INTELLIGENCE LEARNING

BOE304/ BOE404/ BOE304H/ BOE404H
ENERGY SCIENCE AND ENGINEERING

UNIT 1 ONE SHOT

INTELLIGENCE LEARNING

SYLLABUS

Unit 1 : Energy and its Usage:

Units and scales of energy use, Mechanical energy and transport, Heat energy: Conversion between heat and mechanical energy, Electromagnetic energy: Storage, conversion, transmission and radiation, Introduction to the quantum, energy quantization, Energy in chemical systems and processes, flow of CO2, Entropy and temperature, carnot and Stirling heat engines, Phase change energy conversion, refrigeration and heat pumps, Internal combustion engines, Steam and gas power cycles, the physics of power plants. Solid-state phenomena including photo, thermal and electrical aspects .

ENERGY AND ITS TYPES

Energy is the ability to do work. It makes things move, light up, heat up, and function. Think of energy as **fuel** for everything your body, vehicles, machines, lights, and even your phone.

Types of Energy

Energy comes in many forms. The main types are:

1. Kinetic Energy:- Energy of moving things.

Example: A running person, a flying bird, a moving car.

2. Potential Energy:- Stored energy that can be used later.

Example: Water stored in a dam, a stretched rubber band.

3. Thermal Energy (Heat):- Energy from heat.

Example: Fire, boiling water, cooking gas.

4. Chemical Energy:- Energy stored in substances (like food, fuel).

Example: Energy from eating food, petrol in vehicles.

5. Electrical Energy:- Energy from electric current.

Example: Fans, lights, fridges, TVs.

6. Nuclear Energy:- Energy from splitting atoms.

Example: Nuclear power plants, atomic bombs.

7. Sound Energy:- Energy that comes through vibrations.

Example: Music from a speaker, ringing bell.

8. Light (Radiant) Energy:- Energy that travels in waves.

Example: Sunlight, lasers, bulbs.

Sources of Energy

Renewable Energy (Never runs out)

Solar (Sun), **Wind** (Air), **Hydro** (Water), **Biomass** (Plants, waste), **Geothermal** (Heat from Earth)

Non-Renewable Energy (Limited supply)

Coal, **Oil**, **Natural Gas**, **Nuclear Fuels** (Uranium)

How Do We Use Energy?

1. In Homes:- Cooking, lighting, fans, TV, fridge.

2. In Transportation:- Cars, buses, trains, airplanes (using petrol, diesel, electricity).

3. In Industries:- Machines, production, heating, making goods.

4. In Agriculture:- Tractors, water pumps, cold storage.

5. In Our Bodies:- We eat food to get energy to walk, think, grow, and work.

Challenges in Energy Use

- Pollution from burning fuels.
- Global warming and climate change.
- Limited non-renewable sources.
- Need for clean energy alternatives

Ways to Use Energy Wisely (Energy Conservation)

- Switch off lights/fans when not in use.
- Use energy-efficient appliances (LED, inverter AC).
- Walk, cycle, or use public transport.
- Use renewable sources like solar panels.

Why Energy Usage is Important?

Energy helps us live a comfortable life. It drives economic development. It powers healthcare, education, and technology.

What Are Units of Energy?

A **unit of energy** tells us **how much energy** is being used, produced, or stored. Just like we measure weight in **kilograms** and distance in **meters**, we measure energy in **special units**.

Main Units of Energy

Unit Name	Symbol	Used For
Joule	J	Standard unit of energy (used in science)
Kilojoule	kJ	1 kJ = 1,000 Joules
Calorie	cal	Energy in food (small unit)
Kilocalorie	kcal	1 kcal = 1,000 calories (used in diet)
Kilowatt-hour	kWh	Electricity use (used in homes and industries)
BTU (British Thermal Unit)	BTU	Used in air conditioners and heating systems

Scales of Energy Use

Depending on who or what is using energy, the scale (amount) changes:

1. Small Scale (Personal Use)

Mobile charging = ~5 Wh (watt-hours)

Boiling 1 liter of water = ~0.1 kWh

TV for 1 hour = ~0.1 to 0.2 kWh

2. Household Use

Monthly electricity bill = ~100–300 kWh (units)

AC use daily = 1–2 kWh

Fridge daily = 0.8–1.5 kWh

3. Industrial Scale

Factories = Thousands of kWh per day

Steel plant = Millions of kWh per year

4. National Scale

India’s total energy use = Terawatt-hours (TWh) = Billions of kWh

1 TWh = 1,000,000,000 kWh

What is Mechanical Energy?

Mechanical Energy is the energy a body has due to its motion or position.
It is mainly of two types:

1. Kinetic Energy:- energy of movement
Example: A moving car, flying airplane

2. Potential Energy:- stored energy because of position
Example: Fuel stored in a vehicle, water stored at height

Formula:- Mechanical Energy = Kinetic Energy + Potential Energy

Kinetic Energy (KE):

$$KE = \frac{1}{2}mv^2$$

Where:

- m = mass (in kg)
- v = velocity (in m/s)

Potential Energy (PE):

$$PE = mgh$$

Where:

- m = mass (in kg)
- g = acceleration due to gravity (9.8 m/s²)
- h = height (in meters)

How is Mechanical Energy Used in Transport?

Transport Mode	Mechanical Energy Used
Car	Engine converts chemical energy (fuel) to mechanical energy to rotate wheels.
Bicycle	You pedal – your muscle energy becomes mechanical energy.
Train	Engine (electric/diesel) creates mechanical energy to move coaches.
Airplane	Jet engines create thrust (a type of mechanical energy) to fly.
Ship	Engines or turbines produce mechanical motion to push water backward and move forward.

How Does It Work?

Let's break it down step by step:

1. Fuel or Electricity is the source (stored energy).

2. It gets **converted into motion** (mechanical energy).

3. Moving parts (wheels, propellers, tracks) help in transportation.

4. Mechanical energy is also used for: **Braking**, **Steering**, **Lifting and lowering parts** of vehicles.

What is Heat Energy?

