

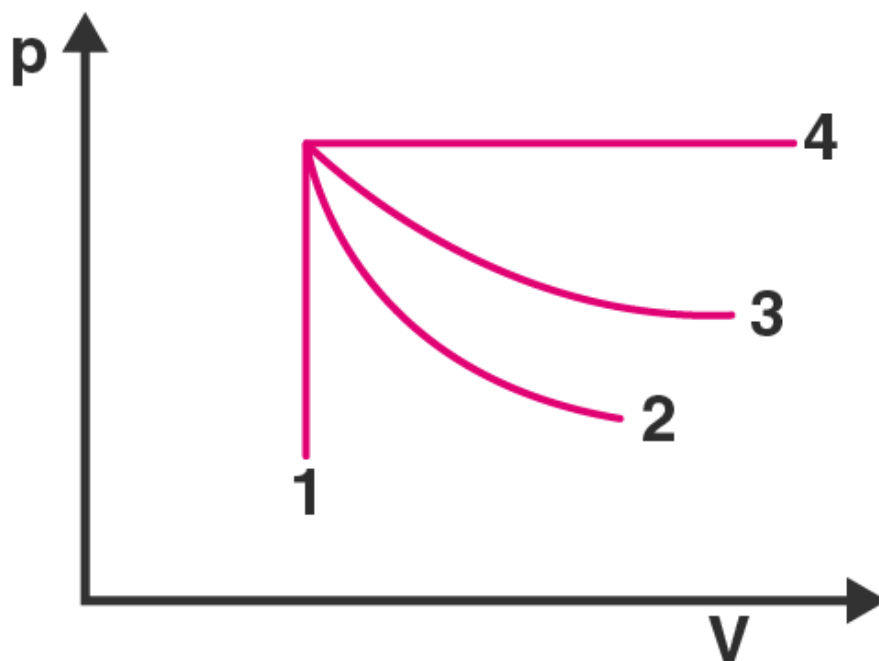
Chapter 12: Thermodynamics

NCERT Exemplar · Class 11 · Physics

Questions

Question 12.1

An ideal gas undergoes four different processes from the same initial state. Four processes are adiabatic, isothermal, isobaric, and isochoric. Out of 1, 2, 3, and 4 which one is adiabatic



A.

4

B.

3

C.

2

D.

1

Answer

Correct option: C

Solution

The correct answer is c) 2

Question 12.2

If an average person jogs, he produces 14.5×10^3 cal/min. This is removed by the evaporation of sweat. The amount of sweat evaporated per minute is assuming 1 kg requires 580×10^3 cal for evaporation

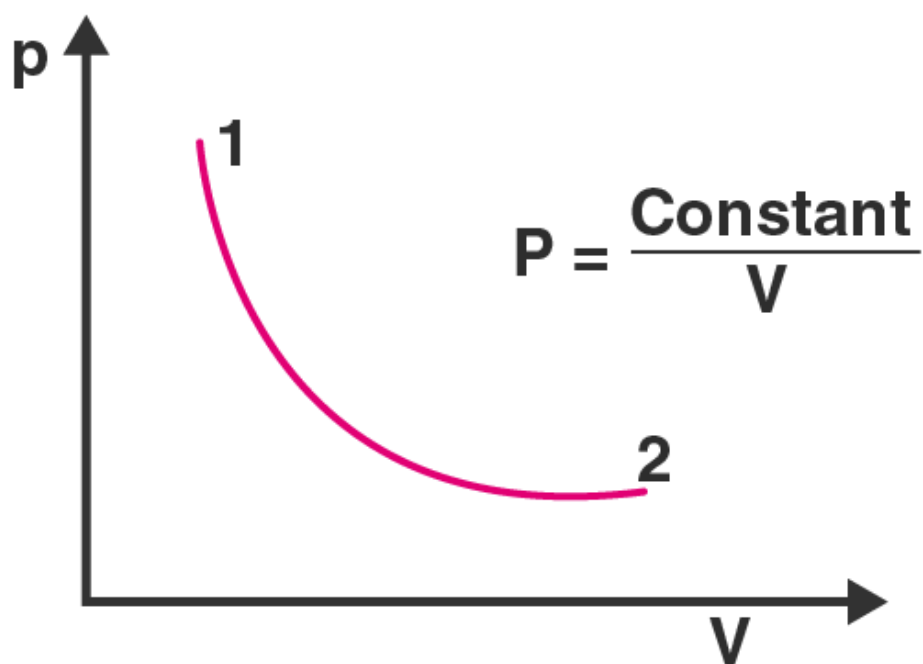
- a) 0.25 kg
- b) 2.25 kg
- c) 0.05 kg
- d) 0.20 kg

Solution

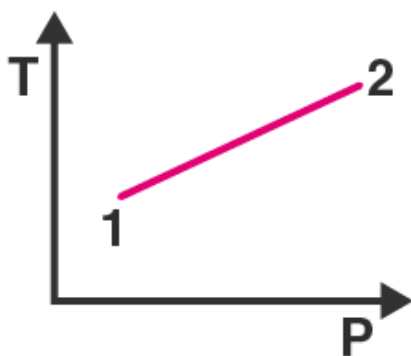
The correct answer is a) 0.25 kg

Question 12.3

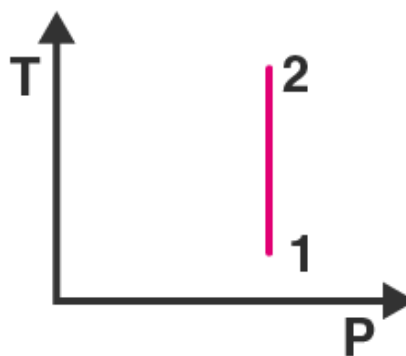
Consider P-V diagram for an ideal gas shown in the figure.



