Question 1: (a) Write the contributions of the following scientists (any five): (2×5=10)(i) Anton Van Leeuwenhoek (ii) Louis Pasteur (iii) Stanley Prusiner (iv) Anand Mohan Chakraborty (v) Ronald Ross (vi) Paul Ehrlich (b) Define the following terms (any four): (2×4=8)Capsid, Coenocytic hyphae, Plaque, Pyrenoids, Eyespot

Contributions of Scientists:

- **Anton Van Leeuwenhoek:**
    - Considered the "Father of Microbiology."
    - First to observe and describe single-celled organisms, which he called "animalcules" (now known as microorganisms).
    - Improved the microscope and made over 500 optical lenses.
    - Observed bacteria, protozoa, sperm cells, blood cells, and microscopic structure of muscle and wood.
- **Louis Pasteur:**
    - Proved that microorganisms cause fermentation and disease (germ theory of disease).
    - Developed the process of pasteurization to prevent spoilage of milk and wine.
    - Developed vaccines for rabies and anthrax.
    - Disproved spontaneous generation with his swan-neck flask experiment.
- **Stanley Prusiner:**

  - Discovered prions, infectious proteinaceous particles that cause neurodegenerative diseases.
  - Coined the term "prion."
  - Awarded the Nobel Prize in Physiology or Medicine in 1997 for his discovery.
- **Anand Mohan Chakraborty:**
  - Pioneered the development of genetically engineered microorganisms.
  - Known for developing a strain of *Pseudomonas putida* capable of degrading multiple components of crude oil, which was the first genetically engineered organism to be patented.
- **Ronald Ross:**
  - Demonstrated that malaria is transmitted by mosquitoes.
  - Identified the malaria parasite in the gut of mosquitoes.
  - Awarded the Nobel Prize in Physiology or Medicine in 1902 for his work on malaria.
- **Paul Ehrlich:**
  - Pioneered chemotherapy and developed the first effective treatment for syphilis (Salvarsan).
  - Made significant contributions to immunology, including the development of the side-chain theory of antibody formation.

- Coined the term "magic bullet."

Definitions of Terms:

- **Capsid:**
  - The protein shell that encloses the genetic material (DNA or RNA) of a virus.
  - Composed of protein subunits called capsomeres.
  - Protects the viral genome and aids in attachment to host cells.
- **Coenocytic hyphae:**
  - Fungal hyphae that lack septa (cross-walls) and are essentially continuous, multinucleated tubes of cytoplasm.
  - Commonly found in some groups of fungi, such as Zygomycetes.
  - Allows for rapid flow of nutrients and cytoplasm throughout the mycelium.
- **Plaque:**
  - A clear area or zone of lysed cells on a lawn of bacteria (or other host cells) on an agar plate.
  - Formed by bacteriophages (viruses that infect bacteria) that infect and kill host cells in a localized area.
  - Used to quantify the number of infectious viral particles in a sample.

- **Pyrenoids:**
  - Proteinaceous structures found within the chloroplasts of certain algae and hornworts.
  - Associated with the synthesis and storage of starch.
  - Often surrounded by starch grains.
- **Eyespot (Stigma):**
  - A light-sensitive organelle found in certain unicellular algae (e.g., *Chlamydomonas*) and some protozoa.
  - Composed of photoreceptor pigments (often carotenoids) and lipid droplets.
  - Helps the organism detect light and navigate towards optimal light conditions for photosynthesis (phototaxis).

Question 2: (a) Differentiate between the following (any three): (4×3=12)(i) Biofertilizers and Biopesticides (ii) Lytic and lysogenic phages (iii) Acellular and cellular slime molds (iv) Viroids and Prions (b) What are the various types of viral capsid symmetry. Explain with suitable diagram and example. (6)

(a) Differentiation:

- **(i) Biofertilizers and Biopesticides:**
  - **Biofertilizers:**
    - Contain living microorganisms that, when applied to seeds, plant surfaces, or soil, colonize the rhizosphere or

the interior of the plant and promote growth by increasing the supply or availability of primary nutrients to the host plant.

  - Examples include nitrogen-fixing bacteria (*Rhizobium*, *Azotobacter*), phosphate-solubilizing bacteria (*Bacillus*, *Pseudomonas*), and mycorrhizal fungi.
  - Primary function is to enhance plant nutrition.

- **Biopesticides:**
  - Are naturally occurring substances or microorganisms (e.g., bacteria, fungi, viruses) that can control pests (insects, weeds, nematodes, plant diseases).
  - Examples include *Bacillus thuringiensis* (Bt) for insect control, entomopathogenic fungi, and viral insecticides.
  - Primary function is to protect plants from pests and diseases.

- **(ii) Lytic and lysogenic phages:**
  - **Lytic Phages (Virulent Phages):**
    - Always lead to the lysis (destruction) of the host bacterial cell.
    - After infecting a host cell, the phage replicates rapidly, produces new phage particles, and then causes the host cell to burst, releasing the progeny phages.

- The phage DNA does not integrate into the host genome.
- Characterized by a shorter, more destructive life cycle.

- **Lysogenic Phages (Temperate Phages):**
  - Can either enter a lytic cycle or integrate their genetic material into the host bacterial chromosome, becoming a prophage.
  - In the lysogenic cycle, the prophage replicates along with the host cell DNA without causing immediate lysis.
  - The prophage can remain dormant for many generations and may later excise from the host genome and enter a lytic cycle (induction).
  - Can confer new properties to the host cell (lysogenic conversion).

- **(iii) Acellular and cellular slime molds:**
  - **Acellular Slime Molds (Plasmodial Slime Molds):**
    - Exist as a large, multinucleated, amoeboid mass of protoplasm called a plasmodium during their vegetative stage.
    - The plasmodium lacks cell walls and moves by amoeboid movement, engulfing food particles.
    - When conditions are unfavorable, the plasmodium forms sporangia that produce spores.

        - Example: *Physarum*.
    - **Cellular Slime Molds:**
        - Exist as individual, free-living amoeboid cells during their vegetative stage.
        - When food is scarce, individual amoebae aggregate to form a slug-like pseudoplasmodium (a collective of individual cells, not a true syncytium).
        - The pseudoplasmodium then differentiates into a fruiting body that produces spores.
        - Example: *Dictyostelium*.
- **(iv) Viroids and Prions:**
    - **Viroids:**
        - Small, circular, single-stranded RNA molecules that are infectious agents.
        - Lack a protein coat (capsid) and do not encode any proteins.
        - Replicate using the host cell's machinery.
        - Known to cause diseases primarily in plants.
        - Smaller than viruses.
    - **Prions:**

- Infectious proteinaceous particles that lack nucleic acid (DNA or RNA).
- Are misfolded forms of normal cellular proteins (PrP^C) that can induce other normal proteins to misfold.
- Cause neurodegenerative diseases in animals and humans (e.g., CJD, BSE, scrapie).
- Highly resistant to conventional sterilization methods.

(b) What are the various types of viral capsid symmetry. Explain with suitable diagram and example. There are primarily three types of viral capsid symmetry:

- **Helical Symmetry:**
  - **Explanation:** In viruses with helical symmetry, the capsomeres (protein subunits) are arranged in a spiral or helix around a central axis. This forms a hollow cylinder, and the nucleic acid (RNA or DNA) is embedded within this groove, following the helical path of the capsomeres. The length of the helix is determined by the length of the nucleic acid.
  - **Example:** Tobacco Mosaic Virus (TMV), Influenza virus, Rabies virus.
- **Icosahedral Symmetry (Cubic Symmetry):**
  - **Explanation:** Icosahedral symmetry is characterized by a polyhedral (typically 20-sided) shape, which is an efficient way

to enclose a volume using a minimal number of identical subunits. An icosahedron has 20 equilateral triangular faces, 12 vertices, and 30 edges. The capsomeres are arranged in a precise, symmetrical pattern on these faces. This structure is often described as "spherical" under electron microscopy due to its overall rounded appearance.

