Heat and Thermodynamics

SQ 6.1 What is meant by thermal equilibrium? Explain briefly.

Thermal Equilibrium
Two bodies are in thermal equilibrium when they have the same temperature and no net heat flows between them when they are in thermal contact.

Explanation
Heat initially flows from the hotter body to the colder body. When their temperatures become equal, the net flow of heat stops.

SQ 6.2 What is meant by internal energy? How is it related to temperature of an ideal gas?

Internal Energy
It is the sum of the microscopic kinetic and potential energies of the particles of a system:
$U = KE + PE.$

Ideal Gas
Intermolecular potential energy is neglected, so
$PE = 0$
and internal energy consists only of molecular kinetic energy. Therefore, it depends only on absolute temperature and increases when temperature increases.

SQ 6.3 State 2nd law of thermodynamics in two different forms.

Kelvin–Planck Statement
No cyclic heat engine can convert all the heat taken from a single reservoir completely into work; some heat must be rejected.

Clausius Statement
Heat cannot, by itself, flow from a colder body to a hotter body. External work is required.

SQ 6.4 Is it possible to construct a heat engine of 100% efficiency? Explain.

Maximum Efficiency
For an ideal Carnot engine,
$\eta = 1 - \frac{T_C}{T_H}.$

Condition for 100% Efficiency
For
$\eta = 1$
the sink temperature must be
$T_C = 0\,\mathrm{K}$
Since absolute zero cannot be attained, a heat engine of 100% efficiency is impossible.

SQ 6.5 Differentiate between reversible and irreversible processes.

Reversible Process	Irreversible Process
It proceeds through equilibrium states and can be reversed by an infinitesimal change.	It does not pass through complete equilibrium states and cannot be exactly reversed.
Both system and surroundings can be restored with no net change.	Exact restoration leaves a net change in the surroundings.
It is ideally slow and has no dissipative effects.	It involves finite gradients, friction, turbulence or heat loss.
Total entropy remains constant.	Total entropy increases.

SQ 6.6 Why adiabat is steeper than isotherm? Explain.

Isothermal Process
The temperature remains constant and the gas obeys
$PV = \text{constant}$

Adiabatic Process
No heat is exchanged and the gas obeys
$PV^\gamma = \text{constant}$
where $\gamma > 1$. During expansion, the gas also cools, so its pressure decreases more rapidly with volume. Therefore, the adiabat is steeper than the isotherm.

SQ 6.7 A refrigerator transforms heat from cold to hot body. Does this violate the second law of thermodynamics? Justify your answer.

No Violation
A refrigerator transfers heat from a cold region to a hot region by using external work supplied to its compressor.

Energy Balance
$Q_H = Q_C + W.$
The second law forbids this transfer only when it occurs without external work.

SQ 6.8 Explain briefly heat death of universe in terms of entropy.

Entropy Increase
In natural processes, the total entropy of an isolated system increases.

Heat Death
If the universe eventually reaches maximum entropy, energy will be uniformly distributed and no temperature differences will remain. With no usable energy gradients, no further macroscopic work can be performed.

SQ 6.9 Is it possible for a cyclic reversible heat engine to absorb heat at constant temperature and transforms it completely into work without rejecting some heat at low temperature? Explain.

Not Possible
Such an engine would have
$Q_C = 0$
and
$\eta = 1$
converting heat from one reservoir completely into work in a cycle. This violates the Kelvin–Planck statement of the second law. Even a reversible engine must reject heat to a lower-temperature reservoir.

SQ 6.10 **How does behaviour of real gases differ from ideal gas at high pressure and low temperature? Identify the reasons behind these differences based on kinetic theory of gases.**

Ideal Behaviour

An ideal gas assumes point particles with no intermolecular forces.

Real-Gas Deviation

At high pressure, the finite volume of molecules becomes significant. At low temperature, molecular kinetic energy decreases and intermolecular attractions become important. Thus a real gas no longer follows

$PV = nRT$

exactly and may liquefy.

SQ 6.11 **Show that area under P-V graph is equal to work done.**

Work Done

For a gas at constant pressure P, if a piston of area A moves through distance Δx

$W = F\Delta x = PA\Delta x.$

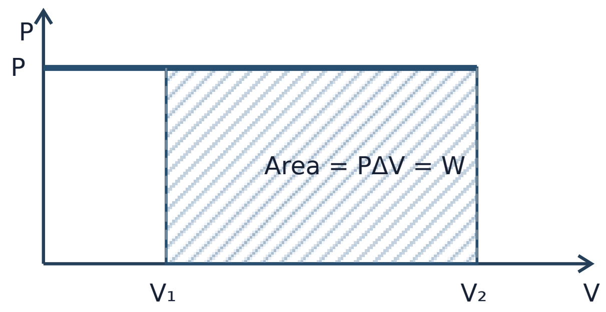
Since

$A\Delta x = \Delta V$

$W = P\Delta V = P(V_2 - V_1).$

Graphical Meaning

On the P-V graph, the shaded rectangle has height P and width ΔV. Therefore, its area $P\Delta V$ is equal to the work done.



SQ 6.12 **How is work done (i) by a gas (ii) on a gas?**

Work Done by a Gas

When a gas expands from V_1 to V_2 against constant pressure P, it pushes the surroundings and

$W_{by} = P(V_2 - V_1).$

This work is positive.

Work Done on a Gas

When the gas is compressed from V_1 to V_2, the surroundings push it and

$W_{on} = P(V_1 - V_2).$

This work is positive for compression, where $V_1 > V_2$.

CRQ 6.1 **Explain how thermodynamics relates to the concept of energy conservation.**

First Law

Thermodynamics applies conservation of energy to heat, work and internal energy:

$\Delta U = Q - W,$

where W is work done by the system.

Meaning

Heat supplied to a system either increases its internal energy or is used to do work. Energy changes form but is neither created nor destroyed.

CRQ 6.2 **Explain how thermodynamics applies to biological systems, such as human body.**

Energy Input

The body converts the chemical energy of food into internal energy, mechanical work and heat. The first law gives the energy balance.

Temperature Control

Metabolism produces heat, while sweating, radiation and convection transfer heat to the surroundings and help maintain body temperature.

Second Law

Biological processes increase the total entropy of the body and surroundings, so a continuous supply of usable energy is necessary.

CRQ 6.3 **A gas is expanding adiabatically. Explain what happens to temperature and pressure of the gas.**

Adiabatic Condition

No heat enters or leaves the gas, so

$Q = 0$

As the gas expands, it does work at the expense of its internal energy:

$\Delta U = -W.$

Result

Internal energy and temperature decrease. The pressure also decreases because the volume increases and the temperature falls. For an ideal gas,

$PV^\gamma = \text{constant}.$

CRQ 6.4 **A coffee cup is left on a table, and overtime coffee cup cools down. Explain thermodynamics processes occurring during this process.**

Heat Transfer

Because the coffee is hotter than its surroundings, energy leaves it by conduction through the cup, convection to air, radiation and evaporation.

Energy Change

The coffee's internal energy and temperature decrease while the surroundings gain heat.

Equilibrium and Entropy

Cooling continues until thermal equilibrium is reached. The total entropy of the coffee and surroundings increases, in agreement with the second law.

CRQ 6.5 **How can we explain different weather patterns through thermodynamical processes like wind, rain, etc.**

Wind

Uneven solar heating creates temperature and pressure differences. Warm air rises and cooler air moves in, producing wind.

Rain

Rising air expands and cools. Water vapour condenses to form clouds, and sufficiently large droplets fall as rain.