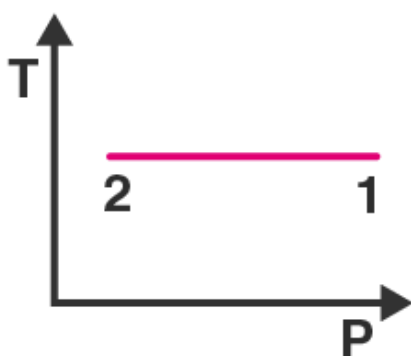
Out of the following diagrams, which represent the T-P diagram?



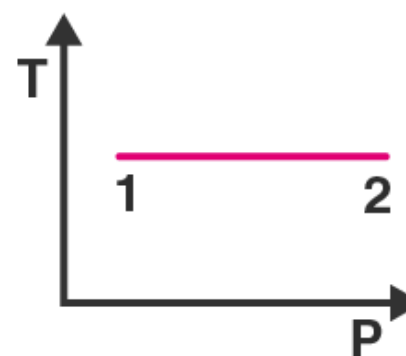
(i)



(ii)



(iii)



(iv)

a) iv

b) ii

c) iii

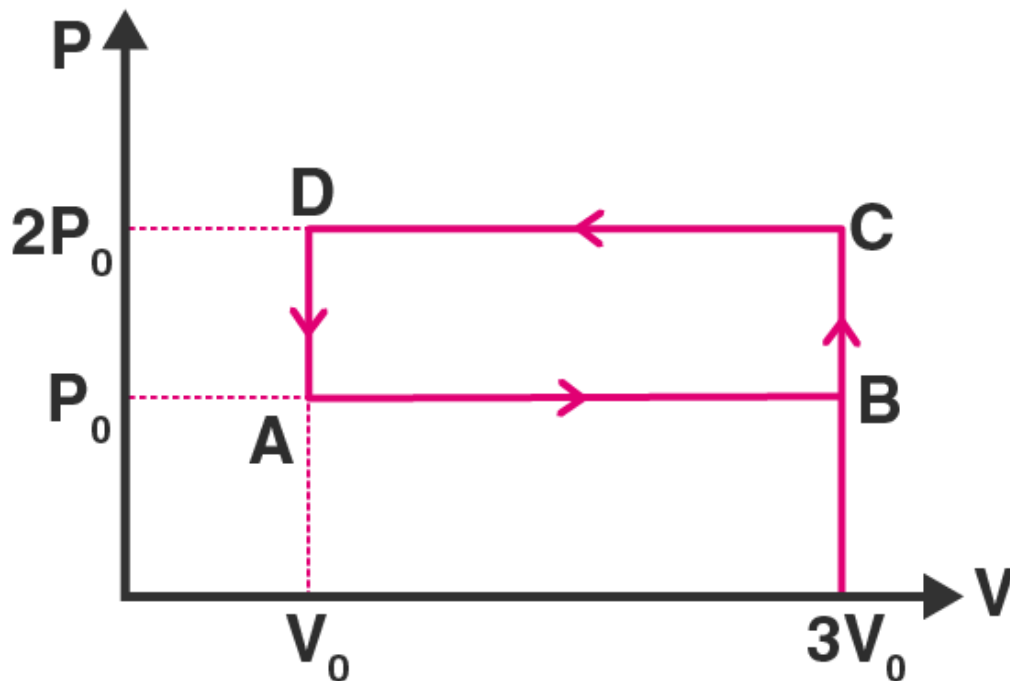
d) i

Solution

The correct answer is c) iii

Question 12.4

An ideal gas undergoes cyclic process ABCDA as shown in the given P-V diagram. The amount of work done by the gas is



- a) $6P_0V_0$
- b) $-2P_0V_0$
- c) $+2P_0V_0$
- d) $+4P_0V_0$

Solution

The correct answer is d) $+4P_0V_0$

Question 12.5

Consider two containers A and B containing identical gases at the same pressure, volume, and temperature. The gas in container A is compressed to half of its volume isothermally while the gas in the container B is compressed to half of its original value adiabatically. The ratio of final pressure of a gas in B to that of gas in A is

- a)

$$2^{\gamma-1}$$

b)

$$\left(\frac{1}{2}\right)^{\gamma-1}$$

c)

$$\left(\frac{1}{1-\gamma}\right)^2$$

d)

$$\left(\frac{1}{\gamma-1}\right)^2$$

Solution

The correct answer is a)

$$2^{\gamma-1}$$

Question 12.6

Three copper blocks of masses M_1 , M_2 , and M_3 kg respectively are brought into thermal contact till they reach equilibrium. Before contact, they were at T_1 , T_2 , T_3 ($T_1 > T_2 > T_3$). Assuming there is no heat loss to the surroundings, the equilibrium temperature T is

a)

$$T = \frac{T_1 + T_2 + T_3}{3}$$

b)

$$T = \frac{M_1 T_1 + M_2 T_2 + M_3 T_3}{M_1 + M_2 + M_3}$$

c)

$$T = \frac{M_1 T_1 + M_2 T_2 + M_3 T_3}{3(M_1 + M_2 + M_3)}$$

d)

$$T = \frac{M_1 T_1 s + M_2 T_2 s + M_3 T_3 s}{M_1 + M_2 + M_3}$$

Solution

The correct answer is b)

$$T = \frac{M_1 T_1 + M_2 T_2 + M_3 T_3}{M_1 + M_2 + M_3}$$

Multiple Choice Questions II

Question 12.7

Which of the process described below are irreversible?