- **Example:** Adenovirus, Herpes simplex virus, Poliovirus.

- **Complex Symmetry:**
  - **Explanation:** Viruses with complex symmetry do not fit into the simple helical or icosahedral categories. Their capsids may have a combination of structures, or they may have additional components that give them a unique and intricate morphology. These viruses are often larger and more elaborate than those with simple symmetries.
  - **Example:** Bacteriophages (e.g., T4 phage), Poxviruses (e.g., Vaccinia virus). T4 phage has an icosahedral head and a helical tail. Poxviruses have an oval or brick-shaped morphology with multiple layers.

Question 3: (a) What is single cell protein? Discuss its production, sources and significance. (3) (b) Discuss the structure, lifecycle and economic importance of Aspergillus. (6) (c) Draw the morphology and discuss the significance of Entamoeba histolytica OR Tetrahymena. (5) (d) Write a note on algal pigments. (4)

(a) What is single cell protein? Discuss its production, sources and significance.

- **Single Cell Protein (SCP):**
  - Refers to the crude or refined protein obtained from unicellular or multicellular microorganisms such as bacteria, yeasts, fungi, and algae.
  - These microorganisms are grown on various carbon sources, and their biomass is then harvested and processed for use as a protein-rich food or feed supplement.
- **Production:**
  - Microorganisms are cultivated in large fermenters under controlled conditions (temperature, pH, aeration, nutrient supply) using suitable carbon sources.
  - After growth, the microbial biomass is harvested, usually by centrifugation or filtration.
  - The harvested biomass is then processed, which may involve washing, drying, and sometimes further purification steps, to obtain the SCP product.
- **Sources:**
  - **Bacteria:** *Methylophilus methylotrophus* (on methanol), *Pseudomonas* (on hydrocarbons).

 - **Yeasts:** *Saccharomyces cerevisiae* (on molasses, sulfite waste liquor), *Candida utilis* (on agricultural wastes).
 - **Fungi (Filamentous Fungi):** *Fusarium graminearum* (on glucose syrup, for Quorn).
 - **Algae:** *Spirulina platensis*, *Chlorella vulgaris* (on wastewater, CO_2).

- **Significance:**
 - **Protein Rich:** High protein content (40-85%) with a good amino acid profile, making it a valuable alternative to conventional protein sources like meat and soy.
 - **Rapid Growth Rate:** Microorganisms have very high growth rates and can be cultivated continuously, leading to high productivity in a small area.
 - **Sustainable:** Can be produced using various waste materials and industrial by-products as substrates, contributing to waste management and reducing reliance on traditional agriculture.
 - **Nutritional Value:** Rich in vitamins (especially B-complex), minerals, essential amino acids, and sometimes fats.
 - **Food Security:** Offers a potential solution to the global food and protein deficiency, especially in developing countries.
 - **Reduced Environmental Impact:** Lower land and water requirements compared to traditional animal farming, and lower carbon footprint.

(b) Discuss the structure, lifecycle and economic importance of Aspergillus.

- **Structure of *Aspergillus***:
  - ***Aspergillus*** is a genus of filamentous fungi, commonly known as molds.
  - **Hyphae:** Composed of septate hyphae (filaments divided by cross-walls) which form a network called a mycelium.
  - **Conidiophore:** A distinctive feature is the specialized aerial hyphae called a conidiophore, which arises from a foot cell.
  - **Vesicle:** The conidiophore terminates in a swollen, spherical, or club-shaped structure called a vesicle.
  - **Phialides (Sterigmata):** Covering the surface of the vesicle are single or double layers of flask-shaped cells called phialides (also known as sterigmata).
  - **Conidia:** These phialides produce chains of asexual spores called conidia (sing. conidium) in a basipetal succession (the youngest spore is at the base of the chain). Conidia are typically spherical and give *Aspergillus* colonies their characteristic colors (green, black, yellow, etc.).
  - **Ascospores (Sexual Spores):** Some species also produce sexual spores called ascospores within ascocarps, although asexual reproduction via conidia is more common.
- **Lifecycle of *Aspergillus***:

- *Aspergillus* primarily reproduces asexually through the formation of conidia.
- **Asexual Cycle:**
   i. **Conidium Germination:** A conidium lands on a suitable substrate (e.g., food, organic matter) and germinates, forming a germ tube.
   ii. **Mycelial Growth:** The germ tube develops into a network of septate hyphae, forming a mycelium that grows into and on the substrate, absorbing nutrients.
   iii. **Conidiophore Formation:** Specialized hyphae differentiate to form upright conidiophores, each with a swollen vesicle at its tip.
   iv. **Phialide and Conidia Production:** Phialides develop on the vesicle, and from these, chains of conidia are produced.
   v. **Dispersal:** Conidia are released into the air and can be dispersed by wind, leading to new infections or colonization.
- **Sexual Cycle (less common or not observed in all species):**
   vi. Some species of *Aspergillus* are known to have a sexual stage, involving the fusion of two compatible nuclei (karyogamy) and subsequent meiosis.

vii. This results in the formation of ascospores within a sexual fruiting body (ascocarp).

- **Economic Importance of *Aspergillus***:
    - **Beneficial Aspects:**
        - **Industrial Production:**
            - **Citric Acid:** *Aspergillus niger* is widely used for the industrial production of citric acid, a common food additive and preservative.
            - **Enzymes:** Various species produce a wide range of enzymes, including amylases (for starch hydrolysis), glucoamylase, pectinases, cellulases, and proteases, used in food processing, textile, and detergent industries.
            - **Organic Acids:** Production of other organic acids like gluconic acid, gallic acid, and itaconic acid.
            - **Fermentation:** Used in the production of traditional fermented foods like soy sauce (koji fermentation) and sake.
        - **Bioremediation:** Some *Aspergillus* species are capable of degrading various pollutants, including heavy metals and xenobiotics.
        - **Biocontrol:** Certain species can act as biocontrol agents against plant pathogens.

- **Harmful Aspects:**
  - **Food Spoilage:** *Aspergillus* species are common contaminants of food and can cause spoilage of grains, nuts, fruits, and vegetables, leading to significant economic losses.
  - **Mycotoxin Production:** Several species, particularly *Aspergillus flavus* and *Aspergillus parasiticus*, produce highly toxic secondary metabolites called mycotoxins, such as aflatoxins. Aflatoxins are potent carcinogens and can contaminate crops like peanuts, corn, and tree nuts, posing serious health risks to humans and animals.
  - **Human Diseases (Aspergillosis):** *Aspergillus fumigatus* is a major opportunistic human pathogen that can cause a range of diseases collectively known as Aspergillosis. These include allergic reactions (allergic bronchopulmonary aspergillosis), chronic lung conditions (aspergilloma), and severe invasive infections (invasive aspergillosis) in immunocompromised individuals.
  - **Plant Diseases:** Some species can cause post-harvest rot and diseases in plants.

(c) Draw the morphology and discuss the significance of Entamoeba histolytica OR Tetrahymena. I will discuss the morphology and significance of *Entamoeba histolytica*.

