Announcements

Week 4

The Topics & Reading Assignments Schedule for week 4 lists the topics that we will cover and the reading assignment for the week.

After you complete the reading assignment, complete Reading Quiz Week 4 by Monday, Sept 25 at 8:00 AM.

Pre-lecture slides (posted before each lecture) and post-lecture slides (posted after each lecture):

Section 101	Section 102	Section 103
Sep 25: pre /post Lecture Slides Water boils at low pressure recorded demo	Sep 25: pre /post Lecture Slides Water boils at low pressure video	Sep 26: pre /post Lecture Slides
Sep 27: pre /post Lecture Slides	Sep 27: pre /post Lecture Slides	Sep 28: pre /post Lecture Slides
Sep 29: pre /post Lecture Slides	Sep 29: pre /post Lecture Slides	

Tutorial 3: Available in Canvas on Sep 24 at 8 AM; due 10 PM on the day that YOUR tutorial section meets. Solutions

Homework:

- Mastering Physics 3: Available in Mastering Physics on Wednesday, Sep 27 at 5 PM; due Wednesday, Oct 4 at 5 PM
- Written Homework 3: Available in Canvas on Wednesday, Sep 27 at 5 PM; due Wednesday, Oct 4 at 5 PM. Solutions

QUIZ 2: Available in Canvas on Thursday, Sep 28 between 5 PM and 10 PM. You will have 25 minutes to complete the questions from when you start.

- Please consider doing reading assignments a bit <u>ahead</u> of the schedule (desynchronization between MWF & TuTh sections due to different timelines)

Last Time

- Ideal Gas Law

$$\boxed{PV = nRT}$$

$$Q = \Delta E + W$$

- 1st Law of Thermodynamics

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

net change in the energy of the object*)

heat supplied to the object (thermodynamics)

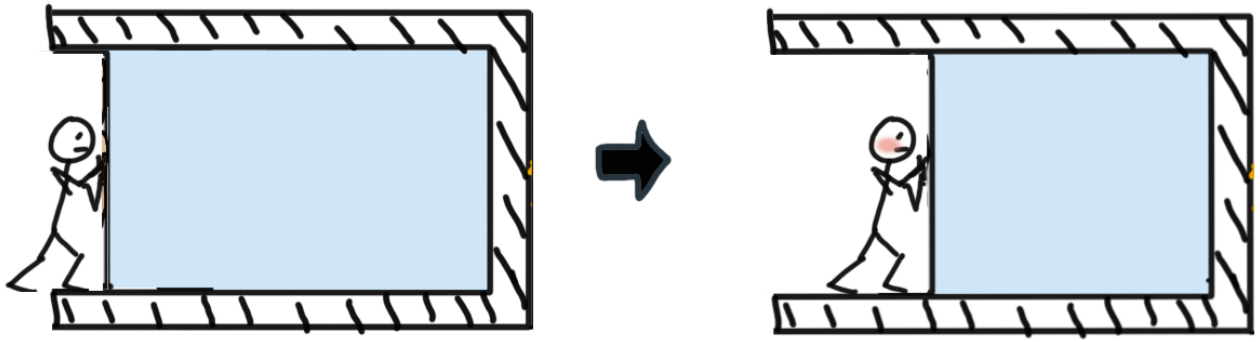
work done by the object (mechanics)

Lecture 15.

Work done by a gas.

Internal energy.

Q: 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 PAd

C. W is negative and equal to $-PAd$

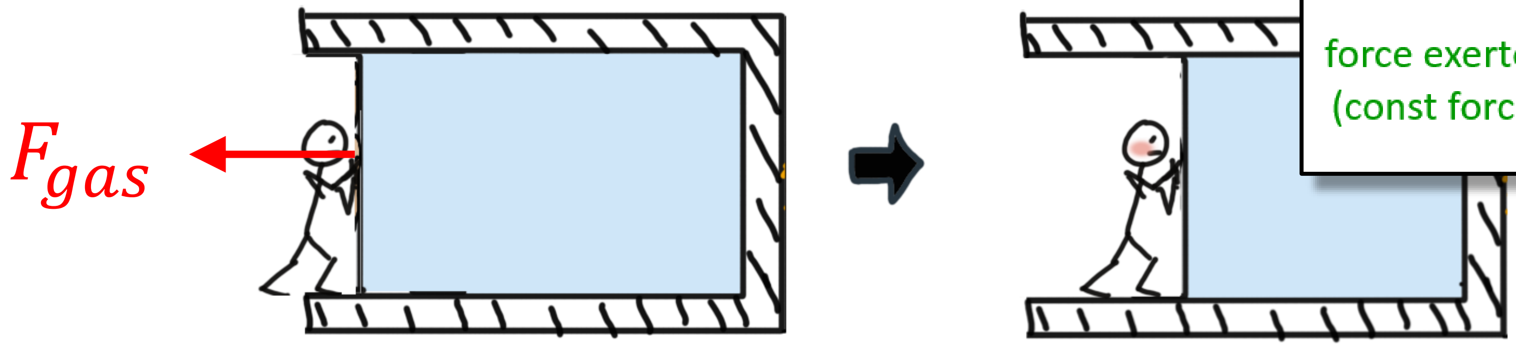
D. Not enough information to answer

$W = F \cdot \Delta x$

in the direction of $\vec{F}$

Q: 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:

$$P = \frac{F}{A}$$



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

force exerted (const force)

