Microbiology

Unit 2 · Lesson 3 · Algae, protozoa and extremophiles

The notes for Lesson 3 of Unit 2: chapters 2.5 to 2.7 of the unit book, with their figures, worked examples, exam traps and quizzes, in one file. The full unit book, with every chapter, the exam question bank and the glossary, is linked at the end.

Lesson 3 of 3 | 3 chapters | Chapters 2.5 to 2.7

About these notes

These are the notes for **Lesson 3 · Algae, protozoa and extremophiles** of the University free n easy video lessons on Microbiology Unit 2, Bacteria, Fungi, Algae and Protozoa. They are chapters 2.5 to 2.7 of the unit book, unchanged, so a page here is the same page in the full book.

2.5 Algae: morphology, reproduction and industrial uses

Algae are photosynthetic eukaryotes, mostly aquatic, that have chlorophyll a but lack the roots, stems, leaves and vascular tissue of plants. They range from single cells a few micrometres across (**microalgae**, such as *Chlorella*) to seaweeds many metres long (**macroalgae**, such as kelps). Algae make a large share of the oxygen on Earth and stand at the base of aquatic food chains. Industry harvests them for agar, carrageenan and alginate, grows them for food supplements and pigments, and studies them as a source of biofuel; some also make deadly toxins that reach us through seafood.

You need: prokaryotic and eukaryotic cells compared (Unit 1). Photosynthesis in microbes is in Unit 4; algae in wastewater ponds are in Unit 6.

Thallus organisation and the main groups

The body of an alga is called a **thallus**. Its forms run from simple to complex: **unicellular** (*Chlamydomonas*, motile; *Chlorella*, non-motile), **colonial** (*Volvox*, a hollow ball of cells), **filamentous** (*Spirogyra*, *Ulothrix*), **siphonous** (*Caulerpa*, one large multinucleate cell) and **parenchymatous** sheets and blades (*Ulva*, the brown kelps). The study of algae is called **phycology**.

Algae are classified by four features: their pigments, their storage food, their cell wall and their flagella. The table gives the groups most asked in exams.

GROUP	PIGMENTS	STORAGE FOOD	CELL WALL	EXAMPLES
Green algae (Chlorophyta)	chl a, b; carotenoids	starch	cellulose	*Chlamydomonas*, *Chlorella*, *Ulva*, *Spirogyra*
Brown algae (Phaeophyta)	chl a, c; fucoxanthin	laminarin, mannitol	cellulose + alginate	*Sargassum*, *Laminaria*, *Fucus*
Red algae (Rhodophyta)	chl a; phycoerythrin, phycocyanin	floridean starch	cellulose + agar or carrageenan	*Gracilaria*, *Gelidium*, *Kappaphycus*
Diatoms (Bacillariophyta)	chl a, c; fucoxanthin	chrysolaminarin, oil	silica frustule in two halves	*Navicula*, *Pseudo-nitzschia*
Dinoflagellates (Dinophyta)	chl a, c; peridinin	starch, oil	cellulose plates (theca)	*Alexandrium*, *Gonyaulax*
Euglenoids (Euglenophyta)	chl a, b	paramylon	no wall; protein pellicle	*Euglena*

The "blue-green algae" are not algae: they are **cyanobacteria**, prokaryotes with chlorophyll a and phycobilins. *Spirulina* (correctly *Arthrospira*), *Nostoc* and *Anabaena* are cyanobacteria. Most syllabi still discuss them with algae because their uses overlap, but in an answer always say they are bacteria.

Reproduction and life cycles

Algae reproduce in three ways.

- **Vegetative**: by cell division in unicells and by **fragmentation** of filaments and thalli.
- **Asexual**: by spores made by mitosis. **Zoospores** are flagellated and swim (*Chlamydomonas*, *Ulothrix*); **aplanospores** are non-motile; **akinetes** are thick-walled resting cells.
- **Sexual**: by fusion of gametes. In **isogamy** the two gametes look alike (many *Chlamydomonas* species); in **anisogamy** they differ in size (*Chlamydomonas braunii*); in **oogamy** a large non-motile egg is fertilised by a small motile sperm (*Volvox*, *Fucus*). *Spirogyra* shows **conjugation**: a tube forms between two filaments and the content of one cell moves into the other.

Where meiosis falls in the life cycle gives three patterns (Figure 2.5.1). In a **haplontic** cycle the organism is haploid (n) and only the zygote is diploid (2n); the zygote undergoes meiosis at once. In a **diplontic** cycle the organism is diploid and only the gametes are haploid. In a

haplodiplontic cycle (alternation of generations) a haploid gametophyte and a diploid sporophyte are both multicellular; in *Ulva* they even look the same (isomorphic).