- **Morphology of *Entamoeba histolytica*:**

- *Entamoeba histolytica* is a parasitic protozoan that exists in two main forms: the trophozoite and the cyst.
- **Trophozoite (Vegetative Form):**
    - **Size:** Typically 15-60 μm in diameter (can be larger, up to 90 μm, when actively invading tissue).
    - **Shape:** Irregular and amoeboid, capable of rapid, unidirectional movement using a broad, finger-like pseudopod (ectoplasm).
    - **Cytoplasm:** Differentiated into a clear, outer ectoplasm and a granular, inner endoplasm. The endoplasm often contains ingested red blood cells (a key diagnostic feature when present), indicating tissue invasion.
    - **Nucleus:** Single, spherical nucleus with a small, centrally located nucleolus (karyosome) and fine, evenly distributed peripheral chromatin. This nuclear morphology is crucial for identification.
    - **Vacuoles:** May contain food vacuoles with bacteria or host cells.
    - **Motility:** Exhibits progressive, directional motility.
- **Cyst (Infective Form):**
    - **Size:** Smaller than the trophozoite, typically 10-20 μm in diameter.
    - **Shape:** Spherical or ovoid.

- **Wall:** Possesses a thick, resistant cyst wall that protects it from adverse environmental conditions (e.g., gastric acid).
- **Nuclei:** Immature cysts contain one nucleus. Mature (infective) cysts contain four nuclei, each with the characteristic central karyosome and peripheral chromatin.
- **Chromatoid Bodies:** Often present in young cysts. These are rod-shaped or bar-like structures with rounded ends, composed of condensed RNA and protein. They disappear as the cyst matures.
- **Glycogen Vacuole:** A large glycogen vacuole may be present in immature cysts but usually disappears in mature cysts.

- **Significance of *Entamoeba histolytica***:
  - **Causative Agent of Amoebiasis:** *Entamoeba histolytica* is the causative agent of amoebiasis (also known as amoebic dysentery or amoebic colitis), a parasitic infection of the human gastrointestinal tract.
  - **Disease Manifestations:**
    - **Intestinal Amoebiasis:** Ranges from asymptomatic carriage to severe dysentery. Symptoms include abdominal pain, cramping, diarrhea (often bloody and mucoid, hence "amoebic dysentery"), tenesmus, and

fever. In severe cases, it can lead to toxic megacolon or amoeboma (a mass-like lesion in the colon).

- **Extraintestinal Amoebiasis:** Occurs when trophozoites invade beyond the intestine, typically reaching the liver via the portal vein, leading to amoebic liver abscesses (ALA). ALA is the most common extraintestinal manifestation, characterized by fever, right upper quadrant pain, and hepatomegaly. Less commonly, amoebiasis can spread to the lungs, brain (amoebic brain abscess), or skin.

- **Transmission:** Primarily through the fecal-oral route, by ingestion of infective cysts in contaminated food or water, or direct contact with contaminated hands.
- **Global Health Impact:** Amoebiasis is a significant public health problem, particularly in tropical and subtropical regions with poor sanitation and hygiene. It is estimated to cause millions of cases and tens of thousands of deaths globally each year, making it one of the leading causes of parasitic disease mortality.
- **Diagnosis and Treatment:** Diagnosis involves microscopic examination of stool samples for cysts and trophozoites, and molecular methods (e.g., PCR) for more sensitive detection. Serological tests are useful for extraintestinal amoebiasis. Treatment typically involves amoebicidal drugs like metronidazole, followed by a luminal agent to eradicate cysts.

- **Prevention:** Improving sanitation, safe water supply, proper food hygiene, and personal cleanliness are crucial for preventing the spread of the infection.

(d) Write a note on algal pigments.

- **Algal Pigments:**
  - Algal pigments are diverse photosynthetic pigments found in various groups of algae that enable them to capture light energy for photosynthesis.
  - The specific combination of pigments present in an algal group determines its characteristic color and its ability to absorb different wavelengths of light, allowing them to thrive in various aquatic environments.

- **Major Types of Algal Pigments:**
  - **1. Chlorophylls:**
    - **Primary Pigment:** Chlorophylls are the primary photosynthetic pigments responsible for the green color in most plants and algae. They absorb light primarily in the blue and red regions of the spectrum and reflect green light.
    - **Types:**
      - **Chlorophyll a:** Found in all photosynthetic eukaryotes (including all algae) and cyanobacteria. It is the primary reaction center pigment.

- **Chlorophyll b:** Found in green algae (Chlorophyta) and euglenoids. It is an accessory pigment, broadening the range of light absorbed.
- **Chlorophyll c:** Found in diatoms, dinoflagellates, brown algae (Phaeophyceae), and some other heterokont algae.
- **Chlorophyll d:** Found in some red algae (Rhodophyta) and cyanobacteria (e.g., *Acaryochloris marina*).
- **Chlorophyll f:** Recently discovered in some cyanobacteria.

- **2. Carotenoids:**
  - **Accessory Pigments:** Carotenoids are yellow, orange, or red fat-soluble pigments that absorb light in the blue-violet region of the spectrum and transfer the energy to chlorophyll.
  - **Photoprotection:** They also play a crucial role in photoprotection, dissipating excess light energy and preventing oxidative damage to chlorophyll.
  - **Types:**
    - **Carotenes:** Pure hydrocarbons, such as beta-carotene (found in most algae).

        - **Xanthophylls:** Oxygenated derivatives of carotenes, such as fucoxanthin (in brown algae and diatoms, giving them a brownish color), lutein (in green algae), and zeaxanthin.

- **3. Phycobiliproteins:**
    - **Water-Soluble Pigments:** These are water-soluble protein-bound pigments found in cyanobacteria (blue-green algae) and red algae (Rhodophyta). They are located in specialized structures called phycobilisomes on the thylakoid membranes.
    - **Light Harvesting:** They are highly efficient in absorbing light in the green, yellow, and orange regions of the spectrum, which chlorophylls absorb poorly. This allows these algae to photosynthesize effectively in deeper waters where green and blue light penetrate.
    - **Types:**
        - **Phycoerythrin:** Red pigment, abundant in red algae, responsible for their red color. Absorbs blue-green light.
        - **Phycocyanin:** Blue pigment, abundant in cyanobacteria, giving them their characteristic blue-green color. Absorbs orange-red light.

        - **Allophycocyanin:** A blue pigment that acts as an energy transfer bridge between phycoerythrin/phycocyanin and chlorophyll a.

- **Ecological Significance:**
    - **Adaptation to Light Conditions:** The diversity of pigments allows different algal groups to adapt to varying light conditions and depths in aquatic environments. For example, red algae with phycoerythrin can absorb blue-green light that penetrates deeper into water, enabling them to live in deeper marine environments.
    - **Classification:** The specific types and ratios of pigments are often used as important chemotaxonomic markers in the classification of different algal divisions.

Question 4: Write a short note on the following (any four): (4×4=16)(i) Current Developments in Space Microbiology (ii) Economic Importance of algae (iii) Waste management (iv) Phage therapy (v) Human microbiome (b) Discuss bioleaching with suitable example. (2)

(i) Current Developments in Space Microbiology:

- Space microbiology is an emerging field that studies microorganisms in space environments (e.g., on spacecraft, International Space Station - ISS, planetary surfaces) and their interactions with space conditions (microgravity, radiation, altered atmospheric composition).
- **Microbial Contamination & Biofilm Formation:** A significant focus is on understanding and mitigating microbial contamination of

spacecraft and the ISS. Microbes can form biofilms on surfaces, potentially leading to equipment degradation, corrosion, and health risks for astronauts. Research aims to develop effective cleaning protocols, antimicrobial surfaces, and monitoring techniques.