Heat energy (thermal energy) is a form of energy that is transferred due to a temperature difference between two objects or systems. It flows from a hot body to a cold body, until both reach the same temperature (thermal equilibrium).

Conversion Between Heat and Mechanical Energy

The conversion between heat energy and mechanical energy is explained by the First Law of Thermodynamics, which states:

$Q = \Delta U + W$

Where:

Q = Heat supplied to the system

ΔU = Change in internal energy

W = Work done by the system (mechanical energy)

This means that heat energy added to a system is partly used to increase internal energy and partly converted to mechanical work.

Heat to Mechanical Energy (Heat Engines)

A heat engine is a device that converts heat energy into mechanical work using a working fluid (like steam or gas).

Working Principle:

1. Heat is supplied from a high-temperature source (boiler or fuel combustion).
2. The working fluid expands (usually becomes steam or gas).
3. This expansion pushes pistons or turbine blades.
4. That motion is mechanical energy.
5. Some heat is lost to a low-temperature sink (exhaust).

Efficiency (Carnot Efficiency):

η=1−TC\TH

Where:

η = Efficiency

TH = High temperature (source)

TC = Low temperature (sink)

No heat engine can convert 100% of heat into work — some heat is always lost.

Mechanical Energy to Heat (Friction and Resistance)

When mechanical energy (motion) is resisted (by friction or compression), it gets converted into heat.

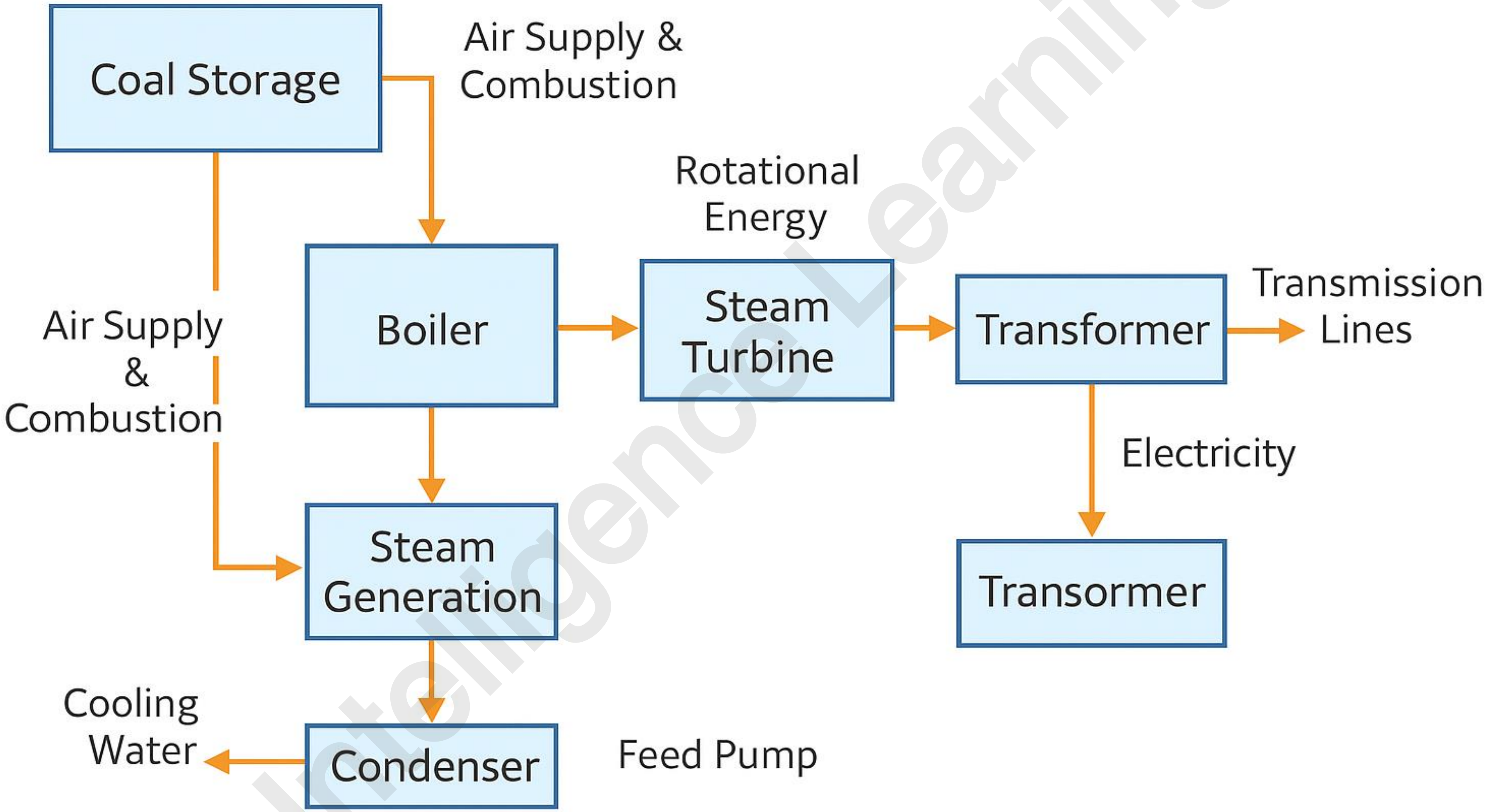
Examples:

Brakes in a car: kinetic energy → heat

Rubbing surfaces: movement → heat

Compression of gas: mechanical work → heat (as in diesel engines)

This is explained by energy conservation — mechanical work is transformed into thermal energy.


