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Step-by-step coloured PDF solutions for the 2026-27 NCERT (Latest Edition), Class 12 Biology, Chapter 8

Chapter 8: Microbes in Human Welfare

About this Chapter

Beneficial roles of **microbes** in human welfare: LAB in curd, yeast in bread and beverages, antibiotic-producing moulds, methanogens for **biogas**, biocontrol agents, and N-fixing **biofertilisers**. You will also learn BOD and the two stages of sewage treatment.

Topics covered: Household products • Industrial products (antibiotics, organic acids, enzymes) • Sewage treatment & BOD • Biogas • Biocontrol • Biofertilisers

Quick Formula Sheet

LAB: *Lactobacillus* - milk $\rightarrow$ curd; adds vit. B_{12}.

Yeast: *S. cerevisiae* - dough, beer, wine.

Penicillin: *Penicillium notatum* (fungus).

BOD: O_2 needed to oxidise organic matter in 1 L water; higher $\Rightarrow$ more polluted.

Biogas: *Methanobacterium* $\rightarrow CH_4 + CO_2 + H_2$.

Biofertilisers: *Rhizobium*, *Azotobacter*, *Anabaena/Nostoc*, *Glomus*.

Exercises

Q 8.1 Bacteria cannot be seen with the naked eyes, but these can be seen with the help of a microscope. If you have to carry a sample from your home to your biology laboratory to demonstrate the presence of microbes with the help of a microscope, which sample would you carry and why?

SOLUTION

Concept used. Microbes are micro-organisms (bacteria, fungi, protozoa, viruses) too small to be seen with the unaided eye. They are visible only when present in very large numbers (forming colonies, films, or clumps) or when viewed under a microscope. To demonstrate their presence in a classroom, we pick a household sample where the microbial population is naturally very high and easy to make a smear or wet-mount from.

> ☞ **Where to look for microbes**
> Anything that has *fermented*, *rotted*, or shows visible *growth/colonies* is a hotspot for microbes: curd, idli/dosa batter, bread dough, stagnant pond water, the white scum on cheese, a black mould patch on bread.

Step 1. **Best sample to carry: a small spoonful of fresh curd (dahi) in a clean, capped vial.** A small drop of curd added to fresh milk acts as inoculum (or "starter") because that drop already contains *millions* of lactic acid bacteria (LAB), chiefly *Lactobacillus*. So a teaspoon of home-made curd packs an extremely high microbial load in a tiny volume, which is perfect for microscopy.

Step 2. **Why curd works so well.** The LAB in curd:

- are abundant (densities of 10^8 to 10^9 cells per mL),
- are easy to stain (a drop of curd + a drop of methylene blue on a slide is enough),
- show a clear rod shape (*Lactobacillus*) or chain-of-cocci shape (*Streptococcus*) under $400\times$ to $1000\times$ magnification,
- are non-pathogenic (safe to handle in a school lab).

Step 3. **How to prepare the slide in the lab.**

- Take a tiny drop of curd on a clean glass slide.
- Add 1–2 drops of distilled water and mix with a needle to thin the smear.
- Add a drop of methylene blue stain, wait 1–2 minutes, blot the excess.
- Place a coverslip and view under the high-power objective of a compound microscope.
- You will see clusters of rod-shaped *Lactobacillus* bacteria - direct visual proof that microbes were present in the curd you carried from home.

Step 4. **Other equally good samples**: yeast paste from bread dough or idli/dosa batter (shows budding *Saccharomyces cerevisiae* cells), a slimy bit of pond water, or scrapings from a slice of bread on which mould has just begun to appear.

Final Answer: Carry a small spoonful of curd (or a pinch of idli/dosa batter or bread dough). Curd contains millions of *Lactobacillus* cells per drop, which can be easily stained with methylene blue and seen under a compound microscope as rod-shaped bacteria.

☞ Exam Tip

NCERT, NEET and CBSE board papers love this question because it links *everyday food* with *microbiology technique*. Always name a specific microbe (*Lactobacillus*) and a specific food (curd) - vague answers like "some bacteria from kitchen" lose marks.

EXPERT'S SOLUTION *: Aanya Iyer, M.Sc Microbiology, JNU*

Picture-first. Think of the curd sitting in your fridge as a teeming microbial city. Each *droplet* is a concentrated suspension of bacteria. So the cheapest, safest and most reliable demonstration sample is also the one most students already have at home - curd.
Concept restated. Microbes need either (i) special staining or (ii) very high cell density to be visible under a school-grade light microscope (resolution $\sim$0.2 μm). Curd ticks both boxes: dense population plus easy stainability.

Step 1. Why curd over plain milk. Fresh milk also has microbes but in lower numbers. In curd, LAB have multiplied many-fold while metabolising lactose to lactic acid (the sourness you taste is the signature of this metabolism). So curd is milk that has been "microbially enriched".

Step 2. Identification under the scope. Use $40\times$ objective with methylene blue. *Lactobacillus* appears as small (1–2 μm), straight, blue-stained rods, often in short chains. *Streptococcus thermophilus* (if present) appears as round cells in chains. Both are visible at $400\times$ total magnification.

Step 3. Backup samples for variety.

- *Idli/dosa batter* (urad-dal + rice fermented overnight): shows mixed bacterial population + yeasts producing the CO_2 that makes the batter rise.
- *Bread dough*: shows oval-to-spherical yeast cells of *Saccharomyces cerevisiae*, sometimes with visible budding.
- *Bottom layer of pickle brine*: shows acid-tolerant LAB.

Step 4. Safety note for the practical. All these samples are GRAS (Generally Recognised As Safe) microbes. Avoid carrying samples like stool, raw sewage, or pus from infected sites - these may contain pathogens and are not appropriate for a school lab.

Why this matters. The lesson goes beyond the question: microbes are *everywhere*, even in the food you call "pure". Sterility, in everyday cooking, is a myth - and a useful myth to break for any future biology student.

> **Final Answer:** A drop of curd is the ideal sample. Mounted with methylene blue and viewed at $400\times$, it reveals millions of *Lactobacillus* rods - irrefutable proof that microbes exist in everyday food.

Q 8.2 **Give examples to prove that microbes release gases during metabolism.**

SOLUTION

Concept used. Many microbes break down (**ferment**) sugars and other organic substrates anaerobically (or facultatively). The metabolic by-products almost always include one or more *gases*. The gas evolved depends on the microbe and the substrate. We can recognise gas release by visible bubbling, by "puffing-up" of dough, by holes in cheese, or by flammable biogas in a closed digester.

☞ **Two common fermentation pathways**

- **Alcoholic fermentation** (yeast on sugars):
$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2\ C_2H_5OH + 2\ CO_2$
- **Methanogenesis** (anaerobic bacteria on organic waste, especially cellulose-rich dung):
Mixed organic matter $\rightarrow CH_4 + CO_2 + H_2 + H_2S$ (biogas).

Step 1. **Example 1 - Puffing of bread dough and idli/dosa batter (CO_2 release).** Bread dough is fermented by baker's yeast, *Saccharomyces cerevisiae*. Yeast respires the sugars in flour anaerobically, producing ethanol and CO_2. The CO_2 bubbles get trapped in the gluten/protein network, making the dough rise.

$$C_6H_{12}O_6 \xrightarrow{\textit{S. cerevisiae}} 2\ C_2H_5OH + 2\ CO_2\,(\uparrow)$$

The same CO_2 release happens in idli and dosa batter, fermented by a mixed flora of bacteria and yeasts.

Step 2. **Example 2 - Holes ("eyes") in Swiss cheese (CO_2 release).** *Propionibacterium shermanii* (called *P. sharmanii* in NCERT) ferments lactate in cheese curd to propionic acid, acetic acid and large volumes of CO_2. Trapped CO_2 bubbles form the characteristic large round "eyes" that Swiss cheese is famous for.

Step 3. **Example 3 - Production of biogas from cattle dung ($CH_4 + CO_2 + H_2$ release).** Methanogenic bacteria like *Methanobacterium* thrive anaerobically on the cellulose in cattle dung. They produce a gas mixture rich in methane (CH_4), with CO_2, H_2 and traces of H_2S. This flammable mixture is **biogas** ("gobar gas"), used for cooking and lighting in rural India.

Step 4. **Example 4 - Brewing of beer, wine, whisky (ethanol + CO_2).** *Saccharomyces cerevisiae* (brewer's yeast) ferments malted cereals or fruit juices. The visible bubbling of fermenting must in a brewery is CO_2 escaping. The same reaction as in step 1.

Step 5. **Example 5 - Anaerobic sludge digester of a sewage plant.** The remaining sludge from secondary treatment is fed to anaerobic digesters, where bacteria release $CH_4 + CO_2 + H_2S$. This is the same biogas, harvested as fuel right at the sewage plant.

> **Final Answer:** Curd + idli/dosa/bread dough rising, holes in Swiss cheese, fermenting beer/wine bubbling, biogas from dung, and gas from sewage digesters - all demonstrate that microbes release gases (CO_2, CH_4, H_2, H_2S) as metabolic by-products.

♥ Why we care about microbial gases

These "waste" gases drive a huge slice of human food and energy industry: the leavening of every loaf of bread, the bubbles in every beer, the fuel that lights rural kitchens, and the texture of every cheese. Without microbial gas release, none of this would exist.

EXPERT'S SOLUTION *: Karan Banerjee, Ph.D Molecular Biology, NCBS Bangalore*

Structural observation. Whenever you see a food or process *puffing, rising, bubbling, fizzing, or hissing*, suspect microbial gas release. Group the examples by the gas they release and remember one "poster microbe" per group.

- Gas = CO_2: yeast (*S. cerevisiae*) in bread/beer/wine; *Propionibacterium shermanii* in Swiss cheese; LAB in idli batter.
- Gas = $CH_4 + CO_2 + H_2$: methanogens (*Methanobacterium*) in biogas plants and rumen of cattle.
- Gas = H_2S: sulphur-reducing bacteria in anaerobic sludge digesters.

Step 1. **Visualising the bread example.** Mix flour, water and yeast; the dough doubles in size in 1–2 h. Cut a section: you will see hundreds of tiny gas pockets. Those pockets are the CO_2 released by *S. cerevisiae* as it converts the flour's sugars to ethanol and CO_2. The same gas, in a brewing vat, is what makes the wort foam.

