Chapter 4: Thermodynamics

EXERCISES [PAGES 107 - 108]

Exercises | Q 1.1 | Page 107

Choose the correct option.
A gas in a closed container is heated with 10 J of energy, causing the lid of the container to rise 2m with 3N of force. What is the total change in energy of the system?

1. 10 J
2. **4 J**
3. - 10 J
4. - 4 J

SOLUTION

4 J

Explanation:

For this problem, use the first law of thermodynamics. The change in energy equals the increase in heat energy minus the work done.

$\Delta U = Q - W$

We are not given a value for work, but we can solve for it using the force and distance. Work is the product of force and displacement.

$W = F \Delta x$

$W = 3N \times 2m$

$W = 6\ J$

Now that we have the value of work done and the value for heat added, we can solve for the total change in energy.

$\Delta U = Q - W$

$\Delta U = 10\ J - 6\ J$

$\mathbf{\Delta U = 4\ J}$

Exercises | Q 1.2 | Page 107

Choose the correct option.
Which of the following is an example of the first law of thermodynamics?

1. The specific heat of an object explains how easily it changes temperatures.
2. **While melting, an ice cube remains at the same temperature.**
3. When a refrigerator is unplugged, everything inside of it returns to room temperature after some time.
4. After falling down the hill, a ball's kinetic energy plus heat energy equals the initial potential energy.

SOLUTION

While melting, an ice cube remains at the same temperature.

Exercises | Q 1.3 | Page 107

Choose the correct option.
Efficiency of a Carnot engine is large when
(A) T_H is large
(B) T_c is low
(C) T_H - T_c is large
(D) T_H - T_c is small

SOLUTION

(A) T_H is large

(B) T_c is low

(C) T_H - T_c is large

Explanation:

$$\left[\eta = \frac{T_H - T_c}{T_H} = 1 - \frac{T_c}{T_H}\right]$$

Exercises | Q 1.4 | Page 107

Choose the correct option.
The second law of thermodynamics deals with transfer of:
(A) work done
(B) energy
(C) momentum
(D) heat

SOLUTION

(B) energy

(D) heat

Exercises | Q 1.5 | Page 107

Choose the correct option.
During refrigeration cycle, heat is rejected by the refrigerant in the:

1. **condenser**
2. cold chamber
3. evaporator
4. hot chamber

SOLUTION

condenser

Exercises | Q 2.1 | Page 107
Answer in brief:
A gas contained in a cylinder surrounded by a thick layer of insulating material is quickly compressed has there been a transfer of heat?

SOLUTION

No. There is no transfer of heat energy, as the cylindrical vessel is surrounded by an insulating material, which doesn't allow heat transfer.

Exercises | Q 2.2 | Page 107

Answer in brief:
Give an example of some familiar process in which no heat is added to or removed form a system, but the temperature of the system changes.

SOLUTION

Adiabatic compression is the process in which no heat is transferred to or from the system but the temperature of the system changes. When we compress gas in an adiabatic process the volume of the gas will decrease and the temperature of the gas rises as it is compressed which we have seen the warming of a bicycle pump. Conversely, the temperature falls when the gas expands but the heat remains constant throughout the process.

Exercises | Q 2.3 | Page 107
Give an example of some familiar process in which heat is added to an object, without changing its temperature.

SOLUTION

(i) Melting of ice (ii) Boiling of water.

Exercises | Q 2.4 | Page 107

Answer in brief.
What sets the limits on the efficiency of a heat engine?

SOLUTION

The temperature of the cold reservoir sets the limit on the efficiency of a heat engine.

Note: $\eta = 1 - \frac{T_c}{T_H}$

This formula shows that for maximum efficiency, T_c should be as low as possible and T_H should be as high as possible.

For a Carnot engine, efficiency

$\eta = 1 - \frac{T_c}{T_H}$. $\eta \to 1$ as $T_c \to 0$.