Coal Storage
Air Supply & Combustion
Boiler
Rotational Energy
Steam Turbine
Transformer
Transmission Lines
Air Supply & Combustion
Electricity
Steam Generation
Transormer
Cooling Water
Condenser
Feed Pump

Block	Function
Coal Storage	Stores fuel (coal or oil) used for burning.
Boiler	Burns fuel to produce heat.
Steam Generation	Water is heated in the boiler to produce high-pressure steam.
Steam Turbine	Steam pressure rotates the turbine shaft (mechanical energy).
Generator	Turbine shaft drives the generator to produce electricity.
Transformer	Increases voltage for efficient transmission of electricity.
Transmission Lines	Carry electricity to homes, schools, and industries.
Condenser	Cools and condenses used steam back into water.
Feed Pump	Pumps water back to the boiler to repeat the cycle.

What is Electromagnetic Energy?

Electromagnetic (EM) energy is the energy carried by electric and magnetic fields that travel through space as waves.

In engineering, we mainly focus on electricity, electromagnetic waves, and their applications.

1. Storage of Electromagnetic Energy

How it's stored:

Electromagnetic energy is not stored directly, but converted and stored as:

Type	Example	Explanation
Electrical Energy	Battery	EM energy is stored as chemical energy
Magnetic Field Energy	Inductor/coil	Stores energy in the magnetic field when current flows
Capacitor	Circuits	Stores energy in the electric field

Engineering Usage:

- Batteries in Evs.
- Inductors in SMPS or transformers.
- Capacitors in electronic circuits.

2. Conversion of Electromagnetic Energy

EM energy can be converted into:

From	To
EM energy → Mechanical	Electric motor
EM energy → Heat	Induction heater, microwave
EM energy → Light	LED, laser
EM energy → Sound	Loudspeaker
Other forms → EM energy	Dynamo (mechanical to electrical), solar cell (light to electric)

3. Transmission of Electromagnetic Energy

How it moves from one place to another:

Medium	Method	Example
Wires	Electrical transmission	Power lines, electric cables
Air (Free Space)	Electromagnetic waves	Wi-Fi, radio, TV, satellites
Fiber Optics	Light pulses	Internet, telephone communication

4. Radiation of Electromagnetic Energy

What is Radiation?

Radiation means EM energy is **emitted or sent out** in the form of **waves or particles**.

Source	Type of Radiation	Use
Sun	Light, UV, IR	Solar energy, drying clothes
Antenna	Radio waves	Broadcasting and telecom
X-ray Machine	X-rays	Medical imaging
Microwave	Microwaves	Heating food

Conclusion

Electromagnetic energy plays a vital role in engineering — from generating and storing electricity to transmitting data and signals. Understanding how to store, convert, transmit, and radiate this energy is key to working in electrical, electronics, communication, and power systems.

What is Quantum Theory?

Quantum theory (or quantum mechanics) is the branch of physics that explains the behavior of very small particles — like electrons, atoms, and photons — which classical physics cannot describe accurately. At the microscopic (atomic and subatomic) level, particles behave differently than in our everyday world.

Why is it Needed?

Classical physics (like Newton's laws) could not explain:

Blackbody radiation, Photoelectric effect, Atomic spectra, Electron behavior in atoms

To solve these problems, scientists developed quantum theory.

What is Quantization?

Quantization means that energy is not continuous, but exists in fixed packets or discrete amounts called quanta.

Example: Planck's Quantum Theory

Max Planck (1900) proposed that energy is emitted or absorbed in small packets called quanta.

The energy of each quantum is given by: $E=h\cdot f$

Where:

E = energy (in joules) f = frequency of radiation (in Hz)

h = Planck's constant (6.626×10−346.626 \times 10^{-34}6.626×10−34 J·s)

This explained **blackbody radiation** which classical theory failed to describe.

Energy in Chemical Systems and Processes

What is Chemical Energy?

Chemical energy is the energy stored in the bonds of atoms and molecules.
During a chemical reaction, these bonds break and form, releasing or absorbing energy.

Types of Chemical Reactions Based on Energy

Type	Description	Example
Exothermic	Releases energy (heat)	Combustion of fuel
Endothermic	Absorbs energy	Photosynthesis, melting ice

Common Chemical Processes

Process	Energy Role
Combustion	Releases energy by burning fuels (coal, gas, oil).
Photosynthesis	Stores solar energy in plant biomass.
Respiration	Releases energy from food in cells.
Battery Operation	Converts chemical energy to electrical energy.
Electrolysis	Uses electrical energy to split molecules (e.g., water into H_2 and O_2).
Fuel Cells	Chemical energy of hydrogen is converted to electricity with water as waste.

What is CO_2 Flow?