- **Astronaut Health:** Spaceflight alters the human immune system, making astronauts more susceptible to infections. Microorganisms behave differently in microgravity (e.g., altered virulence, increased antibiotic resistance). Studies are investigating changes in the astronaut microbiome, host-pathogen interactions, and strategies to maintain astronaut health during long-duration missions.
- **Life Support Systems:** Microorganisms are integral to biological life support systems (e.g., closed-loop systems for waste recycling, air purification, and food production) for future long-duration space missions. Research focuses on optimizing microbial consortia for efficiency and stability in these systems.
- **Astrobiology & Planetary Protection:** A key aspect is the search for extraterrestrial life and ensuring planetary protection. This involves developing sterilization protocols for spacecraft to prevent forward contamination (transporting Earth microbes to other celestial bodies) and backward contamination (bringing potentially harmful alien microbes back to Earth). Studies on extremophiles and their survival in space-like conditions provide insights into the potential for life beyond Earth.
- **Bioregenerative Systems:** Investigating the use of microbes for in-situ resource utilization (ISRU) on other planets, such as

bioconversion of Martian regolith, biological resource recovery, and microbial production of essential compounds.

- **Current Research:** Includes advanced sequencing technologies to characterize space microbiomes, studying microbial adaptation to microgravity (e.g., changes in gene expression and growth patterns), and developing new countermeasures against microbial threats in space.

(ii) Economic Importance of Algae:

- Algae are diverse photosynthetic organisms that play significant roles in various industries and ecological systems, contributing economically in several ways.
- **Food and Feed:**
  - **Human Consumption:** Seaweeds (macroalgae) like Nori (*Porphyra*), Kombu (*Laminaria*), and Wakame (*Undaria*) are staple foods in many Asian cuisines, providing vitamins, minerals, and fiber.
  - **Health Foods/Supplements:** Microalgae such as *Spirulina* (a cyanobacterium) and *Chlorella* are marketed as superfoods or dietary supplements due to their high protein, vitamin, and antioxidant content.
  - **Animal Feed:** Algal biomass is used as a nutritional supplement in aquaculture and livestock feed, enhancing growth and nutrient content.

- **Hydrocolloids:**
  - **Agar:** Extracted from red algae (*Gelidium*, *Gracilaria*), used as a gelling agent in food (jelly, desserts), a solidifying agent in microbiological culture media, and in pharmaceuticals.
  - **Carrageenan:** Extracted from red algae (*Chondrus crispus*, *Eucheuma*), used as a thickening, stabilizing, and emulsifying agent in dairy products, processed meats, and cosmetics.
  - **Alginates:** Extracted from brown algae (*Laminaria*, *Macrocystis*), used as thickeners, gelling agents, and stabilizers in food, textiles, pharmaceuticals, and dentistry.
- **Biofuels:**
  - Microalgae are being explored as a sustainable source of biofuels (biodiesel, bioethanol, biohydrogen) due to their high lipid content, rapid growth rate, and ability to grow on non-arable land and wastewater.
- **Bioremediation:**
  - Algae are used in wastewater treatment to remove nutrients (nitrogen, phosphorus), heavy metals, and other pollutants. They can also absorb CO2, contributing to carbon sequestration.
- **Pharmaceuticals and Cosmetics:**

- Algae produce various bioactive compounds with potential medicinal properties, including antimicrobials, antioxidants, anti-inflammatory agents, and anticancer compounds.
- Algal extracts are used in cosmetics for their moisturizing, anti-aging, and skin-conditioning properties.

- **Fertilizers:**
  - Seaweed extracts and meal are used as organic fertilizers and soil conditioners, improving soil structure and nutrient availability.
- **Research and Education:**
  - Algae serve as important model organisms in biological research, particularly in photosynthesis, genetics, and cell biology.

(iii) Waste Management:

- Waste management refers to the activities and processes required to manage waste from its inception to its final disposal. This includes collection, transport, treatment (e.g., recycling, incineration, composting), and disposal of waste materials, along with monitoring and regulation.
- **Objectives:** The primary objectives are to minimize the adverse impacts of waste on human health, the environment, and aesthetics, while maximizing resource recovery and promoting sustainability.

- **Types of Waste:** Waste can be categorized into various types, including municipal solid waste (household, commercial), industrial waste, hazardous waste, agricultural waste, construction and demolition waste, electronic waste (e-waste), and biomedical waste.
- **Key Principles (Hierarchy of Waste Management):**
  - **Reduce:** Minimizing the amount of waste generated at the source (e.g., reducing consumption, using durable products).
  - **Reuse:** Using items multiple times before discarding them (e.g., reusable bags, refillable bottles).
  - **Recycle:** Processing discarded materials into new products to prevent waste of potentially useful materials, reduce consumption of fresh raw materials, and reduce energy usage (e.g., paper, plastic, glass, metals).
  - **Recovery:** Recovering energy from waste through processes like incineration with energy recovery (waste-to-energy) or anaerobic digestion for biogas.
  - **Disposal:** The least preferred option, involving landfilling or incineration without energy recovery, for waste that cannot be reduced, reused, recycled, or recovered.
- **Techniques and Methods:**
  - **Landfilling:** Burying waste in designated sites, often with liners to prevent leachate leakage. Modern landfills are engineered to minimize environmental impact.

  - **Incineration:** Burning waste to reduce its volume and sometimes generate energy. Requires proper emission controls.
  - **Composting:** Biological decomposition of organic waste (food scraps, yard waste) into a nutrient-rich soil amendment.
  - **Anaerobic Digestion:** Breakdown of organic matter by microorganisms in the absence of oxygen to produce biogas (methane and carbon dioxide).
  - **Bioremediation:** Using microorganisms to break down or detoxify hazardous waste.
  - **Pyrolysis and Gasification:** Thermal decomposition of waste in the absence or limited presence of oxygen to produce fuels or chemicals.
  - **Integrated Waste Management:** A holistic approach that combines various waste management techniques to achieve optimal environmental and economic outcomes.
- **Challenges:** Rapid population growth, urbanization, increasing consumption patterns, inadequate infrastructure, lack of public awareness, and proper segregation practices pose significant challenges.
- **Importance:** Effective waste management is crucial for public health, environmental protection, resource conservation, climate change mitigation, and sustainable development.

(iv) Phage Therapy:

- **Phage Therapy:** Phage therapy is the therapeutic use of bacteriophages (viruses that specifically infect and lyse bacteria) to treat bacterial infections. It involves administering phages that are highly specific to the pathogenic bacteria causing the infection, leaving beneficial bacteria largely unharmed.
- **Mechanism of Action:** When administered, phages bind to specific receptors on the bacterial cell surface, inject their genetic material, hijack the bacterial machinery to replicate themselves, and then lyse (burst) the bacterial cell, releasing new phage particles. These new phages can then infect other target bacteria, continuing the cycle.
- **Advantages:**
  - **Specificity:** Phages are highly specific to their target bacteria, minimizing disruption to the host's normal microbiome (unlike broad-spectrum antibiotics). This reduces the risk of side effects like dysbiosis or antibiotic-associated diarrhea.
  - **Self-replicating:** Phages replicate at the site of infection as long as target bacteria are present, potentially requiring lower initial doses.
  - **Overcoming Antibiotic Resistance:** Phage therapy offers a promising alternative for treating infections caused by multidrug-resistant (MDR) bacteria, for which conventional antibiotics are ineffective.

  - **Safety Profile:** Generally considered safe, as phages are naturally occurring and ubiquitous, and human body usually clears them once the bacterial target is eliminated.
  - **Penetration:** Can penetrate biofilms, which are often resistant to antibiotics.

- **Disadvantages/Challenges:**
  - **Narrow Host Range:** While an advantage, the high specificity can also be a disadvantage, as a specific phage may only target a few strains of a bacterial species. This often necessitates using a "phage cocktail" (a mixture of different phages) to ensure broader coverage.
  - **Immune Response:** The host immune system can neutralize phages, especially if administered repeatedly.
  - **Regulatory Hurdles:** The regulatory pathways for approving phage therapies are still evolving in many Western countries, unlike in Eastern Europe and Georgia where it has been used for decades.
  - **Bacterial Resistance:** Bacteria can develop resistance to phages, although the rapid evolution of phages can potentially counteract this.
  - **Endotoxin Release:** Lysis of Gram-negative bacteria can release endotoxins, potentially leading to a temporary inflammatory response.