Figure 2.5.1 The three life cycles of algae as rings, read clockwise. Blue is haploid, orange is diploid. Notice where meiosis (M) falls: straight after the zygote in haplontic algae, at gamete formation in diplontic algae, and at spore formation on the sporophyte in haplodiplontic algae.

Industrial uses

- **Phycocolloids** (gels from seaweed walls). **Agar** from red algae such as *Gelidium* and *Gracilaria* solidifies microbiological media because almost no bacteria digest it and it melts near 85 °C but sets only around 32–40 °C (Unit 4). **Carrageenan** from *Kappaphycus alvarezii*, farmed along the Tamil Nadu coast near Ramanathapuram, thickens ice cream, toothpaste and chocolate milk. **Alginate** from brown algae (*Sargassum*, *Turbinaria*, *Laminaria*) is used in wound dressings, textile printing and to entrap cells and enzymes as beads in bioprocessing.
- **Food and feed**: *Chlorella* and the cyanobacterium *Arthrospira* (Spirulina) are sold as protein-rich supplements; microalgae feed fish and shrimp larvae in hatcheries.
- **Pigments and nutraceuticals**: β-carotene from *Dunaliella salina*, grown in salt ponds; astaxanthin from *Haematococcus pluvialis*; phycocyanin from Spirulina as a natural blue colour; DHA (an omega-3 fatty acid) from the dinoflagellate *Crypthecodinium cohnii* for infant formula.
- **Diatomaceous earth**: fossil diatom silica, used as a filter aid in breweries, as a mild abrasive and as an insecticide dust.
- **Environment and energy**: algae in oxidation ponds supply oxygen to bacteria treating sewage (Unit 6); oil-rich microalgae can be turned into biodiesel, though cost of growing and harvesting is still the main barrier.

During harmful algal blooms ("red tides") shellfish concentrate toxins: saxitoxins from *Alexandrium* cause **paralytic shellfish poisoning**; domoic acid from the diatom *Pseudo-nitzschia*

causes **amnesic shellfish poisoning**; okadaic acid from *Dinophysis* causes **diarrhetic shellfish poisoning**; ciguatoxins from *Gambierdiscus* reach reef fish and cause **ciguatera**. In fresh water, the cyanobacterium *Microcystis* makes microcystins that damage the liver. These toxins are heat stable, so cooking does not help.

WORKED EXAMPLE

Question (6 marks). A start-up in Gujarat runs an open raceway pond of 2,000 m² growing an oil-rich microalga. Assume an areal productivity of 15 g dry biomass per m² per day, a lipid content of 25% of dry weight, 300 operating days a year, 80% lipid extraction efficiency and an oil density of 0.9 kg/L. Find (a) the daily biomass, (b) the oil recovered per year in litres, and (c) the oil yield per hectare per year.

1. **Daily biomass** = area × productivity = 2,000 m² × 15 g m^{-2} day^{-1} = 30,000 g day^{-1} = **30 kg dry biomass per day**.
2. **Daily lipid in the biomass** = 30 kg × 0.25 = 7.5 kg day^{-1}.
3. **Lipid recovered per year** = 7.5 kg day^{-1} × 300 days × 0.80 = 1,800 kg $year^{-1}$.
4. **Volume** = mass ÷ density = 1,800 kg ÷ 0.9 kg L^{-1} = **2,000 L of oil per year**.
5. **Per hectare**: 1 ha = 10,000 m², which is 5 times the pond area, so 2,000 L × 5 = **10,000 L ha^{-1} $year^{-1}$**.
6. **Comment**: the yield per hectare is high compared with oil crops, which is the case for algal biofuel; the catch is the energy and cost of mixing, harvesting dilute cells and extracting the oil.

EXAM TRAPS

- Blue-green algae are cyanobacteria (prokaryotes). Spirulina is a cyanobacterium, not a green alga.
- Agar comes from red algae; alginate from brown algae. Students swap them every year.
- Storage foods are a classic one-mark question: starch (green), laminarin and mannitol (brown), floridean starch (red), paramylon (euglenoids).
- In a haplontic cycle the zygote is the only diploid cell; do not draw a diploid adult for *Chlamydomonas*.
- Algal toxins in shellfish are not destroyed by cooking. "Boil the prawns" is a wrong control measure.

