

Thermodynamics — Assignment 2

Class 11 Physics · Higher-difficulty challenge set + integrated problems · Answer key included · Narayan Gurukul Academy

Instructions: (1) Attempt all questions; start with the topic-wise challenge set, then attempt the integrated (multi-topic) problems.
(2) Give all answers with correct SI units. $g = 10 \text{ m/s}^2$ unless stated.
(3) A final answer key is provided at the end — try the full set before checking it.

Part A — Topic-wise challenge questions

Thermal Equilibrium and the Zeroth Law

2 Mark Questions

1. State the zeroth law of thermodynamics and explain how it justifies the use of a thermometer.
2. Explain the meaning of thermal equilibrium and give two examples.

3 Mark Questions

1. State and explain the zeroth law of thermodynamics, and show how it leads to the definition of temperature.

Heat, Work and Internal Energy

2 Mark Questions

1. A gas expands from 2 m^3 to 5 m^3 at a constant pressure of $4 \times 10^5 \text{ Pa}$. Find the work done by the gas.

3 Mark Questions

1. A gas is compressed at constant pressure of $2 \times 10^5 \text{ Pa}$ from 4 m^3 to 2 m^3 . Find the work done on the gas and state its sign.

The First Law of Thermodynamics

2 Mark Questions

1. In a certain process 1000 J of heat is supplied to a gas and it does 600 J of work. Find the change in its internal energy.

3 Mark Questions

1. A gas absorbs 400 J of heat and does 250 J of work. Find the change in internal energy. If the gas instead expands doing 400 J of work while absorbing 600 J, find the new ΔU .

Thermodynamic Processes

2 Mark Questions

1. One mole of an ideal gas expands isothermally at 300 K from 1 m^3 to 3 m^3 . Find the work done. ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.)

3 Mark Questions

1. A gas is expanded adiabatically from a pressure of $2 \times 10^5 \text{ Pa}$ and volume 0.5 m^3 so that its pressure becomes $8 \times 10^4 \text{ Pa}$. If $\gamma = 1.4$, find the new volume.

Specific Heats of a Gas

2 Mark Questions

1. For a diatomic gas with $C_V = 5R/2$, find C_P and γ .
2. Find the change in internal energy of 2 moles of a monatomic gas heated from 300 K to 400 K. ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.)

3 Mark Questions

1. A diatomic gas of 3 moles is heated at constant pressure from 300 K to 400 K. Find the heat supplied given $C_P = 7R/2$ and $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.

Heat Engines, Refrigerators and the Second Law

2 Mark Questions

1. A heat engine absorbs 1000 J from a hot reservoir and rejects 600 J to the cold reservoir. Find its efficiency.
2. Compute the Carnot efficiency of an engine operating between 400 K and 300 K.

3 Mark Questions

1. A Carnot engine works between temperatures 500 K and 300 K. Find (a) its efficiency and (b) the heat rejected per cycle if it absorbs 4000 J per cycle.

Part B — Integrated problems (multi-topic)

1. One mole of an ideal gas expands isothermally at 300 K from 1 m^3 to 3 m^3 . Find the work done, the heat absorbed and the change in internal energy. ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.)
2. A gas absorbs 1000 J of heat and does 600 J of work. Find its change in internal energy. If the same quantities are viewed as part of a heat-engine cycle absorbing 1000 J from a hot reservoir and rejecting 600 J, find the engine efficiency.
3. A gas is expanded adiabatically from a pressure of $2 \times 10^5 \text{ Pa}$ and volume 0.5 m^3 so that its pressure becomes $8 \times 10^4 \text{ Pa}$. If $\gamma = 1.4$, find the new volume and the work done during the expansion.
4. A Carnot engine works between temperatures 500 K and 300 K, absorbing 4000 J of heat per cycle. Find (a) its efficiency, (b) the heat rejected per cycle and (c) the work done per cycle.
5. Two moles of a monatomic ideal gas are heated from 300 K to 400 K at constant volume. Find the heat supplied. ($R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$.)

Answer Key

Thermal Equilibrium and the Zeroth Law

2M(0): If two bodies A and C (the thermometer) are in thermal equilibrium, no heat flows; a thermometer therefore measures the same temperature for any body with which it is in equilibrium. 2M(1): Thermal equilibrium means no net heat flow (same temperature); examples: hot tea cooling to room temperature; the bulb of a mercury thermometer equilibrating with a patient. 3M(0): The zeroth law lets us assign a single number — temperature — common to all bodies in equilibrium with one another; it is the transitivity that makes thermometry possible.

Heat, Work and Internal Energy

2M(1): $W = P\Delta V = 4 \times 10^5 \times (5 - 2) = 1.2 \times 10^6 \text{ J}$. 3M(1): $W_{\text{by gas}} = P\Delta V = 2 \times 10^5 \times (2 - 4) = -4 \times 10^5 \text{ J}$, so the work done ON the gas is $4 \times 10^5 \text{ J}$ (positive).

The First Law of Thermodynamics

2M(0): $\Delta U = Q - W = 1000 - 600 = 400 \text{ J}$. 3M(1): $\Delta U = 400 - 250 = 150 \text{ J}$; the second case gives $\Delta U = 600 - 400 = 200 \text{ J}$.

Thermodynamic Processes

2M(1): $W = nRT \ln(V_2/V_1) = 1 \times 8.31 \times 300 \times \ln 3 \approx 2.74 \times 10^3 \text{ J}$. 3M(1): $V_2 = V_1(P_1/P_2)^{1/\gamma} = 0.5 \times (2 \times 10^5/8 \times 10^4)^{1/1.4} = 0.5 \times 2.5^{1/1.4} \approx 0.96 \text{ m}^3$.

Specific Heats of a Gas

2M(1): $C_P = C_V + R = 7R/2$; $\gamma = C_P/C_V = 7/5 = 1.4$. 2M(2): $\Delta U = (3/2)nR\Delta T = 1.5 \times 2 \times 8.31 \times 100 = 2493 \text{ J} \approx 2.5 \times 10^3 \text{ J}$. 3M(1): $Q = nC_P\Delta T = 3 \times (7R/2) \times 100 = 3 \times 29.1 \times 100 \approx 8.73 \times 10^3 \text{ J}$.

Heat Engines, Refrigerators and the Second Law

2M(0): $\eta = W/Q_1 = (1000 - 600)/1000 = 40\%$. 2M(1): $\eta = 1 - T_2/T_1 = 1 - 300/400 = 25\%$. 3M(1): (a) $\eta = 1 - 300/500 = 40\%$; (b) $Q_2 = Q_1 \times T_2/T_1 = 4000 \times 300/500 = 2400 \text{ J}$.

Integrated problems

1: $W = nRT \ln(V_2/V_1) \approx 2.74 \times 10^3 \text{ J}$; $\Delta U = 0$ (isothermal ideal gas) $Q = W \approx 2.74 \times 10^3 \text{ J}$. 2: $\Delta U = 1000 - 600 = 400 \text{ J}$; $\eta = W/Q_1 = 400/1000 = 40\%$. 3: $V_2 \approx 0.96 \text{ m}^3$ (see part A); $W = (P_1V_1 - P_2V_2)/(\gamma - 1) = (10^5 - 7.7 \times 10^4)/0.4 \approx 5.76 \times 10^4 \text{ J}$. 4: $\eta = 40\%$; $Q_2 = 2400 \text{ J}$; $W = Q_1 - Q_2 = 1600 \text{ J}$. 5: At constant volume $Q = \Delta U = (3/2)nR\Delta T = 1.5 \times 2 \times 8.31 \times 100 \approx 2.49 \times 10^3 \text{ J}$.