- **Current Status and Future:** Phage therapy is gaining renewed interest globally due to the rise of antibiotic-resistant "superbugs." Research is active in developing standardized phage preparations, optimizing delivery methods, and conducting clinical trials for various infections, including cystic fibrosis, chronic wound infections, and urinary tract infections. It holds significant promise as a complementary or alternative approach to antibiotics.

(v) Human Microbiome:

- **Human Microbiome:** The human microbiome refers to the collective genetic material (genomes) of all the microorganisms (bacteria, archaea, fungi, viruses, protozoa) that live in or on the human body. These microorganisms, collectively called the microbiota, inhabit various body sites, including the gut, skin, oral cavity, respiratory tract, and urogenital tract, with the gut microbiome being the largest and most diverse.
- **Composition and Diversity:** The human microbiome is highly diverse and dynamic, varying significantly among individuals and across different body sites. It is influenced by factors such as genetics, diet, lifestyle, age, geographical location, and antibiotic use.
- **Key Functions and Significance:**
    - **Digestion and Nutrient Absorption:** Gut microbiota aid in the digestion of complex carbohydrates and fibers that human enzymes cannot break down, producing short-chain fatty acids (SCFAs) like butyrate, which provide energy to host cells and

have anti-inflammatory effects. They also synthesize essential vitamins (e.g., vitamin K, B vitamins).

- **Immune System Development and Modulation:** The microbiome plays a crucial role in training and shaping the immune system, distinguishing between beneficial microbes and pathogens. It influences immune cell development and activity, contributing to both local and systemic immunity.
- **Protection Against Pathogens:** A healthy microbiome provides colonization resistance, competing with and inhibiting the growth of pathogenic microorganisms by occupying ecological niches and producing antimicrobial compounds.
- **Metabolism:** Influences host metabolism, including energy harvesting, fat storage, and drug metabolism.
- **Brain-Gut Axis:** Emerging research highlights a bidirectional communication pathway between the gut microbiome and the brain (microbiome-gut-brain axis), influencing mood, behavior, cognitive function, and neurological disorders.
- **Drug Metabolism:** Microbes can modify the efficacy and toxicity of drugs.

- **Dysbiosis and Disease:** An imbalance or alteration in the composition and function of the microbiome (dysbiosis) is increasingly linked to various diseases, including inflammatory bowel disease (IBD), obesity, type 2 diabetes, allergies, autoimmune diseases, certain cancers, and neurological conditions.

- **Therapeutic Potential:** Understanding the human microbiome offers new avenues for therapeutic interventions, such as:
    - **Probiotics:** Live microorganisms that, when administered in adequate amounts, confer a health benefit on the host.
    - **Prebiotics:** Non-digestible food ingredients that selectively stimulate the growth and/or activity of beneficial bacteria in the colon.
    - **Fecal Microbiota Transplantation (FMT):** Transferring fecal matter from a healthy donor to a recipient to restore a balanced gut microbiome, particularly effective for recurrent *Clostridioides difficile* infection.
    - **Targeted Microbiome Modulation:** Developing precision therapies to alter specific microbial communities or their functions for disease treatment.

(b) Discuss bioleaching with suitable example.

- **Bioleaching:**
    - Bioleaching is a biotechnological process that uses microorganisms, typically bacteria or archaea, to extract metals from ores or other solid materials.
    - It is an environmentally friendly alternative to conventional pyrometallurgical (high temperature) or hydrometallurgical (strong chemicals) processes, which can be energy-intensive and produce significant pollution.

    - The process relies on the ability of specific microbes to oxidize metal sulfides or other metal-containing compounds, converting insoluble metal compounds into soluble forms that can then be recovered from the leachate (the liquid containing the dissolved metal ions).

- **Mechanism:**
    - The most common microorganisms involved in bioleaching are chemolithoautotrophic acidophiles, primarily *Acidithiobacillus ferrooxidans* (formerly *Thiobacillus ferrooxidans*) and *Acidithiobacillus thiooxidans*.
    - These bacteria obtain energy by oxidizing inorganic compounds, such as ferrous iron (Fe^{2+}) and reduced sulfur compounds (e.g., sulfide, elemental sulfur).
    - **Direct Mechanism:** The bacteria directly attack the metal sulfide minerals, oxidizing the sulfide component to sulfate and solubilizing the metal.
        - Example: $CuFeS_2 \text{ (chalcopyrite)} + O_2 \xrightarrow{bacteria} Cu^{2+} + Fe^{3+} + SO_4^{2-}$
    - **Indirect Mechanism:** The bacteria first oxidize ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}). The highly oxidative ferric iron then chemically attacks the metal sulfide mineral, dissolving the metal and regenerating ferrous iron, which the bacteria then re-oxidize. This creates a cyclical process.
        - Example (for copper extraction from chalcopyrite):

        - Bacterial oxidation of ferrous iron: $4Fe^{2+} + O_2 + 4H^+ \xrightarrow{Acidithiobacillus} 4Fe^{3+} + 2H_2O$
        - Chemical oxidation of chalcopyrite by ferric iron: $CuFeS_2 + 2Fe^{3+} \longrightarrow Cu^{2+} + 3Fe^{2+} + 2S^0$
        - Bacterial oxidation of elemental sulfur (produced in the above reaction): $2S^0 + 3O_2 + 2H_2O \xrightarrow{Acidithiobacillus} 2H_2SO_4$ (which maintains the acidic environment)
    - The solubilized metal ions (e.g., Cu^{2+}) are then recovered from the leachate using standard hydrometallurgical techniques like solvent extraction and electrowinning.

- **Suitable Example (Copper Mining):**
    - Bioleaching is widely used in the mining industry, particularly for the extraction of copper from low-grade sulfide ores, such as chalcopyrite ($CuFeS_2$).
    - **Process:** Ore is crushed and placed in heaps or agitated tanks. An acidic solution (often containing inoculum of *Acidithiobacillus* species) is percolated through the ore. As the solution trickles down, the bacteria facilitate the oxidation of the copper sulfide minerals, releasing copper ions into the solution. The copper-rich solution (pregnant leach solution) is collected at the bottom, and copper is then recovered.

- This method is cost-effective and environmentally advantageous for processing ores that are too low-grade to be economically viable with traditional smelting methods.

Question 5: (a) Diagrammatically explain the structure and reproduction in Chlamydomonas. (5) (b) Write a note on various types of vaccines. (5) (c) What are Probiotics? Discuss the health benefits conferred by them. (4) (d) Discuss any two fermented foods. (4)

(a) Diagrammatically explain the structure and reproduction in Chlamydomonas. I cannot generate diagrams. However, I can provide a detailed explanation of the structure and reproduction in *Chlamydomonas*.

- **Structure of *Chlamydomonas***:
  - *Chlamydomonas* is a genus of single-celled, biflagellate green algae, typically pear-shaped or ovoid.
  - **Cell Wall:** A rigid, glycoprotein-rich cell wall surrounds the protoplast, providing structural support.
  - **Plasma Membrane:** Located just inside the cell wall, regulating the passage of substances.
  - **Chloroplast:** A large, cup-shaped or H-shaped chloroplast occupies a significant portion of the cell volume. It contains thylakoids (arranged in stacks or groups) where photosynthesis occurs.