displacement <u>in the direction of the force</u>

A. $W = 0$: the little man is doing the work

B. W is positive and equal to PAd

C. W is negative and equal to $-PAd$ ✓

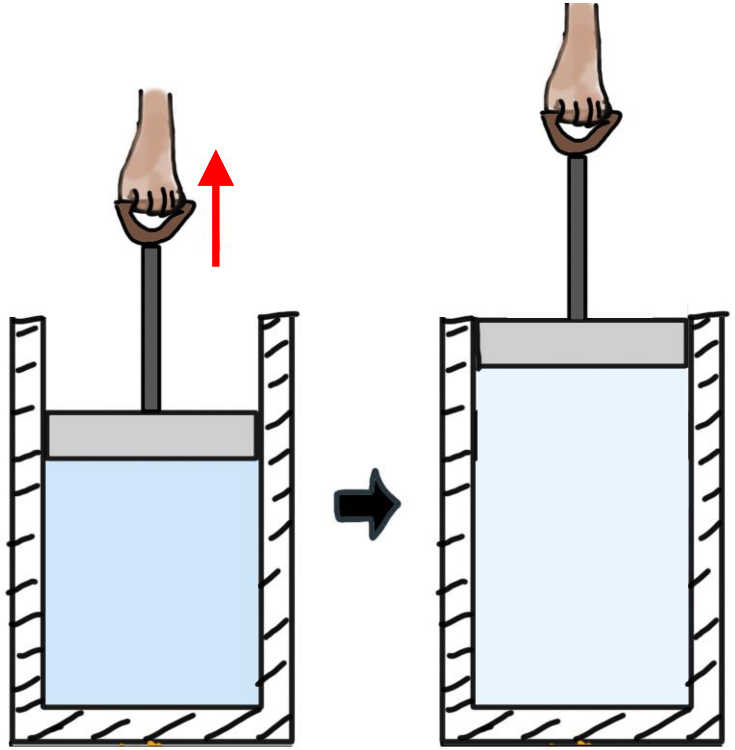
D. Not enough information to answer

$$F_{gas} = PA$$

Displacement <u>in the direction of the force</u> is $\Delta x_{\parallel} = -d$

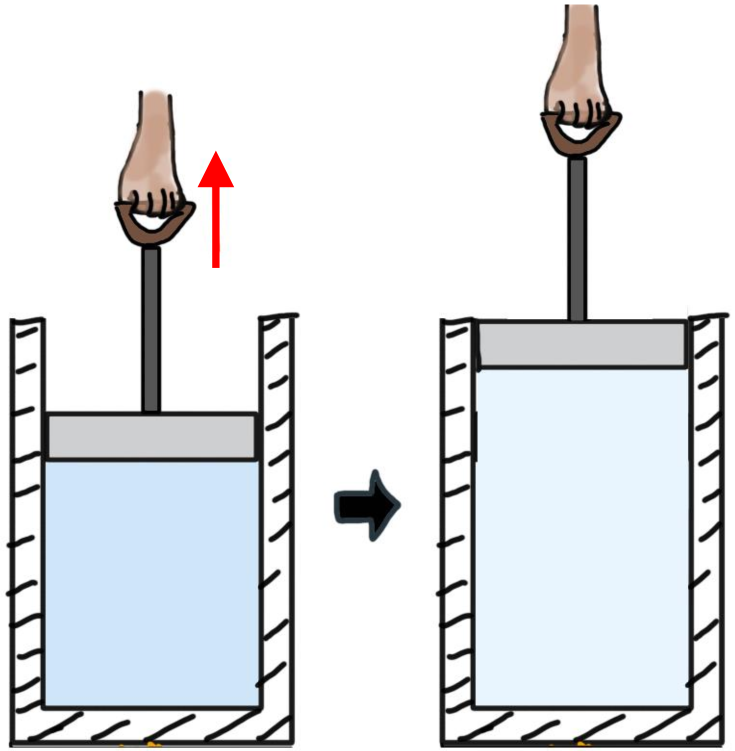
$$W = F_{gas}\Delta x_{\parallel} = -PAd$$

Q: 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

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



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

force exerted (const force)

displacement in the direction of the force

- Gas pushes up and expands $\Longrightarrow$ positive work
- Person pulls up & piston moves up $\Longrightarrow$ positive work

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 ✓

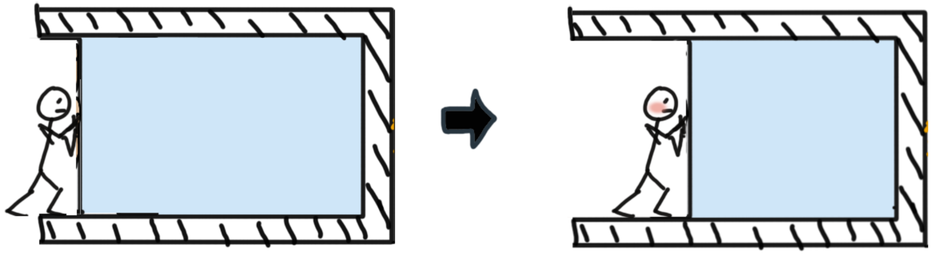
C. The work done by the gas is negative and the work done by the person is positive

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

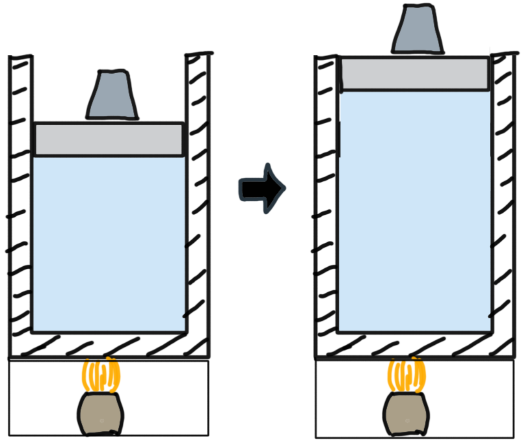
Work done by a gas (constant pressure)

- $W = F \cdot \Delta x$
- $P = F / A$
- $\Delta V = A \, \Delta x$

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



Compression: $\Delta V < 0$
W_{gas} negative



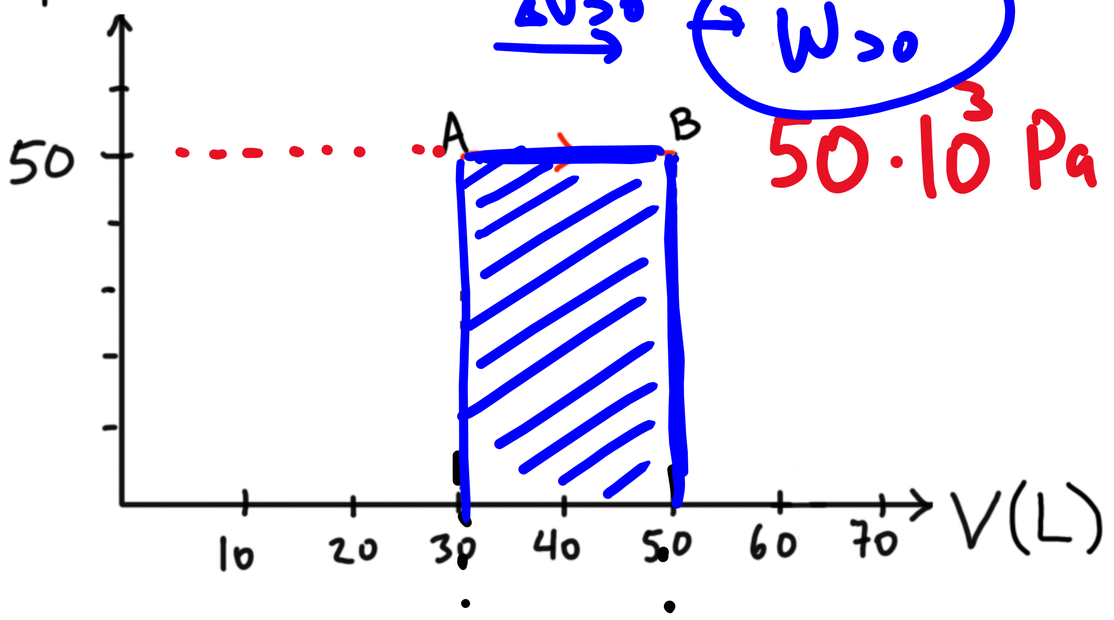
Expansion: $\Delta V > 0$
W_{gas} positive

