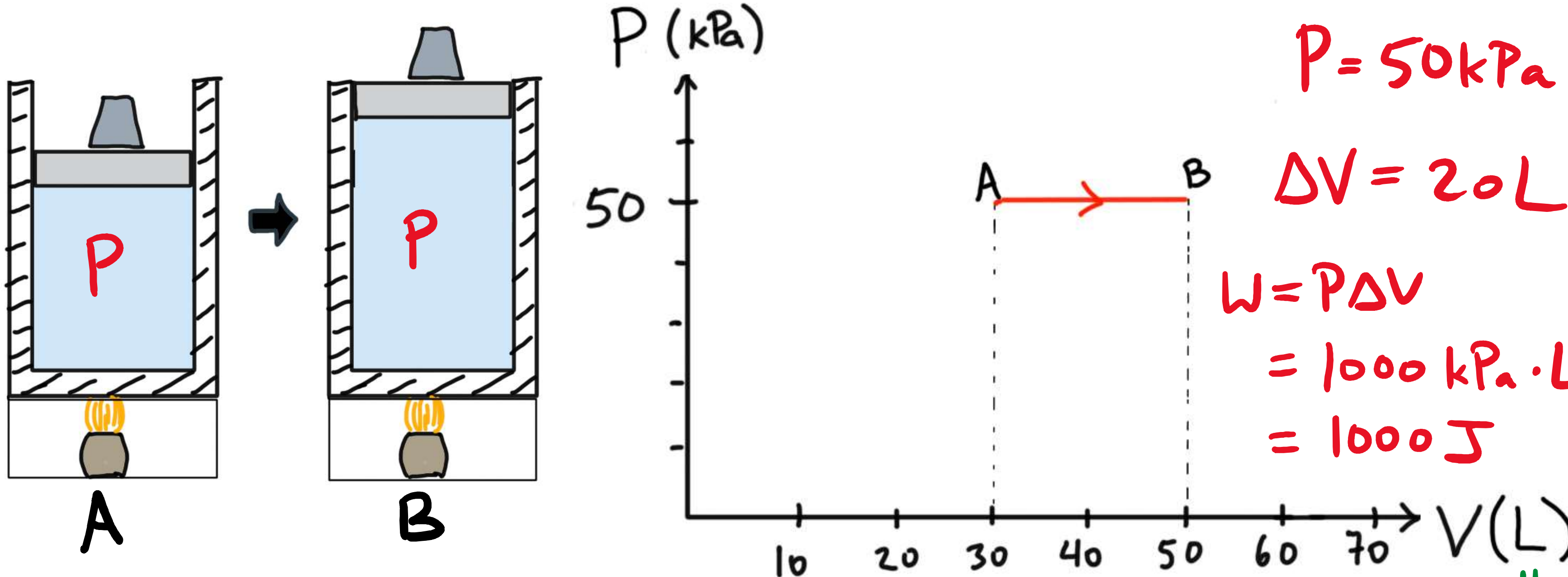

$P = 50\,kPa$

$\Delta V = 20\,L$

$W = P\Delta V$

$= 1000\,kPa \cdot L$

$= 1000\,J$

$L = 10^{-3}\,m^3$

$kPa \times L = (10^3\,Pa) \times (10^{-3}\,m^3) = J$