Exercises | Q 2.5 | Page 107
Answer in brief.
Why should a Carnot cycle have two isothermal two adiabatic processes?

SOLUTION

With two isothermal and two adiabatic processes, all reversible, the efficiency of the Carnot engine depends only on the temperatures of the hot and cold reservoirs.

[**Note:** This is not so in the Otto cycle and Diesel cycle.]

Exercises | Q 3.1 | Page 107
A mixture of hydrogen and oxygen is enclosed in a rigid insulating cylinder. It is ignited by a spark. The temperature and pressure both increase considerably. Assume that the energy supplied by the spark is negligible, what conclusions may be drawn by application of the first law of thermodynamics?

SOLUTION

The internal energy of a system is the sum of potential energy and kinetic energy of all the constituents of the system. In the example stated above, the conversion of potential energy into kinetic energy is responsible for a considerable rise in pressure and temperature of the mixture of hydrogen and oxygen ignited by the spark.

Exercises | Q 3.2 | Page 107

A resistor held in running water carries electric current. Treat the resistor as the system (a) Does heat flow into the resistor? (b) Is there a flow of heat into the water? (c) Is any work done? (d) Assuming the state of resistance to remain unchanged, apply the first law of thermodynamics to this process.

SOLUTION

(a) Heat is generated into the resistor due to the passage of electric current. In the usual notation, heat generated = I^2Rt.

(b) Yes. Water receives heat from the resistor.

(c) $I^2Rt = MC\Delta T + P\Delta V$
(Q) (Δ U) (W)

Here, I = current through the resistor, R = resistance of the resistor, t = time for which the current is passed through the resistor, M = mass of the water, S = specific heat of water, T = rise in the temperature of water, P = pressure against which the work is done by the water, Δ U = increase in the volume of the water.

Exercises | Q 3.3 | Page 107

A mixture of fuel and oxygen is burned in a constant-volume chamber surrounded by a water bath. It was noticed that the temperature of water is increased during the process. Treating the mixture of fuel and oxygen as the system, (a) Has heat been transferred? (b) Has work been done? (c) What is the sign of ΔU?

SOLUTION

(a) Heat has been transferred from the chamber to the water bath.

(b) No work is done by the system (the mixture of fuel and oxygen) as there is no change in its volume

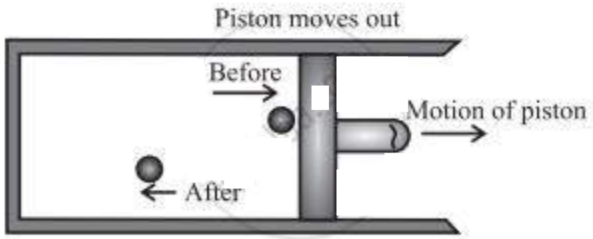
(c) There is an increase in the temperature of the water. Therefore, ΔU is positive for water.
For the system (the mixture of fuel and oxygen), ΔU is negative.

Exercises | Q 3.4 | Page 107

Draw a p-V diagram and explain the concept of positive and negative work. Give one example each.

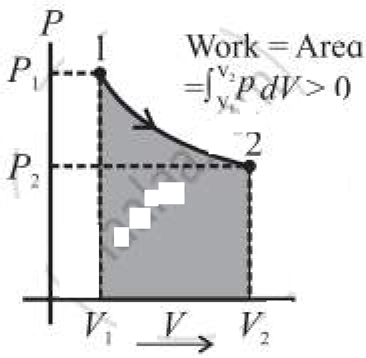
SOLUTION

Consider some quantity of an ideal gas enclosed in a cylinder fitted with a movable, massless, and frictionless piston.