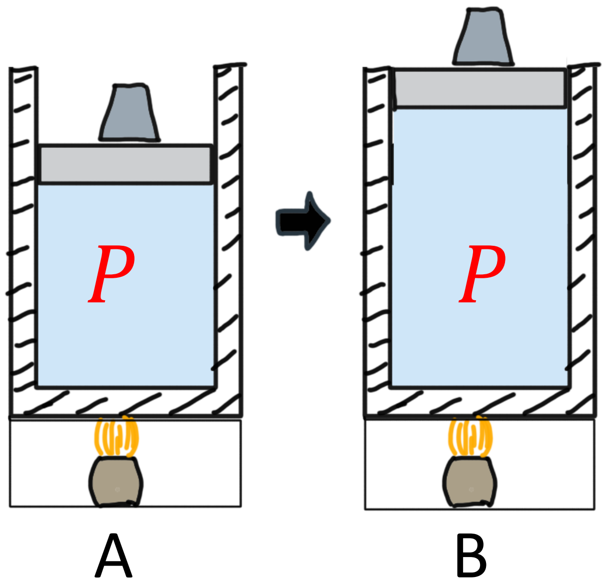
Q: The graph shows how the pressure and volume of the gas in the cylinder change during the process A → B. How much work does the gas do in this process?