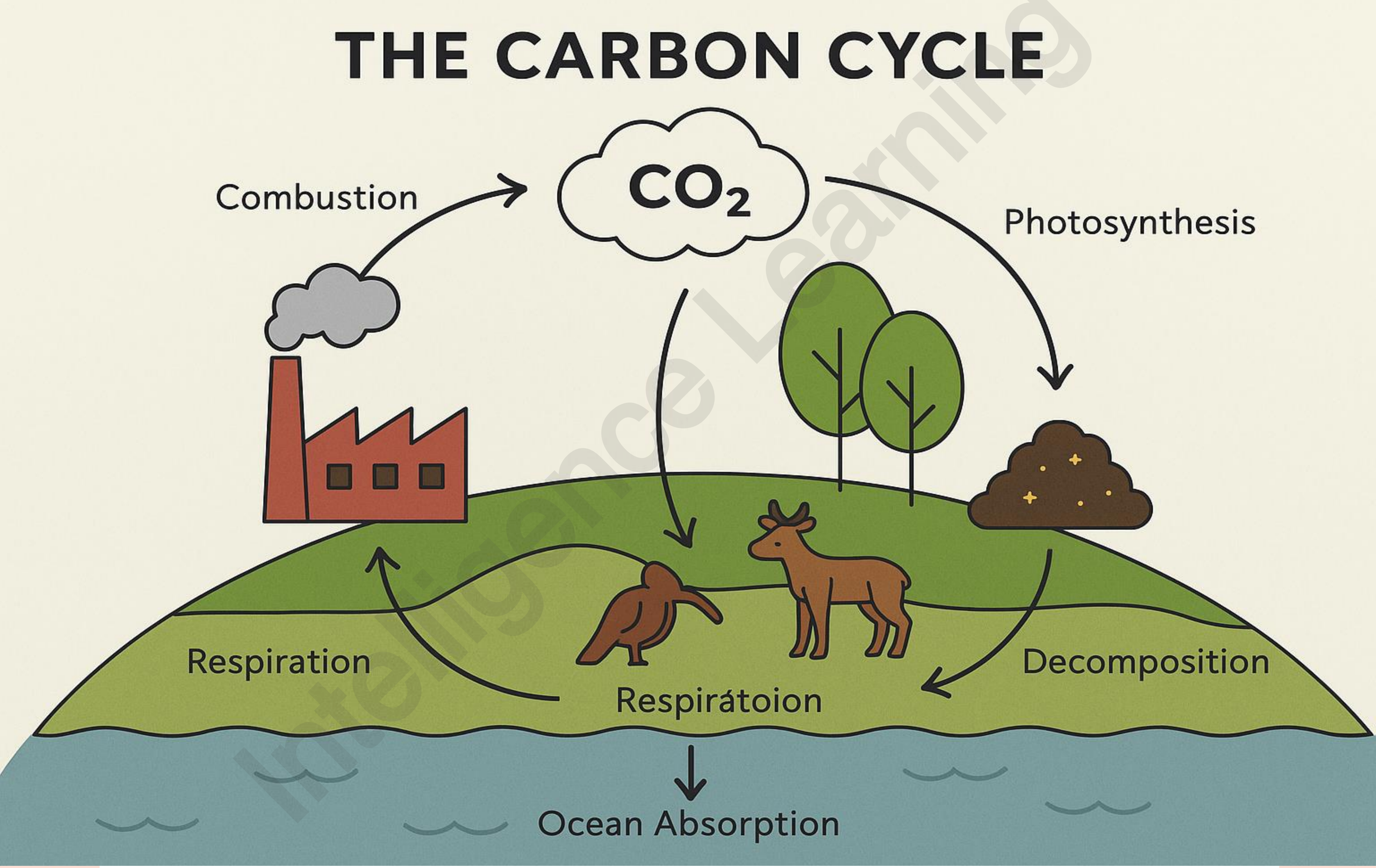
The **flow of carbon dioxide (CO_2)** refers to the **production, movement, and absorption** of CO_2 through natural and human-made systems.

Major Sources of CO_2 (Release into Atmosphere)

Source	Description
Combustion of Fossil Fuels	Burning coal, petrol, diesel in power plants, vehicles
Industrial Processes	Cement production, steel manufacturing
Deforestation	Trees absorb CO_2 — cutting them releases stored carbon
Respiration	Living beings release CO_2 while breathing
Waste Decomposition	Bacteria release CO_2 and methane during decay

Major Sinks of CO_2 (Absorption or Removal)

Sink	Description
Photosynthesis by Plants	Plants absorb CO_2 to make food
Oceans	CO_2 dissolves in seawater
Soil and Forests	Store carbon long-term (carbon sinks)
Carbon Capture Technology	Captures CO_2 from factories and stores underground (engineering method)


THE CARBON CYCLE
CO_2
Combustion
Photosynthesis
Respiration
Decomposition
Respirátoion
Ocean Absorption
Intelligence Learning

What is Entropy (S)?

Entropy is a fundamental concept in thermodynamics. It measures the degree of disorder or randomness of particles in a system. Entropy also represents the unavailable energy that cannot be used to do useful work.

Low entropy = more order (example: ice, tightly arranged molecules)

High entropy = more disorder (example: steam, free-moving molecules)

Entropy increases when:

A solid melts into a liquid

A liquid turns into gas

Heat is added to a system

What is Temperature (T)?

Temperature is a measure of the average kinetic energy of particles in a substance. In thermodynamics, temperature tells us how hot or cold something is. It also determines the direction of heat flow — from high to low temperature.

Relationship Between Entropy and Temperature

In **reversible thermodynamic processes**, the relationship between entropy and temperature is:

dS=dQrev\T

Where:

dS = small change in entropy

dQrev = small amount of reversible heat added to the system

T = absolute temperature (in Kelvin)

Meaning:

At higher temperatures, the same amount of heat causes a smaller increase in entropy.

At lower temperatures, the same heat causes a larger increase in entropy.

SUMMARY

- **Entropy (S)** measures randomness or unavailable energy.
- **Temperature (T)** measures how hot something is and influences how entropy changes.
- Their relationship: **dS=dQrev\T**
- shows that the same heat causes more disorder (entropy) at lower temperatures.
- Understanding this relationship helps engineers design more efficient energy systems and processes.

1. Carnot Heat Engine (Theoretical Model)

The Carnot engine is a perfect, ideal heat engine that sets the maximum possible efficiency limit. It is not practical but is used as a standard for comparison.

Carnot Cycle (4 Steps):

1. **Isothermal Expansion** – Heat absorbed at constant temperature from a hot source.
2. **Adiabatic Expansion** – Gas expands without heat exchange; temperature drops.
3. **Isothermal Compression** – Heat rejected to a cold sink at constant temperature.
4. **Adiabatic Compression** – Volume decreases, temperature increases without heat exchange.

Efficiency: $\eta = 1 - TC \backslash TH$

Where:

TH: Temperature of hot reservoir (in Kelvin)

TC: Temperature of cold reservoir (in Kelvin)

Features:

- Reversible and ideal engine.
- No energy loss assumed.
- Used only for theoretical calculations.
- Sets maximum efficiency limit.

2. Stirling Heat Engine (Practical Model)

The **Stirling engine** is a **real, closed-cycle regenerative engine** that works with an enclosed gas (like air, helium, or hydrogen) and uses **external heating**.

