ENVIRONMENTAL PHYSICS

PHYS3141

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ASSIGNMENT - 5

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Q1) Write about wind power, tidal power and hydropower.

WIND POWER

• Wind power generation

Modern wind turbines, typically featuring two or three blades with a diameter of about 33 meters, can produce substantial power.

For example,

A turbine can generate 300 kW at a wind speed of Beaufort scale 6 (strong breeze). Wind farms, such as the Fair Isle scheme established in 1982, demonstrate this potential, generating 50 MW and meeting 90% of the island's electricity needs.

• Physics of Wind Power

→ The kinetic energy in wind can be expressed as

$$\frac{1}{2}\rho v^2 \text{ where}$$

ρ is the density
v is wind velocity

The maximum power available per unit area from wind is reached when the wind direction is perpendicular to the turbine, given by

$$P_0/A = \frac{\rho u^3}{2}.$$

- Coefficient Performance

The efficiency of wind turbines is measured using the coefficient of performance (CP) which indicates how much of the available wind power is converted into usable energy. The theoretical maximum CP, known as the Betz limit is 0.59, achieved at an interface factor $a = \frac{1}{3}$.

In practice, modern turbines typically achieve CP values around 0.4.

TIDAL POWER

In principle there is a lot of energy available but there is the problem both of energy density (how many estuaries are suitable) and of environmental problems.

The largest tidal installation (and has been for many years) is at La Rance (France) with a capacity of 240 MW. The configuration of the estuary is close to ideal, but : (i) tidal

(i) Tidal barrages are expensive

(ii) It would drastically change the environment of the estuary.

The basic idea is to trap the tide behind a barrier and let the water out through a turbine at low tide. If the tidal range is R and the estuary area is A, then the mass of water trapped behind the barrier is ρAR, and the center of gravity is $R/2$ above the low tide level. The maximum energy per tide is therefore $(\rho AR) g (R/2)$. Averaged over a tidal period of τ, this gives a mean power available of

$$\langle P \rangle = \rho A R^2 g / 2\tau .$$

HYDRO POWER

The main advantage of hydroelectric power is that the energy density is high. The drawbacks are :

- Hydroelectric schemes require large dams.
- These cause large social and ecological changes.

Water passes from a dam down a tube and through a turbine. The idea is to convert the potential energy of the water first into kinetic and then into electrical energy.

If ρ is the density of water, Q is the flow-rate then P_0, the maximum power available to be generated, is given by

$$P_0 = \rho g h Q,$$

where h is the height drop

If the speed of the water is v, the power available is

$$\rho Q v^2/2.$$

The change of momentum of the fluid is

$$F = 2\rho Q(v_j - v_t),$$

$(v_j - v_t)$ is the speed of water jet

The power transfered is

$$P = Fv_t = 2\rho Q(v_j - v_t)v_t$$

The maximum for (v_j/v_t) is 0.5.

Q2. Write a note of Nuclear Power Generation.

A. NUCLEAR POWER GENERATION

- Methods of Nuclear Power Generation

→ Thermal Reactors : Use fission of uranium or thorium isotopes to generate energy.

→ Breeder Reactors : Convert U-238 into fissile plutonium (Pu-239) while also generating energy.

→ Fusion Reactors : Utilize the reaction

$$^{2}D_{1} + ^{3}T_{1} \longrightarrow ^{4}He_{2} + ^{1}n_{0} + \text{energy}$$

- Key Components of Nuclear Reactors

→ Nuclear Fuel : Typically uranium or thorium, which undergo fission when bombarded by neutrons, releasing significant energy and additional neutrons.

→ Chain reaction : A sustained release of energy relies on the production of more neutrons than are consumed, characterized by critical factor K:

$$K = \frac{\text{neutrons produced in the } (n-1)\text{th generation}}{\text{neutrons produced in the } n^{th} \text{ generation}}$$

→ Control of K: Must be close to 1 for stability

- Types of Radioactive Wastes :

→ Low-Level Waste : Includes materials from hospitals (ex, contaminated items).