Step 2. **Visualising the cheese example.** As Swiss cheese ripens, *P. shermanii* feeds on the lactate left in the curd. Each colony locally produces enough CO_2 to inflate a pocket of cheese matrix - that pocket becomes one of the famous Swiss eyes. The size and number of eyes is, literally, a microbial gas signature.

Step 3. **Visualising the biogas example.** A floating-drum biogas plant has a metal dome that physically rises as methanogens release $CH_4 + CO_2$ from the slurry beneath. The fact that the dome rises is direct, mechanical proof of microbial gas release.

Step 4. Quantitative angle (worth bonus marks). 1 mole of glucose (180 g) gives *exactly* 2 moles of CO_2 during alcoholic fermentation. So 180 g glucose $\rightarrow$ $2 \times 22.4\,L = 44.8\,L$ of CO_2 at STP. That is a lot of gas - enough to easily lift a kilogram of dough.

Why this matters. Microbial gas release is not just curious - it is the engine behind leavening, brewing, cheese-making and the entire renewable biogas industry.

> **Final Answer:** Yeast in dough/beer, *Propionibacterium* in Swiss cheese, methanogens in biogas plants and rumen, and bacteria in anaerobic sludge digesters all release CO_2, CH_4, H_2 or H_2S during metabolism.

Q 8.3 In which food would you find lactic acid bacteria? Mention some of their useful applications.

SOLUTION

Concept used. Lactic acid bacteria (LAB) are a group of Gram-positive, rod- or sphere-shaped bacteria that anaerobically ferment lactose (milk sugar) and other carbohydrates to lactic acid. The common genera are *Lactobacillus*, *Streptococcus*, *Lactococcus* and *Leuconostoc*. LAB are non-pathogenic and are widely used in food preservation, nutrition and human health (as **probiotics**).

Step 1. Foods that contain LAB.

- *Curd / yoghurt / dahi* - the classic example. *Lactobacillus* converts milk to curd.
- *Cheese* - many varieties (cheddar, mozzarella, Roquefort) use LAB during ripening.
- *Idli and dosa batter* - fermented by a mixed culture of LAB and wild yeasts.
- *Dhokla, kanji, sauerkraut, kimchi, pickles, yakult* - all rely on LAB fermentation.
- *Fermented butter milk and lassi* - products of LAB.

Step 2. Useful applications of LAB.

- **Conversion of milk to curd.** LAB produce acids that coagulate and partially digest the milk proteins (mainly casein). This curdles the milk and turns it into a thick, tangy semi-solid.

- **Improving nutritional quality.** During curd formation LAB increase the content of *vitamin* B_{12} (cyano-cobalamin). Curd is therefore a better B_{12} source than plain milk - especially valuable for vegetarians.
- **Checking disease-causing microbes in the human gut.** LAB are part of our natural intestinal flora. The lactic acid they secrete lowers gut pH, suppressing pathogenic bacteria. This is the principle behind *probiotic drinks* like Yakult.
- **Food preservation.** Lactic acid acts as a natural preservative - it inhibits the growth of spoilage microbes. This is why curd, pickles, sauerkraut and kimchi keep for weeks without refrigeration.
- **Texture, flavour and aroma of cheese.** LAB metabolism produces small molecules (diacetyl, acetate, propionate) that give cheese its characteristic sharp/tangy flavour.
- **Production of dough for idli, dosa, dhokla.** LAB sourness + CO_2 release together give the puffed, slightly sour traditional Indian breakfast foods.

> **Final Answer:** LAB are found in curd, cheese, idli/dosa batter, dhokla, kanji, lassi, sauerkraut, kimchi and pickles. They convert milk to curd, increase vitamin B_{12} content, suppress harmful gut microbes, preserve food, flavour cheese, and leaven traditional Indian breads.

✗ Common Mistake

A common slip is to confuse LAB with *Saccharomyces cerevisiae*. LAB are *bacteria* (curd, cheese); *S. cerevisiae* is a *yeast* (bread, beer, wine). Both ferment, but they are taxonomically very different.

EXPERT'S SOLUTION : *Pooja Reddy, M.Sc Biotechnology, AIIMS Delhi*

Quick reading. A two-line answer in the exam is: *LAB are found in curd and dairy ferments; they convert milk to curd, enrich it with* B_{12}*, and act as probiotics that check gut pathogens.* Then expand each point if the question is for 5+ marks.

- **Where LAB live.** Anywhere with available lactose or other sugars and a low-oxygen environment - milk, fermenting vegetables, even the human intestine.
- **Three core jobs.** (i) Acidify milk → curd; (ii) make B_{12}; (iii) crowd out pathogens.

Step 1. The biochemistry behind "milk → curd". Milk has ~5% lactose. LAB enzymes break it: lactose → glucose + galactose → pyruvate → **lactic acid**. The lactic acid drops the pH from ~6.7 to ~4.5. At pH 4.5, casein micelles lose their charge and aggregate - the visible thickening you see when milk sets into curd.

Step 2. **Why B_{12} rises in curd.** Some LAB strains synthesise cobalamin from the cobalt and amino-acid precursors in milk. Plant foods rarely contain B_{12}, so curd is one of the most reliable vegetarian sources of this vitamin.

Step 3. **Probiotic effect inside the gut.**

- LAB lower pH (lactic and acetic acid release).
- Pathogens like *Salmonella* and *E. coli* O157:H7 grow poorly at low pH.
- Result: a curd-eating gut has fewer harmful microbes.

Step 4. **Big-picture applications.**

- *Food industry.* Curd, cheese, butter, kefir, yakult.
- *Medicine.* Probiotic capsules to recover gut flora after a course of antibiotics or after diarrhoea.
- *Preservation.* Pickling and sauerkraut.
- *Animal husbandry.* Silage (preserved cattle fodder) fermented by LAB.

Why this matters. LAB are the friendliest microbes you eat every day. They are also the simplest case study for "microbe-as-helper" - perfect to anchor your understanding of the chapter.

> **Final Answer:** LAB live in curd, cheese, idli batter, pickles and the human gut. They turn milk to curd, raise B_{12}, preserve food, and act as probiotics that suppress harmful gut bacteria.

Q 8.4 **Name some traditional Indian foods made of wheat, rice and Bengal gram (or their products) which involve use of microbes.**

SOLUTION

Concept used. Indian traditional cuisine uses microbial **fermentation** extensively. Different microbes (mostly LAB and wild yeasts) act on the carbohydrates and proteins of wheat, rice or Bengal gram (chana, besan) flours to produce: a sour-tangy taste from lactic acid, a puffed/spongy texture from CO_2, plus improved digestibility and nutritional value (more B-complex vitamins, lower phytic acid).

Step 1. **Foods from wheat (or wheat flour, maida, suji).**

- *Bread / pav / kulcha* - leavened by baker's yeast *Saccharomyces cerevisiae*; CO_2 release makes the dough rise.
- *Bhatura / naan* - yoghurt + flour fermented overnight by LAB and yeast.
- *Jalebi batter* - fermented overnight, microbes contribute to the sourness and

bubbles.

Step 2. Foods from rice (or rice flour) usually mixed with urad/chana dal.

- *Idli* - rice + urad dal batter, fermented overnight by LAB (∼*Leuconostoc mesenteroides*) and wild yeasts; steam-cooked.
- *Dosa* - same batter, pan-cooked thin.
- *Uttapam, appam* - fermented rice batters.
- *Khaman / dhokla* - uses chickpea/Bengal-gram flour with a rice component; LAB fermentation gives the spongy, mildly sour cake.

Step 3. Foods from Bengal gram (chana, besan).

- *Dhokla* - besan (Bengal-gram flour) + semolina batter fermented by LAB; steamed.
- *Khandvi* - besan-based rolled snack; fermentation by LAB during batter preparation gives the slight tang.

Step 4. Microbes involved (summary).

- *Saccharomyces cerevisiae* - baker's yeast, leavens bread/naan/bhatura/jalebi.
- *Lactobacillus, Streptococcus, Leuconostoc mesenteroides* - LAB that sour and aerate idli/dosa/dhokla batter.
- Wild yeasts and lactobacilli together provide both gas (CO_2) and sourness (lactic acid).

Final Answer: Wheat: bread, bhatura, naan, kulcha (yeast + LAB). Rice: idli, dosa, uttapam, appam (LAB + wild yeast on rice-dal batter). Bengal gram: dhokla and khandvi (LAB on besan/rice batter).

☞ Exam Tip

In the exam, always name the microbe alongside the food. "Idli is fermented" is half marks; "idli is made from rice and urad-dal batter fermented by *Leuconostoc mesenteroides* and *Saccharomyces cerevisiae*" is full marks.

EXPERT'S SOLUTION : *Aditya Kumar, Ph.D Molecular Biology, NCBS Bangalore*

Strategic angle. Group the foods by main grain. Then attach a single "signature microbe" to each group. Easier to memorise, easier to write in a 3-mark question.

Step 1. Wheat group (signature microbe = *Saccharomyces cerevisiae*).

- Bread, pav, naan, kulcha, bhatura.
- Mechanism: yeast respires the small amount of free sugar in flour, producing

CO_2 which makes the dough rise.
- Side bonus: a tiny amount of ethanol forms; it cooks off when the bread is baked.

Step 2. **Rice group (signature microbe = *Leuconostoc mesenteroides* + *S. cerevisiae*).**
- Idli, dosa, uttapam, appam, neer dosa.
- Mechanism: LAB produce lactic acid (the slight sour taste); yeasts produce CO_2 (the spongy holes in idli).
- Side bonus: fermentation reduces **phytic acid** (an anti-nutrient in dals), improving iron and zinc absorption.

Step 3. **Bengal-gram / besan group (signature microbe = LAB).**
- Dhokla, khandvi.
- Mechanism: LAB on the besan batter give the characteristic sour taste; soda ($NaHCO_3$) added at the end gives the final lift.

Step 4. **Bonus example beyond the question.**
- *Toddy* - fermented sap of certain palms; not based on wheat/rice/gram, but worth knowing.
- *Cheese* - bacterial and fungal fermentation of milk; LAB plus moulds.