Expansion of a gas

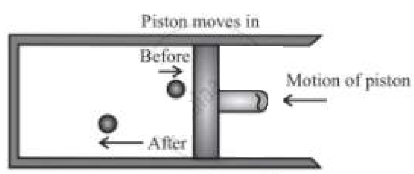
Suppose the gas is allowed to expand by moving the piston outward extremely slowly. There is a decrease in the pressure of the gas as the volume of the gas increases. The figure shows the corresponding P-V diagram.



Positive work with varying pressure

In this case, the work done by the gas on its surroundings,

$$W = \int_{v_1}^{v_2} PdV \text{ (= area under the curve) is positive}$$



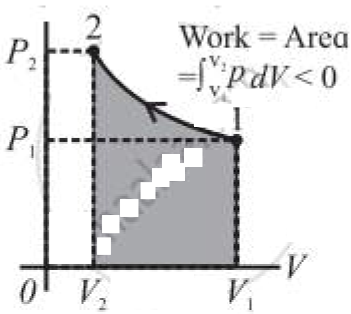
compression of a gas

initial condition, the piston is moved inward extremely slowly so that the gas is compressed. There is an increase in the pressure of the gas as the volume of the gas decreases. The figure shows the corresponding P-V diagram.

In this case, the work done by the gas on its surroundings,

$$W = \int_{v_1}^{v_2} PdV \text{ (= area under the curve) is negative}$$

the volume of the gas has decreased from V_2 to V_1



Negative work with varying pressure

The figure shows the corresponding P-V diagram.

Exercises | Q 3.5 | Page 107

Answer in brief:
A solar cooker and a pressure cooker both are used to cook food. Treating them as thermodynamic systems, discuss the similarities and differences between them.

SOLUTION

Solar cooker:

- Solar cooker was invented by Horace Benedict de saussure in 1767.
- Solar cooker is a device used to cook food by using no fuel, instead of sunlight.
- Solar cookers use a parabolic reflector to collect the rays of the sun and focus them at the cooker to heat it and cook the food in the cooker.
- Today the solar cookers are a little bit expensive than pressure cookers.
- Big solar cookers can be used to make food for people on a larger scale.

Pressure Cooker-

- Pressure cooker was invented by Denis papin.
- Pressure cookers are the most common cookers used in our houses and can be found in every house.
- Pressure cookers require water to convert it into steam for raising the internal temperature and pressure that permits quick cooking.
- Pressure cooker are cheaper than solar cookers.
- Pressure cookers requires a fuel for heating the liquid inside them.

Exercises | Q 4 | Page 108

A gas contained in a cylinder fitted with a frictionless piston expands against a constant external pressure of 1 atm from a volume of 5 liters to a volume of 10 liters. In doing so it absorbs 400 J of thermal energy from its surroundings. Determine the change in the internal energy of the system.

SOLUTION

Data: $P = 1$ atm $= 1.013 \times 10^5$ Pa,
$V_1 = 5$ liters $= 5 \times 10^{-3} m^3$,
$V_2 = 10$ liters $= 10 \times 10^{-3} m^3$,
$Q = 400$ J.

The work done by the system (gas in this case) on its surroundings,

$W = P(V_2 - V_1)$

$= (1.013 \times 10^5 \text{ Pa}) (10 \times 10^{-3} m^3 - 5 \times 10^{-3} m^3)$

$= 1.013 (5 \times 10^2)$ J

$= 5.065 \times 10^2$ J

The change in the internal energy of the system,

$\Delta U = Q - W = 400 \text{ J} - 506.5 \text{ J} = -106.5 \text{ J}$

The minus sign shows that there is a decrease in the internal energy of the system.

Exercises | Q 5 | Page 108

A system releases 125 kJ of heat while 104 kJ of work is done on the system. Calculate the change in internal energy.

SOLUTION

Data: $Q = -125$ kJ, $W = -104$ kJ

$\Delta U = Q - W = -125 \text{ kJ} - (-104 \text{ kJ})$

$= (-125 + 104) \text{ kJ} = -21$ kJ.

This is the change (decrease) in the internal energy.