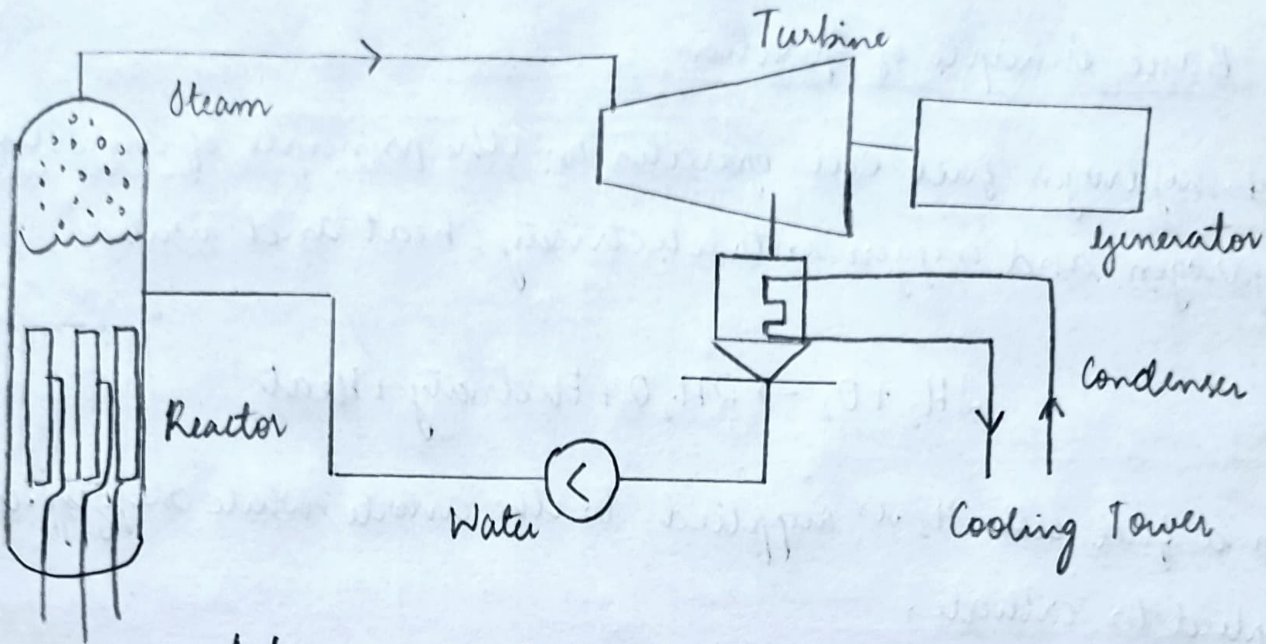
→ Medium-level waste ; Comprises reactor component and materials.

→ High-level waste : Contains long-lived decay products and actinides, requiring careful management.

- Management of Radioactive Waste :

→ Incoporating decay products in glass or artificial minerals for deep burial.

→ Low and medium-level waste disposal remains a significant challenge due to larger volumes.



NUCLEAR POWER REACTOR

Q3. Write about hydrogen cell in detail.

A. HYDROGEN FUEL CELLS

Hydrogen fuel cells are electrochemical devices that convert chemical energy from hydrogen into electrical energy through a chemical reaction with oxygen, producing water as the only byproduct. This technology is considered a clean energy solution and has gained significant attention for its potential applications in various sectors, including transporation, stationary power generation and portable devices.

- **Basic Principle of Operation**

A hydrogen fuel cell operates on the principle of converting hydrogen and oxygen into electricity, heat and water.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Electricity} + \text{Heat}$$

In a fuel cell, H_2 is supplied to the anode, while oxygen is supplied to cathode.

- **Components of Hydrogen Fuel Cell**

→ **Anode**: The electrode where oxidation occurs. Hydrogen molecules are split into protons (H^+) and electrons at the anode.

$$\cancel{H_2 +}$$

$$H_2 \rightarrow 2H^+ + 2e^-$$

→ **Cathode**: The electrode where reduction occurs. Oxygen molecules combine with electrons from the external circuit and protons from the electrolyte to form water.

$$2H^+ + 2e^- + \frac{1}{2}O_2 \rightarrow H_2O$$

→ **Electrolyte** : A substance that allows protons to pass through while being impermeable to electrons, facilitating the separation of charges and ensuring the flow of electricity.

