UNIT = 16 FIRST LAW OF THERMODYNAMICS

BOOK NUMERICAL

1. A gas undergoes isothermal expansion at a constant temperature of 300 K. If the gas absorbs 500 J of heat during the process, calculate the work done by the gas.

Data:	SOLUTION:
T = 500 k $\Delta Q = 500J$ $\Delta W = ?$	According to first law of thermodynamics $\Delta Q = \Delta U + \Delta W$ *In an isothermal process, the change in internal energy (ΔU) of an ideal gas is zero* $500 = 0 + \Delta W$ $500\,J = \Delta W$

2 A piston compresses a gas isothermally. If the initial volume is 0.02 m³ and the final volume is 0.01 m³, and the initial pressure is 200 kPa, determine the final pressure. Assume the gas behaves ideally.

Data:	SOLUTION:
$V_1 = 0.02\ m^3$ $V_2 = 0.01\ m^3$ $P_1 = 200\ KPa = 200 \times 10^3\ Pa$ $P_1 = 2.0 \times 10^5\ Pa$ $P_2 = ?$	*In an isothermal process, the temperature is kept constant* *According to Boyle's law* $P_1 V_1 = P_2 V_2$ $2.0 \times 10^5 \times 0.02 = P_2 \times 0.01$ $\frac{2.0 \times 10^5 \times 0.02}{0.01} = P_2$ $4.0 \times 10^5\ Pa = P_2$

3 **A system undergoes an isobaric process, keeping the pressure constant at 15 kPa. If the volume increases from 0.05 m³ to 0.08 m³, and the change in its internal energy is 150 J. Calculate the heat added to the system**

DATA:

$P = 15\,KPa = 15 \times 10^3\ Pa$

$P = 1.5 \times 10^4\ Pa$

$V_1 = 0.05\ m^3$

$V_2 = 0.08\ m^3$

$\Delta U = 150\,J$

$\Delta Q = ?$

SOLUTION:

In an isobaric process,

$\Delta W = P\,\Delta V$

According to first law of thermodynamics

$\Delta Q = \Delta U + P\,\Delta V$

$\Delta Q = \Delta U + P(V_2 - V_1)$

$\Delta Q = (150) + 1.5 \times 10^4(0.08 - 0.05)$

$\Delta Q = (950) + 1.5 \times 10^4(0.03)$

$\Delta Q = 150 + 450 = 5450\,J$

$\Delta Q = 600\,J$

4 **During an isochoric process, the internal energy of a gas increases by 300 J. If no work is done, determine the heat added to the system.**

Data:

$\Delta U = 300 J$

$\Delta Q = ?$

SOLUTION

During an isochoric process, the volume remains constant, meaning no work is done on or by the system

$\Delta W = 0$

According to first law of thermodynamics

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

$\Delta W = 0$

$\Delta Q = 300 + 0$

$\Delta Q = 300\ J$

5 **A gas undergoes a cyclic process, starting at point A with a volume of 0.02 m³, going to B (isochoric heating), then to C (isothermal expansion), and back to A. If the heat added during isothermal expansion is 1000 J and the heat rejected during isochoric heating is 500 J, calculate the net work done by the system.**

SOLUTION

the net work done by the system during the cyclic process, we can use the first law of thermodynamics, which states:

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

In a cyclic process, the change in internal energy

$\Delta U = 0$

$\Delta Q = 0 + \Delta W$

$\Delta Q = \Delta W \ldots\ldots (i)$

Heat added during isothermal expansion

$Q_{in} = 1000\,J$

Heat rejected during isochoric heating

$Q_{out} = 500\,J$

$\Delta Q = Q_{in} - Q_{out}$

$\Delta Q = 1000 - 500 = 500\ J$

Substituting the expression of ΔQ in equation (i), we get

$\Delta W = 500\,J$

6 **A gas expands from 0.03 m³ to 0.06 m³ against a constant pressure of 10 kPa. Calculate the work done in both a reversible and an irreversible process, and compare the results**

DATA $V_1 = 0.03\ m^3$ $V_2 = 0.06\ m^3$ $P = 10\ KPa = 10 \times 10^3\ Pa$ **SOLUTION** *The work done by a gas during expansion at constant pressure can be calculated using the formula* $\Delta W = P\Delta V$ $\Delta W = P(V_2 - V_1)$	$\Delta W = 10 \times 10^3\ (0.06 - 0.03)$ $\Delta W = 10 \times 10^3\ (0.03)$ $\Delta W = 300J$ *In both reversible and irreversible processes, under constant pressure, the work done will be the same because it depends solely on the pressure and the volume change.*