Stirling Cycle (4 Steps):

1. **Isothermal Expansion** – Gas is heated from outside, expands, and pushes the piston.
2. **Constant-Volume Heat Removal** – Gas is cooled, pressure drops.
3. **Isothermal Compression** – Gas is compressed at low temperature.
4. **Constant-Volume Heat Addition** – Gas is reheated by the regenerator.

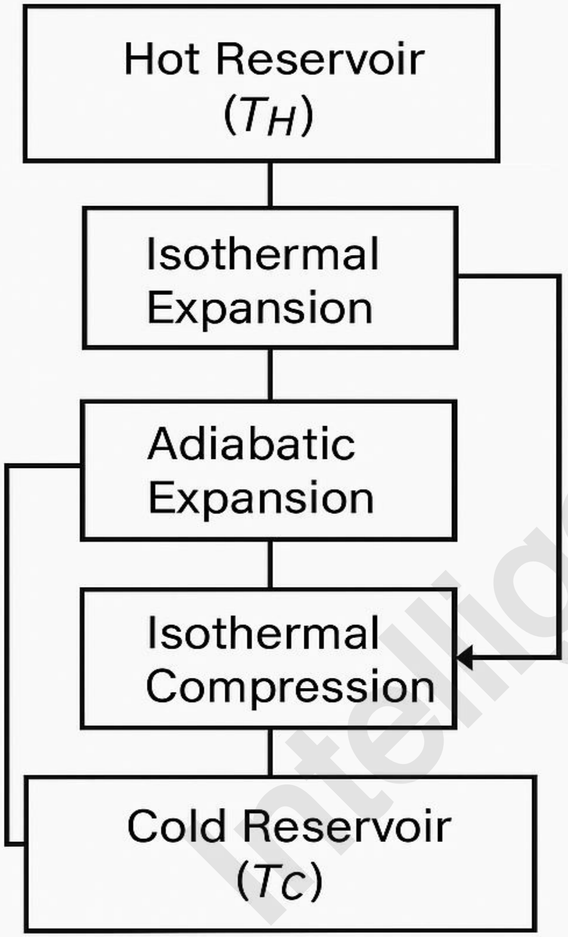
Key Components:

- **Regenerator** – Stores and recycles heat between processes.
- **Displacer piston** – Moves gas between hot and cold sides.
- **Power piston** – Converts gas motion into mechanical work.

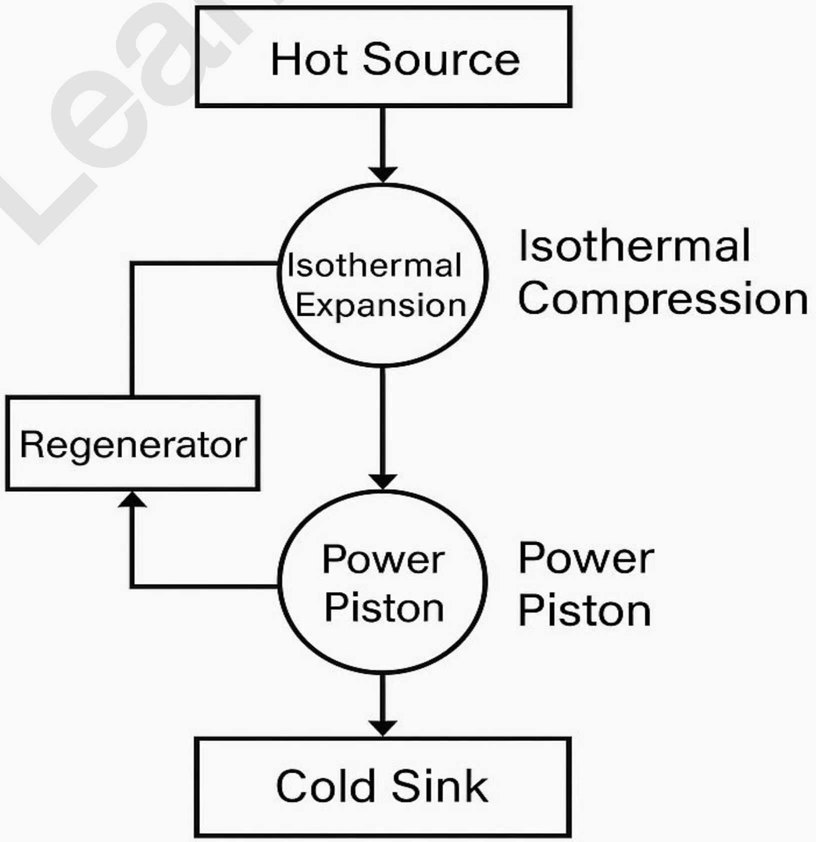
Features:

- Efficient and very quiet.
- Works with any external heat source (solar, gas flame, biomass).
- Used in submarines, spacecraft, and solar-powered systems.
- Can be made very reliable with no internal combustion.

Carnot Heat Engine



Stirling Heat Engine



What is Phase Change Energy Conversion?

Phase change energy conversion refers to the transformation of energy during a change in the state (phase) of a substance like from solid to liquid, liquid to gas, or gas to liquid, without changing its temperature. This energy is called latent heat (hidden heat).