$W = P \Delta V$

$\Delta V > 0 \rightarrow W > 0$

$50 \cdot 10^3$ Pa





$20\,L =$

$= 10^{-3} m^3$

$1\ kPa = 10^3\ Pa$

$1\ L = 10^{-3}\ m^3$

$PV = nRT$

A. -100,000 J

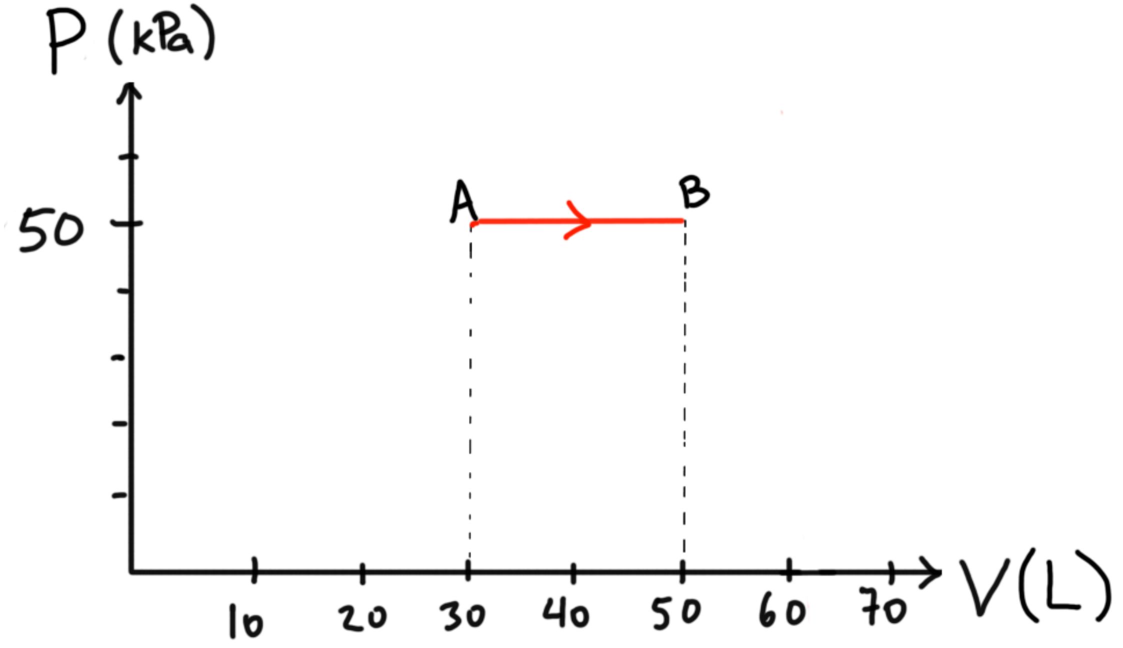
B. 100 J

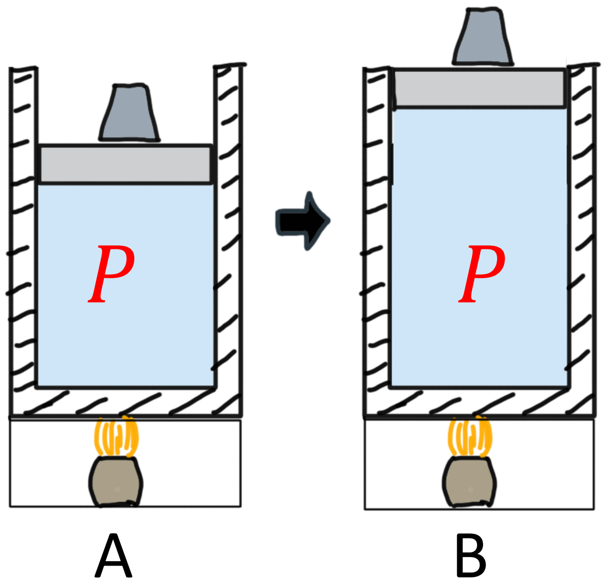
C. 1,000 J

D. 2,500 J

E. 100,000 J

Q: 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. -100,000 J

B. 100 J

C. 1,000 J ✓

D. 2,500 J

E. 100,000 J

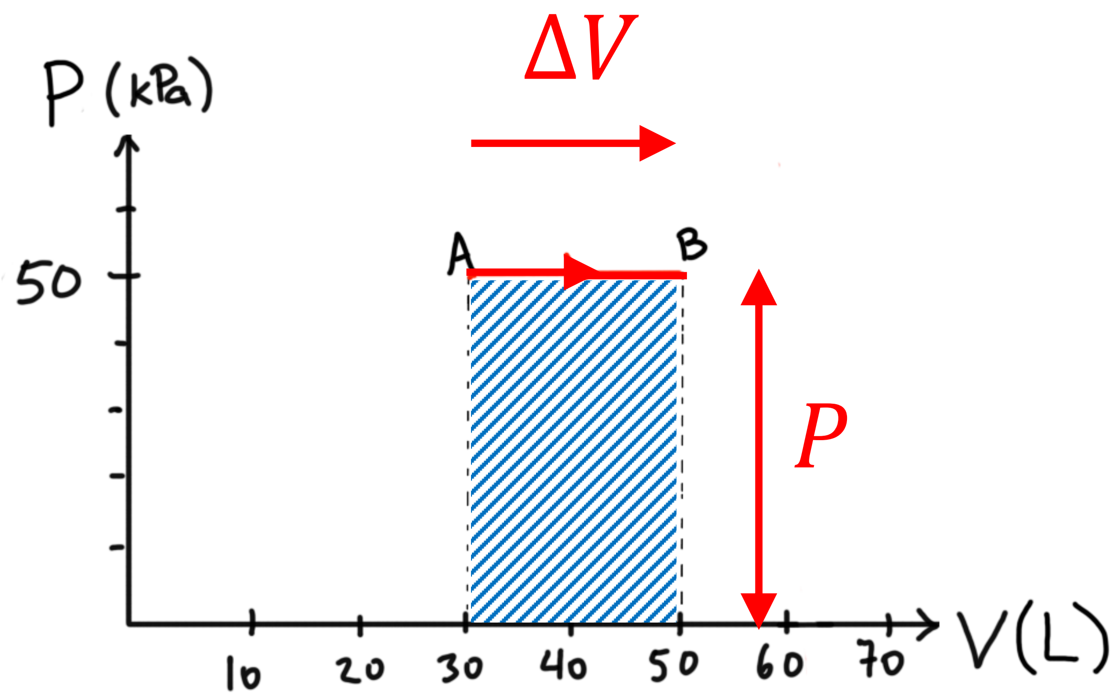
$P = 50\ kPa$

$\Delta V = 20\ L$

$W = P\Delta V = 1000\ kPa \cdot L = 1000$ J

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

Work is the area under the P vs V graph (constant pressure)

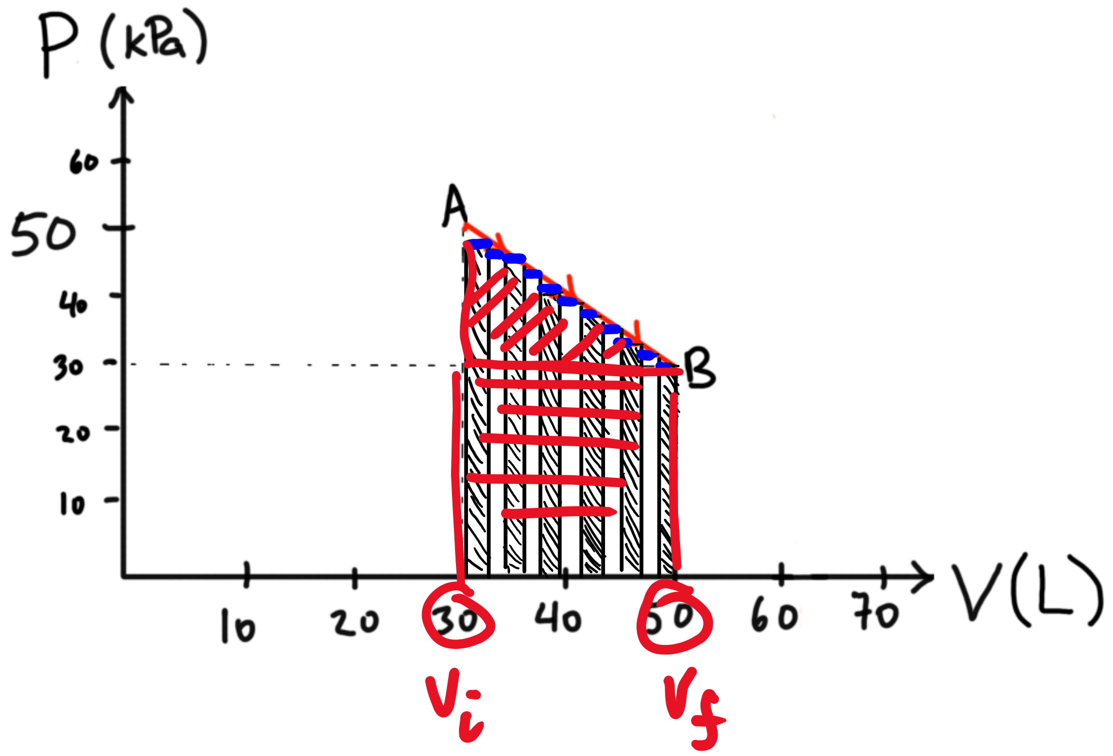


$$W = P \cdot \Delta V$$

$+$ if volume is increasing

$-$ if volume is decreasing

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

$W = A_\Delta + A_\square$

here

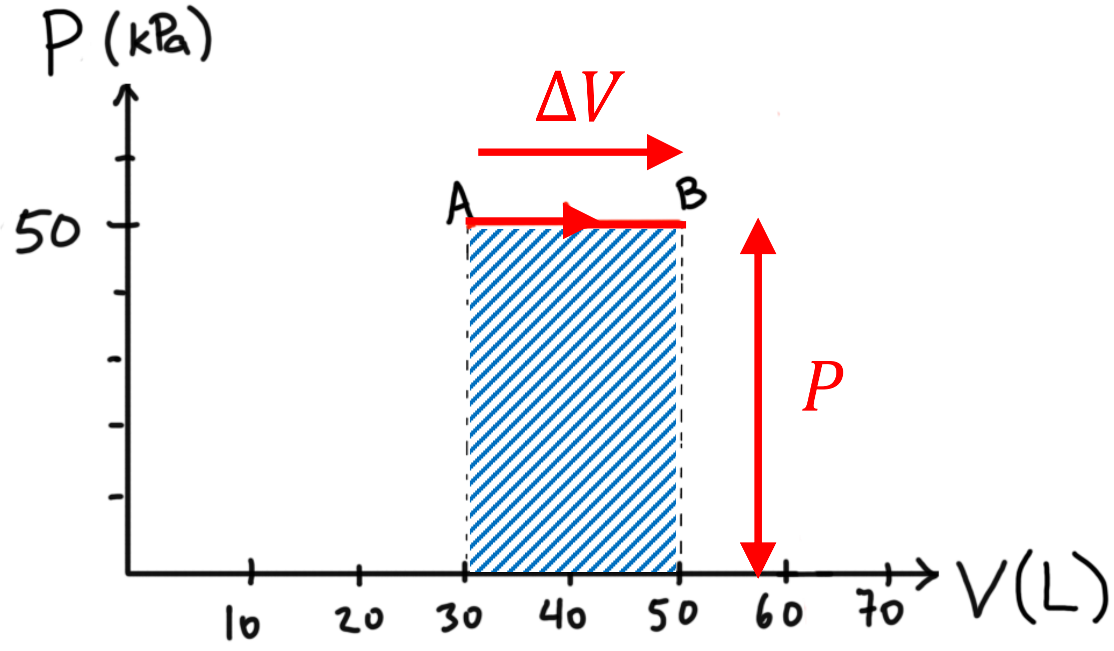
Result: W is area under the P vs V graph