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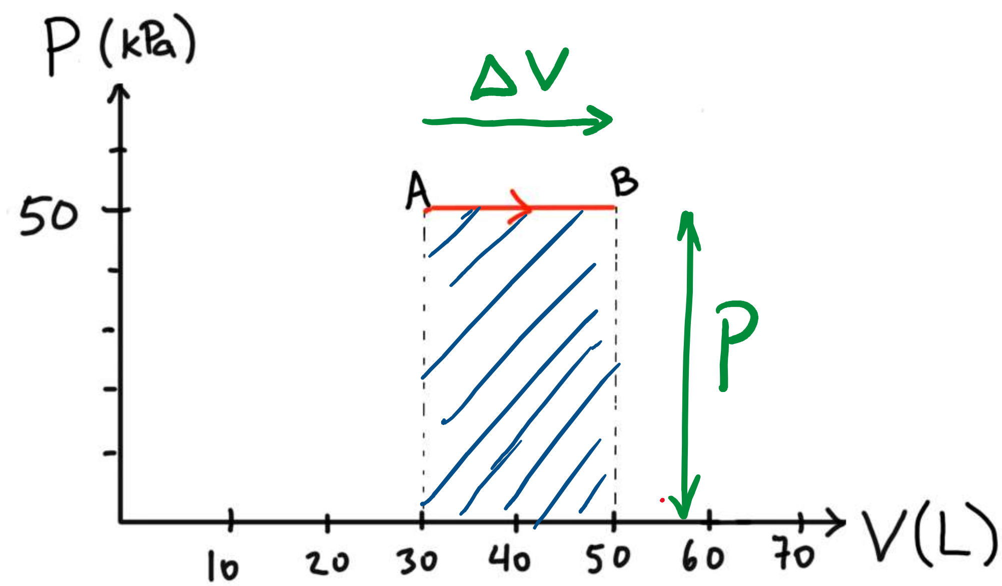
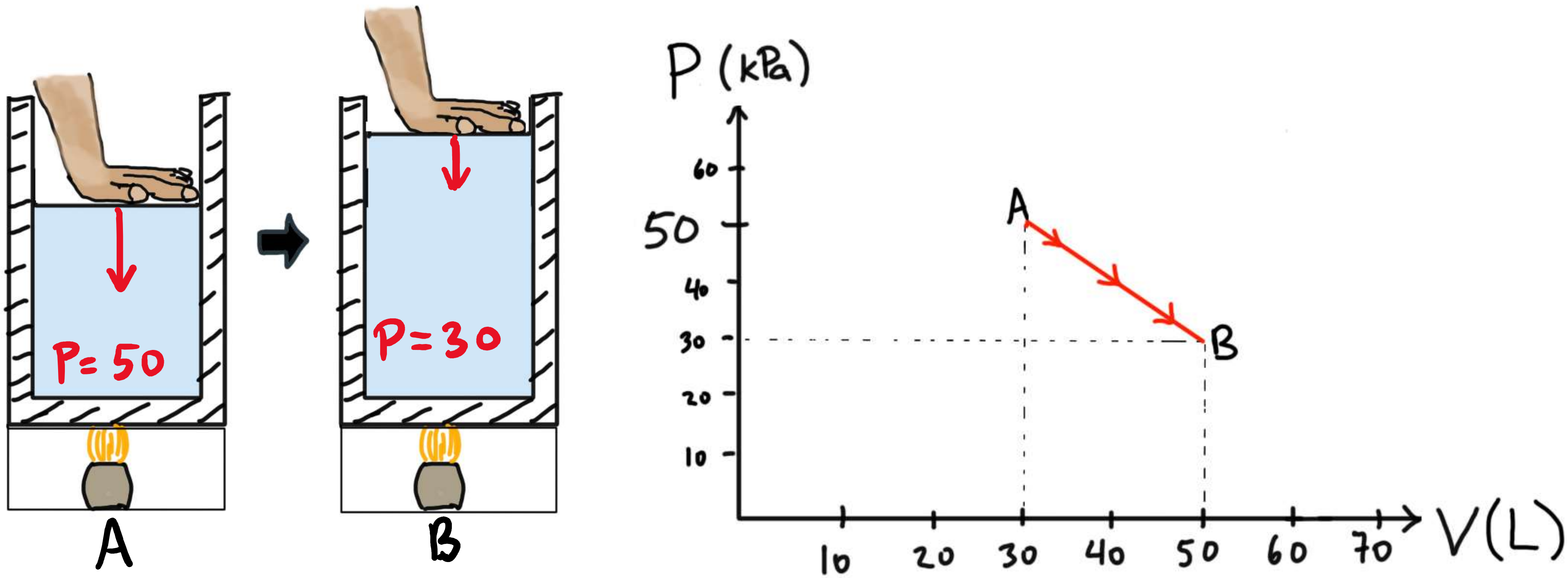
Work is the area under the P vs V graph