Why this matters. Traditional Indian cuisine is one of the world's richest collections of natural microbial bioreactors. Each "puffed" or "sour" Indian food is a tiny biology experiment running on your kitchen counter overnight.

> **Final Answer:** Wheat: bread, naan, bhatura (yeast). Rice: idli, dosa (LAB + yeast). Bengal gram: dhokla, khandvi (LAB on besan).

Q 8.5 **In which way have microbes played a major role in controlling diseases caused by harmful bacteria?**

SOLUTION

Concept used. **Antibiotics** are chemical substances produced by some microbes (mostly fungi, actinomycetes and bacteria) that can kill or retard the growth of other microbes - especially the disease-causing ones. The word *anti-biotic* literally means "against life" (with respect to harmful microbes) and *pro-life* (with respect to humans).

☞ **Penicillin: the chance discovery**

In 1928, Alexander Fleming noticed that around a contaminating mould (*Penicillium notatum*) on his *Staphylococcus* culture plate, bacteria were not growing. He isolated the antibacterial substance and called it **penicillin**. Ernest Chain and Howard Florey later established its full potential. The trio won the 1945 Nobel Prize in Medicine.

Step 1. **Microbes are the natural source of nearly every antibiotic in clinical use.** Examples:

- *Penicillin* - from the fungus *Penicillium notatum* (and later *P. chrysogenum*).
- *Streptomycin* - from the bacterium *Streptomyces griseus*.
- *Tetracycline* - from *Streptomyces aureofaciens*.
- *Chloramphenicol* - from *Streptomyces venezuelae*.
- *Erythromycin* - from *Streptomyces erythraeus*.

Step 2. **How antibiotics kill or stop bacteria.** They target structures or processes *specific to bacteria* (and absent in human cells), e.g.:

- Penicillin breaks down the *peptidoglycan cell wall* of bacteria.
- Streptomycin and tetracycline jam the *70S bacterial ribosome*, stopping protein synthesis.
- Result: bacteria die or stop dividing; human cells are unaffected.

Step 3. **Diseases brought under control by microbial antibiotics.**

- Plague (caused by *Yersinia pestis*).
- Whooping cough or kali khansi (*Bordetella pertussis*).
- Diphtheria or gal ghotu (*Corynebacterium diphtheriae*).
- Leprosy or kusht rog (*Mycobacterium leprae*).
- Pneumonia, tuberculosis, typhoid, cholera and many more.

Step 4. **World War II turning point.** Penicillin was used on a large scale to treat wounded American soldiers in World War II. It saved millions of lives that would otherwise have been lost to bacterial wound infections.

Step 5. **Net impact.** Before antibiotics, infectious diseases were a leading cause of death worldwide. Today, with microbial antibiotics, most bacterial infections are easily treatable. We literally cannot imagine modern medicine without antibiotics - and we owe each of them to a microbe.

> **Final Answer:** Microbes produce *antibiotics* - natural chemicals like penicillin, streptomycin, tetracycline, chloramphenicol and erythromycin. These kill or stop disease-causing bacteria, bringing under control deadly illnesses such as plague, diphtheria, whooping cough, leprosy, pneumonia and tuberculosis.

♥ Why this matters

A single discovery - penicillin from a contaminating mould - changed the trajectory of human life expectancy more than any other 20th-century invention. Microbes did not just *cause* disease; they also gave us the tools to cure most of it.

EXPERT'S SOLUTION *: Vivaan Sharma, M.Sc Microbiology, JNU*

Strategic angle. The question is short, but a top-scoring answer must include three things: (i) a definition of antibiotic, (ii) at least 3–4 named antibiotic–microbe pairs, and (iii) named diseases controlled.

Step 1. Define cleanly. Antibiotics are antimicrobial chemicals produced by some microbes that kill or inhibit the growth of other (disease-causing) microbes.

Step 2. Name antibiotic–source pairs.

- Penicillin ← *Penicillium notatum*.
- Streptomycin ← *Streptomyces griseus*.
- Tetracycline ← *Streptomyces aureofaciens*.
- Chloramphenicol ← *Streptomyces venezuelae*.
- Erythromycin ← *Streptomyces erythraeus*.

Step 3. Name diseases controlled. Plague, leprosy, whooping cough, diphtheria, pneumonia, TB, typhoid, cholera, meningitis.

Step 4. Mention selective toxicity. Antibiotics target bacterial-specific features (peptidoglycan wall, 70S ribosome). Human cells lack these, so we are unharmed - that is what makes antibiotics safe medicine.

Step 5. Historical anchor. Fleming (1928) → Florey & Chain (1940s) → WW2 mass production → Nobel 1945.

Step 6. Three big classes of bacteria-targeting antibiotics.

- *Cell-wall inhibitors* (penicillin, cephalosporin) - block peptidoglycan cross-linking; bacteria burst by osmotic lysis.
- *Protein-synthesis inhibitors* (streptomycin, tetracycline, chloramphenicol, erythromycin) - bind the bacterial 70S ribosome and stop translation; bacteria stop dividing.

- *Nucleic-acid inhibitors* (rifampicin, fluoroquinolones) - block bacterial RNA/DNA synthesis.

Step 7. **Why microbes make antibiotics in the first place.** In soil, fungi and actinomycetes use these molecules as natural chemical weapons against neighbouring bacteria competing for the same scarce nutrients. We humans simply harvested this microbial arms race for clinical use.

Step 8. **Cure-versus-prevention.** Antibiotics *cure* an already-established bacterial infection. They do not work on viruses (colds, flu, COVID), so doctors do not prescribe them for viral illnesses - a common patient confusion.

Why this matters. Today, antibiotic *resistance* is a growing crisis because we are overusing these microbe-derived drugs. The same microbes that gave us cures may yet take them away if we are not careful. Always finish your full antibiotic course; never self-medicate.

> **Final Answer:** Microbes synthesise antibiotics (penicillin, streptomycin, tetracycline, chloramphenicol, erythromycin) that selectively kill bacterial pathogens, bringing plague, diphtheria, whooping cough, leprosy, pneumonia and many other infections under control.

Q 8.6 Name any two species of fungus, which are used in the production of the antibiotics.

SOLUTION

Concept used. An **antibiotic** is a microbial product that kills or inhibits other microbes. Fungi were the very first organisms found to make antibiotics, and they remain a major source of broad-spectrum antibiotics today. The most famous antibiotic-producing fungi belong to the genus *Penicillium*.

Step 1. **Species 1: *Penicillium notatum*.** This is the original mould that Alexander Fleming observed on his contaminated *Staphylococcus* plate in 1928. It produces **penicillin**, the first commercially-used antibiotic and the prototype of all β-lactam antibiotics. Penicillin destroys the peptidoglycan cell wall of Gram-positive bacteria.

Step 2. **Species 2: *Penicillium chrysogenum*.** A higher-yielding cousin of *P. notatum*; it produces penicillin in much larger amounts and is the strain most modern commercial penicillin fermentations actually use. Industrial strain improvement (mutagenesis + selection) on *P. chrysogenum* has raised penicillin titres from a few mg/L to several g/L.

Step 3. Other antibiotic-producing fungi (for extra marks).

- *Cephalosporium acremonium* - produces **cephalosporin** (closely related to penicillin).
- *Trichoderma polysporum* - produces *cyclosporin A* (immunosuppressant, not strictly an antibiotic but bioactive).
- *Aspergillus fumigatus* - produces fumagillin (antiamoebic).

> **Final Answer:** Two fungi that produce antibiotics: *Penicillium notatum* and *Penicillium chrysogenum* - both sources of *penicillin*. (*Cephalosporium acremonium*, producing cephalosporin, is another good example.)

✗ Common Mistake

Do not name *Streptomyces* here. *Streptomyces* is an *actinomycete* (a filamentous **bacterium**), not a fungus, even though it looks fungus-like. Streptomycin, tetracycline, chloramphenicol come from *Streptomyces*, but the question explicitly asks for *fungi*.

EXPERT'S SOLUTION : *Sneha Mehta, Ph.D Organic Chemistry, IISc Bangalore*

Strategic angle. The cleanest answer is two species from the genus *Penicillium*: *P. notatum* and *P. chrysogenum*. Both make penicillin and both are unambiguously fungi.

Step 1. ***Penicillium notatum* - the historic one.** Fleming's original strain; the one in every textbook history of antibiotics.

Step 2. ***Penicillium chrysogenum* - the industrial one.** Found by Mary Hunt on a mouldy cantaloupe in 1943 (the famous "mouldy melon" story); it produces $\sim 200\times$ more penicillin than *P. notatum*, which is why modern penicillin factories use it.

Step 3. **Optional third example.** *Cephalosporium acremonium* (now renamed *Acremonium chrysogenum*) makes the cephalosporins - a whole family of β-lactam antibiotics important for treating Gram-negative infections.

Step 4. **Distinguishing fungi from bacteria-derived antibiotics.**

- Fungi $\rightarrow$ penicillin, cephalosporin, griseofulvin.
- Bacteria (actinomycetes) $\rightarrow$ streptomycin, tetracycline, chloramphenicol, erythromycin.

Why this matters. The *Penicillium* story is the gold-standard example of accidental scientific discovery. A contaminating mould led directly to the modern antibiotic era - a useful reminder that careful observation often beats grand experiments.

Final Answer: *Penicillium notatum* and *Penicillium chrysogenum* - both produce *penicillin* and both are fungi.

Q 8.7 **What is sewage? In which way can sewage be harmful to us?**

SOLUTION

Concept used. Sewage is the term for the municipal waste water generated by households and other establishments in towns and cities. It consists mainly of human and animal excreta, used kitchen water, soap, detergents, paper, rags and food remains. Crucially, it is rich in two things: *organic matter* and *microbes* - many of which are **pathogenic** (disease-causing).

Figure 8.7 An aerial view of a sewage plant

Fig 8.7 – Aerial view of a typical sewage treatment plant (NCERT Class 12 Biology, Chapter 8).