A.

the increase in temperature of an iron rod by hammering it

B.

a gas in a small container at a temperature T_1 is brought in contact with a big reservoir at a higher temperature T_2 which increases the temperature of the gas

C.

a quasi-static isothermal expansion of an ideal gas in a cylinder fitted with a frictionless piston

D.

an ideal gas is enclosed in a piston-cylinder arrangement with adiabatic walls. A weight W is added to the piston resulting in compression of gas

Solution

The correct answers are

- a) the increase in temperature of an iron rod by hammering it
- b) a gas in a small container at a temperature T_1 is brought in contact with a big reservoir at a higher temperature T_2 which increases the temperature of the gas
- d) an ideal gas is enclosed in a piston-cylinder arrangement with adiabatic walls. A weight W is added to the piston resulting in compression of gas

Question 12.8

An ideal gas undergoes isothermal process from some initial state i to final state f . Choose the correct alternatives

A.

$$dU = 0$$

B.

$$dQ = 0$$

C.

$$dQ = dU$$

D.

$$dQ = dW$$

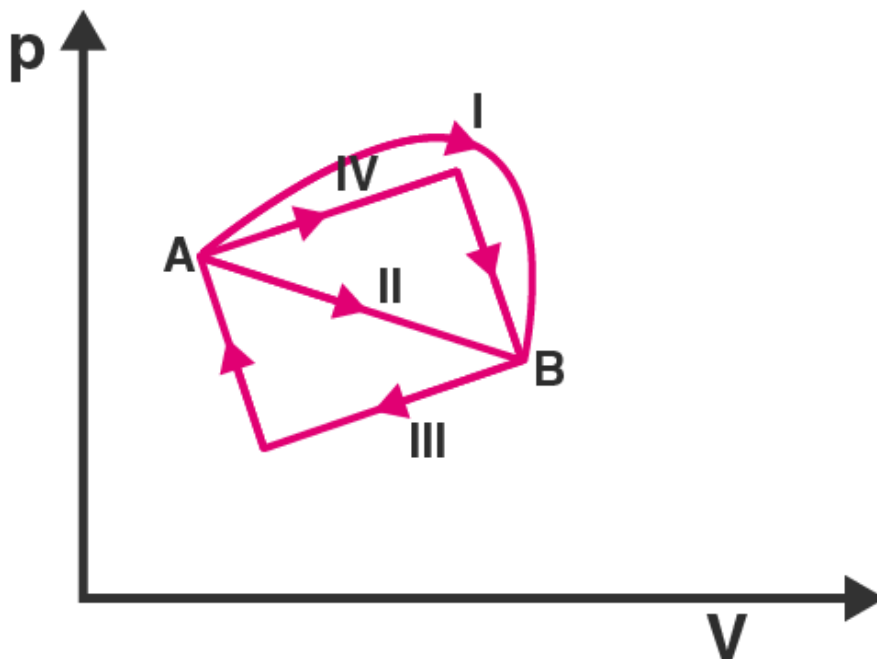
Solution

The correct answers are

- a) $dU = 0$
- d) $dQ = dW$

Question 12.9

Figure shows the P-V diagram of an ideal gas undergoing a change of state from A to B. Four different parts I, II, III, and IV as shown in the figure may lead to the same changes of state.



- a) change in internal energy is the same in IV and III cases, but not in I and II
- b) change in internal energy same in all the four cases
- c) work done is maximum in case I
- d) work done is minimum in case II

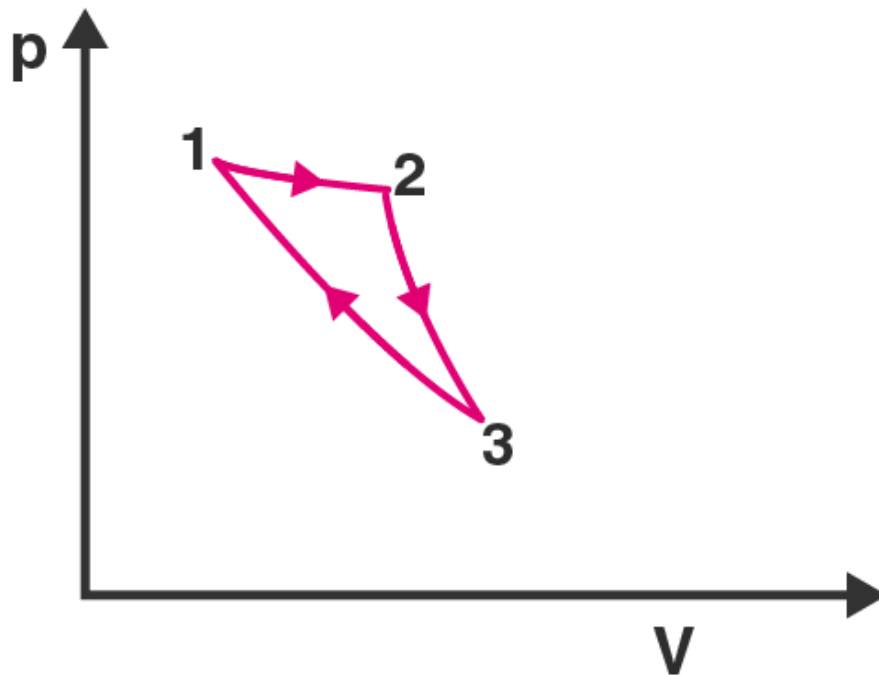
Solution

The correct answers are

- b) change in internal energy same in all the four cases
- c) work done is maximum in case I