Exercises | Q 6 | Page 108

The efficiency of a Carnot cycle is 75%. If the temperature of the hot reservoir is 727°C, calculate the temperature of the cold reservoir.

SOLUTION

Data: $\eta = 75\% = 0.75$, $T_H = (273 + 727) \text{ K} = 1000 \text{ K}$

$$\eta = 1 - \frac{T_C}{T_H}$$

$$\therefore \frac{T_C}{T_H} = 1 - \eta$$

$$\therefore T_C = T_H (1 - \eta) = 1000 \text{ K} (1 - 0.75)$$

$= 250\ K = (250 - 273)°C$

$= - 23°C$

This is the temperature of the cold reservoir.

Exercises | Q 7 | Page 108

A Carnot refrigerator operates between 250°K and 300°K. Calculate its coefficient of performance.

SOLUTION

Data: $T_C = 250K$, $T_H = 300K$

$$K = \frac{T_C}{T_H - T_C} = \frac{250K}{300K - 250K} = 5$$

This is the coefficient of performance of the refrigerator.

Exercises | Q 8 | Page 108

An ideal gas is taken through an isothermal process. If it does 2000 J of work on its environment, how much heat is added to it?

SOLUTION

Data: W = 2000 J, isothermal process

In this case, the change in the internal energy of the gas, Δ U, is zero as the gas is taken through an isothermal process.

Hence, the heat added to it,

Q = Δ U + W = O + W = 2000 J

Exercises | Q 9 | Page 108

An ideal monatomic gas is adiabatically compressed so that its final temperature is twice its initial temperature. What is the ratio of the final pressure to its initial pressure?

SOLUTION

Data: $T_f = 2T_i$, monatomic gas ∴ Y = 5/3

$P_iV_iY = P_fV_fY$ in an adiabatic process

Now, PV = ηRT ∴ $V = \frac{\eta RT}{P}$

$$\therefore V_i = \frac{\eta R T_i}{P_i} \text{ and } V_f = \frac{\eta R T_f}{P_f}$$

$$\therefore P_i \left(\frac{\eta R T}{P_i}\right)^{\Upsilon} = P_f \left(\frac{\eta R T_f}{P_f}\right)^{\Upsilon}$$

$$\therefore P_i^{1-\Upsilon} T_i^{\Upsilon} = P_f^{1-\Upsilon} T_f^{\Upsilon}$$

$$\therefore \left(\frac{T_f}{T_i}\right)^{\Upsilon} = \left(\frac{P_i}{P_f}\right)^{1-\Upsilon}$$

$$\therefore \left(\frac{T_f}{T_i}\right)^{\Upsilon} = \left(\frac{P_f}{P_i}\right)^{\Upsilon-1}$$

$$\therefore 2^{5/3} = \left(\frac{P_f}{P_i}\right)^{5/3-1} = \left(\frac{P_f}{P_i}\right)^{2/3}$$

$$\therefore \frac{5}{3} \log 2 = \frac{2}{3} \log \frac{P_f}{P_i}$$

$$\therefore \frac{5}{3} \times 0.3010 = \frac{2}{3} \log \left(\frac{P_f}{P_i}\right)$$

$$\therefore (2.5)\,(0.3010) = \log \left(\frac{P_f}{P_i}\right)$$

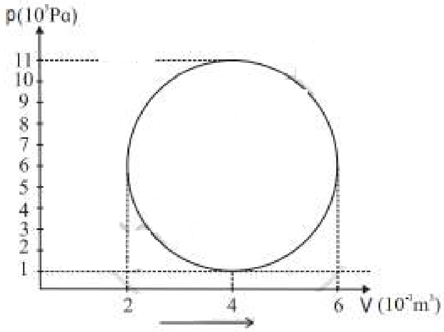
$$\therefore 0.7525 = \log \left(\frac{P_f}{P_i}\right)$$

$$\therefore \frac{P_f}{P_i} = \text{antilog } 0.7525 = 5.656$$

This is the ratio of the final pressure (Pf) to the initial pressure (Pi).