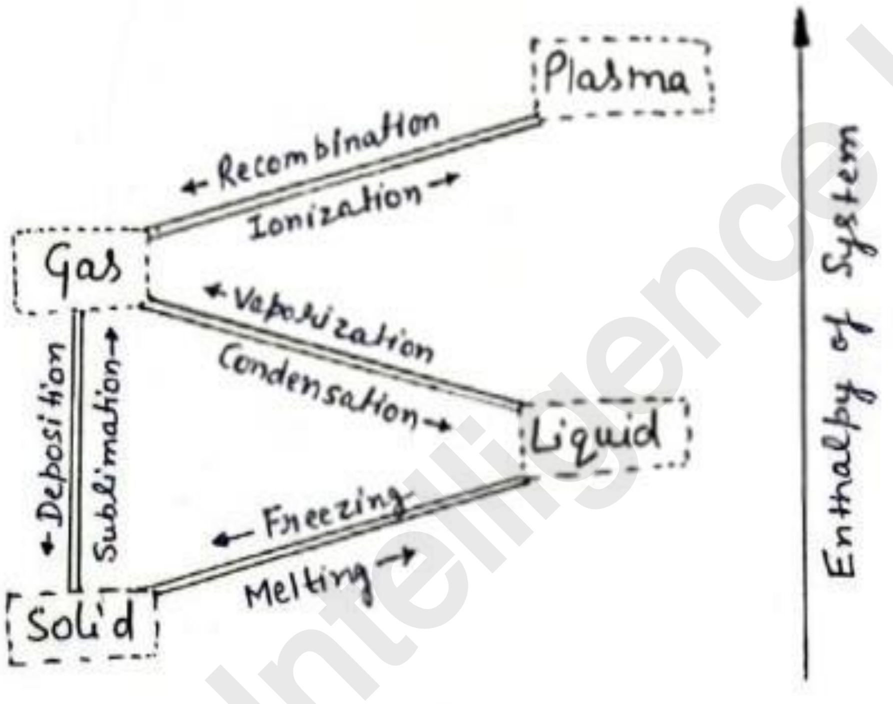
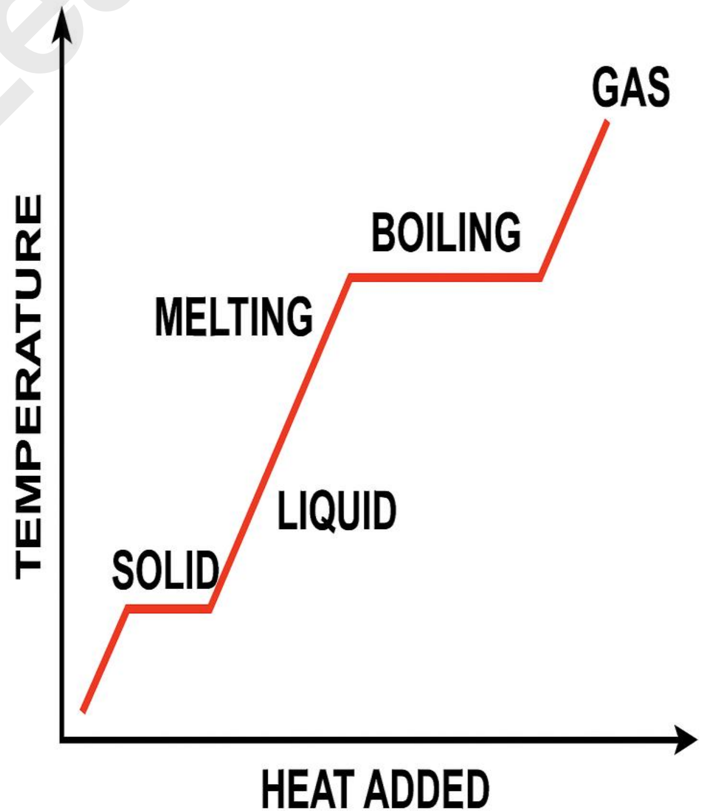


Fig : Diagram of Phase change



1. Refrigeration

Purpose:- To remove heat from a low-temperature space and reject it to a high-temperature surrounding.

Working Principle:- Uses the reverse of the Carnot cycle (or vapor compression cycle) to extract heat from the space to be cooled.

Basic Components:

1. **Evaporator:** Absorbs heat (cooling effect).
2. **Compressor:** Increases pressure & temperature.
3. **Condenser:** Rejects heat to surroundings.
4. **Expansion Valve:** Lowers pressure and temperature of refrigerant.

Coefficient of Performance (COP) for Refrigeration:

COP(ref)=QL\W

Where:

QL: Heat removed from the low-temperature area

W: Work input

2. Heat Pump:

Purpose:- To add heat to a high-temperature space by extracting it from a low-temperature source.

Working Principle:- Same thermodynamic cycle as refrigeration, but the desired effect is **heating**.

Basic Components:- Same as refrigeration systems (evaporator, compressor, condenser, expansion valve)

Coefficient of Performance (COP) for Heat Pump:

COP(HP)=QH\W

Where:

QH: Heat delivered to the high-temperature area

W: Work input

Relation Between Them:

COP(HP)=COP(ref)+1

This means a heat pump always has a COP higher than a refrigerator operating between the same two temperatures.

Internal Combustion Engines (ICE)

An **Internal Combustion Engine** is a heat engine where **fuel combustion occurs inside the engine cylinder**, producing power directly.

Basic Principle:

Converts **chemical energy of fuel** (like petrol or diesel) into **mechanical energy**.
Works on the principle of the **thermodynamic cycle** (like Otto or Diesel cycle).

Main Types of Internal Combustion Engines:

Type	Fuel Used	Example Vehicle	Cycle Used
Petrol Engine	Petrol	Cars, Bikes	**Otto Cycle**
Diesel Engine	Diesel	Trucks, Buses, Trains	**Diesel Cycle**
Gas Engine	CNG/LPG	CNG Vehicles, Gensets	**Otto/Dual Cycle**

Working of a 4-Stroke:

Intake Stroke: Air-fuel mixture is drawn in
Compression Stroke: Mixture is compressed
Power Stroke: Mixture ignites and expands, pushing piston
Exhaust Stroke: Burnt gases are expelled

Main Parts of ICE:

Cylinder – where combustion happens.