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

start

In summary: Work done by a gas is the area under the P vs V graph

constant pressure

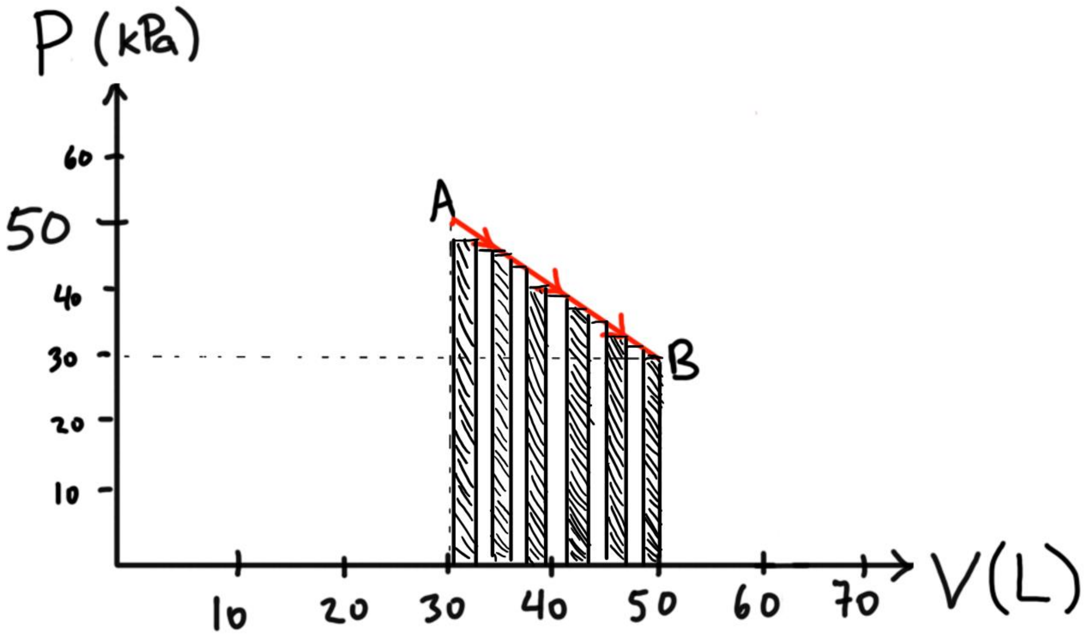


$$W = P \cdot \Delta V$$

$+$ if volume increasing
$-$ if volume decreasing

} by hands

changing pressure



W is area under P vs V graph

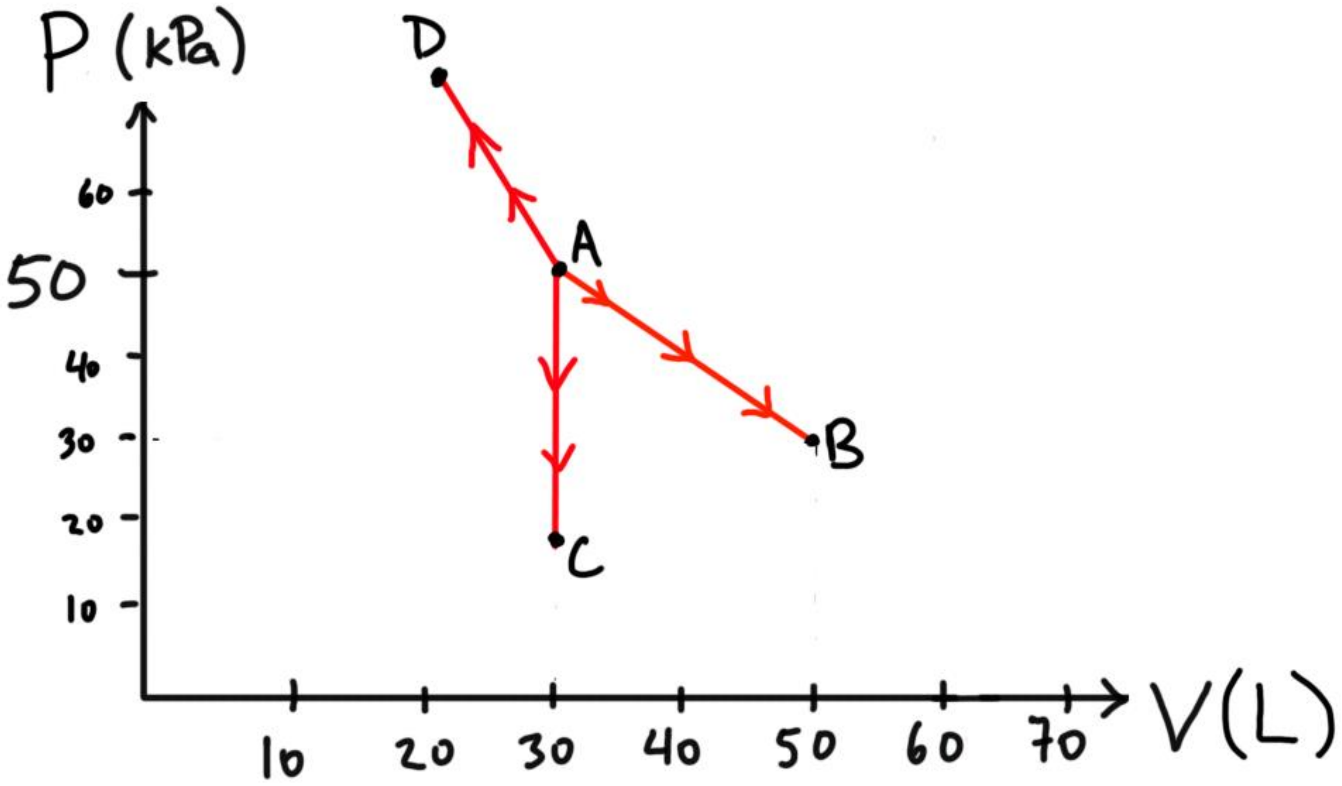
$$W = \int_{V_i}^{V_f} P(V)\, dV$$

finish

start

sign accounted for