- **Pyrenoid:** Located within the chloroplast, usually at its posterior end. It is a proteinaceous structure associated with starch synthesis and storage.
- **Nucleus:** A single, large nucleus is centrally located within the cytoplasm.
- **Contractile Vacuoles:** Two small, pulsating contractile vacuoles are located at the anterior end, near the base of the flagella. They regulate osmotic balance by expelling excess water.
- **Eyespot (Stigma):** A small, orange-red, light-sensitive organelle embedded in the chloroplast, near the anterior end. It helps the alga detect light and orient itself for photosynthesis (phototaxis).
- **Flagella:** Two equal-sized, anteriorly inserted flagella emerge from the cell. They are whip-like appendages used for motility. They exhibit a 9+2 microtubule arrangement.
- **Cytoplasm:** Fills the cell, containing ribosomes, mitochondria, Golgi apparatus, and other organelles.

- **Reproduction in *Chlamydomonas*:**
  - *Chlamydomonas* exhibits both asexual and sexual modes of reproduction.
  - **Asexual Reproduction (Most Common):**

viii. **Withdrawal of Flagella:** Under favorable conditions, the mature motile cell retracts or sheds its flagella.

ix. **Mitotic Divisions:** The cell undergoes successive mitotic divisions (usually 2-3 divisions, resulting in 4-8 daughter cells, sometimes more). These divisions occur within the confines of the parent cell wall.

x. **Formation of Zoospores:** Each daughter protoplast develops a cell wall and two flagella, becoming a miniature motile cell called a zoospore.

xi. **Release:** The parent cell wall ruptures, releasing the zoospores, which then grow into mature cells.

xii. **Aplanospores (Less Common):** Under unfavorable conditions, the protoplast may divide to form non-motile, thick-walled spores called aplanospores, which can survive adverse conditions and later germinate into new cells when conditions improve.

xiii. **Palmella Stage (Temporary):** Under very unfavorable conditions, cells may lose flagella, divide repeatedly, and become embedded in a common gelatinous matrix, forming a non-motile colony called the Palmella stage. These cells eventually develop flagella and become motile when conditions improve.

- **Sexual Reproduction:**

xiv. **Gamete Formation:** Under unfavorable conditions (e.g., nitrogen starvation, high light intensity), vegetative cells act as gametes or produce gametes. *Chlamydomonas* can be isogamous (gametes are morphologically similar, but physiologically distinct as "+" and "-" strains) or anisogamous.

xv. **Gamete Fusion:** Compatible gametes (e.g., "+" and "-" strains) come into contact and fuse at their anterior ends. Their flagella dissociate, and their protoplasts fuse (plasmogamy), followed by nuclear fusion (karyogamy), forming a diploid zygote.

xvi. **Zygospore Formation:** The zygote develops a thick, resistant cell wall, becoming a dormant, thick-walled zygospore. This resting stage helps it survive harsh conditions.

xvii. **Meiosis:** When conditions become favorable, the zygospore undergoes meiosis.

xviii. **Zoospores/Haploid Cells:** Meiosis produces four (or more) haploid zoospores or germinating cells, which are then released.

xix. **Growth:** These haploid cells develop into new haploid vegetative *Chlamydomonas* cells, completing the life cycle.

(b) Write a note on various types of vaccines.

- **Vaccines:** Vaccines are biological preparations that provide active acquired immunity to a particular infectious disease. They typically contain an agent that resembles a disease-causing microorganism, which is often made from weakened or killed forms of the microbe, its toxins, or one of its surface proteins. The agent stimulates the body's immune system to recognize the agent as foreign, destroy it, and "remember" it, so that the immune system can mount a rapid and effective response upon subsequent exposure to the actual pathogen.
- **Various Types of Vaccines:**
  - **1. Live-Attenuated Vaccines:**
    - **Description:** Contain a weakened (attenuated) form of the living pathogen that has lost its ability to cause disease but can still replicate in the host.
    - **Mechanism:** Elicit a strong and long-lasting immune response, mimicking a natural infection, including both humoral (antibody) and cell-mediated immunity.
    - **Advantages:** Usually provide lifelong immunity with one or two doses.
    - **Disadvantages:** Not suitable for immunocompromised individuals or pregnant women due to the small risk of reversion to virulence. Require cold chain for storage.

    - **Examples:** Measles, Mumps, Rubella (MMR), Varicella (chickenpox), Oral Polio Vaccine (OPV), Rotavirus, Yellow Fever.

- **2. Inactivated (Killed) Vaccines:**
    - **Description:** Contain whole pathogens that have been inactivated or killed, typically by heat or chemicals, so they cannot replicate or cause disease.
    - **Mechanism:** Primarily induce a humoral immune response (antibody production).
    - **Advantages:** Safer for immunocompromised individuals as there is no risk of disease. More stable than live vaccines.
    - **Disadvantages:** Generally produce a weaker immune response and often require multiple doses (boosters) to maintain immunity.
    - **Examples:** Inactivated Polio Vaccine (IPV), Hepatitis A, Rabies, most Influenza (flu shots), Typhoid (Vi capsular polysaccharide vaccine).

- **3. Subunit Vaccines:**
    - **Description:** Contain only specific purified components of the pathogen (e.g., proteins, polysaccharides, or toxoids) that are highly immunogenic, rather than the whole microbe.

- **Types:**
  - **Protein Subunit Vaccines:** Use specific proteins from the pathogen. Example: Hepatitis B vaccine (uses surface antigen protein).
  - **Polysaccharide Vaccines:** Use long chains of sugar molecules from the capsule of certain bacteria. Example: Pneumococcal polysaccharide vaccine (PPSV23).
  - **Conjugate Vaccines:** Polysaccharides are often poor antigens in young children. In conjugate vaccines, the polysaccharide is chemically linked (conjugated) to a protein carrier, making it more immunogenic. Example: *Haemophilus influenzae* type b (Hib), Pneumococcal conjugate vaccine (PCV13), Meningococcal conjugate vaccine.
  - **Toxoid Vaccines:** Use inactivated bacterial toxins (toxoids) that have been chemically treated to lose their toxicity but retain their immunogenicity. They protect against the toxins produced by bacteria, not the bacteria themselves. Example: Diphtheria, Tetanus (part of DTaP vaccine).
- **Advantages:** Very safe as they contain no live components or whole dead cells.

- **Disadvantages:** May require multiple doses and often need adjuvants (substances that enhance the immune response).

- **4. Viral Vector Vaccines:**
  - **Description:** Use a modified harmless virus (the "vector") to deliver genetic material (DNA or RNA) encoding a specific antigen from the target pathogen into host cells. The host cells then produce the antigen, triggering an immune response.
  - **Mechanism:** Induce both humoral and cell-mediated immunity.
  - **Advantages:** Can elicit strong and long-lasting immunity.
  - **Disadvantages:** Pre-existing immunity to the vector virus could reduce efficacy.
  - **Examples:** AstraZeneca and Johnson & Johnson COVID-19 vaccines (use adenoviruses). Ebola vaccine.

- **5. Nucleic Acid (DNA/RNA) Vaccines:**
  - **Description:** Deliver genetic material (DNA or mRNA) directly into host cells. The host cells then use this genetic material to produce the pathogen's antigen, which then triggers an immune response.

- **Mechanism:** The host cell's machinery produces the antigen, presenting it to the immune system, leading to both humoral and cell-mediated immunity.
- **Advantages:** Rapid development and manufacturing, no live pathogen involved, high potency.
- **Disadvantages:** Relatively new technology, long-term safety and efficacy data still accumulating for some.
- **Examples:** Pfizer-BioNTech and Moderna COVID-19 vaccines (mRNA vaccines).