Question 12.10

Consider a cycle followed by an engine



1 to 2 is isothermal

2 to 3 is adiabatic

3 to 1 is adiabatic

Such a process does not exist because

- a) heat is completely converted to mechanical energy in such a process, which is not possible**
- b) mechanical energy is completely converted to heat in this process, which is not possible**
- c) curves representing two adiabatic processes don't intersect**
- d) curves representing an adiabatic process and an isothermal process don't intersect**

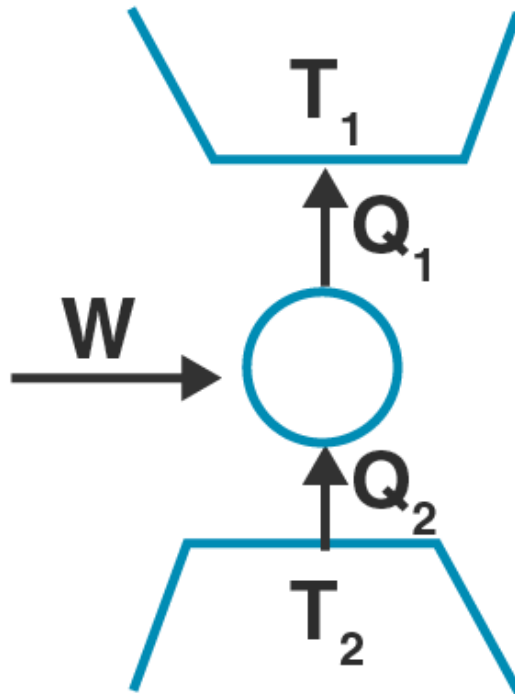
Solution

The correct answers are

- a) heat is completely converted to mechanical energy in such a process, which is not possible**
- c) curves representing two adiabatic processes don't intersect**

Question 12.11

Consider a heat engine as shown on the figure. Q_1 and Q_2 are heat added to heat bath T_1 and heat taken from T_2 in one cycle of the engine. W is the mechanical work done on the engine.



If $W > 0$, then possibilities are:

- a) $Q_1 > Q_2 > 0$
- b) $Q_2 > Q_1 > 0$
- c) $Q_2 < Q_1 < 0$
- d) $Q_1 < 0, Q_2 > 0$

Solution

The correct answers are

- a) $Q_1 > Q_2 > 0$
- c) $Q_2 < Q_1 < 0$

Very Short Answers

Question 12.12

Can a system be heated and its temperature remains constant?

Solution

For temperature to remain constant, the work done by the system against the surrounding should compensate with the heat that is supplied.

According to the given information,

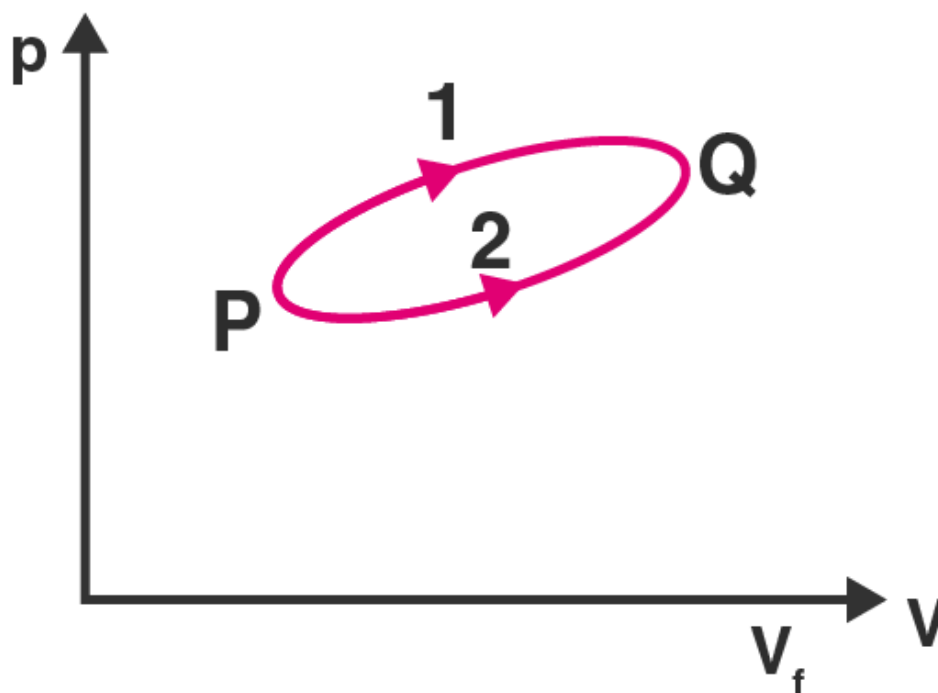
$$\Delta T = 0 \Rightarrow \Delta U = 0$$

Therefore,

$$\Delta Q = \Delta U + \Delta W \Rightarrow \Delta Q = \Delta W$$

Question 12.13

A system goes from P to Q by two different paths in the P-V diagram as shown in the figure. Heat given to the system in the path 1 is 1000 J. The work done by the system along path 1 is more than path 2 by 100 J. What is the heat exchanged by the system in path 2?