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



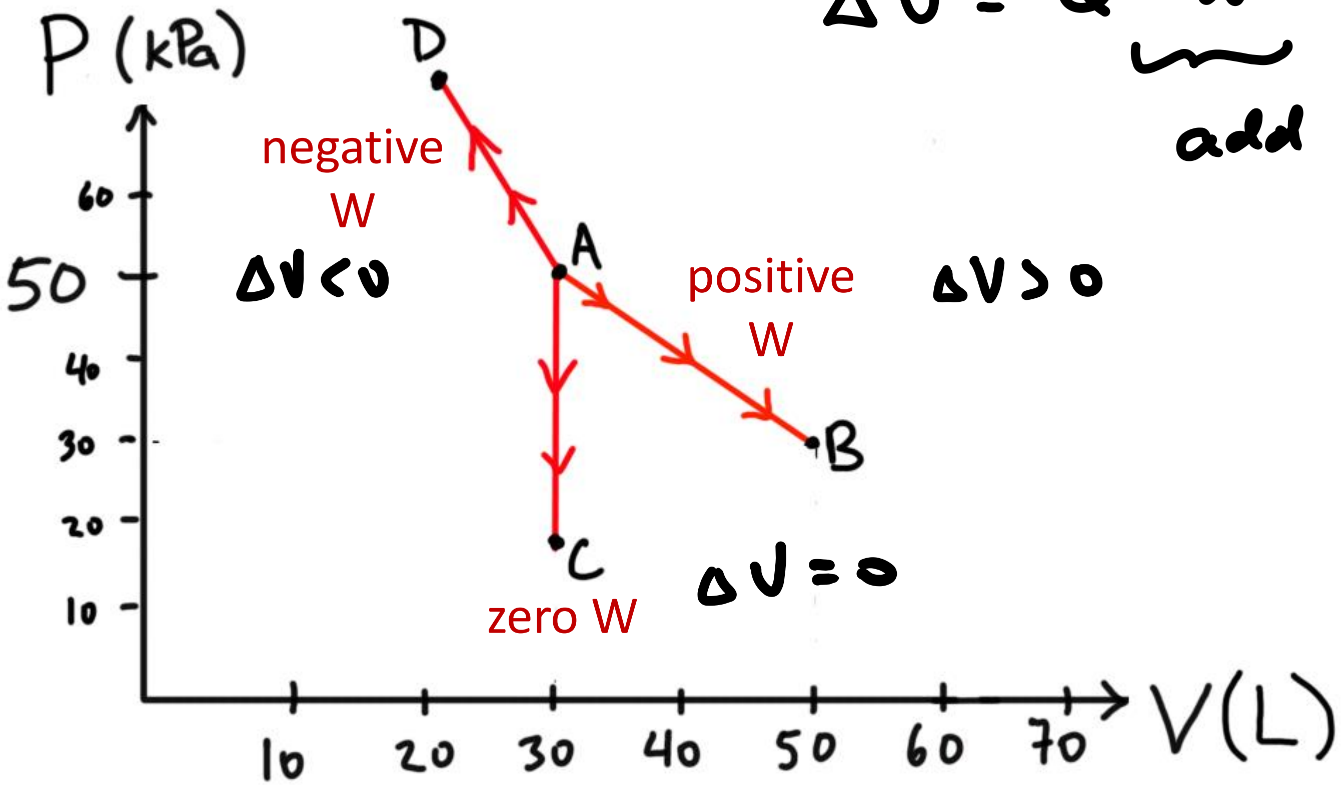
A. A → B

B. A → C

C. A → D

D. Both A → B and A → C

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



$\Delta U = Q - \underbrace{W}$

add energy

A. A → B

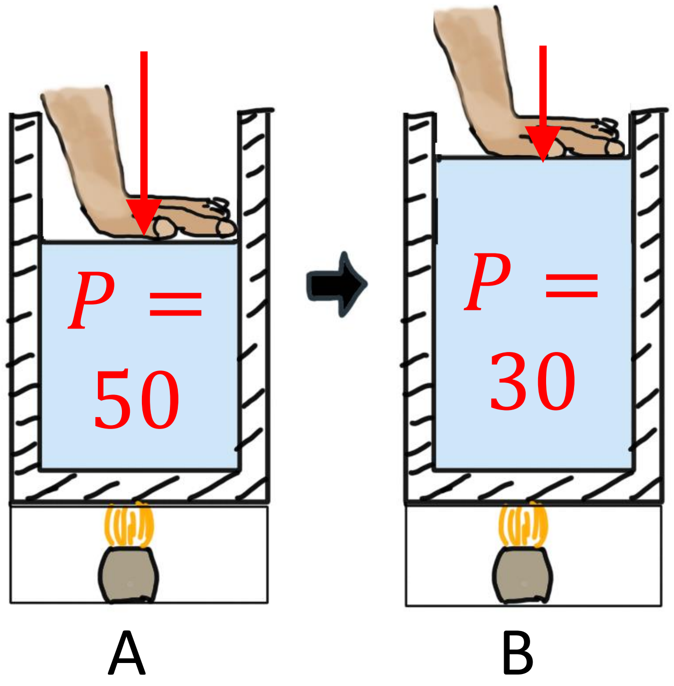
B. A → C

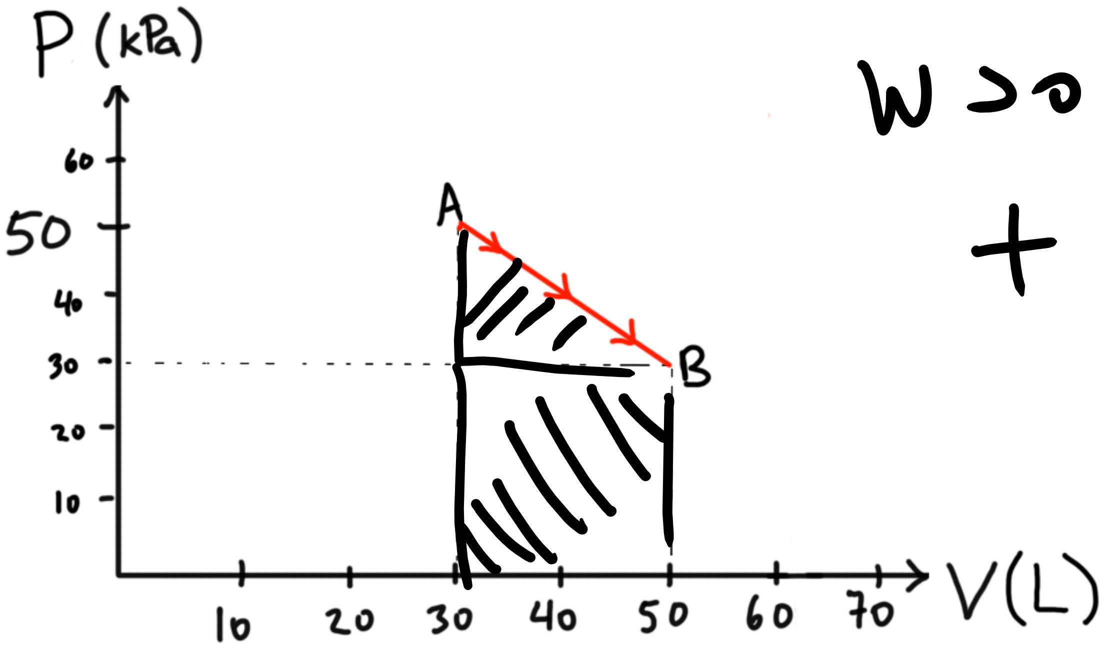
C. A → D

D. Both A → B and A → C

W is negative if V decreases, so A → D

Q: 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?