7 **A 50 g piece of copper at 100 ⁰C is placed in 200 g of water at 20 ⁰C. if the final temperature of the system is measured at 21.8 ⁰C. Calculate the specific heat of copper?**

Data: $m_c = 50\ g$ $m_w = 200\ g$ $C_w = 4.18\ J/g℃$	$C_c = ?$ $T_1 = 100\ ℃$ $T_2 = 20\ ℃$ $T_{mix} = 21.82\ ℃$

SOLUTION

Heat lost by copper = heat absorbed by water + heat absorbed by the calorimeter

$$m_C C_c\ \Delta T = m_w C_w\ \Delta T$$

$$m_C C_c\ (T_1 - T_{mix}) = m_w C_w\ (T_{mix} - T_2)$$

$$50 \times C_c\ (100 - 21.82) = 200 \times 4.18\ (21.82 - 20)$$

$$50 \times C_c\ (78.18) = 200 \times 4.18\ (1.82)$$

$$3909 \times C_c = 1521.52$$

$$C_c = \frac{1521.52}{3909}$$

$$C_c = 0.389\ J/g℃$$

Corrected numerical 7

A Student in a physics lab is to determine the specific heat of copper experimentally, he heats a 150 g piece of copper at 100 ^{0}C and then carefully pours the piece of copper into a calorimeter cup, Containing 200 g of water at 20 ^{0}C. The final temperature of the mixture in the cup is measured at 25 ^{0}C. If the aluminum has a mass of 45 g. What is the specific heat of copper?

Data:	
$m_c = 150\ g = 0.15\ kg$	$C_{Al} = 920\ J/kg℃$
$m_w = 200\ g = 0.200\ kg$	$T_1 = 100\ ℃$
$C_w = 4186\ J/kg℃$	$T_2 = 20\ ℃$
$m_{Al} = 45\ g = 0.045\ kg$	$T_{mix} = 25\ ℃$

SOLUTION

Heat lost by copper = heat absorbed by water + heat absorbed by the calorimeter

$$m_C C_c\ \Delta T = m_w C_w\ \Delta T + m_{Al} C_{Al}\ \Delta T$$

$$m_C C_c\ (T_1 - T_{mix}) = m_w C_w\ (T_{mix} - T_2) + m_{Al} C_{Al}\ (T_{mix} - T_2)$$

$$0.15 \times C_c\ (100 - 25) = 0.2 \times 4186\ (25 - 20) + 0.045 \times 920\ (25 - 20)$$

$$0.15 \times C_c\ (75) = 0.2 \times 4186\ (5) + 0.045 \times 920\ (5)$$

$$11.25 \times C_c = 4186 + 207$$

$$11.25 \times C_c = 4393$$

$$C_c = \frac{4393}{11.25}$$

$$C_c = 390.4\ J\ /\ kg\ ℃$$

8 **How much heat is required to raise the temperature of 1 kg of lead from 25 ^{0}C to 100 ^{0}C? (specific heat of lead = 0.128 J/g ^{0}C)**

Data:	SOLUTION
$m_{lead} = 1\ kg = 1000\ kg$	$\Delta Q = m_{lead}\ C_{lead}\ \Delta T$
$T_1 = 25\ ℃$	$\Delta Q = m_{lead}\ C_{lead}\ (T_2 - T_1)$
$T_2 = 100\ ℃$	$\Delta Q = (1000)\ (0.128)\ (100 - 25)$
$C_{lead} = 0.128\ J/g\ ℃$	$\Delta Q = (1000)\ (0.128)\ (75)$
$\Delta Q = ?$	$\Delta Q = 9600\ J$

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WORKED EXAMPLE

1 **The volume occupied by 1.00 mol of a liquid at 50 °C is 2.4 x 10^{-5} m^3. When the liquid is vaporized at an atmospheric pressure of l .03 x 10^5 Pa, the vapor has a volume of 5.9x10^{-2} m^3. The latent heat to vaporize 1.00 mol of this liquid at 50 °C and at atmospheric pressure is 3.48 x 10^4 J. Determine the change in internal energy ΔU of the system.**

DATA: $n = 1.00\ mole$ $V_1 = 2.4 \times 10^{-5}\ \mathrm{m}^3$ $P = 1.03 \times 10^5\ Pa$ $\mathrm{V}_2 = 5.9 \times 10^{-2}\ \mathrm{m}^3$ $L_V = 3.48 \times 10^4\ J$ $\Delta U = ?$ **SOLUTION:** *The work done is given by* $\Delta W = P\ \Delta V$	$\Delta \mathrm{W} = \mathrm{P}(V_2 - V_1)$ $\Delta \mathrm{W} = 1.03 \times 10^5 (5.9 \times 10^{-2} - 2.4 \times 10^{-5})$ $\Delta \mathrm{W} = 1.03 \times 10^5 (0.05897)$ $\Delta \mathrm{W} = 6.074 \times 10^3\ J$ According to first law of thermodynamics $3.48 \times 10^4 = \Delta \mathrm{U} + 6.074 \times 10^3$ $\Delta \mathrm{U} = 3.48 \times 10^4 - 6.074 \times 10^3$ $\Delta \mathrm{U} = 2.872 \times 10^3\ J$