Solution

From path 1, $Q_1 = +1000 \text{ J}$

Work done = $W_1 - W_2 = 100$

Where,

W_1 is the work done through path 1

W_2 is the work done through path 2

Therefore, $W_2 = W_1 - 100$

$$\Delta U = Q_1 - W_1 = Q_2 - W_2$$

Substituting the values, we get $Q_2 = 900 \text{ J}$

Question 12.14

If a refrigerator's door is kept open, will the room becomes cool or hot? Explain.

Solution

If a refrigerator's door is kept open, the room becomes hot because the amount of heat absorbed by the refrigerator and the work done by the refrigerator will be rejected to the room.

Question 12.15

Is it possible to increase the temperature of a gas without adding heat to it? Explain.

Solution

Yes, it is possible to increase the temperature of a gas without adding heat to it. This is possible during adiabatic compression.

Question 12.16

Air pressure in a car tyre increases during driving. Explain.

Solution

Air pressure in a car tyre increases during driving while the volume remains constant which is based on the Charle's law. Pressure is proportional to the temperature. Therefore, the pressure of the gas increases.

Short Answers

Question 12.17

Consider a Carnot's cycle operating between $T_1 = 500\text{K}$ and $T_2 = 300\text{K}$ producing 1 kJ of mechanical work per cycle. Find the heat transferred to the engine by the reservoirs.

Solution

Given,

Temperature of the source, $T_1 = 500\text{ K}$

Temperature of the sink, $T_2 = 300\text{ K}$

Work done per cycle, $W = 1\text{ kJ} = 1000\text{ J}$

Heat transferred to the engine per cycle, $Q_1 = ?$

Efficiency of a Carnot engine

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{500} = \frac{2}{5}$$

$$\eta = \frac{W}{Q_1} \Rightarrow Q_1 = \frac{W}{\eta} = 2500\text{ J}$$

$$Q_1 - Q_2 = W, Q_2 = Q_1 - W$$

$$= 2500\text{ J} - 1000\text{ J} = 1500\text{ J}$$

Question 12.18

A person of mass 60 kg wants to lose 5 kg by going up and down a 10 m high stairs. Assume he burns twice as much fat while going up than coming down. If 1 kg of fat is burnt on expending 7000

kilocalories, how many times must he go up and down to reduce his weight by 5 kg?

Solution

Given,

Height of the stairs, $h = 10 \text{ m}$

Work done to burn 5 kg of fat $= (5)(7000 \times 10^3)(4.2) = 147 \times 10^6 \text{ J}$

Work done towards burning of fat in one trip $= mgh + 1/2 mgh = 3/2 mgh = (3/2)(60)(10)(10) = 9 \times 10^3 \text{ J}$

Therefore, no. of trips required $= 16.3 \times 10^3$ times.

Question 12.19

Consider a cycle tyre being filled with air by a pump. Let V be the volume of the tyre and at each stroke of the pump ΔV of air is transferred to the tube adiabatically. What is the work done when the pressure in the tube is increased from P_1 to P_2 ?

Solution

Following is the equation before and after the stroke:

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

$$P(V + \Delta V)^\gamma = (P + \Delta P)V^\gamma \Rightarrow PV^\gamma \left(1 + \frac{\Delta V}{V}\right)^\gamma = P\left(1 + \frac{\Delta P}{P}\right)V^\gamma$$

$$PV^\gamma \left(1 + \gamma \frac{\Delta V}{V}\right) \approx P\left(1 + \frac{\Delta P}{P}\right)V^\gamma$$

$$\gamma \frac{\Delta V}{V} = \frac{\Delta P}{P}$$

Therefore, work done is given as

$$W = \frac{(P_2 - P_1)V}{\gamma}$$

Question 12.20

In a refrigerator, one removes heat from a lower temperature and deposits to the surroundings at a higher temperature. In this process, mechanical work has to be done, which is provided by an electric motor. If the motor is of 1kW power, and heat is transferred from -3°C to 27°C , find the heat taken out of the refrigerator per second assuming its efficiency is 50% of a perfect engine.

Solution

Efficiency of the Carnot engine is

$$\eta = 1 - \frac{T_2}{T_1}$$

Where

$$T_1 = 300 \text{ K}$$

$$T_2 = 270 \text{ K}$$

It is given that efficiency is $50\% = 0.5$

Efficiency of refrigerator = 0.05

We know that

$$\eta_{ref} = \frac{W}{Q_1} \Rightarrow Q_1 = \frac{W}{\eta_{ref}} = 20 \text{ kJ}$$

Therefore, the efficiency of the refrigerator is

$$Q_2 = Q_1 - \eta_{ref} Q_1 = Q_1(1 - \eta_{ref}) = 19 \text{ kJ}$$

Question 12.21

If the coefficient of performance of a refrigerator is 5 and operates at the room temperature, find the temperature inside the refrigerator.