$\Delta V > 0$

$W > 0$

+

A. 200 J

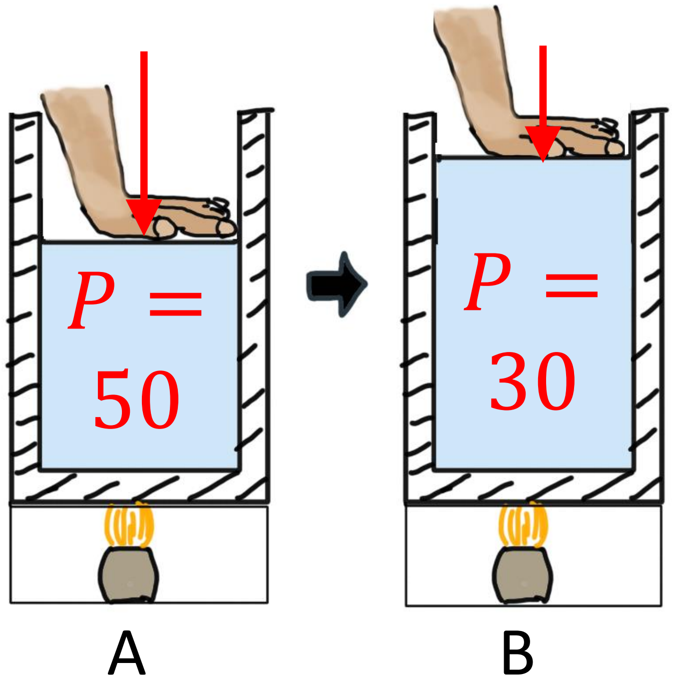
B. 600 J

C. -600 J

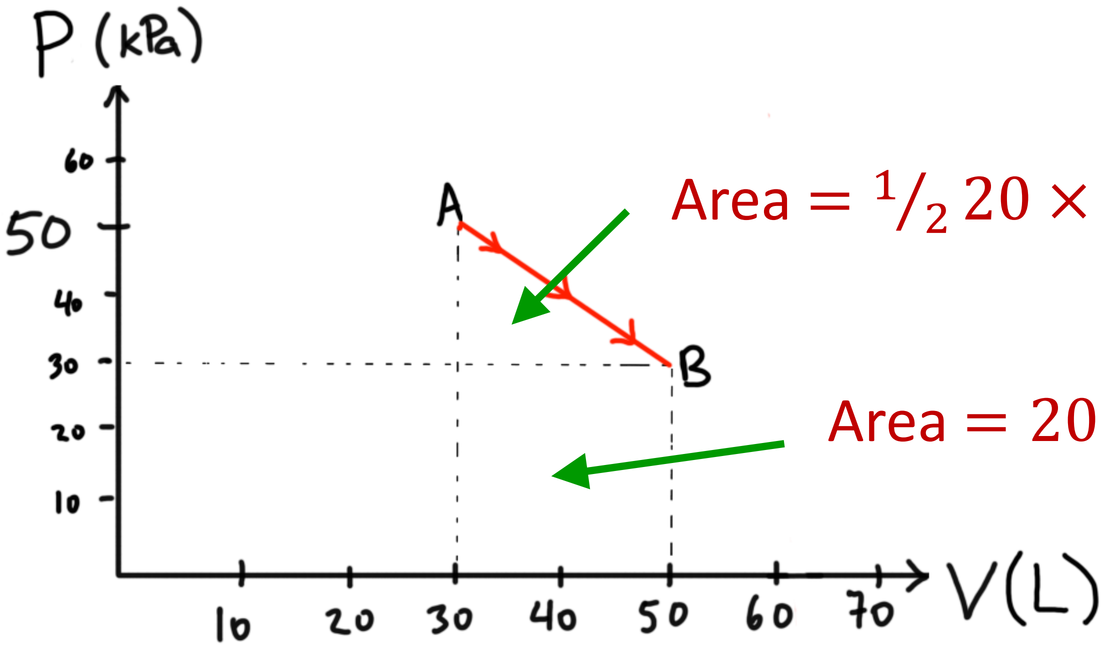
D. 800 J

E. -800 J

Q: 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?



Work done by the gas is area under the P vs V graph:



Area $= {}^{1}/_{2}\, 20 \times 20 = 200$ J

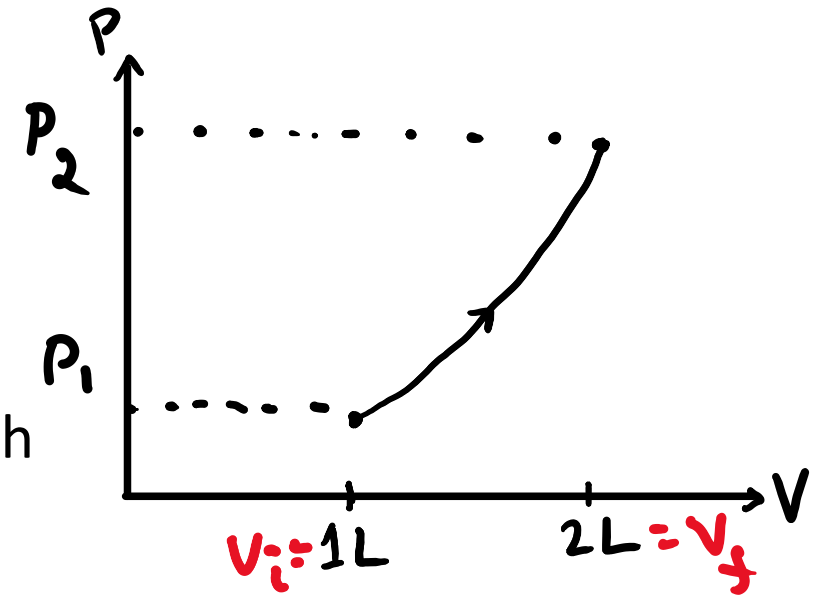
Area $= 20 \times 30 = 600$ J

A. 200 J
B. 600 J
C. -600 J
D. 800 J
E. -800 J

- $W = 200$ J $+ 600$ J $= 800$ J
- V is increasing, so W is positive

Q: An ideal gas is heated and allowed to expand from a volume 1 L to a volume 2 L in such a way that the pressure is equal to $\boxed{P = a\,V^2}$ where $a = 100$ kPa/L^2.