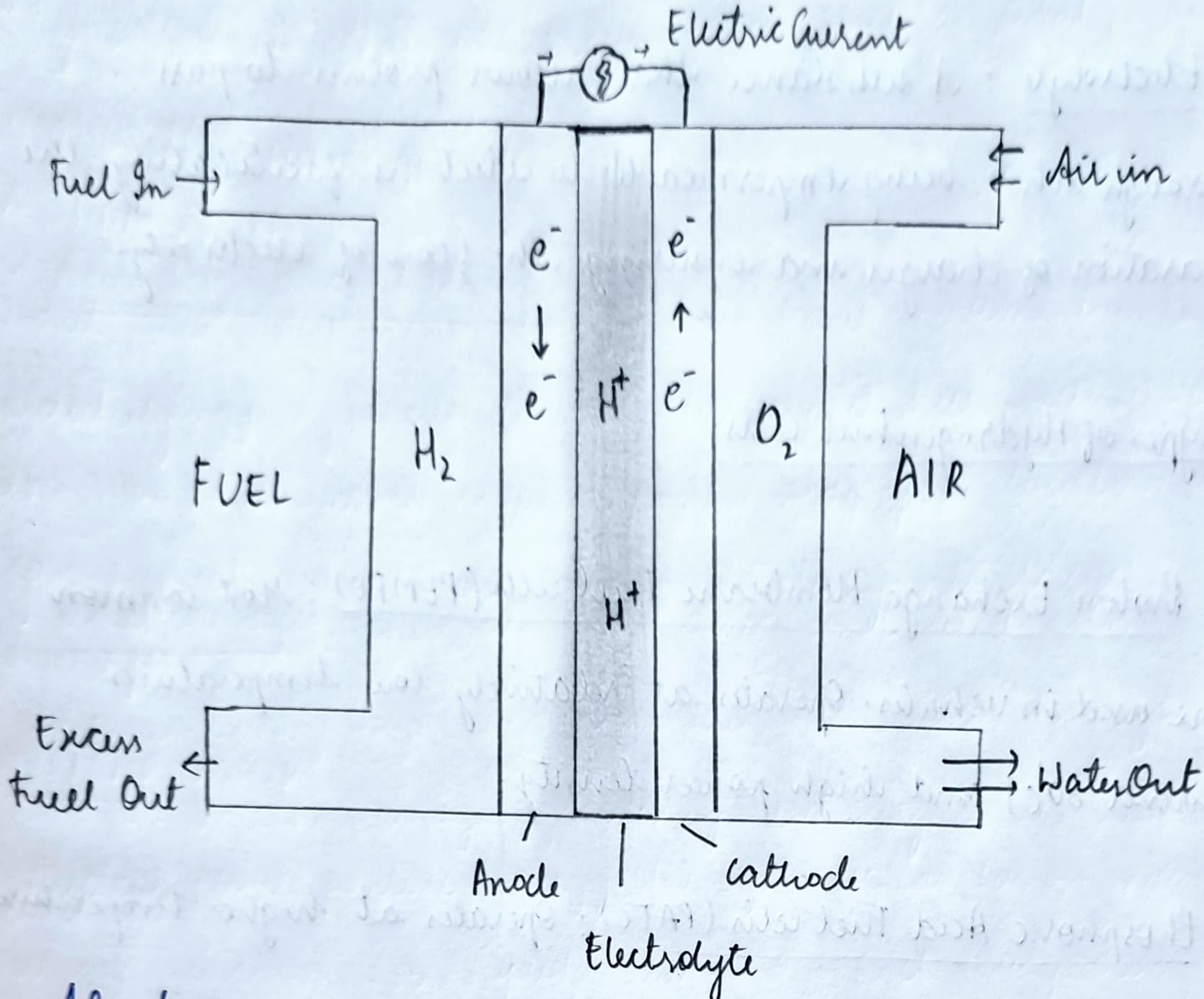
• **Types of Hydrogen Fuel Cells**

→ **Proton Exchange Membrane Fuel Cells (PEMFC)** : Most common type used in vehicles. Operates at relatively low temperatures (around 80°C) and high power density.

→ **Phosphoric Acid Fuel Cells (PAFC)** : Operates at higher temperatures (150-200°C) and are used for stationary power generation.

→ **Alkaline Fuel Cells (AFC)** : Use an alkaline electrolyte and were historically used in space applications.

→ **Solid Oxide Fuel Cells (SOFC)** : Operate at very high temperatures (600-1000°C) and are suitable for stationary applications.



- **Advantages**
  → Environmental Friendly
  → High efficiency
  → Renewable Hydrogen Production
- **Challenges**
  → Hydrogen Protection and Storage
  → Infrastructure Development
  → Cost

Q9. Write an essay on renewable sources, such as tidal power, nuclear power, fossil fuels.

A. TIDAL POWER

Tidal power converts the energy from tidal movements into electricity, relying on the predictable gravitational pull of the moon and sun. There are 2 main methods :

1. <u>Tidal Barrages</u> : These are large dams constructed across estuaries. During high and low tides, water flows through turbines in the barrage, generating electricity as the water level changes.

2. <u>Tidal Stream Generators</u> : Turbines placed in tidal streams capture kinetic energy from moving water, similar to underwater wind turbines.

• <u>Energy Potential</u>

The potential energy E of tidal water at a height h is calculated as :

$$E = \rho g h V$$

Where

ρ is water density.

g is gravitational accelaration

V is the volume of water.

· **Advantages and Challenges** :

Tidal energy is renewable, predictable, and has low carbon emissions. However, it requires specific geographic location and can impact marine ecosystems, particularly with large barrages.

NUCLEAR POWER

· Nuclear power produces energy through nuclear fission, mainly using uranium-235 or plutonium-239 as fuel. This process involves splitting atomic nuclei to release energy:

1. Fission Reaction : A typical fission reaction for uranium-235 is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{Energy}$$

This reaction releases a large amount of heat, which is used to generate electricity.