Solution

To find the temperature inside the refrigerator, we need to find the work done

$$W = 0$$

$$Q_1 = Q_2$$

$$\beta = \infty$$

Where β is the coefficient of performance

Given,

$$T_1 = 27 + 273 = 300 \text{ K}$$

Coefficient of performance of refrigerator $\omega = 5$

Coefficient of performance is given as

$$\beta = \frac{Q_2}{Q_1 - Q_2}$$

Using the above equation, the temperature can be determined

$$\omega = \frac{T_2}{T_1 - T_2}$$

$$T_2 = -23^\circ\text{C}.$$

Question 12.22

The initial state of a certain gas is P_i, V_i, T_i . It undergoes expansion till its volume becomes V_f .

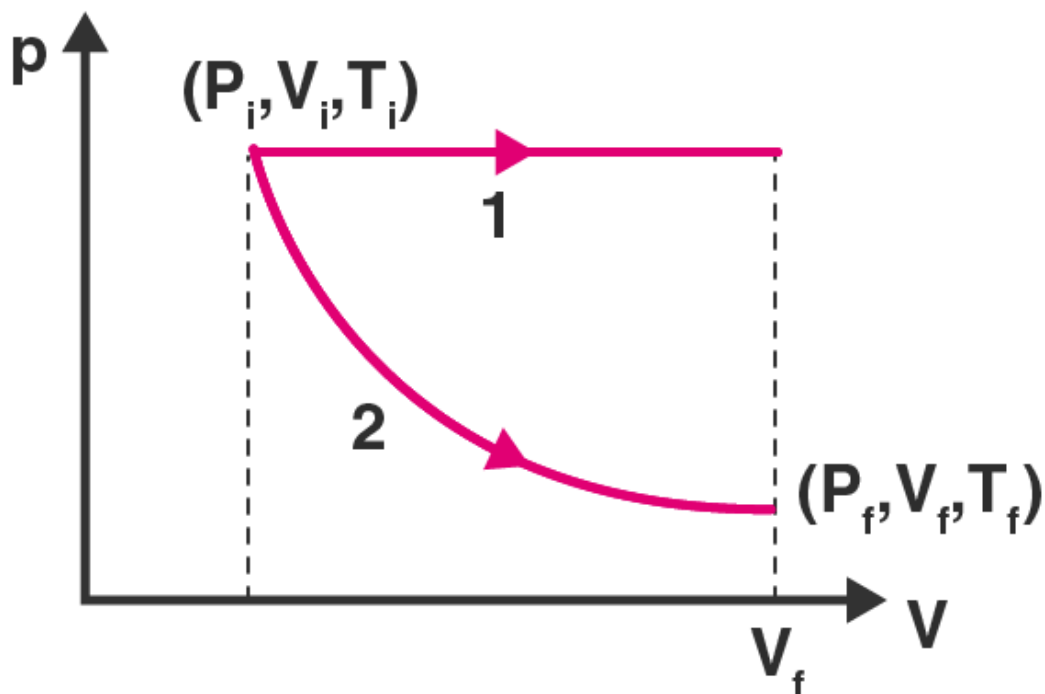
Consider the following two cases:

a) the expansion takes place at constant temperature

b) the expansion takes place at constant pressure

Plot the P-V diagram for each case. In which of the two cases, is the work done by the gas more?

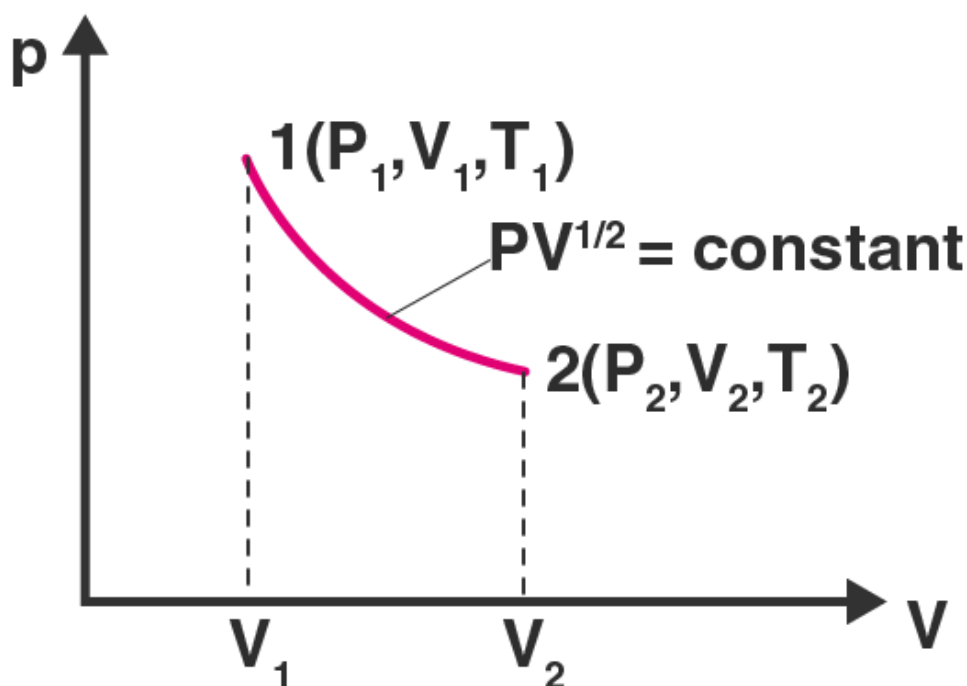
Solution



Long Answers

Question 12.23

Consider a P-V diagram in which the path followed by one mole of a perfect gas in a cylindrical container is shown in the figure.