Step 1. **What is sewage? (the textbook definition).**

- Sewage = municipal waste water from cities and towns.
- A major component is *human excreta* (urine + faeces).
- Other components: detergents, soaps, food scraps, kitchen oil, hair, paper, used water from baths and toilets, and (often) industrial effluents and storm-water runoff that join the sewer line.
- Two main constituents matter biologically: *large amounts of organic matter* and *large numbers of microbes*.

Step 2. **Why sewage is dangerous if released untreated.**

- Many of the microbes in sewage are pathogens. They cause water-borne diseases like *cholera*, *typhoid*, *dysentery*, *hepatitis A* and *E*, *polio*, *diarrhoea*, *gastroenteritis* and parasitic infections like amoebiasis, ascariasis and giardiasis.

- Drinking water contaminated with sewage is the main route by which these diseases spread, often in explosive outbreaks (especially after floods).
- Sewage also contains parasitic worm eggs (round-worm, hook-worm), which can survive long periods in water and soil.

Step 3. Environmental harm.

- Untreated sewage discharged into rivers and lakes raises the BOD of the water (see Q11). Aerobic bacteria consume the dissolved oxygen, leading to *fish kills*.
- Excess nitrogen and phosphate in sewage cause **eutrophication** - explosive algal blooms followed by anoxic conditions that destroy aquatic life.
- Toxic chemicals (heavy metals, pesticides, drug residues) in untreated sewage accumulate up the food chain.

Step 4. Public-health corollary. This is precisely why every city must run sewage treatment plants (STPs). The Ganga Action Plan and Yamuna Action Plan of the Indian Ministry of Environment and Forests were launched to add STP capacity for these heavily-polluted rivers.

> **Final Answer:** Sewage is the municipal waste water of cities (mostly human excreta + organic matter + microbes). It is harmful because the pathogenic microbes in it cause water-borne diseases like cholera, typhoid, dysentery, hepatitis and polio, while its organic and nutrient load pollutes rivers, depletes dissolved oxygen, and kills aquatic life.

☞ Exam Tip

A 3-mark answer must mention BOTH the public-health danger (water-borne diseases like cholera, typhoid, hepatitis) AND the environmental impact (rise in BOD, fish kills, eutrophication). Vague answers like "sewage is dirty" lose marks.

EXPERT'S SOLUTION *: Dev Joshi, M.Sc Biotechnology, AIIMS Delhi*

Quick reading. A perfect 4-marker answer here is split 50:50 - define sewage in 2 lines, then list 4–5 specific harms (diseases + ecology).

Step 1. Define. "Sewage is the liquid waste of cities, mainly human excreta along with kitchen and toilet water, very rich in organic matter and pathogenic microbes." Add: a major fraction is human excreta.

Step 2. Harm 1 - pathogenic load. Sewage carries the bacteria, viruses and protozoa responsible for cholera (*Vibrio cholerae*), typhoid (*Salmonella typhi*), bacillary dysentery (*Shigella*), viral hepatitis A/E, polio, amoebiasis (*Entamoeba* *histolytica*) and giardiasis (*Giardia lamblia*).

Step 3. **Harm 2 - contamination of drinking water.** If sewage seeps into wells, hand-pumps or supply pipes (a common failure in low-income settlements), it triggers diarrhoeal epidemics. Cholera outbreaks in Indian history were almost always linked to mixing of sewage with drinking water.

Step 4. **Harm 3 - eutrophication of receiving waters.** Sewage is rich in nitrogen and phosphorus. Discharge into a river feeds algal blooms; the algae die and decompose, consuming all the dissolved oxygen, suffocating fish - a process called **eutrophication**.

Step 5. **Harm 4 - rise in BOD.** Microbes in untreated sewage consume large amounts of dissolved O_2 from the receiving water body. High BOD $\Rightarrow$ less O_2 left for aquatic animals $\Rightarrow$ aquatic ecosystem collapses.

Step 6. **Harm 5 - odour, aesthetics and tourism.** Open sewage drains release H_2S and ammonia. Beyond stench, this also damages river-front tourism and property values.

Why this matters. The single biggest gain in average life expectancy in the last 150 years came not from any drug but from *sewage treatment* + *piped drinking water*. Public sanitation, in other words, has saved more lives than every antibiotic combined.

> **Final Answer:** Sewage is municipal waste water dominated by human excreta and organic matter, packed with pathogens. It causes water-borne disease epidemics (cholera, typhoid, hepatitis), depletes dissolved oxygen (high BOD), and triggers eutrophication of rivers and lakes.

Q 8.8 What is the key difference between primary and secondary sewage treatment?

SOLUTION

Concept used. Sewage treatment occurs in two main stages. The first stage is **primary treatment** - purely a physical process (filtration, sedimentation) that removes solid particles. The second stage is **secondary treatment** - a *biological* process in which aerobic microbes consume the dissolved organic matter, sharply reducing the **BOD** of the effluent.

Figure 8.6 Secondary treatment

Fig 8.6 – Secondary (biological) treatment: aeration tanks where aerobic microbes form flocs and consume the organic matter. NCERT Class 12 Biology, Chapter 8.

Step 1. Primary treatment - physical removal of solids.

- Floating debris (plastic, rags, leaves) is removed by sequential filtration through screens.
- Grit (soil, small pebbles, sand) is removed by sedimentation in grit chambers.
- In the primary settling tank, all heavier solids that settle by gravity form the *primary sludge*.
- The supernatant liquid is called the primary *effluent*, which is then sent for secondary treatment.
- *No microbial action is involved here; it is purely physical.*

Step 2. Secondary (biological) treatment - microbial breakdown of dissolved organic matter.

- Primary effluent is fed into large aeration tanks.
- Tanks are constantly agitated mechanically; air is pumped in.
- Aerobic microbes grow vigorously and form **flocs** - masses of bacteria associated with fungal filaments forming mesh-like structures.
- These flocs consume most of the dissolved organic matter in the effluent.
- This sharply *reduces the BOD* of the water.
- The treated water is then passed to a settling tank; the bacterial flocs sediment as **activated sludge**.
- Part of the activated sludge is recycled as inoculum to the aeration tank; the rest is sent to anaerobic sludge digesters where biogas is produced.

Step 3. Tabulated comparison.

Feature	**Primary treatment**	**Secondary treatment**
Nature of process	Physical (filtration, sedimentation)	Biological (microbial degradation)
Role of microbes	None	Central: aerobic microbes form flocs and consume organic matter
What is removed	Large/heavy solids (debris, grit, sludge)	Dissolved and fine suspended organic matter
Effect on BOD	Small reduction	*Large* reduction in BOD
Output	Primary effluent and primary sludge	Treated effluent (low BOD), activated sludge
Typical equipment	Screens, grit chambers, settling tanks	Aeration tanks, settling tanks, digesters

Step 4. One-line key difference. Primary treatment is *physical* (removes solids, no microbes involved). Secondary treatment is *biological* (uses aerobic microbes in flocs to consume the organic matter and drastically reduce the BOD).

> **Final Answer:** Primary treatment is a *physical* process (filtration + sedimentation) that removes large/small solids. Secondary treatment is a *biological* process where aerobic microbes form flocs in aeration tanks and consume the dissolved organic matter, sharply reducing the BOD of the effluent.

☞ Exam Tip

Always mention BOD reduction explicitly in the secondary-treatment part. The single sentence "Primary is physical, secondary is biological, secondary drastically reduces BOD" captures the full mark even in a 1-mark question.

EXPERT'S SOLUTION : *Priya Verma, Ph.D Molecular Biology, NCBS Bangalore*

Structural observation. Read the answer as a comparison table in your head: *primary = physical = solids out*; *secondary = biological = organic matter out*.

Step 1. Primary step in detail.

- Coarse bar screens trap rags, plastic, large debris.
- Grit chambers settle out sand and pebbles.
- Primary settling tanks allow heavier suspended solids to sink as primary sludge.
- Result: a clarified liquid called primary effluent moves forward.

Step 2. Secondary step in detail.

- Aeration tank: air pumped in, water stirred. Aerobic bacteria like *Zoogloea* *ramigera* form *flocs* (slimy clumps with embedded fungal filaments).

- These flocs digest the dissolved organic matter (sugars, proteins, fats) leftover in the primary effluent.
- BOD drops typically from ∼300–500 mg/L (raw sewage) to ∼10–30 mg/L (after secondary).
- Final settling tank: flocs settle as activated sludge.
- Some sludge is recycled to seed the aeration tank; the rest goes to anaerobic digesters that release biogas.

Step 3. **Why the two-step design.**

- Removing solids first (primary) prevents the aeration tank from getting clogged with sand and rags.
- Doing biology second (secondary) makes the microbes' job tractable - they only have to deal with dissolved/fine organic matter, not chunks.

Step 4. **Optional tertiary stage.** Modern plants also have a tertiary treatment that removes residual nutrients (N, P), disinfects with chlorine or UV, and yields water clean enough for reuse.

Step 5. **Role of the anaerobic sludge digester.** The excess activated sludge (after recycling part of it) is pumped into large anaerobic digesters. Here, methanogens like *Methanobacterium* degrade the leftover organic matter without oxygen, releasing biogas (methane, CO_2, H_2S). So a well-designed STP not only cleans water but also generates its own fuel.

Step 6. **Two-line summary you can write in any exam.** "Primary treatment is physical (screens, grit chambers, primary settling tank) and removes solid particles. Secondary treatment is biological (aerobic flocs in aeration tanks), reduces BOD by 90+%, and produces activated sludge."

Why this matters. Primary versus secondary is not just a definition - it is the design logic of every sewage plant on earth. "Solids first, microbes second" is the single most important sentence in modern sanitation engineering.

> **Final Answer:** Primary = physical removal of solids (filtration + sedimentation, no microbes). Secondary = biological treatment by aerobic microbes in aeration tanks, drastically lowering the BOD.

Q 8.9 **Do you think microbes can also be used as source of energy? If yes, how?**

SOLUTION

Concept used. Yes. Certain anaerobic microbes called **methanogens** grow on cellulose-rich organic matter and release a mixture of gases - chiefly methane (CH_4), with CO_2, H_2 and traces of H_2S. This combustible mixture is called **biogas**. It is harvested in a *biogas plant*, also called a gobar-gas plant, and used as a clean fuel for cooking, lighting, and even running small engines.