Exercises | Q 10 | Page 108

A hypothetical thermodynamic cycle is shown in the figure. Calculate the work done in 25 cycles.



SOLUTION

Work done in 1 cycle = Area enclosed

by the PV curve.

$$= \frac{\pi}{4} \times (P_2 - P_1)(V_2 - V_1)$$

$$= \frac{\pi}{4} \times \left[(11 - 1) \times 10^5\right]\left[(6 - 2) \times 10^{-3}\right]$$

$$= \frac{\pi}{4} \times \left(10^6\right)\left(4 \times 10^{-3}\right)$$

$$= \pi \times 10^3$$

$$= 3.14 \times 10^3 \text{ J}$$

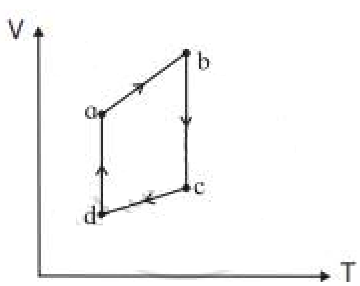
Work done in 25 cycles

$$= 25 \times 3.14 \times 10^3$$

$$= 7.85 \times 10^4 \text{ J.}$$

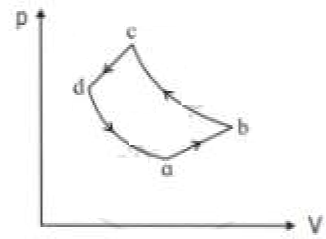
Exercises | Q 11 | Page 108

The figure shows the V-T diagram for one cycle of a hypothetical heat engine which uses the ideal gas. Draw (a) the p-V diagram and (b) p-T diagram of the system



SOLUTION

(a) **P-V diagram (Schematic)**



ab: isobaric process,

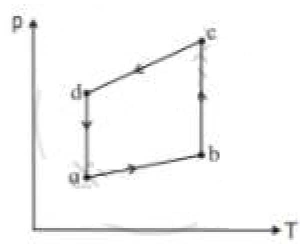
bc: isothermal process,

cd: isobaric process,

da: isothermal process

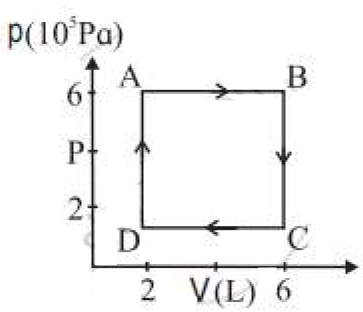
$$\frac{P_a V_a}{T_a} = \frac{P_b V_b}{T_b} = \frac{P_c V_c}{T_c} = \frac{P_d V_d}{T_d} = \eta R$$

(b) **P-T diagram (Schematic)**



Exercises | Q 12 | Page 108

A system is taken to its final state from initial state in hypothetical paths as shown figure calculate the work done in each case.



SOLUTION

Data: $P_A = P_B = 6 \times 10^5$ Pa, $P_C = P_D = 2 \times 10^5$ Pa

$V_A = V_D = 2$ L, $V_B = V_C = 6$ L, 1 L = $10^{-3} m^3$

(i) The work d one along the path A → B (isobaric process), $W_{AB} = P_A (V_B - V_A)$
$= (6 \times 10^5 \text{ Pa}) (6 - 2) (10^{-3} m^3) = 2.4 \times 10^3$ J

(ii) W_{BC} = zero as the process is isochoric
(V = constant).

(iii) The work done along the path C → D (isobaric process), $W_{CD} = P_C (V_D - V_C)$
$= (2 \times 10^5 \text{ Pa}) (2 - 6) (10^{-3} m^3) = - 8 \times 10^2$ J

(iv) W_{DA} = zero as V = constant.