· Chain Reaction : The neutrons produced can trigger further fission events, creating a sustained chain reaction.

· Reactor Control : Control rods absorb excess neutrons to regulate the reaction and prevent runaway reactions, making the process safe for power generation.

· Waste Management : The process generates radioactive waste, which requires secure storage and long-term disposal methods.

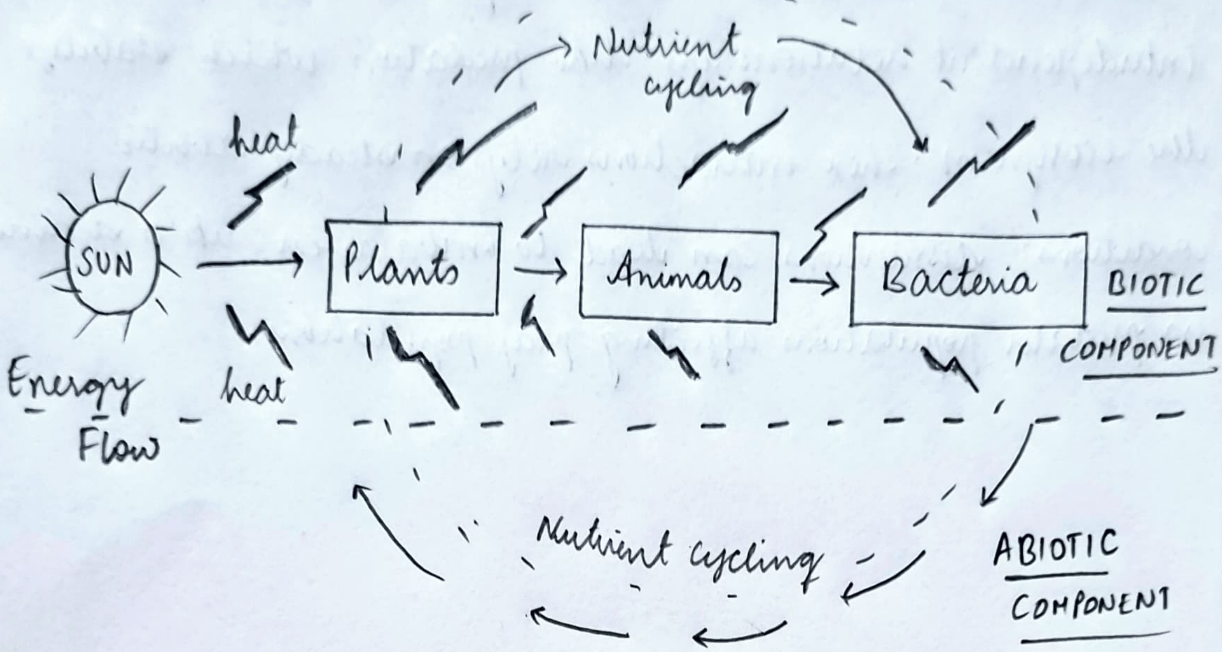
· Advantages and Disadvantages : Nuclear power produces large amounts of electricity with low greenhouse gas emission but poses risks of radioactive contamination and requires extensive waste management.

Q5 Discuss the equilibrium between biotic and abiotic environmental components.

A. The equilibrium between biotic and abiotic environmen-tal components is essential for maintaining a stable and functional ecosystem. This balance ensures the availability of resources, regulates population dynamics, and supports biodiversity.

1. Nutrient Cycling : Abiotic factors like soil, water and sunlight support the growth of plants (producers), which are a primary biotic component. Plants in turn provide food and oxygen for consumers and decomposers, who break down dead organic material into nutrients. This cycle recirculates essential elements, supporting a sustainable system.

2. Energy Flow : Sunlight, an aboitic factor, provides energy for photosynthesis in plants, which forms the base of the food chain. This energy flow is essential for sustaining biotic populations and maintaining balance. The energy is transfered through trophic levels (producers to consumers) in the ecosystem.



3. Population Regularization : Abiotic factors like temperature, water availability and soil quality set limits on population sizes of biotic components. Extreme abiotic conditions (ex; floods, droughts) can decrease population of species, preventing over-population and helping maintain ecosystem balance.

4. Habitat Conditions : Biotic organisms adapt to abiotic factors like temperature, PH and salinity, which shape their habitats. If these abiotic fators are disturbed it can upset equilibrium, leading to species migration, adaption or even extinction.

5. Symbiotic Relationships: Biotic components often form interdependent relationships like predation which stabilize the ecosystem. These interactions rely on steady abiotic conditions; disruptions can lead to imbalances, like a decline in predator populations affecting prey populations.