$$W = P\Delta V$$

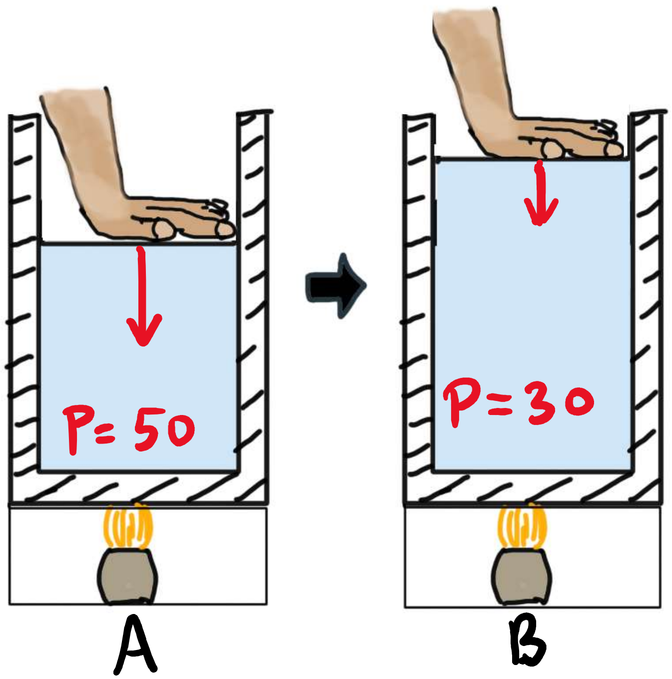
\+ if V increasing

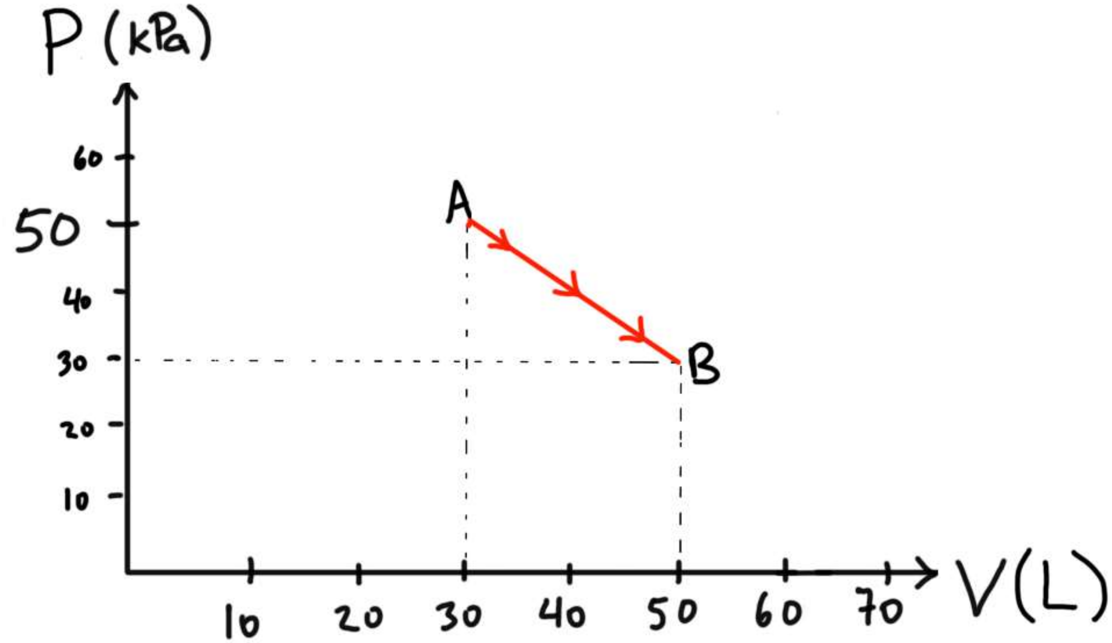
\- if V decreasing



The graph shows how the pressure and volume of the gas in the cylinder change during the process A -> B. How much work does the gas do in this process?