CHECK YOURSELF

– REMEMBER **Name the pigment that gives brown algae their colour and the one that gives red algae theirs.** 2 marks

Fucoxanthin in brown algae; phycoerythrin in red algae.

– REMEMBER **Name one alga used for each: agar, carrageenan, alginate, β-carotene.** 2 marks

Gelidium or *Gracilaria*; *Kappaphycus*; *Sargassum*, *Laminaria* or *Turbinaria*; *Dunaliella salina*.

– UNDERSTAND **Distinguish isogamy, anisogamy and oogamy.** 3 marks

Isogamy: fusing gametes alike in size and form. Anisogamy: both motile but of different sizes. Oogamy: a large non-motile egg and a small motile male gamete.

– UNDERSTAND **Why is agar preferred to gelatin for solid culture media?** 2 marks

Very few microbes digest agar, so it stays solid; and it remains solid at 37 °C (and higher incubation temperatures) once set, while gelatin melts near body temperature and is digested by many bacteria.

– APPLY **Repeat the worked example with 20 g m^{-2} day^{-1} and 30% lipid, other values unchanged. Find the oil per year.** 3 marks

Biomass 2,000 × 20 = 40 kg day^{-1}; lipid 12 kg day^{-1}; recovered 12 × 300 × 0.8 = 2,880 kg; volume 2,880 ÷ 0.9 = **3,200 L per year**.

– APPLY **Several people fall ill with tingling lips and numbness after eating mussels collected during a red tide. Name the syndrome and the likely toxin and organism.** 3 marks

Paralytic shellfish poisoning, caused by saxitoxins from dinoflagellates such as *Alexandrium*, concentrated by the filter-feeding mussels.

– ANALYZE **Compare open raceway ponds with closed photobioreactors for growing microalgae.** 5 marks

Ponds: cheap to build and run, easy to scale, but lower cell density, contamination by other algae and grazers, water loss by evaporation and poor control of temperature and CO_2. Photobioreactors: higher density and productivity, sterile and controlled, suited to high-value products (astaxanthin, DHA), but costly to build, cool and clean. Choice follows product value.

BEYOND THE SYLLABUS

Seaweed farming is growing in India's coastal states as a livelihood and a carbon-friendly crop, and seaweed-based biostimulants are sold to farmers. Microalgae are being engineered as "green cell factories" for proteins and vaccines, and diatom silica is studied as a template for nanomaterials. The economics of algal biofuel remain hard; life-cycle assessments are the tool used to judge it. Search "seaweed cultivation India Kappaphycus" or "microalgae techno-economic analysis". Not for the exam.

2.6 Protozoa and helminths

Protozoa are single-celled eukaryotes that feed like animals, by eating or absorbing organic matter, and most of them move. Helminths are parasitic worms: multicellular animals with organs, which are not microbes at all but are taught in microbiology because their eggs, larvae and cysts are found by the microscope in stool, blood and food. Both groups spread mainly through contaminated water and food, insect bites and poor sanitation, so they matter a great deal in India, where amoebic dysentery, giardiasis, malaria, kala-azar, worm infections and filariasis are all public health problems.

You need: eukaryotic cell structure (Unit 1). Malaria is treated in detail in Unit 6 (Common infections); here it appears only as an example of a sporozoan.

Protozoa: structure and life stages

A protozoan cell has a nucleus, mitochondria (absent or reduced in some, such as *Giardia*), and no cell wall; many have a firm, flexible outer layer called the **pellicle**. Freshwater forms use **contractile vacuoles** to pump out water. Food is taken in by phagocytosis into food vacuoles or, in ciliates, through a mouth-like **cytostome**.

Many parasitic protozoa have two stages. The **trophozoite** is the active, feeding, dividing form found in the host. The **cyst** is a dormant form with a tough wall that survives outside the body and is the infective stage when swallowed. This is why cysts, not trophozoites, spread amoebiasis and giardiasis through water: trophozoites die in the stomach acid, cysts pass through.

Reproduction. Asexual reproduction is by **binary fission** (longitudinal in flagellates, transverse in ciliates), **multiple fission** or **schizogony** (one cell divides into many, as in *Plasmodium* in red

blood cells) and budding. Sexual reproduction is by **conjugation** in ciliates (two cells exchange micronuclei) and by **gamete fusion** in sporozoa, as in the sexual cycle of *Plasmodium* inside the mosquito.

Classification by locomotion, with diseases

The traditional classification, still used in Indian syllabi, groups protozoa by how they move. Modern classification by DNA splits them across many lineages, but the four classic groups remain the best map for exams.