How much work is done by the gas?



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

The mathematical recipe:

1) Find a function $F(V)$ whose <u>derivative</u> is $P(V)$
2) The integral is $F(V_f) - F(V_i)$

1) F: $\frac{d}{dV} F(V) = P(V) = aV^2$

2) $F(V_f = 2L) - F(V_i = 1L) = \text{answer}$

A. 125 J
B. 233 J
C. 315 J
D. 410 J
E. ☹

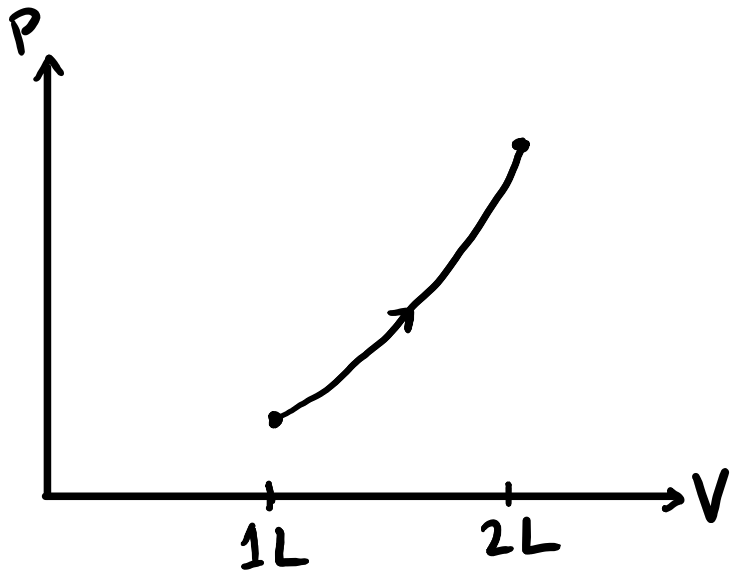
x^2 - want to get

Step 1

$$\frac{d}{dx}x^n = n \cdot x^{n-1}$$

$$\frac{d}{dx}x^3 = \underline{\underline{3}}\,x^2$$

$$\frac{a}{3}\frac{d}{dx}x^3 = \frac{a}{\cancel{3}} \cdot \cancel{3}x^2 = ax^2$$



$P = aV^2, a = 100$ kPa/L^2

$$P(V) = aV^2 \rightarrow F(V) = \frac{a}{3}V^3$$

Step 2: Answer = $F(V_f) - F(V_i) = ?$

A. 125 J

B. 233 J

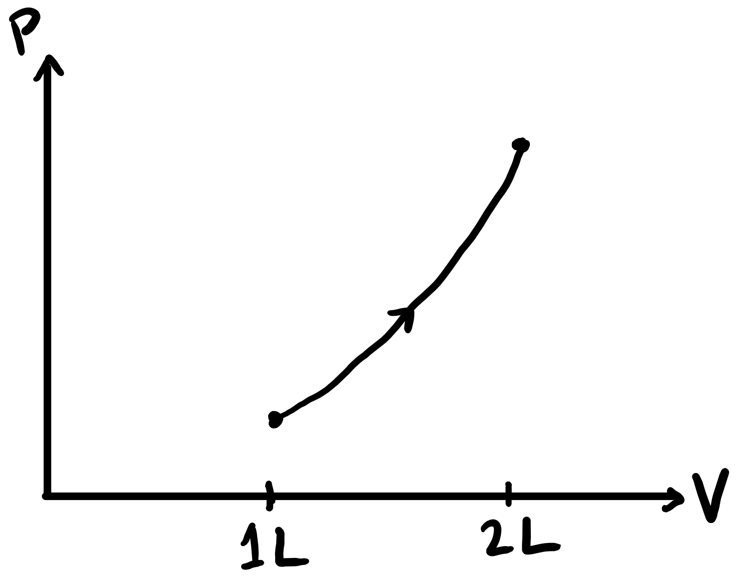
C. 315 J

D. 410 J

E. ☹

Q: An ideal gas is heated and allowed to expand from a volume 1 L to a volume 2 L in such a way that the pressure is equal to $P = a\,V^2$ where $a = 100$ kPa/L^2.

How much work is done by the gas?



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

The mathematical recipe:

1) Find a function $F(V)$ whose <u>derivative</u> is $P(V)$
2) The integral is $F(V_f) - F(V_i)$

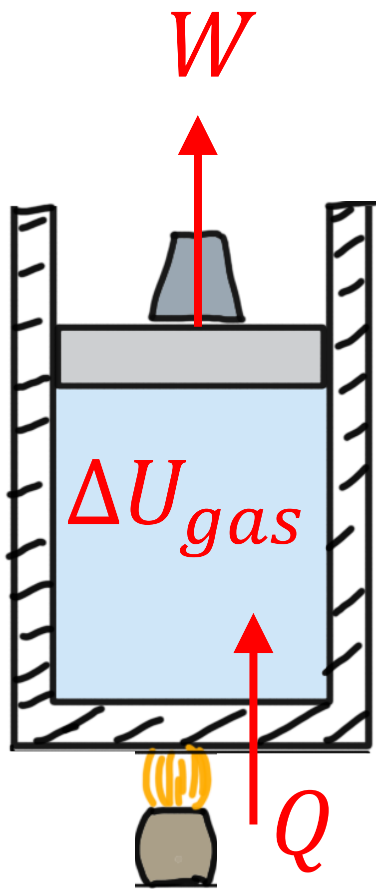
$$\frac{d}{dx}x^n = nx^{n-1} \Rightarrow F(V) = \frac{1}{3}aV^3 \Rightarrow \frac{d}{dV}F(V) = aV^2 = P(V)$$

$$W = \frac{1}{3}aV_f^3 - \frac{1}{3}aV_i^3 = \frac{100}{3}(2^3 - 1^3) = 233\text{ J}$$

A. 125 J
B. 233 J ✓
C. 315 J
D. 410 J
E. ☹

First Law of Thermodynamics ✓

(conservation of energy)



If the gas does work (or work is done on the gas), its internal energy will change.

?

$$\boxed{\Delta U = Q - W}$$

net change in the internal energy of the object*)

heat supplied <u>to</u> the object (thermodynamics)

work done <u>by</u> the object (mechanics)

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*) We called it ΔE_{gas} earlier

Demo: Work done on a gas