- **6. Whole Cell Vaccines (Historical/Less Common Now):**
  - **Description:** Contain entire dead bacterial cells. Often associated with more side effects than subunit vaccines.
  - **Examples:** Whole-cell Pertussis (part of DTP, largely replaced by acellular pertussis vaccine - DTaP).

(c) What are Probiotics? Discuss the health benefits conferred by them.

- **Probiotics:**
  - Probiotics are live microorganisms that, when administered in adequate amounts, confer a health benefit on the host.
  - They are typically beneficial bacteria and sometimes yeasts, commonly found in fermented foods or as dietary supplements.
  - The most common genera of bacteria used as probiotics are *Lactobacillus* and *Bifidobacterium*. Other examples include

Saccharomyces boulardii (a yeast) and some *Streptococcus* species.

- **Health Benefits Conferred by Probiotics:**
  - **1. Gut Health and Digestive Balance:**
    - **Restoring Gut Microbiome:** Help restore the balance of beneficial bacteria in the gut, especially after antibiotic use, illness, or stress, which can cause dysbiosis.
    - **Diarrhea Management:** Effective in preventing and treating various types of diarrhea, including antibiotic-associated diarrhea (AAD), traveler's diarrhea, and infectious diarrhea.
    - **Irritable Bowel Syndrome (IBS) and Inflammatory Bowel Disease (IBD):** May alleviate symptoms like bloating, gas, and abdominal pain in IBS and support remission in some IBD patients by reducing inflammation and improving gut barrier function.
    - **Constipation:** Some strains can help improve bowel regularity.
  - **2. Immune System Modulation:**
    - **Enhancing Immunity:** Probiotics interact with the gut-associated lymphoid tissue (GALT), which is a major part of the immune system. They can enhance the production of antibodies, activate immune cells (e.g., T cells, B cells,

macrophages), and modulate cytokine production, leading to a stronger immune response against pathogens.

- **Reduced Infections:** May reduce the frequency and severity of common infections, particularly respiratory tract infections and urinary tract infections.

- **3. Nutrient Absorption and Metabolism:**
  - **Vitamin Synthesis:** Certain probiotic strains can synthesize B vitamins (e.g., B12, folate) and vitamin K.
  - **Mineral Absorption:** May improve the absorption of certain minerals, such as calcium and iron.
  - **Short-Chain Fatty Acids (SCFAs):** Ferment dietary fibers to produce SCFAs (e.g., butyrate), which serve as an energy source for colonocytes and have systemic health benefits, including anti-inflammatory effects and metabolic regulation.
- **4. Mental Health (Gut-Brain Axis):**
  - **Mood and Cognitive Function:** Emerging research suggests a connection between the gut microbiome and the brain (gut-brain axis). Probiotics may influence neurotransmitter production (e.g., serotonin), reduce stress, anxiety, and depression symptoms, and potentially impact cognitive function.
- **5. Vaginal Health:**

- **Preventing Urogenital Infections:** Certain *Lactobacillus* strains can help maintain a healthy acidic environment in the vagina, preventing the overgrowth of pathogenic bacteria and yeasts, thereby reducing the risk of bacterial vaginosis and yeast infections.

- **6. Skin Health:**
  - **Eczema and Allergies:** Some studies suggest that maternal and early-life probiotic supplementation may reduce the risk or severity of allergic diseases like eczema in infants.

- **7. Other Potential Benefits:**
  - **Weight Management:** Research is exploring their role in metabolic health and potential impact on weight.
  - **Oral Health:** May help in preventing dental caries and periodontal diseases.
  - **Cholesterol Reduction:** Some strains might have a modest effect on lowering cholesterol levels.

(d) Discuss any two fermented foods.

- **Fermented Foods:** Fermented foods are foods or beverages produced through the controlled growth of microorganisms (bacteria, yeasts, or molds) and enzymatic conversions of food components. This process, fermentation, alters the food's composition, flavor, aroma, texture, and nutritional value, and often enhances its shelf life.

- **1. Yogurt:**
  - **Description:** Yogurt is a fermented dairy product made by the bacterial fermentation of milk.
  - **Microorganisms Involved:** Primarily two types of lactic acid bacteria (LAB): *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. These are thermophilic (heat-loving) bacteria. Sometimes, *Lactobacillus acidophilus*, *Bifidobacterium* species, and *Lactobacillus casei* are added as probiotic cultures.
  - **Production Process:**

    xx. **Milk Preparation:** Milk (typically cow's milk, but can be sheep, goat, or buffalo milk) is heated to about 80-90°C (pasteurization) to kill undesirable microorganisms and denature milk proteins, which helps in forming a stable gel.

    xxi. **Cooling:** The milk is then cooled to an optimal fermentation temperature, usually around 40-45°C.

    xxii. **Inoculation:** A starter culture containing the specific bacterial strains is added to the cooled milk.

    xxiii. **Fermentation:** The bacteria ferment the lactose (milk sugar) into lactic acid. The lactic acid causes the milk proteins (casein) to coagulate and thicken, giving yogurt its characteristic texture and tangy flavor. This process usually takes several hours.

xxiv. **Cooling and Storage:** Once the desired acidity and texture are reached, the yogurt is cooled to stop fermentation and stored at refrigeration temperatures.

- **Economic and Nutritional Importance:**
    - **Digestibility:** Lactic acid breaks down lactose, making yogurt more digestible for lactose-intolerant individuals.
    - **Nutrient Content:** Rich in protein, calcium, vitamins (B vitamins), and minerals.
    - **Probiotic Benefits:** Many yogurts contain live and active cultures, contributing to gut health, improving digestion, and boosting the immune system.
    - **Versatility:** Consumed as a standalone product, in smoothies, dips, sauces, and as an ingredient in various culinary dishes.
    - **Global Market:** A major product in the dairy industry worldwide due to its health benefits and versatility.

- **2. Kimchi:**
    - **Description:** Kimchi is a traditional Korean side dish made from fermented vegetables, primarily napa cabbage and Korean radish, along with a variety of seasonings.
    - **Microorganisms Involved:** A diverse community of lactic acid bacteria (LAB) is responsible for kimchi fermentation. Key genera include *Leuconostoc*, *Lactobacillus*, *Weissella*, and

Pediococcus. These bacteria are naturally present on the raw vegetables.

- **Production Process:**

  xxv. **Vegetable Preparation:** Cabbage and other vegetables are salted (brined) to draw out water and inhibit spoilage microorganisms.

  xxvi. **Rinsing:** The salted vegetables are rinsed to remove excess salt.

  xxvii. **Seasoning:** A paste of various spices and ingredients is prepared, which typically includes gochugaru (Korean chili powder), garlic, ginger, green onions, jeotgal (fermented seafood), and sometimes fruit (e.g., pear, apple).

  xxviii. **Mixing and Packing:** The seasoning paste is thoroughly mixed with the vegetables, and the mixture is packed tightly into airtight containers.

  xxix. **Fermentation:** The containers are left at room temperature for a few days to initiate fermentation, then typically moved to cooler temperatures (e.g., refrigeration or traditional kimchi refrigerators) for slower, prolonged fermentation. LAB ferment the sugars in the vegetables, producing lactic acid, acetic acid, carbon dioxide, and other compounds that give kimchi its distinctive sour, spicy, and umami flavor.

- **Economic and Nutritional Importance:**
  - **Probiotic Rich:** Kimchi is a rich source of diverse probiotic bacteria, contributing to gut microbiome diversity and health.
  - **Nutrient Content:** High in vitamins (especially Vitamin C, A, and some B vitamins), dietary fiber, and minerals (e.g., calcium, iron).
  - **Antioxidants:** Contains various antioxidants from its vegetable and spice ingredients.
  - **Immune Boosting:** The probiotics and nutrients contribute to a stronger immune system.
  - **Culinary Staple:** An essential part of Korean cuisine, served with almost every meal. Its popularity has grown globally as a healthy and flavorful fermented food.
  - **Longevity:** The fermentation process significantly extends the shelf life of the vegetables.