- **Sarcodina (amoebae)**: move and feed by **pseudopodia**. *Entamoeba histolytica* causes **amoebic dysentery** (stools with blood and mucus) and can reach the liver to form an **amoebic liver abscess**. Its cyst has four nuclei when mature; the harmless gut amoeba *Entamoeba coli* has up to eight.
- **Mastigophora (flagellates)**: move by **flagella**. *Giardia lamblia* (also called *G. intestinalis* or *G. duodenalis*) has a pear-shaped trophozoite with a ventral sucking disc and causes **giardiasis**, with greasy, foul-smelling diarrhoea. *Leishmania donovani*, spread by sandflies (*Phlebotomus*), causes **kala-azar** (visceral leishmaniasis), still found in Bihar, Jharkhand and nearby states. *Trypanosoma brucei* causes African sleeping sickness (tsetse fly) and *T. cruzi* causes Chagas disease in Latin America. *Trichomonas vaginalis* is sexually transmitted.
- **Ciliophora (ciliates)**: move by many **cilia** and have two kinds of nuclei (a macronucleus for daily function and a micronucleus for reproduction). *Paramecium* is the free-living model; *Balantidium coli* is the only ciliate that commonly infects humans, causing dysentery, often with pig contact.
- **Sporozoa (Apicomplexa)**: adults have no organs of locomotion and all are parasites with complex life cycles. *Plasmodium* causes **malaria** (female *Anopheles* mosquito; Unit 6). *Toxoplasma gondii* comes from cat faeces and undercooked meat and is dangerous in pregnancy. *Cryptosporidium* causes watery diarrhoea and its oocysts resist chlorine, so filtration is needed in water treatment.

Helminths: flukes, tapeworms and roundworms

Helminths are classified by body shape:

- **Platyhelminthes (flatworms)**, flat and without a body cavity. **Trematodes (flukes)** are leaf-shaped with suckers and usually use snails as intermediate hosts: *Schistosoma* (blood flukes; larvae penetrate skin in water), *Fasciola hepatica* (liver fluke). **Cestodes (tapeworms)** are ribbon-like, with a head (**scolex**) bearing suckers and sometimes hooks, and a chain of segments (**proglottids**), each with its own reproductive organs. *Taenia solium* (pork tapeworm), *T. saginata* (beef tapeworm) and *Echinococcus granulosus* (dog tapeworm, causes hydatid cysts in humans).

- **Nematodes (roundworms)**, round in section, with a complete gut and separate sexes. *Ascaris lumbricoides* (large roundworm; eggs in soil and on vegetables), *Enterobius vermicularis* (pinworm; night-time anal itching in children), the hookworms *Ancylostoma duodenale* and *Necator americanus* (larvae enter through bare feet and the adults suck blood, causing iron-deficiency anaemia), *Trichuris trichiura* (whipworm), *Trichinella spiralis* (larvae in undercooked pork muscle) and *Wuchereria bancrofti* (lymphatic filariasis or elephantiasis, spread by *Culex* mosquitoes).

The soil-transmitted worms (*Ascaris*, hookworm, *Trichuris*) affect school learning and growth in children, which is why India runs mass deworming of children with albendazole through its National Deworming Day programme.

Diagnosis. Stool microscopy is the base test: a **saline wet mount** shows motile trophozoites and helminth eggs, and an **iodine mount** stains cyst nuclei. Concentration methods (formalin–ether sedimentation, flotation) find scanty eggs. Blood films detect malaria and, taken at night, the microfilariae of *W. bancrofti*, which circulate mainly at night. Antigen tests and PCR are increasingly used.