A) 200J
B) 600J
C) 800J
D) 1000J
E)-800J





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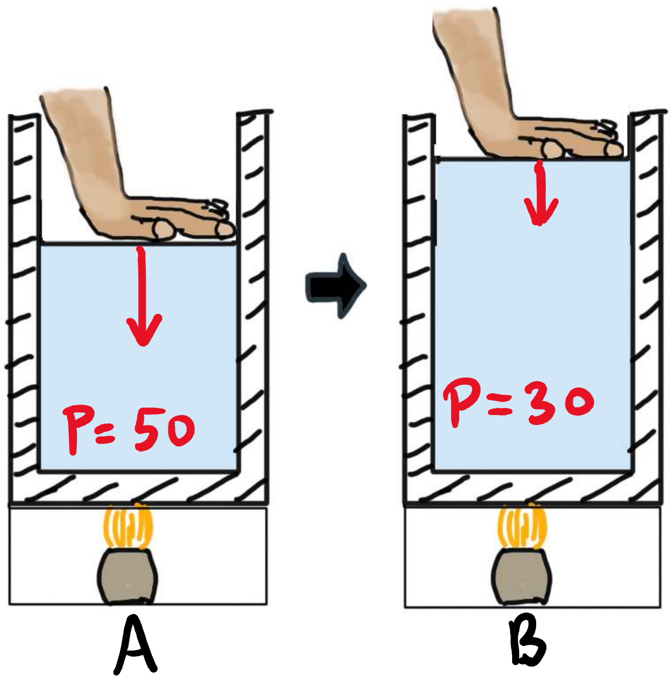
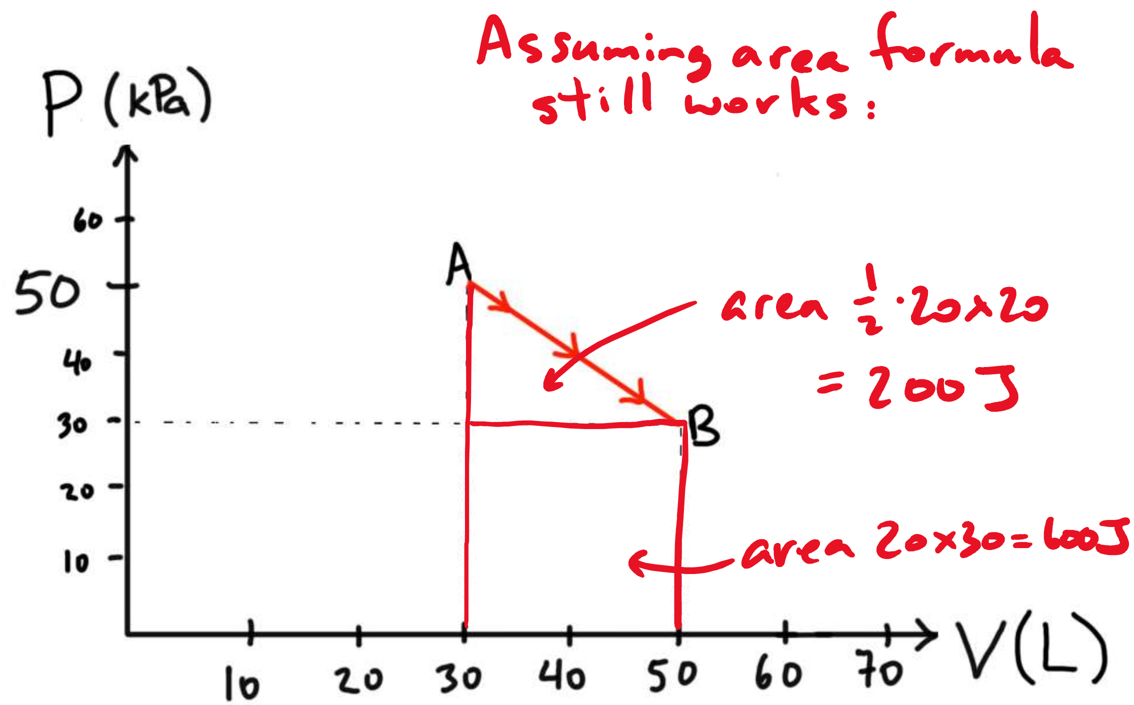