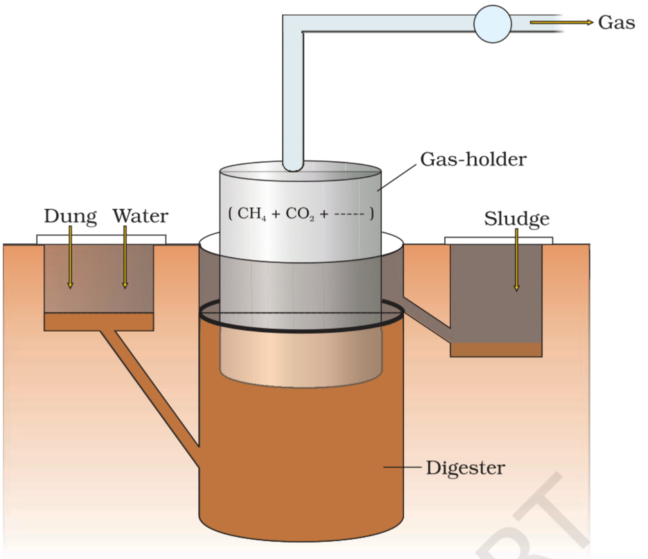

Figure 8.8 A typical biogas plant

Fig 8.8 – A typical biogas (gobar-gas) plant. Dung is mixed with water and fed into the digester; methanogens release $CH_4 + CO_2 + \ldots$ *that collects under the gas-holder dome. The spent slurry is removed as fertiliser. NCERT Class 12 Biology, Chapter 8.*

Step 1. **Yes - microbes are a major source of renewable energy.** The most important example is biogas, produced by methanogens from organic waste.

Step 2. **Microbe responsible.** **Methanogens** are obligate anaerobic bacteria (e.g. *Methanobacterium*, *Methanococcus*, *Methanosarcina*). They live in three main environments:

- the rumen (stomach) of cattle, where they help digest cellulose;
- anaerobic sludge of sewage treatment plants;
- anaerobic chambers of biogas plants (the topic of this question).

Because cattle dung is naturally rich in these bacteria, the dung is the perfect starter for a biogas plant - hence the name “gobar gas”.

Step 3. **Composition of biogas.** Biogas is roughly:

- 50–70% methane (CH_4), the main fuel,
- 25–45% carbon dioxide (CO_2),
- small amounts of H_2, H_2S, N_2.

Step 4. **Construction of a biogas plant** (see Fig 8.8 above).

- A concrete tank, 10–15 feet deep, called the *digester*, is built underground.
- A slurry of cattle dung + water is fed in through the dung inlet.
- A floating metal cover (the *gas-holder*) sits over the slurry. As gas is produced, the dome rises.
- An outlet pipe carries the biogas to nearby houses for cooking and lighting.
- The spent slurry (rich in nitrogen and phosphorus) is pumped out through another outlet and used as fertiliser on fields.

Step 5. The reactions. Under strictly anaerobic conditions:

- Cellulose and other organic matter → organic acids + alcohols (by fermentative bacteria).
- Organic acids/alcohols → acetate + H_2 + CO_2 (by acetogenic bacteria).
- Acetate + H_2 + CO_2 → CH_4 + CO_2 (by methanogens). For example:

$$CO_2 + 4\ H_2 \longrightarrow CH_4 + 2\ H_2O$$

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

Step 6. Other microbial energy routes.

- *Bioethanol* - *Saccharomyces cerevisiae* ferments sugar/cellulose to ethanol used as transport fuel.
- *Hydrogen production* - certain bacteria (e.g. *Clostridium butyricum*) and cyanobacteria evolve H_2 during photosynthesis or anaerobic fermentation.
- *Microbial fuel cells* - bacteria oxidise organic waste at an electrode, generating an electric current directly.

Step 7. Indian context. Biogas technology was developed largely in India by *Indian Agricultural Research Institute (IARI)* and *Khadi and Village Industries Commission (KVIC)*. Biogas plants are most useful in rural India, where cattle dung is plentiful, and they double up as fertiliser sources.

> **Final Answer:** Yes. Methanogenic bacteria like *Methanobacterium* digest cellulose-rich organic matter (cattle dung, plant waste, sewage sludge) anaerobically and release biogas - a mixture of CH_4, CO_2, H_2 - that is used as a clean fuel for cooking, lighting and small engines. Bioethanol, biohydrogen and microbial fuel cells are other microbial energy routes.

♥ Energy + waste management in one device

A biogas plant solves two problems at once: it handles cattle dung (otherwise a waste) and yields cooking fuel + fertiliser. Few technologies are this cleanly circular. India alone has built millions of household biogas plants - every one of them powered by microbial methanogens.

EXPERT'S SOLUTION *: Rohit Pillai, Ph.D Physics, IISc Bangalore*

Strategic angle. Convert the answer into a 4-line skeleton: (i) Yes; (ii) Microbe = methanogen; (iii) Substrate = cellulose-rich organic waste; (iv) Product = biogas (∼70% methane) used as fuel.

Step 1. **Energy carrier.** The relevant chemical species is CH_4. Burning CH_4 releases ∼890 kJ/mol:

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O, \quad \Delta H \approx -890\,\text{kJ/mol}.$$

That is comparable to natural gas, because biogas *is* natural gas (made by microbes instead of geologically).

Step 2. **The chain of microbial communities.**

- Stage A: hydrolytic bacteria break cellulose and proteins into sugars and amino acids.
- Stage B: acidogenic and acetogenic bacteria convert these to acetate, H_2 and CO_2.
- Stage C: methanogens (*Methanobacterium*, *Methanococcus*) convert acetate and H_2/CO_2 to $CH_4 + CO_2$.
- The whole chain is anaerobic, so the digester must be sealed from air.

Step 3. **Engineering the floating-drum plant.**

- Inlet - dung-water slurry enters.
- Digester - methanogens at work below.
- Gas-holder - a floating dome that rises with gas pressure.
- Outlet - slurry (biogas spent slurry, BSS) leaves as nitrogen-rich biofertiliser.

Step 4. **Beyond biogas - three more microbial energy options.**

- *Bioethanol*: yeast on sugarcane/corn starch.
- *Biohydrogen*: cyanobacteria and *Clostridium* producing H_2.
- *Microbial fuel cells (MFCs)*: electrogenic bacteria like *Geobacter* directly produce electricity from organic waste.

Step 5. **What "anaerobic" really means here.** The digester is sealed so air cannot enter. Methanogens are *obligate anaerobes* - oxygen actually kills them. The slurry is kept moist and warm (30–40°C); under these conditions the microbial chain runs steadily for weeks, releasing a near-constant stream of CH_4.

Step 6. **Spent slurry is not waste.** After the methanogens have done their job, the leftover slurry pumped out from the digester is still rich in nitrogen, phosphorus and potassium. Farmers use it directly as a biofertiliser. So one biogas plant delivers *three* outputs: cooking fuel, lighting fuel, and N–P–K fertiliser.

Step 7. Comparison with fossil natural gas. Both are mostly methane and burn with the same energy ($\sim$890 kJ/mol). The difference: fossil gas locks away ancient carbon, biogas only recycles *current* atmospheric CO_2 - so biogas is carbon-neutral over short cycles.

Why this matters. Microbial energy is renewable, carbon-neutral over short cycles, and works on village scale. In a country with 300 million cattle and a strong rural population, biogas is not optional - it is essential.

> **Final Answer:** Yes. Methanogens like *Methanobacterium* anaerobically digest dung/plant waste to give biogas (mostly CH_4), used as cooking and lighting fuel. Bioethanol, H_2 production and microbial fuel cells are further routes.

Q 8.10 Microbes can be used to decrease the use of chemical fertilisers and pesticides. Explain how this can be accomplished.

SOLUTION

Concept used. Microbes can replace chemical inputs in two distinct ways:

- as **biofertilisers** - organisms that enrich the soil with nitrogen, phosphorus or organic matter (substitute for chemical fertilisers like urea, DAP);
- as **biocontrol agents** - organisms that kill or suppress pests, weeds or plant pathogens (substitute for chemical pesticides and weedicides).

Step 1. Biofertilisers - substitutes for chemical fertilisers.

- *Symbiotic nitrogen-fixers. Rhizobium* bacteria live in root nodules of leguminous plants (peas, beans, gram). They fix atmospheric N_2 into ammonia/amino-form nitrogen, which the plant uses as nutrient. The plant in return supplies sugars to the bacteria - a mutualism.
- *Free-living nitrogen-fixers in soil. Azotobacter* and *Azospirillum* live freely in soil and fix atmospheric N_2, enriching soil nitrogen content.
- *Cyanobacteria (blue-green algae). Anabaena, Nostoc, Oscillatoria* fix atmospheric nitrogen and also add organic matter. Especially important in paddy fields, where they serve as natural biofertilisers.
- *Mycorrhiza - fungal symbionts.* Many fungi of the genus *Glomus* form symbiotic associations with plant roots (called *mycorrhiza*). The fungus absorbs phosphorus from soil and passes it to the plant. The plant gains:

- better phosphorus uptake,
- resistance to root-borne pathogens,
- tolerance to salinity and drought,
- overall increase in growth.

Step 2. Biocontrol agents - substitutes for chemical pesticides.

- *Bacillus thuringiensis* (*Bt*) - produces a toxin that kills butterfly caterpillars but is harmless to other insects, mammals and birds. Sold as dried spores in sachets; sprayed on brassicas and fruit trees.
- *Trichoderma* (fungus) - free-living root-zone fungus that is an effective biocontrol against several soil-borne plant pathogens.
- *Baculoviruses* (genus *Nucleopolyhedrovirus*) - viruses that infect only specific insect pests; no harm to plants, mammals, birds, fish or beneficial insects. Ideal for species-specific pest control.
- *Ladybird beetles and dragonflies* - though not microbes, are classic biocontrol agents against aphids and mosquitoes respectively.

Step 3. Combined outcome.

- Less use of urea, superphosphate, DAP $\Rightarrow$ less pollution of soil and groundwater.
- Less use of toxic pesticides (DDT, organophosphates) $\Rightarrow$ less harm to non-target organisms and to humans.
- Soil structure and biodiversity are preserved (a key tenet of **organic farming**).