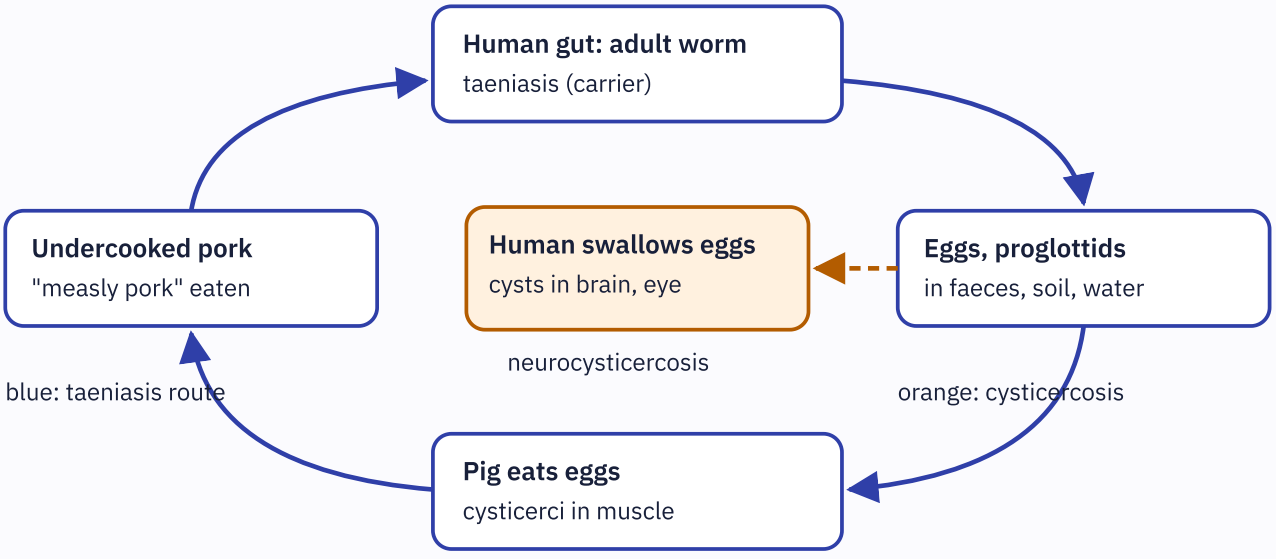


Figure 2.6.1 The two ways *Taenia solium* reaches people. Eating cysticerci in undercooked pork gives an adult tapeworm in the gut (taeniasis, blue ring). Swallowing eggs shed by a human carrier, through food, water or hands, makes the human the intermediate host, with cysts in tissues including the brain (cysticercosis, orange).

WORKED EXAMPLE

Question (6 marks). A 24-year-old vegetarian in Madurai who has never eaten pork has a seizure. A brain scan shows small cysts and a blood test is positive for *Taenia solium* antibodies. The family cook was recently treated for a "tapeworm". Explain how the patient was infected, and propose two control measures.

1. **Name the disease**: **neurocysticercosis**, cysticerci (larval cysts) of *T. solium* in the brain, a leading cause of acquired epilepsy in India.
2. **Which stage infects whom?** Pork with cysticerci gives the **adult worm** (taeniasis). **Eggs** give **cysticercosis**. So the patient must have swallowed eggs; eating pork is not needed, and pork cannot cause cysticercosis directly.
3. **Source**: the cook carried an adult worm and shed eggs in faeces. Without proper hand-washing after the toilet, eggs reached food the patient ate.
4. **Inside the patient**: eggs hatch in the gut, the larvae (oncospheres) enter the blood, lodge in brain and muscle and form cysts. The patient is acting as the intermediate host, a dead end for the worm.
5. **Control**: treat tapeworm carriers, especially food handlers (praziquantel or niclosamide); hand-washing with soap and safe sanitation; wash raw vegetables. For the taeniasis route, meat inspection and thorough cooking of pork.

EXAM TRAPS

- Cysts, not trophozoites, are the infective stage of *E. histolytica* and *Giardia*. Trophozoites are what you see in dysenteric stool.
- Taeniasis (adult worm, from undercooked pork) and cysticercosis (larval cysts, from eggs) are different diseases from the same worm. This is the examiner's favourite trap.
- Helminths are animals, not microbes; only their eggs and larvae are microscopic.
- *Anopheles* spreads malaria; *Culex* spreads bancroftian filariasis; sandflies spread kala-azar; tsetse flies spread sleeping sickness. Match vector to disease carefully.
- Ringworm is a fungus (Chapter 2.4) and pinworm is a nematode.

CHECK YOURSELF

- REMEMBER **Name the four classical groups of protozoa and their means of locomotion.** 2 marks

  Sarcodina, pseudopodia; Mastigophora, flagella; Ciliophora, cilia; Sporozoa, none in the adult (gliding in some stages).

- REMEMBER **Name the vector and the causative agent of kala-azar.** 2 marks

  Sandfly (*Phlebotomus*); *Leishmania donovani*.

- UNDERSTAND **Why do cysts spread protozoan diseases through water better than trophozoites?** 3 marks

  The cyst wall resists drying, cold and stomach acid, so cysts survive for weeks in water and pass through the stomach unharmed. Trophozoites are fragile and die outside the host and in gastric acid.