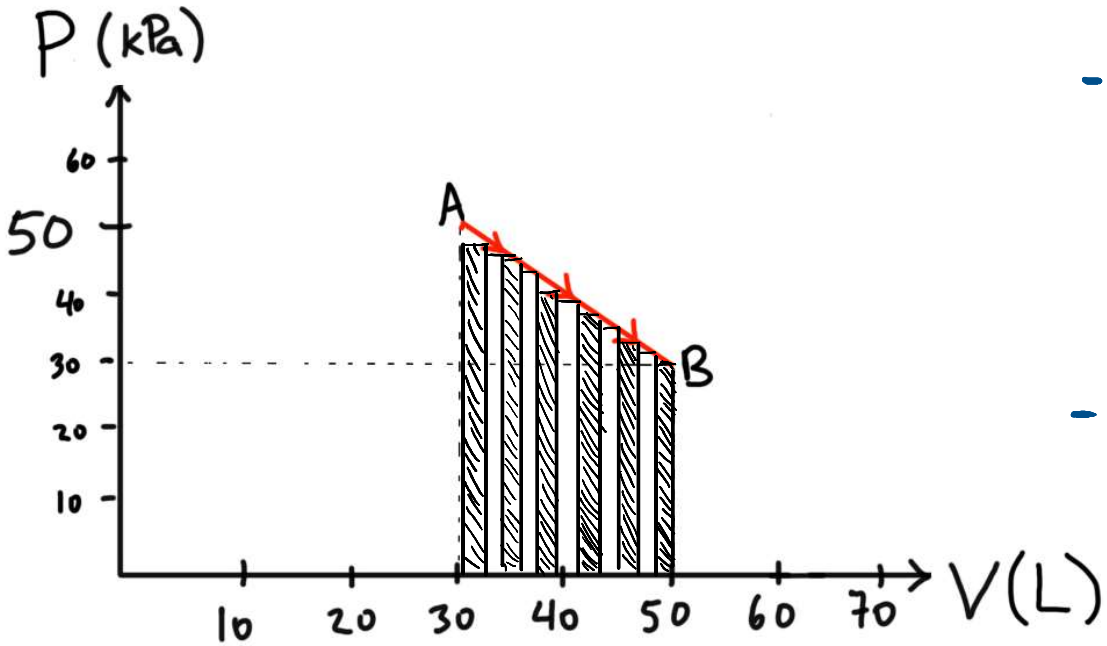
W = 600J + 200 J = 800J

The graph shows how the pressure and volume of the gas in the cylinder change during the process A -> B. How much work does the gas do in this process?

V is increasing so W +ve

A) 200J
B) 600J
C) 800J
D) 1000J
E)-800J

Work done by a gas : changing pressure

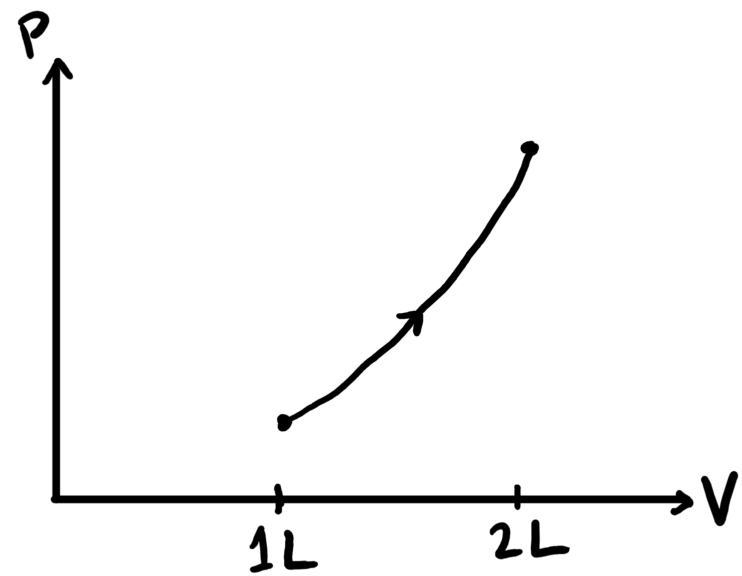


- Break process into small steps with almost constant P
- Add up $dW = P\,dV$ for all parts (area of skinny rectangles)

Result: W is area under the P vs V graph

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

An ideal gas is heated and allowed to expand from a volume 1L to a volume 2L in such a way that the pressure is equal to **P = a V²** where a = 100kPa/L². How much work is done by the gas?



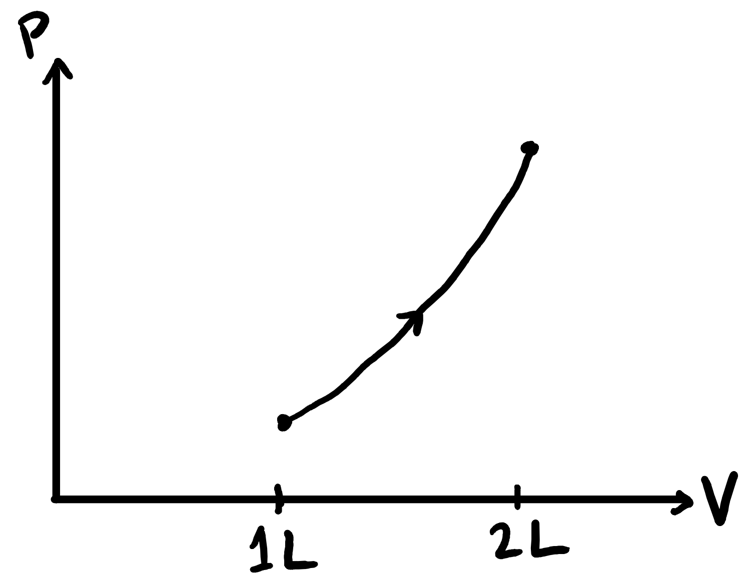
Need: $W = \int_{V_i}^{V_f} P(V)\,dV$ ← area under the curve