> **Final Answer:** Microbes act as biofertilisers - *Rhizobium*, *Azotobacter*, *Azospirillum*, cyanobacteria (*Anabaena, Nostoc*) and mycorrhizal fungi (*Glomus*) enrich soil with nitrogen, phosphorus and organic matter - and as biocontrol agents - *Bacillus thuringiensis*, *Trichoderma* and baculoviruses kill pests and plant pathogens - thereby cutting our dependence on chemical fertilisers and pesticides.

☞ Exam Tip

Always split your answer into TWO clear halves: *biofertilisers* (replace urea/DAP, fix N or mobilise P) and *biocontrol agents* (replace pesticides). One pair of microbe + function from each half is enough for full marks.

EXPERT'S SOLUTION : *Ananya Nair, M.Sc Biotechnology, AIIMS Delhi*

Strategic angle. Build the answer around a 2-column mental table: column 1 = chemical you are replacing, column 2 = microbe doing the replacing.

- Urea / DAP → *Rhizobium*, *Azotobacter*, *Anabaena*, *Glomus*.
- Pesticide (insect) → *Bacillus thuringiensis*, baculoviruses.
- Fungicide → *Trichoderma*.
- Weedicide → mycoherbicides (e.g. *Colletotrichum*-based products).

Step 1. Biofertilisers in three categories.

- *Symbiotic N-fixers*: *Rhizobium* (in legume nodules), *Frankia* (in non-legumes like *Casuarina*).
- *Free-living N-fixers*: *Azotobacter* (aerobic), *Azospirillum* (microaerophilic).
- *Cyanobacterial N-fixers*: *Anabaena*, *Nostoc*, *Oscillatoria* - vital in paddy fields.
- *Mycorrhiza*: *Glomus* species - improve phosphorus uptake.

Step 2. Biocontrol in three categories.

- *Bacterial*: *Bacillus thuringiensis* kills lepidopteran caterpillars; the *Bt*-toxin gene has been engineered into *Bt-cotton*, *Bt-brinjal*.
- *Viral*: baculoviruses (*Nucleopolyhedrovirus*) infect specific pest insects; safe for non-target species.
- *Fungal*: *Trichoderma* against soil-borne plant fungi; *Beauveria bassiana* against insect pests.

Step 3. Why this is better than chemical.

- Specificity: *Bt* kills only certain caterpillars; DDT kills indiscriminately.
- No bio-accumulation: microbes degrade naturally.
- Self-renewing: biofertilisers reproduce, chemicals don't.
- No pollution of groundwater, no eutrophication.

Step 4. Integrated Pest Management (IPM). Modern agriculture often uses a mix: biofertiliser + biocontrol + minimal chemical fertiliser + crop rotation. The microbes are the backbone.

Step 5. Indian-context examples.

- *Bt-cotton* carries the *B. thuringiensis* toxin gene and resists bollworm without sprayed pesticide.
- *Azolla-Anabaena* association is added to rice paddies as a living biofertiliser, supplying 20–40 kg N/ha/season.
- *Rhizobium* seed inoculation is the standard practice for pulse crops (chickpea, soybean, lentil).

Why this matters. Decades of unchecked chemical fertiliser and pesticide use have poisoned soil and groundwater across the Green-Revolution belt. Microbial agriculture is the path back to sustainable yields.

Final Answer: Microbes act as biofertilisers (*Rhizobium, Azotobacter, Azospirillum,* cyanobacteria, mycorrhiza) and as biocontrol agents (*Bacillus thuringiensis*, baculoviruses, *Trichoderma*) - replacing chemical fertilisers and pesticides while protecting soil and water from pollution.

Q 8.11 Three water samples namely river water, untreated sewage water and secondary effluent discharged from a sewage treatment plant were subjected to BOD test. The samples were labelled A, B and C; but the laboratory attendant did not note which was which. The BOD values of the three samples A, B and C were recorded as 20 mg/L, 8 mg/L and 400 mg/L, respectively. Which sample of the water is most polluted? Can you assign the correct label to each assuming the river water is relatively clean?

SOLUTION

Concept used. BOD (Biochemical Oxygen Demand) is the amount of oxygen (in mg per litre of water) that would be consumed if all the organic matter in one litre of water were oxidised by bacteria. BOD is therefore a measure of the organic-matter load in the water: *higher BOD ⇒ more organic pollution ⇒ more polluted water*.

☞ Typical BOD ranges

- **Clean river / lake water:** 1–8 mg/L.
- **Secondary-treated effluent (after STP):** 10–30 mg/L (low; only some residual organic matter left).
- **Raw, untreated sewage:** 200–600 mg/L (very high).

The higher the BOD, the dirtier the water.

Step 1. Match each BOD value to the corresponding water type.

- Sample B: 8 mg/L ⇒ *very low BOD* ⇒ clean water ⇒ **river water**.
- Sample A: 20 mg/L ⇒ moderate BOD ⇒ partly cleaned ⇒ **secondary effluent** from the STP.
- Sample C: 400 mg/L ⇒ very high BOD ⇒ heavy organic load ⇒ **untreated sewage**.

Step 2. Which sample is most polluted? Sample **C (BOD = 400 mg/L)** is the most polluted. Such a heavy organic load would, if discharged into a water body, allow bacteria to consume nearly all the dissolved O_2 - killing fish and other aerobic aquatic life.

Step 3. Reasoning in one line. BOD ordering: $C\,(400) \gg A\,(20) > B\,(8)$. So the pollution ordering is: untreated sewage $\gg$ secondary effluent $>$ river water - which is exactly what we expect physically.

Step 4. Tabulated answer.

Sample	BOD (mg/L)	Identity
A	20	Secondary effluent (after STP)
B	8	River water (clean)
C	400	Untreated sewage (most polluted)

> **Final Answer:** **A** = **secondary effluent** (20 mg/L); **B** = **river water** (8 mg/L, the cleanest); **C** = **untreated sewage** (400 mg/L, the *most polluted*).

☞ Exam Tip

Remember: BOD is *directly proportional* to organic pollution. *Higher BOD* ⇒ *dirtier water*. Some students get this backwards. Picture it like this: more food (organic matter) in the water ⇒ more bacteria ⇒ more O_2 used up. So higher BOD means more pollution.

EXPERT'S SOLUTION : *Tara Desai, M.Sc Biotechnology, AIIMS Delhi*

Quick reading. Whenever you see three BOD numbers in a question, sort them, then match smallest→cleanest, largest→dirtiest.

Step 1. Define BOD precisely. BOD = $\text{mg}\,O_2/\text{L}$ that aerobic bacteria would consume to oxidise all the organic matter in a 1-L sample over a standard period (usually 5 days at 20°C, written BOD_5).

- Cleaner water has less organic matter ⇒ less O_2 needed ⇒ lower BOD.
- Polluted water has more organic matter ⇒ more O_2 needed ⇒ higher BOD.

Step 2. Rank the three samples by BOD.

- $C(400) > A(20) > B(8)$.
- Therefore pollution ranking: $C > A > B$.

Step 3. Assign labels physically.

- River water is described as "relatively clean" ⇒ lowest BOD ⇒ sample B.
- Untreated sewage is the dirtiest by far ⇒ highest BOD ⇒ sample C.
- Secondary effluent has been through aeration tanks where aerobic microbes consumed most of the organic load ⇒ intermediate BOD ⇒ sample A.

Step 4. Sanity check.

- Sample C has $400/8 = 50\times$ the organic load of the river water. Plausible - raw sewage is indeed 50–100× dirtier than river water.
- Sample A's BOD (20 mg/L) is exactly in the typical secondary-effluent range (10–30 mg/L). ✓

Step 5. **Most polluted, identified.** Sample C, with the highest BOD value of 400 mg/L, has the most organic pollution.

Why this matters. BOD is the single most-used number in environmental engineering for monitoring water quality. A 1-mark question of this type tests whether you have internalised the meaning of BOD - not the trivia, but the link from "high number" to "dirty water".

> **Final Answer:** Sample B (8 mg/L) is river water; Sample A (20 mg/L) is secondary effluent; Sample C (400 mg/L) is untreated sewage and is the *most polluted*.

Q 8.12 Find out the name of the microbes from which Cyclosporin A (an immuno-suppressive drug) and Statins (blood cholesterol lowering agents) are obtained.

SOLUTION

Concept used. Microbes synthesise many **bioactive molecules** that we use as drugs. Two important examples from this chapter are *cyclosporin A* (an immunosuppressant used during organ transplants) and *statins* (cholesterol-lowering agents). Both are produced by specific fungi.

Step 1. **Cyclosporin A is obtained from *Trichoderma polysporum***, a fungus.

- Use: it is used as an **immunosuppressive agent** in organ-transplant patients. By suppressing the recipient's immune response, it prevents the body from rejecting the transplanted organ.
- Mechanism: cyclosporin A binds the protein cyclophilin and inhibits calcineurin, blocking T-lymphocyte activation.
- Discovery: extracted in 1971; revolutionised organ transplantation (kidney, liver, heart).

Step 2. **Statins are obtained from *Monascus purpureus***, a yeast (a fungus too, but reproduces by budding like a yeast).

- Use: statins are used as **blood-cholesterol lowering agents**. They reduce LDL ($\sim$"bad" cholesterol) and lower the risk of heart attacks and strokes.
- Mechanism: statins competitively inhibit the enzyme HMG-CoA reductase, which is the rate-limiting step in cholesterol biosynthesis. Less enzyme

activity ⇒ less cholesterol made by the liver ⇒ lower blood cholesterol.

- Modern commercial statins (atorvastatin, simvastatin) are chemically modified versions of the natural *Monascus* product.

Step 3. One-line summary.

- Cyclosporin A ← *Trichoderma polysporum* (fungus).
- Statins ← *Monascus purpureus* (yeast).

> **Final Answer:** Cyclosporin A is obtained from the fungus *Trichoderma polysporum* (used as immunosuppressant during organ transplants). Statins are obtained from the yeast *Monascus purpureus* (used to lower blood cholesterol).