- UNDERSTAND **How do the bodies of cestodes and nematodes differ?** 3 marks

  Cestodes: flat, segmented into proglottids, with a scolex, no gut (absorb food through the body surface), mostly hermaphrodite. Nematodes: round, unsegmented, with a complete gut and separate sexes.

- APPLY **A child from a village who often walks barefoot has pale skin and low haemoglobin. Stool shows thin-shelled oval eggs. What is likely and why?** 3 marks

  Hookworm infection (*Ancylostoma* or *Necator*). Larvae in soil enter through bare feet; adults attach to the intestinal wall and suck blood, causing iron-deficiency anaemia. Treat with albendazole and advise footwear and toilets.

- APPLY **A city's water passed chlorination, yet an outbreak of watery diarrhoea is traced to *Cryptosporidium*. Explain and suggest a fix.** 3 marks

  Cryptosporidium oocysts resist chlorine at normal doses. Add effective filtration (coagulation plus sand or membrane filtration) or UV disinfection, and protect the source from faecal contamination.

– ANALYZE **Compare protozoa and helminths as parasites under cell organisation, multiplication in the host and diagnosis.** 5 marks

Protozoa are single cells and most multiply inside the host, so a few cysts can cause heavy infection; diagnosed by trophozoites or cysts in stool or parasites in blood. Most helminths are multicellular and do not multiply in the human host (worm burden depends on how many eggs or larvae were taken in), with exceptions such as *Strongyloides*; diagnosed by eggs, larvae or proglottids in stool, or microfilariae in night blood.

BEYOND THE SYLLABUS

India has run a kala-azar elimination programme for years, and it uses single-dose liposomal amphotericin B and indoor residual spraying against sandflies. Malaria control now faces artemisinin partial resistance first seen in Southeast Asia and an invasive urban mosquito, *Anopheles stephensi*. Helminths have another side too: the "hygiene hypothesis" studies whether their absence raises allergy and autoimmune disease. Search "kala-azar elimination India" or "One Health parasitology". Not for the exam.

2.7 Extremophiles and their adaptations

Extremophiles are microbes that grow best in conditions that would kill most life: near boiling water, below freezing, in saturated brine, in acid or alkali, under crushing pressure or heavy radiation. Most are archaea or bacteria. Their enzymes, called **extremozymes**, keep working where ordinary enzymes fall apart; the best known is *Taq* DNA polymerase, which made PCR practical.

You need: the cell wall and membrane of 2.2 (archaeal walls and lipids) and the effect of temperature on growth (Unit 4, growth kinetics).

The kinds of extremophile

Every organism has three **cardinal temperatures**: a minimum, an optimum and a maximum for growth. Groups are named by the optimum (Brock's definitions; some books shift the limits slightly).

- **Psychrophiles**: optimum 15 °C or lower, maximum about 20 °C; polar seas and glaciers.

- **Thermophiles**: optimum 45–80 °C, for example *Thermus aquaticus*, first isolated from a hot spring in Yellowstone.
- **Hyperthermophiles**: optimum above 80 °C, mostly archaea such as *Pyrococcus furiosus* and *Methanopyrus kandleri*. *M. kandleri* strain 116 was reported in 2008 to grow at 122 °C under 20 MPa pressure.
- **Halophiles**: need salt. Extreme halophiles such as *Halobacterium salinarum* need very high NaCl and colour solar salt pans red.
- **Acidophiles** (optimum below about pH 5; *Acidithiobacillus*, and *Picrophilus*, which grows near pH 0) and **alkaliphiles** (optimum above about pH 9; soda lakes, alkaliphilic *Bacillus* species).
- **Piezophiles** grow best under deep-sea pressure; *Deinococcus radiodurans* survives huge radiation doses by repairing its broken DNA.