Question 6: (a) Name the microorganism associated with the following (any eight): (1×8=8)(i) Citric acid (ii) Penicillin (iii) Yogurt (iv) Ethanol (v) AIDS (vi) Giardiasis (vii) Enveloped virus (viii) Malaria (ix) CJD (b) Discuss the germ theory of the disease. (4) (c) Who gave the three domain classification system? Write its basis and significance. (6)

(a) Name the microorganism associated with the following (any eight):

- (i) Citric acid: *Aspergillus niger*

- (ii) Penicillin: *Penicillium chrysogenum* (formerly *Penicillium notatum*)
- (iii) Yogurt: *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*
- (iv) Ethanol: *Saccharomyces cerevisiae* (Brewer's yeast/Baker's yeast)
- (v) AIDS: Human Immunodeficiency Virus (HIV)
- (vi) Giardiasis: *Giardia lamblia* (also known as *Giardia intestinalis* or *Giardia duodenalis*)
- (vii) Enveloped virus: Influenza virus (or HIV, Herpes Simplex Virus, Rabies virus, etc.)

- (viii) Malaria: *Plasmodium* species (e.g., *Plasmodium falciparum*, *Plasmodium vivax*)
- (ix) CJD: Prions (specifically the misfolded prion protein, PrPSc)

(b) Discuss the germ theory of the disease.

- **The Germ Theory of Disease:**
    - The germ theory of disease is a fundamental concept in microbiology and medicine that states that many diseases are caused by microorganisms (or "germs") rather than by curses, bad air (miasma), or spontaneous generation.
    - It proposes that specific infectious diseases are caused by specific types of microorganisms that can be transmitted from one host to another.

- **Historical Development and Key Contributors:**
  - **Early Ideas:** While observations hinting at the existence of unseen agents of disease existed for centuries, the theory gained significant traction in the 19th century.
  - **Agostino Bassi (1835):** Demonstrated that a silkworm disease was caused by a fungus, showing for the first time that a microorganism could cause a specific animal disease.
  - **Ignaz Semmelweis (1847):** Showed that handwashing by doctors could significantly reduce the incidence of puerperal fever (childbed fever) in maternity wards, implying an invisible transferable agent.
  - **Louis Pasteur (1860s):**
    - Crucially disproved the theory of spontaneous generation through his famous swan-neck flask experiments, showing that life arises only from pre-existing life (biogenesis).
    - His work on fermentation showed that specific microorganisms caused specific chemical changes, leading him to propose that similar processes might cause diseases.
    - Developed vaccines for anthrax and rabies, further solidifying the link between microbes and disease.
  - **Robert Koch (1870s-1880s):**

- Provided definitive proof for the germ theory by establishing a rigorous set of experimental criteria, known as Koch's Postulates.
- Used these postulates to demonstrate that *Bacillus anthracis* causes anthrax and *Mycobacterium tuberculosis* causes tuberculosis.
- Developed techniques for culturing bacteria and staining them for microscopic observation.

- **Koch's Postulates (Criteria for establishing a causal relationship between a microorganism and a disease):**
    a. The microorganism must be found in abundance in all organisms suffering from the disease but should not be found in healthy organisms.
    b. The microorganism must be isolated from a diseased organism and grown in pure culture.
    c. The cultured microorganism should cause disease when introduced into a healthy organism.
    d. The microorganism must be re-isolated from the inoculated, diseased experimental host and identified as being identical to the original causative agent.
- **Significance:**
    - **Revolutionized Medicine:** The germ theory completely transformed medical understanding and practices, shifting

focus from mystical or environmental causes to identifiable biological agents.

- **Foundation of Modern Medicine:** It is the cornerstone of infectious disease research, diagnosis, treatment, and prevention.
- **Aseptic Techniques:** Led to the development and widespread adoption of antiseptic and aseptic surgical techniques (Joseph Lister).
- **Public Health:** Paved the way for public health measures such as sanitation, clean water supplies, and vaccination programs, dramatically reducing the incidence of infectious diseases.
- **Drug Development:** Enabled the development of antimicrobial drugs (antibiotics, antivirals) specifically targeting pathogenic microorganisms.
- **Microbiology as a Science:** Solidified microbiology as a distinct scientific discipline.

(c) Who gave the three domain classification system? Write its basis and significance.

- **Who gave the three domain classification system?**
  - The three domain classification system was proposed by **Carl Woese** and his colleagues in **1977**.
- **Basis of the Three Domain Classification System:**

- Woese's system is primarily based on **molecular phylogeny**, specifically the comparative analysis of **16S ribosomal RNA (rRNA) gene sequences**.
- **Why 16S rRNA?**
    - It is universally present in all prokaryotic cells (and 18S rRNA in eukaryotes), making it suitable for comparing distantly related organisms.
    - It has highly conserved regions (indicating fundamental evolutionary relationships) and variable regions (allowing for differentiation between species).
    - Its function (protein synthesis) is essential and relatively stable, meaning its sequence changes slowly over evolutionary time, making it an excellent "molecular clock."
- **Discovery of Archaea:** Through his 16S rRNA sequencing, Woese discovered that the prokaryotes, previously considered a single kingdom (Monera), were actually composed of two distinct groups that were as different from each other as they were from eukaryotes. He named one group **Archaebacteria** (later shortened to **Archaea**) and the other **Eubacteria** (now simply **Bacteria**).

- **Three Domains:** The system divides all cellular life into three fundamental domains:

    a. **Bacteria (formerly Eubacteria):**

- Includes most common prokaryotes.
- Have peptidoglycan in their cell walls.
- Have characteristic membrane lipids (ester-linked fatty acids).
- Ribosomes (70S) and RNA polymerase distinct from Archaea and Eukarya.

b. **Archaea (formerly Archaebacteria):**

- Also prokaryotic, but genetically and biochemically distinct from Bacteria.
- Lack peptidoglycan in their cell walls (have pseudopeptidoglycan or S-layers).
- Have unique membrane lipids (ether-linked branched hydrocarbons).
- Ribosomes (70S) and RNA polymerase are more similar to Eukaryotes than to Bacteria.
- Often found in extreme environments (extremophiles – e.g., thermophiles, halophiles, methanogens).

c. **Eukarya (or Eukaryotes):**

- Includes all organisms with eukaryotic cells (cells containing a true nucleus and membrane-bound organelles).
- Includes protists, fungi, plants, and animals.

        - Have 80S ribosomes and RNA polymerase similar to Archaea.

- **Significance of the Three Domain Classification System:**
    - **Revolutionized Understanding of Life:** Fundamentally changed the understanding of evolutionary relationships among all living organisms, revealing a much deeper division within prokaryotes than previously recognized.
    - **Accurate Evolutionary Relationships:** Provides a more accurate phylogenetic tree of life, reflecting evolutionary history more precisely than the five-kingdom system (which placed all prokaryotes together).
    - **Discovery of Archaea:** Led to the recognition of Archaea as a distinct and ancient group of life, bridging the gap between Bacteria and Eukarya, and expanding the known biodiversity of life.
    - **Modern Taxonomy:** Became the widely accepted and foundational system for higher-level classification in biology, replacing the earlier two-kingdom or five-kingdom systems.
    - **Ecological Insights:** Highlighted the vast microbial diversity and their crucial roles in various ecosystems, including extreme environments.
    - **Biotechnological Implications:** The distinct biochemical pathways and enzymes of Archaea (e.g., heat-stable enzymes) have significant biotechnological applications.