- find the work done when the gas is taken from state 1 to state 2
- what is the ratio of temperature T_1/T_2 if $V_2 = 2V_1$
- given the internal energy for one mole of gas at temperature T is $(3/2)RT$, find the heat supplied to the gas when it is taken from state 1 to 2 with $V_2 = 2V_1$.

Solution

Given,

$$PV^{1/2} = K = \text{constant}$$

- Work done for the process 1 to 2

$$W_{1 \rightarrow 2} = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} \frac{K}{\sqrt{V}} dV$$

Solving the above equation, we get

$$W_{1 \rightarrow 2} = 2P_2V_2^{\frac{1}{2}}(\sqrt{V_2} - \sqrt{V_1})$$

b) Ideal gas equation is

$$PV = nRT$$

$$T = PV/nR$$

$$T = \frac{K\sqrt{V}}{nR}$$

$$T \propto \sqrt{V}$$

$$\frac{T_2}{T_1} = \sqrt{\frac{V_2}{V_1}} = \sqrt{\frac{2V_1}{V_1}} = \sqrt{2}$$

c) Internal energy, $U = (3/2)RT$

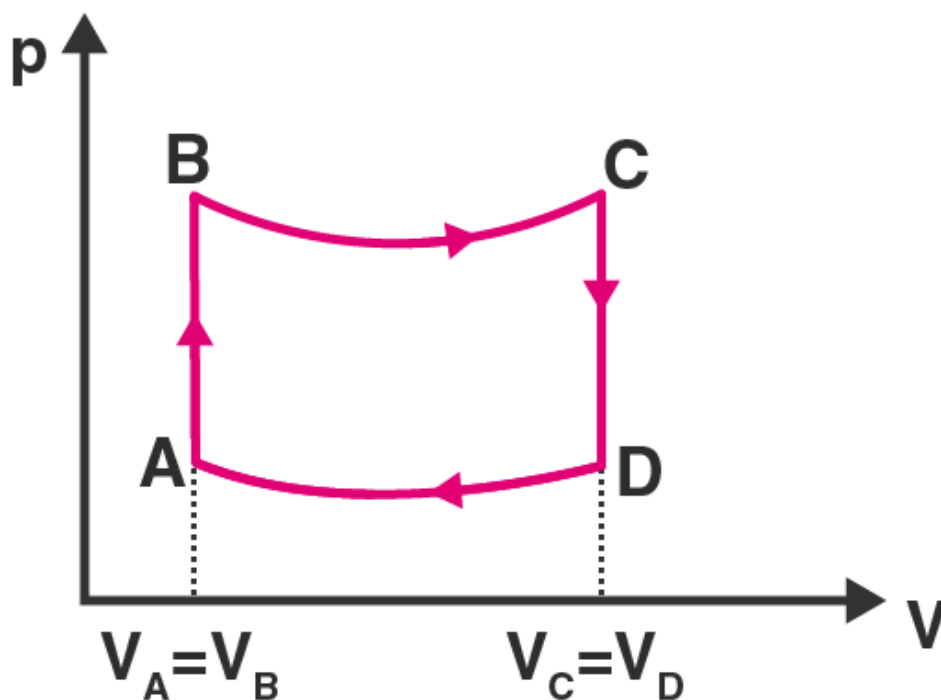
$$\Delta U = U_2 - U_1 = \frac{3}{2}R(T_2 - T_1) = \frac{3}{2}RT_1(\sqrt{2} - 1)$$

$$\Delta W = W_{1 \rightarrow 2} = 2P_1V_1^{\frac{1}{2}}(V_2^{\frac{1}{2}} - V_1^{\frac{1}{2}}) = 2RT_1(\sqrt{2} - 1)$$

$$\Delta Q = \Delta U + \Delta W = \frac{3}{2}RT_1(\sqrt{2} - 1) + 2RT_1(\sqrt{2} - 1) = \frac{7}{2}RT_1(\sqrt{2} - 1)$$

Question 12.24

A cycle followed by an engine is shown in the figure.



A to B: volume constant

B to C: adiabatic

C to D: volume constant

D to A: adiabatic

$$V_C = V_D = 2V_A = 2V_B$$

- in which part of the cycle heat is supplied to the engine from outside?
- in which part of the cycle heat is being given to the surrounding by the engine?
- what is the work done by the engine in one cycle in terms of P_A , P_B , V_A ?
- what is the efficiency of the engine?

Solution

a) For process AB, the heat is supplied to the engine from outside.

$$dQ = dU + dW$$

$$dQ = dU = \text{change in internal energy}$$

b) For process CD, the volume remains constant and pressure decreases as the temperature for this process decreases.