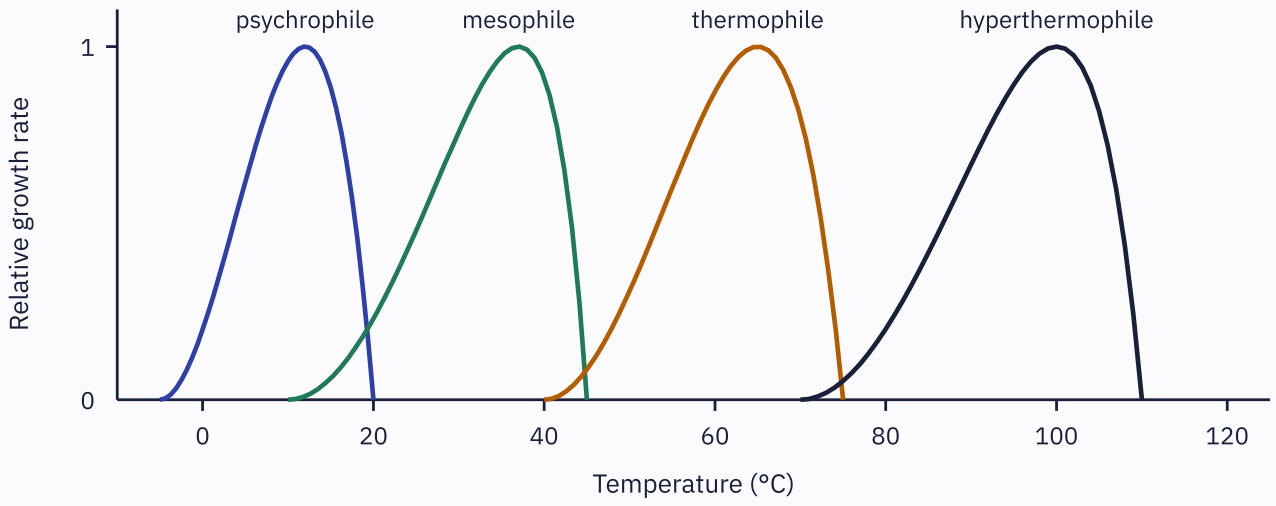


Figure 2.7.1 Growth rate against temperature for four groups, computed from a standard cardinal-temperature model with illustrative minimum, optimum and maximum values (for example 10, 37 and 45 °C for the mesophile). Each curve rises slowly to its optimum, then crashes within a few degrees.

How they survive

- **Heat.** Proteins have more salt bridges and tighter hydrophobic cores. Archaea have **ether-linked lipids**, more stable than the ester links of bacteria, and many hyperthermophiles have **monolayer membranes** of tetraether lipids that cannot peel apart. **Reverse gyrase** adds positive supercoils that stabilise DNA; it is found in hyperthermophiles and not in mesophiles.
- **Cold.** More unsaturated fatty acids keep membranes fluid; flexible enzymes work in the cold; cold-shock and antifreeze proteins help.
- **Salt.** Brine pulls water out of the cell. The **salt-in** strategy (*Halobacterium*) piles up K^+ inside to match the outside, so its proteins are acidic and need salt. The **compatible-solute** strategy

(most halotolerant bacteria) makes small organic molecules such as glycine betaine and ectoine that balance water without harming enzymes.

- **Acid and alkali.** The cytoplasm is kept close to neutral in both. Acidophiles keep protons out; alkaliphiles often run transport on a sodium gradient.

WORKED EXAMPLE

Question (5 marks). An isolate from the Manikaran hot spring in Himachal Pradesh gives these specific growth rates, μ (h^{-1}): 45 °C, 0.05; 55 °C, 0.45; 65 °C, 0.90; 70 °C, 1.10; 75 °C, 0.95; 80 °C, 0.30; 85 °C, 0. (a) Estimate the cardinal temperatures and classify the organism. (b) Find the doubling time at the optimum. (c) Suggest one industrial use of its enzymes.

1. **Optimum**: highest μ in the data, 1.10 h^{-1} at **about 70 °C**.
2. **Minimum**: growth is barely detectable at 45 °C, so the minimum is a little below that, about 40–45 °C. **Maximum**: between 80 °C (still growing) and 85 °C (none), about 82 °C.
3. **Class**: optimum between 45 and 80 °C, so a **thermophile** (not a hyperthermophile, whose optimum is above 80 °C).
4. **Doubling time** in exponential growth: $t_d = \ln 2 / \mu = 0.693 / 1.10\ h^{-1} = 0.63$ h ≈ **38 minutes**.
5. **Use**: heat-stable enzymes, such as a PCR polymerase or amylases for hot starch processing.

EXAM TRAPS

- Thermophile versus hyperthermophile is set by the optimum (80 °C), not by the maximum.
- Psychrotolerant is not psychrophile: *Listeria* grows in the fridge but has a mesophilic optimum.
- Archaeal lipids are ether-linked and built from isoprenoid chains; bacterial lipids are ester-linked fatty acids.
- *Taq* polymerase is from the bacterium *Thermus aquaticus*; *Pfu* polymerase is from the archaeon *Pyrococcus furiosus* and has proofreading.

CHECK YOURSELF

– REMEMBER **Define a hyperthermophile and name one.** 2 marks

A microbe with an optimum growth temperature above 80 °C, for example *Pyrococcus furiosus* or *Methanopyrus kandleri*.