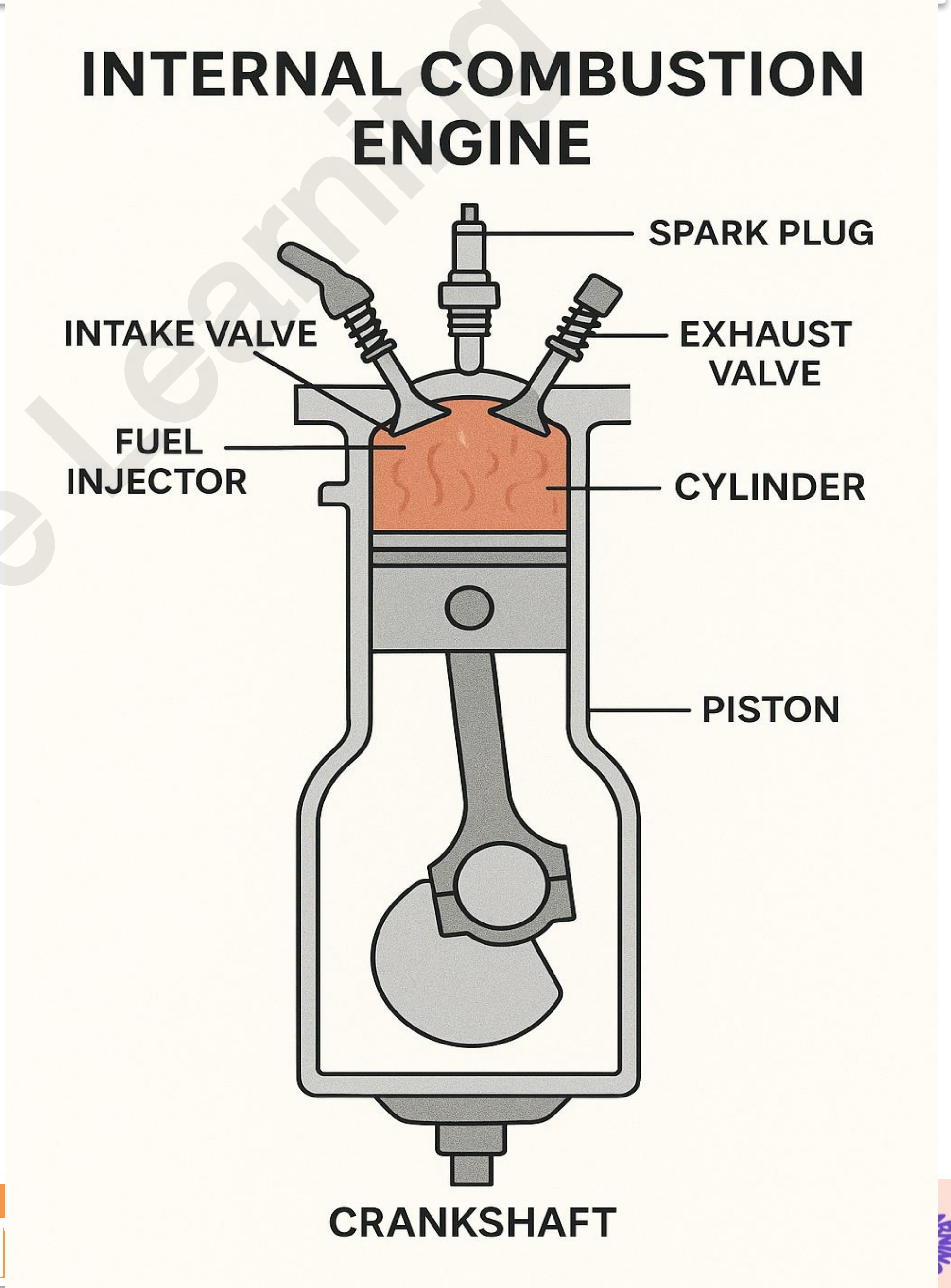
Piston – moves up and down inside the cylinder.

Crankshaft – converts reciprocating motion to rotary motion.

Spark Plug – (only in petrol engines) ignites air-fuel mixture.

Fuel Injector – sprays fuel into cylinder (diesel engines).

Valves – control entry/exit of air-fuel mixture and exhaust.



A 2-stroke engine completes a power cycle in just two strokes of the piston.

In the first stroke, the piston compresses the fuel-air mixture while fresh charge enters the crankcase.
In the second stroke, the mixture ignites, pushing the piston down and expelling exhaust gases.
Fresh mixture then enters the cylinder as the cycle repeats, producing power every revolution.

Spark Ignition (SI) Engine

Spark Ignition (SI) Engine uses a spark plug to ignite the air-fuel mixture.
It is commonly used in petrol engines where fuel and air are mixed before entering the cylinder.

Compression Ignition (CI) Engine

Compression Ignition (CI) Engine compresses only air, and fuel is injected later, igniting due to high temperature.
This method is used in diesel engines and does not require a spark plug.

Steam and Gas Power Cycles

What is a Power Cycle?

A power cycle is a series of thermodynamic processes that convert heat energy into mechanical work. This mechanical work is then used to generate electricity.

Types of Power Cycles:

A. Steam Power Cycle (Rankine Cycle):

Used in: Thermal power plants, nuclear power plants

Working Fluid: Water/steam

Main Idea: Water is heated to become steam → steam rotates a turbine → work is done → steam is cooled back into water.

Steps:

1. **Boiler:** Heats water to make high-pressure steam.
2. **Turbine:** Steam expands and rotates the turbine (produces work).
3. **Condenser:** Steam cools and turns back into water.
4. **Pump:** Water is pumped back to the boiler.

Physics:- Based on **Rankine cycle.** Uses the principles of **thermodynamics**: heat transfer, pressure, energy conversion.

B. Gas Power Cycle (Brayton Cycle):

Used in: Gas turbines, jet engines, combined cycle plants

Working Fluid: Air and fuel mixture

Main Idea: Air is compressed → fuel is added and burned → hot gases expand through turbine → power is produced.