2 **When a balloon is inflated, its rubber walls push against the air around it. Calculate the work done when the balloon is blown up from 0.015 m^3 to 0.030 m^3. Atmospheric pressure= 1.0 x 10^5 Pa.**

DATA: $V_1 = 0.015\ \mathrm{m}^3$ $\mathrm{V}_2 = 0.030\ \mathrm{m}^3$ $P = 1.0 \times 10^5\ Pa$ $\Delta W = ?$ **SOLUTION:** *The work done is given by* $\Delta W = P\ \Delta V$	$\Delta \mathrm{W} = \mathrm{P}(V_2 - V_1)$ $\Delta \mathrm{W} = 1.0 \times 10^5 (0.030 - 0.015)$ $\Delta \mathrm{W} = 1.0 \times 10^5 (0.015)$ $\Delta \mathrm{W} = 1500\ J$

3 **The normal human body temperature is 36.88 °C. What is this temperature on the Fahrenheit scale? A gas confined in a cylinder undergoes an expansion from an initial volume of 2.0 L to a final volume of 4.0 L against a constant external pressure of 2.0 atm. Calculate the work done by the gas during this process.**

DATA: $T_{°C} = 36.88$ ℃ $T_{°F} = ?$ $V_1 = 4.0$ L $V_1 = 4.0 \times 0.001 = 0.004\ m^3$ $V_2 = 2.0$ L $V_1 = 2.0 \times 0.001 = 0.002\ m^3$ $P = 2\ atm = 2 \times 1.01 \times 10^5\ Pa$ $P = 2.02 \times 10^5\ Pa$ $\Delta W = ?$ **SOLUTION:** Celsius to Fahrenheit $T_{°F} = \frac{9}{5} \times T_{°C} + 32$ $T_{°F} = \frac{9}{5} \times (36.88) + 32$ $T_{°F} = 66.38 + 32$ $T_{°F} = 98.38$ °F	*The work done is given by* $\Delta W = P\ \Delta V$ $\Delta W = P(V_2 - V_1)$ $\Delta W = 2.02 \times 10^5 (0.004 - 0.002)$ $\Delta W = 2.02 \times 10^5 (0.002)$ $\Delta W = 404\ J$

4 **Calculate the molar specific heat capacity of a gas when 2 moles of the gas absorb 1500 J of heat energy and its temperature increases by 25 degrees Celsius.**

DATA: $n = 2\ mol$ $Q = 1500\ J$ $\Delta T = 25$ ℃ $\Delta W = ?$	**SOLUTION:** $Q = n\ C\ \Delta T$ $1500 = 2 \times C \times 25$ $1500 = 50 \times C$ $C = 30\ J/kg$ ℃

5 A sample of water with a mass of 200 grams is heated, and its temperature rises from 25 °C to 45 °C. Calculate the heat transferred to the water. Given the specific heat capacity of water (c) is 4.18 J/g °C.

Data:	SOLUTION
$m_w = 200$ g $T_1 = 25$ °C $T_2 = 45$ °C $C_w = 4.18\ J/g$ °C $Q = ?$	$Q = m_w C_w \Delta T$ $Q = m_w C_w (T_2 - T_1)$ $Q = (200)(4.18)(45 - 25)$ $Q = (200)(4.18)(20)$ $Q = 16720\ J$

6 An electric heater supplies 1800 W of power supply heat to a tank of water. How long will it take to heat 200 kg of water in the tank from 10°C to 70°C ?

Data:	SOLUTION
$P = 1800\ W$ $m_w = 200$ kg $T_1 = 10$ °C $T_2 = 70$ °C $C_w = 4184\ J/kg$ °C $t = ?$	$Q = m_w C_w \Delta T$ $P \times t = m_w C_w (T_2 - T_1)$ $1800 \times t = (200)(4184)(70 - 10)$ $1800 \times t = (200)(4184)(60)$ $1800 \times t = 5.02 \times 10^7$ $t = \frac{5.02 \times 10^7}{1800}$ $t = 2.788 \times 10^4\ s$ $t = \frac{2.788 \times 10^4}{3600}$ $t = 7.74\ h$