– REMEMBER **Name two compatible solutes.** 1 mark

Glycine betaine and ectoine (also proline, trehalose).

– UNDERSTAND **Why do growth curves fall steeply above the optimum temperature?** 3 marks

Above the optimum, key proteins denature and membranes become too fluid and leaky; these failures are cooperative and fast, so growth stops within a few degrees. Below the optimum, reaction rates fall gradually.

– APPLY **A psychrophile grows with μ = 0.10 h^{-1} at its optimum. Find its doubling time.** 2 marks

$t_d = 0.693 / 0.10 =$ **6.9 h**.

– ANALYZE **Explain why *Taq* polymerase made automated PCR possible.** 4 marks

Each PCR cycle heats DNA to about 94–95 °C to separate the strands. The first enzyme used, from *E. coli*, was destroyed each cycle and had to be re-added. *Taq* survives repeated heating, so one addition lasts the run, and its 72 °C working temperature improves specificity.

BEYOND THE SYLLABUS

Extremophiles shape the search for life on Mars and the icy moons Europa and Enceladus. Ectoine is sold in skin creams. Search "astrobiology extremophiles" or "extremozymes industrial applications". Not for the exam.

Key terms of this lesson

TERM	MEANING OR FORMULA	CHAPTER
Algal groups	Classified by pigment, storage food, wall and flagella	2.5
Microalgal oil yield	area × productivity × lipid fraction × days × extraction ÷ density	2.5
Trophozoite / cyst	Active feeding form / resistant infective form	2.6
Taeniasis / cysticercosis	Adult worm from pork / larval cysts from swallowed eggs	2.6
Doubling time	$t_d = \ln 2 / \mu = 0.693 / \mu$	2.7
Thermophile / hyperthermophile	Optimum 45–80 °C / above 80 °C	2.7

Glossary (terms used in this lesson)

Agar Gel from red algae, used to solidify culture media.

Alginate Gel-forming polysaccharide from brown algae; used to entrap cells and enzymes.

Cestode Tapeworm: flat, segmented helminth with a scolex and proglottids.

Compatible solute Small organic molecule (glycine betaine, ectoine) that balances osmotic stress without harming enzymes.

Cyst Dormant, thick-walled stage of a protozoan; usually the infective stage.

Cysticercosis Infection of tissues with larval cysts of *Taenia solium*, acquired by swallowing eggs.

Extremophile Microbe that grows best under extreme temperature, salt, pH, pressure or radiation.

Thallus Body of an alga (or fungus) not divided into root, stem and leaf.

Trophozoite Active, feeding, dividing stage of a protozoan.

The full unit book

Every chapter of Unit 2, the unit summary, the exam question bank with model answers and the full glossary: Microbiology · Unit 2 · Bacteria, Fungi, Algae and Protozoa (one file, works offline).

Sources and further reading

Textbooks

- Madigan, Bender, Buckley, Sattley and Stahl, *Brock Biology of Microorganisms*, Pearson: cell structure, cell walls, archaea and extremophiles (from memory; check edition).
- Willey, Sandman and Wood, *Prescott's Microbiology*, McGraw-Hill: bacterial structure, fungi, algae and protists (from memory; check edition).
- Pelczar, Chan and Krieg, *Microbiology*, Tata McGraw-Hill: the classic Indian course text for morphology and the microbial groups (from memory; check).
- Tortora, Funke and Case, *Microbiology: An Introduction*, Pearson: eukaryotic microbes, helminths and food-borne disease (from memory; check).
- Ananthanarayan and Paniker's *Textbook of Microbiology* and Paniker's *Textbook of Medical Parasitology*, Universities Press / Jaypee: Indian context for mycology, protozoa and helminths (from memory; check publishers).

Open resources used

- OpenStax *Microbiology*, "Unique Characteristics of Prokaryotic Cells", as adapted on LibreTexts (CC BY): wall thicknesses, LPS parts and named inclusions. bio.libretexts.org
- Takai and co-workers, "Cell proliferation at 122 °C and isotopically heavy CH_4 production by a hyperthermophilic methanogen under high-pressure cultivation", *PNAS* 105 (2008), abstract: *Methanopyrus kandleri* strain 116 growth limit of 122 °C at 20 MPa. ui.adsabs.harvard.edu
- US Centers for Disease Control and Prevention, "About Cysticercosis": eggs as the infective stage, and why eating pork cannot cause cysticercosis. cdc.gov

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