c) Work done by the engine in one cycle in terms of P_A , P_B , V_A

$$\int_A^B P dV + \int_B^C P dV + \int_C^D P dV + \int_D^A P dV$$

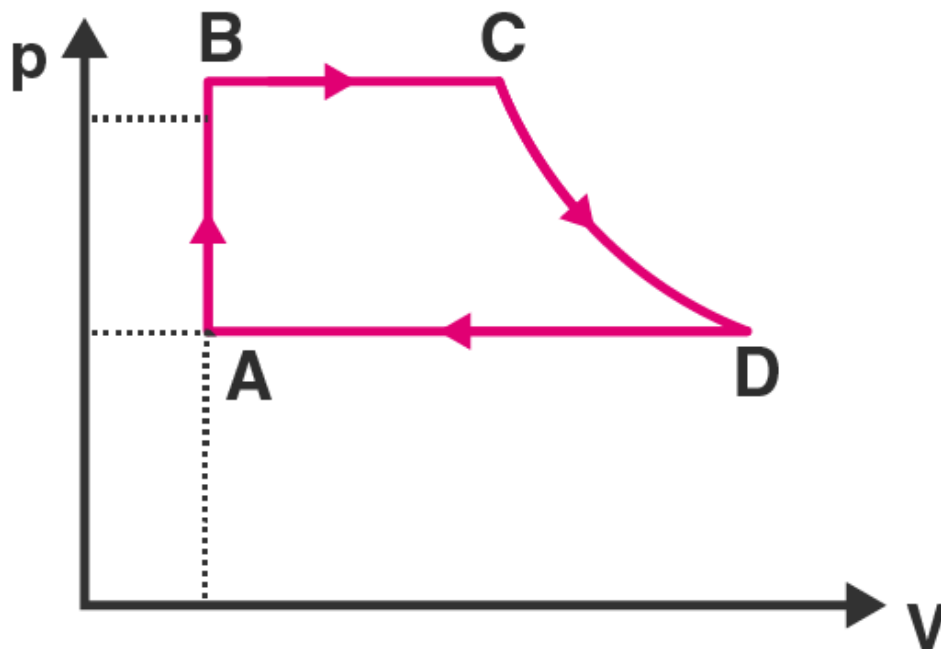
$$\text{Work done} = +\frac{3}{2}\left[1 - \left(\frac{1}{2}\right)^{\frac{2}{3}}\right][P_B - P_A]V_A$$

d) Efficiency is given as:

$$\eta = \frac{W}{Q} = \left[1 - \left(\frac{1}{2}\right)^{\frac{2}{3}}\right]$$

Question 12.25

A cycle followed by an engine is shown in the figure. Find heat exchanged by the engine, with the surroundings for each section of the cycle considering $C_V = (3/2)R$.



AB: constant volume

BC: constant pressure

CD: adiabatic

DA: constant pressure

Solution

a) AB: constant volume

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

$$\Delta Q = \frac{3}{2}(P_B - P_A)V_A$$

b) BC: constant pressure

$$\Delta Q = \Delta U + \Delta W = \frac{5}{2}P_B(V_C - V_A)$$

c) CD: adiabatic $Q_{CD} = 0$

d) DA: constant pressure, there is compression of the gas from V_D to V_A at constant pressure P_A .

Question 12.26

Consider that an ideal gas is expanding in a process given by $P = f(V)$, which passes through a point (V_0, P_0) . Show that the gas is absorbing heat at (P_0, V_0) if the slope of the curve $P = f(V)$ is larger than the slope of the adiabat passing through (P_0, V_0) .

Solution

Slope of the graph,

$$(V_0, P_0) = \left(\frac{dP}{dV}\right)_{V_0, P_0}$$

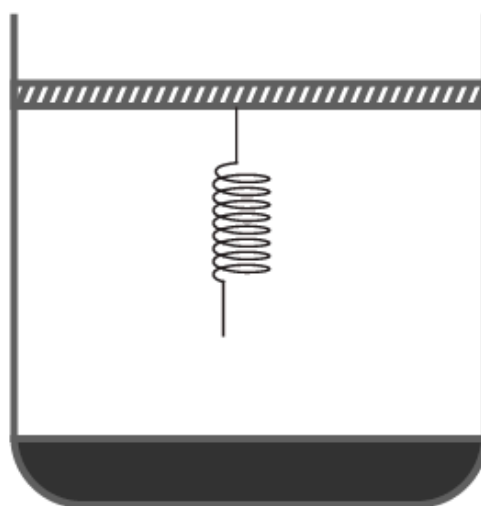
Using the above relation, we can find that

$$V_0 f'(V_0) > -\gamma P_0$$

$$f'(V_0) > \frac{-\gamma P_0}{V_0}$$

Question 12.27

Consider one mole of a perfect gas in a cylinder of unit cross-section with a piston attached. A spring is attached to the piston and to the bottom of the cylinder. Initially the spring is unstretched and the gas is in equilibrium. A certain amount of heat Q is supplied to the gas causing an increase of volume from V_0 to V_1 .



Atmospheric pressure = P_a

- what is the initial pressure of the system?
- what is the final pressure of the system?
- using the first law of thermodynamics, write down the relation between Q , P_a , V , V_0 , and k .

Solution

a) The initial pressure of the system inside the cylinder is $= P_a$

b) The final pressure of the system is $= P_f$

$$P_f = P_a + K (V_1 - V_0)$$

Where $V_1 - V_0$ is the increase in volume

c) The relation between Q , P_a , V , V_0 , and k is:

$$dQ = dU + dW$$

$$dU = C_v (T - T_0)$$

Where,

T is the final temperature of the gas

T_0 is the initial temperature of the gas

$$n = 1$$

$$T_y = T = \frac{P_f V_f}{R} = \frac{P_a + K(V_1 - V_0)V_1}{R}$$

Work done by the gas is given as:

$$dW = P_a(V_1 - V_0) + \frac{1}{2}kx^2$$

$$dQ = dU + dW$$

Using this equation, we get the following required relation:

$$dQ = C_v(T - T_0) + P_a(V_1 - V_0) + \frac{1}{2}k(V_1 - V_0)^2$$