✗ Common Mistake

Do not write "*Trichoderma viride*" or "*Penicillium*" as the cyclosporin A source - those are different organisms. The correct NCERT answer is *Trichoderma polysporum*. Similarly, statins are from *Monascus purpureus*, not from *Penicillium* or *Aspergillus*.

EXPERT'S SOLUTION *: Meera Bhat, Ph.D Organic Chemistry, IISc Bangalore*

Quick reading. Two microbes, two drugs, two mechanisms - memorise as a 2-by-2 table.

Step 1. Cyclosporin A.

- Source: *Trichoderma polysporum*, a soil fungus.
- Action: immunosuppressant; blocks T-cell activation by inhibiting calcineurin.
- Clinical use: prevents rejection of transplanted organs (kidney, heart, liver, bone marrow).

Step 2. Statins.

- Source: *Monascus purpureus* (red rice yeast/fungus).
- Action: competitively inhibits HMG-CoA reductase, the rate-limiting enzyme of cholesterol biosynthesis.
- Clinical use: lowers LDL cholesterol; prevents atherosclerosis, heart attack, stroke.

Step 3. Memory trick.

- *Trichoderma* sounds like "trickier-derma" - used to *trick the immune system* into not rejecting an organ.
- *Monascus* sounds like "Mon-Ass-cuss-out-cholesterol" - used to lower cholesterol.

Step 4. **Three other bioactive microbial products worth knowing.**

- *Streptokinase* from *Streptococcus* - clot buster after a heart attack.
- *Lipases* from various fungi/bacteria - used in detergents to remove oily stains.
- *Pectinases & proteases* - used to clarify bottled fruit juice.

Why this matters. Cyclosporin A made modern organ transplantation possible. Statins are among the world's most-prescribed medicines. Both came from soil-living fungi - a reminder that life-saving drugs often hide in the most unglamorous places.

> **Final Answer:** Cyclosporin A ← *Trichoderma polysporum* (fungus); statins ← *Monascus purpureus* (yeast).

Q 8.13 **Find out the role of microbes in the following and discuss it with your teacher.**
(a) Single cell protein (SCP) **(b) Soil**

SOLUTION

Concept used. Microbes are not only producers of food and medicine - they can also *be* food (Single Cell Protein) and they actively maintain the structure and fertility of soil. This question asks us to explain both roles.

Step 1. **(a) Role of microbes as Single Cell Protein (SCP).**

- *Definition.* Single Cell Protein refers to dried cells of microbes (algae, fungi, bacteria, yeasts) used as protein-rich human or animal food. The cells themselves are the food.
- *Why it matters.* Global population growth (∼8 billion and rising) means conventional agriculture-and-livestock cannot meet protein demand sustainably. SCP grows very fast, on cheap substrates, and yields high-quality protein per unit area.
- *Common SCP microbes.*
  - *Spirulina* (a cyanobacterium) - grown on materials like sewage water and molasses; rich in protein, vitamins and minerals.
  - *Methylophilus methylotrophus* (a bacterium) - grown on methanol; produces tonnes of biomass per day.
  - *Saccharomyces cerevisiae* (yeast) - used as animal feed protein.
  - *Fusarium graminearum* (mycoprotein) - the source of "Quorn", a mycoprotein-based meat substitute.
- *Key advantages.*

    - Microbes can double their mass in hours; cattle take years.
    - Grow on industrial waste (cellulose, methanol, molasses) - turns waste into protein.
    - Rich in essential amino acids, vitamins, minerals.
    - Smaller land and water footprint than meat or pulses.
- *NCERT example to remember.* 250 kg of a cow produces ~200 g of protein per day; 250 kg of *Methylophilus methylotrophus* bacteria can produce 25 tonnes of protein per day. The difference is staggering.

Step 2. (b) Role of microbes in soil.

- *Decomposition of organic matter.* Saprophytic bacteria and fungi decompose dead plants, animals and animal excreta. The breakdown releases CO_2 to the atmosphere and **humus** into the soil, improving soil structure and fertility.
- *Nitrogen fixation.*
    - Symbiotic: *Rhizobium* in root nodules of legumes.
    - Free-living: *Azotobacter*, *Azospirillum*.
    - Cyanobacterial: *Anabaena, Nostoc, Oscillatoria*.
- *Phosphorus solubilisation.* Mycorrhizal fungi (*Glomus* species) form symbiotic associations with plant roots, mobilising soil phosphorus to the plant.
- *Sulphur and other mineral cycling.* Microbes drive the nitrogen, sulphur and phosphorus cycles, recycling elements through ecosystems.
- *Disease suppression.* *Trichoderma* and other antagonistic microbes outcompete root pathogens - improving plant health without chemicals.
- *Soil structure.* Fungal hyphae and bacterial polymers bind soil particles into stable aggregates, improving aeration and water retention.
- *Biocontrol in the rhizosphere.* *Bacillus thuringiensis* and similar microbes suppress harmful insects and worms.

Step 3. Putting both together. Microbes provide food directly (SCP) and indirectly (soil fertility supporting all crop growth). A handful of healthy soil contains more microbial cells than there are humans on earth.

> **Final Answer:** (a) SCP = microbial biomass (*Spirulina*, *Methylophilus methylotrophus*, *Saccharomyces*, *Fusarium graminearum*) eaten as protein-rich food. (b) In soil, microbes decompose organic matter into humus, fix nitrogen (*Rhizobium*, *Azotobacter*, cyanobacteria), solubilise phosphorus (mycorrhiza/*Glomus*), suppress disease (*Trichoderma*), and recycle nutrients - keeping soil fertile.

♥ **Big picture**

Microbes work for us twice over: they ARE food (SCP) and they MAKE food possible (soil fertility). Both roles together support nearly every protein source on the planet.

EXPERT'S SOLUTION *: Aditi Chatterjee, Ph.D Molecular Biology, NCBS Bangalore*

Strategic angle. Two sub-parts = two clear paragraphs. (a) SCP: define, list 4 microbes, list 3 advantages. (b) Soil: list at least 4 different functions with named microbes.

Step 1. SCP - single cell protein.

- Define: "Single cell protein is the dried biomass of microbes used as food or feed."
- Examples: *Spirulina* (sold as health supplement), *Methylophilus methylotrophus* (bacterial protein), *Saccharomyces cerevisiae* (feed yeast), *Fusarium graminearum* (mycoprotein, marketed as Quorn).
- Advantages: fast growth, high protein content, low land/water use, can run on waste streams.
- Disadvantage: high nucleic-acid content (can cause gout if eaten in excess) - addressed by RNA removal during processing.

Step 2. Soil - six microbial functions.

- *Decomposition.* Saprophytic fungi and bacteria break down dead leaves and dung into humus.
- *Nitrogen fixation. Rhizobium* (symbiotic), *Azotobacter/Azospirillum* (free-living), *Anabaena/Nostoc* (cyanobacteria in paddy fields).
- *Phosphorus mobilisation. Glomus* (mycorrhiza) supply P to plants.
- *Soil structure.* Bacterial slime and fungal hyphae bind particles into crumb-like aggregates.
- *Biocontrol. Trichoderma* suppresses root pathogens; *Bacillus thuringiensis* kills harmful insects.
- *Nutrient cycling.* Microbes drive carbon, nitrogen, sulphur and phosphorus cycles.

Step 3. Specific NCERT example for the answer.

- NCERT mentions that 250 kg of *Methylophilus methylotrophus* (with a high growth rate) can produce up to 25 tonnes of protein per day.
- Compare with cow: 250 kg cow gives 200 g protein per day. SCP advantage $\approx 10^5\times$.

Step 4. Soil microbes as the engine of every land ecosystem. One gram of fertile soil holds 10^8–10^9 bacterial cells plus thousands of fungi and protozoa. They drive nutrient release, root protection and water retention all at once - so a healthy soil is, biologically, a working microbial factory and the foundation of every crop you eat.

Why this matters. SCP is one possible answer to feeding 10 billion people. Soil microbes are one of the most under-appreciated supports of all terrestrial life. Together, they argue that microbes deserve much more than "germs" as a label.

> **Final Answer:** (a) SCP = dried microbial biomass (*Spirulina*, *Methylophilus methylotrophus*, yeasts, *Fusarium graminearum*) used as protein food/feed. (b) Soil microbes decompose dead matter, fix nitrogen, solubilise phosphorus, suppress pathogens and maintain soil structure.

Q 8.14 **Arrange the following in the decreasing order (most important first) of their importance, for the welfare of human society. Give reasons for your answer.**
Biogas, Citric acid, Penicillin and Curd

SOLUTION

Concept used. "Most important to human welfare" is judged by (i) the breadth of human need addressed (health, energy, food), (ii) the number of lives saved or quality-of-life improvements delivered, and (iii) how irreplaceable the product is. Health (life-and-death) is generally placed above food (daily quality of life), and food above industrial chemicals.

☞ **A reasonable ordering**

Penicillin > Biogas > Curd > Citric acid.

This ordering is the most defensible - but the question allows reasonable variations, as long as you justify your choice clearly. Award is given for the reasoning, not just the order.

Step 1. Step 1 - Penicillin (most important).

- It was the first antibiotic, isolated from the fungus *Penicillium notatum*.
- Saved millions of lives during World War II and ever since by curing deadly bacterial infections (plague, pneumonia, diphtheria, leprosy, septicaemia).
- Opened the entire era of antibiotic therapy - the single biggest jump in human life expectancy in the 20th century.
- Directly saves lives - health trumps everything else.

Step 2. Step 2 - Biogas (second).

- Produced by anaerobic methanogens on dung/sewage; mostly CH_4.
- Provides clean cooking and lighting fuel to millions of rural households.

- Solves an energy problem (fuel for cooking) AND a waste problem (cattle dung disposal) AND a fertiliser problem (spent slurry).
- Indispensable in rural India, China and much of the developing world.
- Health + environment angle: cleaner indoor cooking ⇒ fewer lung diseases; replaces firewood/kerosene.

Step 3. **Step 3 - Curd (third).**

- Made by lactic acid bacteria from milk.
- A daily food for billions, especially in South Asia. Improves nutritional value of milk (more B_{12}). Acts as a probiotic, suppressing gut pathogens.
- Important for daily nutrition but not directly life-saving the way antibiotics are.