The mathematical recipe:

1) find a function F(V) whose derivative is P(V)

2) the integral is $F(V_f) - F(V_i)$

An ideal gas is heated and allowed to expand from a volume 1L to a volume 2L in such a way that the pressure is equal to $\mathbf{P = a\,V^2}$ where a = 100kPa/L^2. How much work is done by the gas?



Need: $W = \int_{V_i}^{V_f} P(V)\,dV$ ← area under the curve

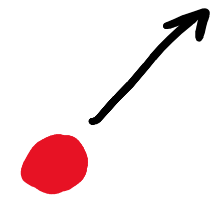
The mathematical recipe:

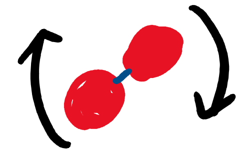
1) find a function F(V) whose derivative is P(V) $F(V) = \frac{1}{3} \cdot a \cdot V^3$

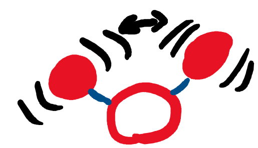
2) the integral is $F(V_f) - F(V_i)$

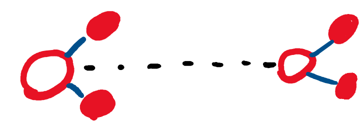
$$W = \frac{1}{3} a V_f^3 - \frac{1}{3} a V_i^3 = \frac{100}{3} \cdot (2^3 - 1^3) = 233\,J$$