Steps:

1. **Compressor:** Compresses incoming air.
2. **Combustion Chamber:** Fuel burns with air to produce hot gases.
3. **Turbine:** Expands hot gases to produce mechanical energy.
4. **Exhaust:** Hot gases leave through the nozzle or exhaust pipe.

Physics:- Based on Brayton cycle. Works on ideal gas laws, conservation of energy, and heat exchange.

Physics Behind Power Plants:

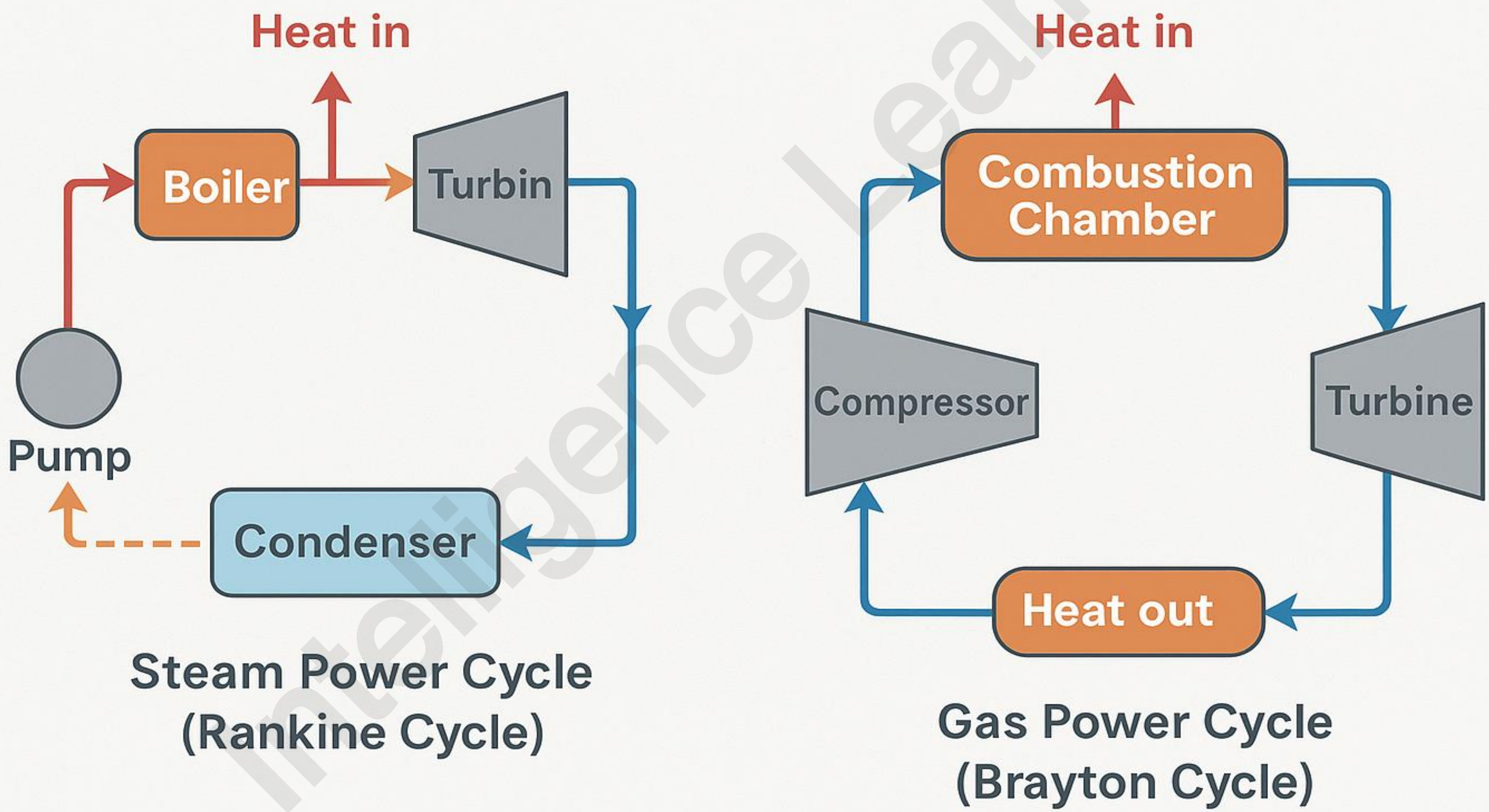
Thermodynamics: Laws of energy conversion.

Heat Transfer: Conduction, convection, and radiation.

Fluid Mechanics: Flow of steam/gas.

Energy Conversion: Chemical → thermal → mechanical → electrical.

STEAM AND GAS POWER CYCLES



Solid-State Phenomena

Solid-state phenomena refer to how solids — especially semiconductors and conductors — respond to light (photo), heat (thermal), and electric fields (electrical). These responses are the foundation of modern electronics and devices.

1. Photoelectric (Photo) Aspect

Phenomenon: Light energy causes electrons to be emitted or excited in solids.

Key Effect: Photoconductivity or photoelectric effect

Applications:

- Solar cells (convert light to electricity)
- Photodiodes, photoresistors
- Light sensors

Engineering Relevance:

Used in optical communication, sensors, imaging, and solar energy systems.

2. Thermal Aspect

Phenomenon: Heat changes the behavior of electrons in a solid.

Key Effects: Thermoelectric effect (Seebeck, Peltier effects) and Temperature-dependent resistance

Applications:- Thermistors, temperature sensors, Thermoelectric generators, CPU cooling systems

Engineering Relevance:- Critical in thermal management, sensing, and energy harvesting.

3. Electrical Aspect

Phenomenon: Electric field moves charges through solids.

Key Concepts:

- Conductivity in metals
- Semiconductor behavior (p-n junctions, transistors)
- Ohm's Law in solids

Applications:- Diodes, transistors, Ics, Batteries, power electronics, Sensors, logic gates

Engineering Relevance:- Forms the backbone of electronics, computers, and power systems.

THANK YOU FOR WATCHING

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