Step 4. **Step 4 - Citric acid (least, in this list).**

- Produced by *Aspergillus niger*; used in foods, beverages, pharmaceuticals, detergents and as a preservative.
- Useful and widespread, but it is mostly a flavouring/processing additive. People could live healthy lives without it.
- No direct life-saving function; the most "replaceable" item in this list.

Step 5. **Final ordering.** Penicillin > Biogas > Curd > Citric acid.

> Final Answer: **Penicillin** > **Biogas** > **Curd** > **Citric acid.** Penicillin saves lives (antibiotic). Biogas powers and cleans up rural living. Curd is a daily nutrient and probiotic. Citric acid is a useful industrial additive but the most replaceable.

EXPERT'S SOLUTION *: Yash Gupta, M.Sc Biotechnology, AIIMS Delhi*

Strategic angle. Use a 3-tier ranking: *life-saving* > *daily essentials* > *industrial convenience*.

- Tier 1 (life-saving): Penicillin.
- Tier 2 (energy + daily nutrition): Biogas, Curd.
- Tier 3 (industrial use): Citric acid.

Step 1. **Penicillin - tier 1.**

- Directly saves lives from bacterial infection.
- Counterfactual: without it, simple wound infections in childbirth, surgery, or wartime would be lethal.
- Worldwide reach (used in every hospital).

Step 2. **Biogas - high tier 2.**

- Provides renewable, clean cooking fuel to millions.
- Reduces deforestation (less firewood demand) and indoor air pollution.
- Reuses cattle dung and sewage; the spent slurry is a high-quality biofertiliser.
- Affects energy AND waste AND fertility simultaneously.

Step 3. Curd - lower tier 2.

- Daily food source; improves micronutrient (B_{12}) intake.
- Probiotic effect against gut infections.
- Important for nutrition but easily substituted with other dairy/probiotic foods.

Step 4. Citric acid - tier 3.

- Industrial use: flavouring, preservation, detergents.
- Convenient but easily substituted by other acids (acetic, tartaric).
- No direct health or energy role.

Step 5. Caveat: subjectivity. If the marker prioritises "number of people impacted daily", curd (1.5+ billion daily users) could be placed higher than biogas. Both orderings are defensible *if your reasoning is clear*. The marks are for the reasoning.

Why this matters. "Importance" is rarely a single-axis quantity. The right answer is whichever ranking you can defend with concrete reasoning - be it lives saved, people fed, energy delivered, or environmental impact.

> **Final Answer:** Penicillin > Biogas > Curd > Citric acid - life-saving drug first, energy fuel second, daily nutrient third, industrial additive last.

Q 8.15 How do biofertilisers enrich the fertility of the soil?

SOLUTION

Concept used. **Biofertilisers** are living organisms (mostly bacteria, cyanobacteria and fungi) that enrich the nutrient quality of soil. They achieve this by (i) fixing atmospheric nitrogen, (ii) solubilising/mobilising phosphorus, and (iii) adding organic matter to soil. Together they reduce the need for chemical fertilisers and support sustainable agriculture.

Step 1. Symbiotic nitrogen fixation - *Rhizobium*.

- *Rhizobium* bacteria live inside **root nodules** of leguminous plants (peas, beans, gram, soybean).

- Inside the nodule, they fix atmospheric N_2 to organic nitrogen ($NH_3 \rightarrow$ amino acids), which the plant uses as nutrient.
- In return, the plant supplies sugars and a protected environment.
- Net result: when legume roots decompose at the end of a season, the soil is enriched with nitrogen - which the next non-leguminous crop can use. This is why farmers *rotate* legumes with grain crops.

Step 2. Free-living nitrogen fixers in soil.

- *Azotobacter* (aerobic) and *Azospirillum* (microaerophilic) fix atmospheric N_2 while living freely in soil.
- They do not need a plant host, so they enrich soil nitrogen everywhere they grow.

Step 3. Cyanobacteria - the paddy-field biofertilisers.

- Autotrophic, photosynthetic microbes (often called **blue-green algae**).
- Many fix atmospheric nitrogen, e.g. *Anabaena, Nostoc, Oscillatoria*.
- In paddy fields they are major biofertilisers, supplying $\sim$25–30 kg N/hectare/season.
- They also *add organic matter* to soil when they die and decompose - increasing humus and soil fertility.

Step 4. Mycorrhiza - fungal biofertilisers.

- Many fungi of the genus *Glomus* form symbiotic associations with plant roots, called **mycorrhiza**.
- The fungus absorbs phosphorus from soil and passes it to the plant.
- Other benefits to the plant: resistance to root-borne pathogens, tolerance to salinity and drought, overall increase in growth.
- The fungus, in return, receives sugars from the plant.

Step 5. Summary of how biofertilisers enrich soil.

- Add *nitrogen* to soil (*Rhizobium, Azotobacter, Azospirillum, Anabaena, Nostoc*).
- Supply *phosphorus* to plant roots (*Glomus* mycorrhiza).
- Add *organic matter / humus* (cyanobacteria, decomposers).
- Improve soil structure and water retention (microbial polymers, fungal hyphae).
- Suppress soil-borne diseases (*Trichoderma*, antagonistic microbes).

Final Answer: Biofertilisers enrich soil by (i) fixing atmospheric N_2 - *Rhizobium* (symbiotic in legume nodules), *Azotobacter/Azospirillum* (free-living), and cyanobacteria *Anabaena/Nostoc* (paddy fields), (ii) mobilising phosphorus to plants via mycorrhizal fungi (*Glomus*), and (iii) adding organic matter that improves soil structure, fertility and disease resistance.

♥ The case for biofertilisers

Chemical fertilisers leach into groundwater, cause eutrophication, and degrade soil over time. Biofertilisers are self-renewing, do not pollute, improve soil structure, and cost a fraction of urea/DAP - a win on every count.

EXPERT'S SOLUTION *: Ishaan Rao, M.Sc Botany, Delhi University*

Strategic angle. The cleanest answer organises biofertilisers into four named categories, each with one "poster microbe" and one named function.

- Symbiotic N-fixer → *Rhizobium* (in legume nodules).
- Free-living N-fixer → *Azotobacter, Azospirillum*.
- Cyanobacterial N-fixer → *Anabaena, Nostoc, Oscillatoria* (paddy fields).
- Mycorrhizal P-mobiliser → *Glomus*.

Step 1. Nitrogen pathway.

- Atmospheric N_2 is inert; plants cannot use it directly.
- Diazotrophic microbes contain the enzyme **nitrogenase**, which reduces N_2 to NH_3:

$$N_2 + 8\,H^+ + 8\,e^- + 16\,ATP \longrightarrow 2\,NH_3 + H_2 + 16\,ADP + 16\,P_i.$$

- This ammonia is absorbed by the plant or oxidised by soil microbes to NO_3^- (nitrate) - also plant-usable.

Step 2. Phosphorus pathway.

- Soil P is usually locked in insoluble salts (Ca/Fe/Al phosphates).
- Mycorrhizal fungi secrete organic acids and phosphatases that solubilise these salts.
- The fungal hyphae act like an extended root system, vastly increasing the volume of soil from which the plant gets P.

Step 3. Organic-matter pathway.

- Cyanobacteria (blue-green algae) and other microbes die and decompose, adding humus.

- Humus improves soil structure (crumb structure), water-holding, cation exchange, and nutrient release.

Step 4. Practical applications in Indian agriculture.

- Pulse farmers inoculate seed with *Rhizobium* cultures before sowing.
- Rice farmers spread *Azolla* (which contains symbiotic *Anabaena*) on paddy fields.
- Horticulture nurseries inoculate seedlings with *Glomus* mycorrhiza for better phosphorus uptake.

Step 5. Why biofertilisers beat chemicals.

- Self-renewing (microbes reproduce, urea doesn't).
- Non-polluting (no NO_3^- runoff into rivers).
- Improve soil over time (chemicals degrade it).

Why this matters. The next agricultural revolution will be *biological*, not chemical. Biofertilisers are the unsung heroes of that revolution - every gram of urea they replace is a gram of pollution avoided and a step toward sustainable farming.

> **Final Answer:** Biofertilisers (*Rhizobium*, *Azotobacter*, *Azospirillum*, cyanobacteria like *Anabaena* and *Nostoc*, mycorrhizal *Glomus*) enrich soil with fixed nitrogen, mobilised phosphorus and added organic matter - replacing chemical fertilisers and improving soil structure and fertility.

Key Takeaways

- **Household microbes:** *Lactobacillus* converts milk to curd; *Saccharomyces cerevisiae* leavens bread, idli and dosa batters; specific bacteria and fungi flavour cheese (e.g. *Propionibacterium shermanii* for Swiss cheese holes).
- **Industrial microbes:** antibiotics come from fungi (*Penicillium notatum, P. chrysogenum* $\rightarrow$ penicillin) and actinomycete bacteria (*Streptomyces* $\rightarrow$ streptomycin, tetracycline, chloramphenicol, erythromycin); organic acids and enzymes from *Aspergillus niger, Acetobacter aceti, Clostridium butylicum, Lactobacillus*; bioactive drugs cyclosporin A (*Trichoderma polysporum*) and statins (*Monascus purpureus*).
- **Sewage treatment:** primary = physical removal of solids; secondary = biological (aerobic microbial flocs in aeration tanks consume organic matter and drastically reduce BOD). Higher BOD $\Rightarrow$ dirtier water.
- **Biogas:** methanogens like *Methanobacterium* digest cellulose-rich dung anaerobically to give $CH_4 + CO_2 + H_2$, harvested in floating-drum gobar-gas plants for cooking and lighting.

- **Biocontrol:** *Bacillus thuringiensis* (caterpillars), *Trichoderma* (plant pathogens), baculoviruses (specific insect pests) - replace toxic pesticides.
- **Biofertilisers:** *Rhizobium* (symbiotic N-fix), *Azotobacter/Azospirillum* (free-living N-fix), *Anabaena/Nostoc* (paddy-field cyanobacteria), *Glomus* (mycorrhizal P-mobiliser) - replace chemical fertilisers and improve soil fertility sustainably.

End of Exercises