U : The energy of a gas

Sum of : kinetic energy 

rotational energy 

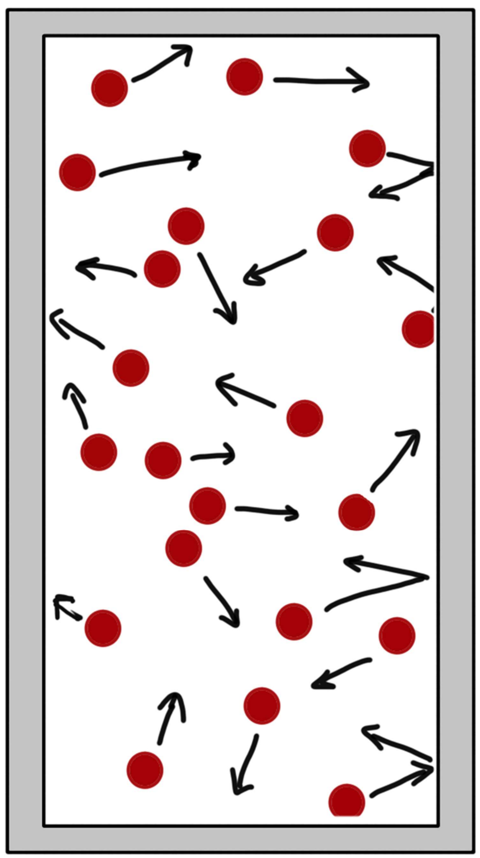
vibrational energy 

electrostatic potential energy 

Main equation : $\Delta U = n C_v \Delta T$

molar specific heat: larger for more complex molecules

Example: Energy of a monatomic ideal gas



U = total kinetic energy of molecules

$= n \times N_A \times E_{kin}^{avg}$

moles Avogadro's number

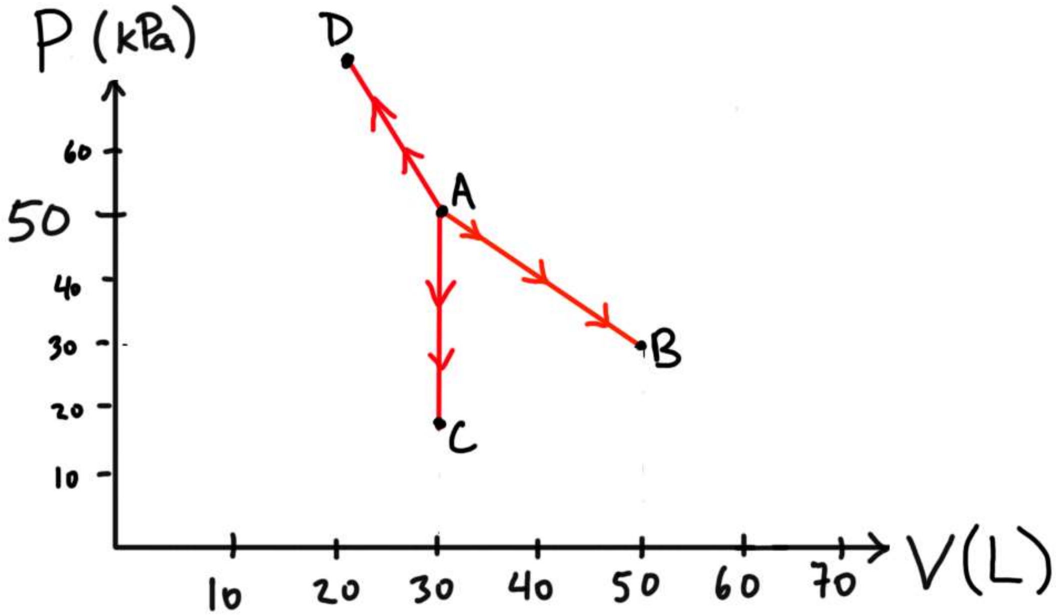
$$E_{kin}^{avg} = \left[\frac{3}{2}\frac{R}{N_A}\right] \times T$$

proportionality constant

Plug in: $U = \frac{3}{2} n R T$

$$\Delta U = n\left[\tfrac{3}{2}R\right]\Delta T$$

C_V for monatomic ideal gas



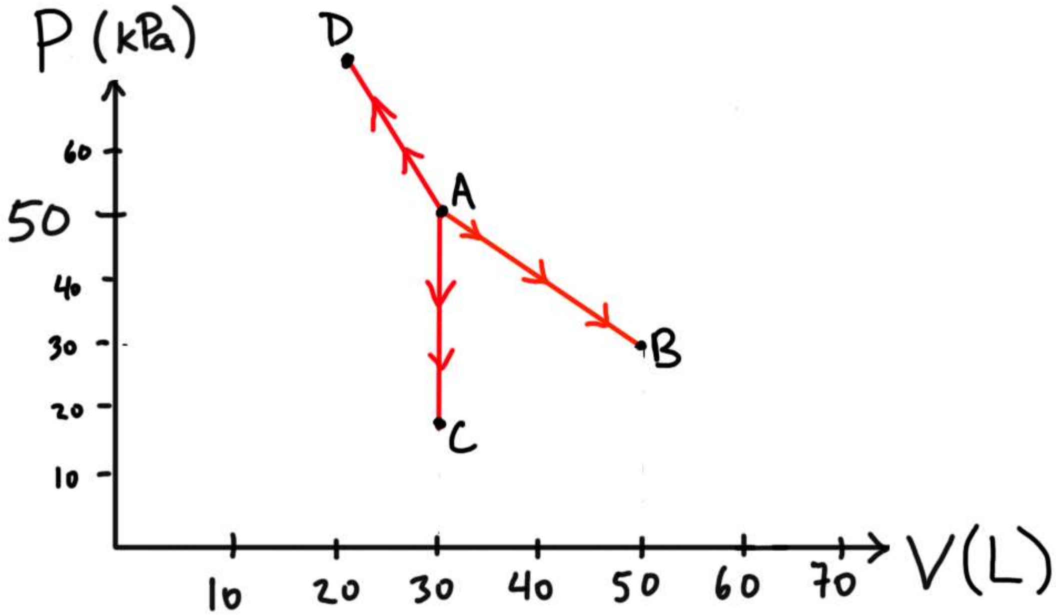
Extra:

During which of the processes shown is the work done by the gas negative?

A) A → B
B) A → C
C) A → D
D) Both A → B and A → C

Extra

During which of the processes shown is the work done by the gas negative?



W negative if V decreases

so A → D

A) A → B

B) A → C

C) A → D

D) Both A → B and A → C