4 · Energy, Environment, Microbiology and Immunity

Pearson Edexcel · International A-Level · Biology

Energy in, energy through, energy lost

A wheat field intercepts sunlight, fixes carbon, feeds a food chain – and loses energy at every step. This unit follows the energy from photon to ecosystem, then turns to the smallest participants: the microbes that recycle, the pathogens that take, and the immune system that defends. WBI14 is also the most calculation-heavy paper after Unit 1: expect NPP, growth constants, diversity indices and time-of-death arithmetic.

WBI14 Energy, Environment, Microbiology and Immunity is the first IA2 unit: 1 hour 30 minutes, 90 marks, all compulsory. It assesses Topic 5 (Energy Flow, Ecosystems and the Environment) and Topic 6 (Microbiology, Immunity and Forensics).

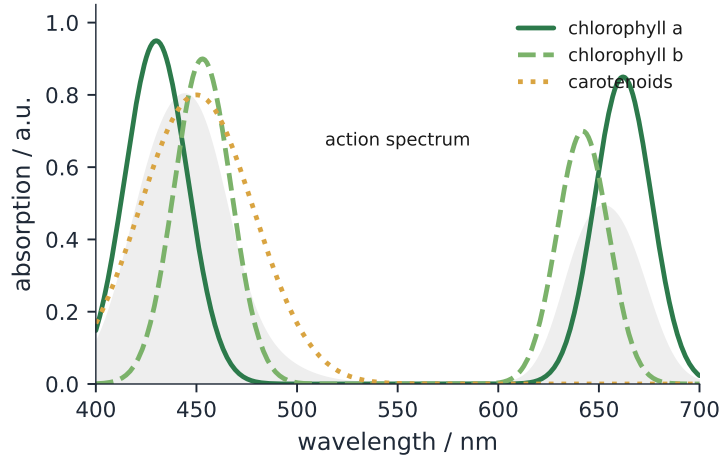
Photosynthesis: two stages, two places

The overall reaction: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$, driven by light energy. In the **thylakoid** membranes, the **light-dependent reactions** photolyse water (releasing O_2 and H^+), **photophosphorylate** ADP and reduce NADP. In the **stroma**, the **light-independent reactions** (Calvin cycle) fix carbon dioxide onto ribulose bisphosphate with rubisco, reduce the products using the ATP and reduced NADP from stage one, and make **GALP** – some to glucose, most to regenerate RuBP.

Structure matches function: thylakoids stacked for absorbing surface; stroma packed with enzymes for the cycle.

■ Pigments and spectra

Chlorophyll a and b absorb red and blue light; carotenoids widen the range and protect. The **absorption spectrum** shows what each pigment takes up; the **action spectrum** shows what rate of photosynthesis each wavelength drives – their agreement is evidence that these pigments do the work. Chromatography separates pigments by solubility; Rf = distance moved by pigment/distance moved by solvent.



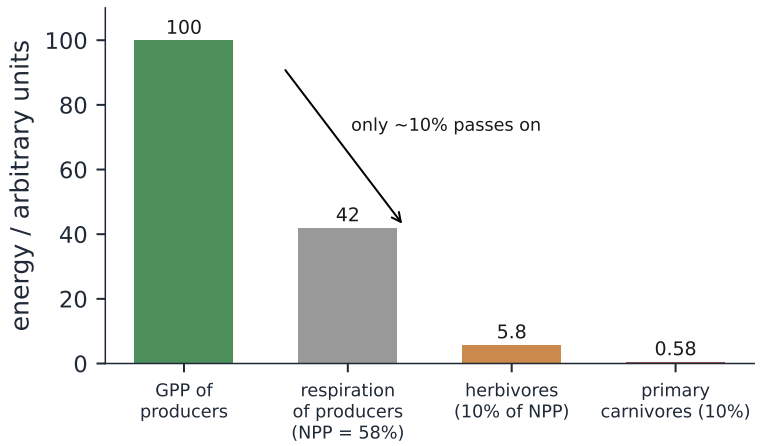
Limiting factors: light intensity, CO_2 concentration, temperature. A greenhouse raises the weakest of the three – and exam answers say which and why.

Productivity and the short food chain

Gross primary productivity (GPP) is the energy fixed by photosynthesis per area per time (kJ m^{-2} yr^{-1}). Plants spend much of it on their own respiration; what remains is **net primary productivity**:

$$\text{NPP} = \text{GPP} - R$$

Only about 10 % of the energy at each trophic level passes upward – lost to respiration as heat, egestion, excretion and parts never eaten. That is why chains rarely exceed four or five levels and why top predators are rare.

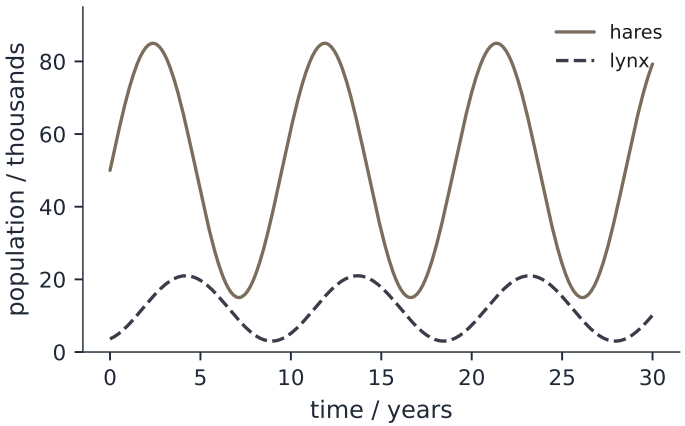


Worked check. A grassland fixes 45 000 kJ m^{-2} yr^{-1} and respirers 19 000. NPP = 26 000 kJ m^{-2} yr^{-1}. Cattle eating that grass keep about 10 %: 2 600 kJ m^{-2} yr^{-1}. Humans eating the cattle keep 260 – the energy arithmetic behind "eating lower on the chain feeds more people".

Ecosystems, populations and succession

Four definitions, precisely: **habitat** (where), **population** (one species' individuals), **community** (all populations), **ecosystem** (community + environment). Abiotic factors (light, water, temperature, pH) and biotic factors (competition, predation, disease) set who lives where and how abundantly – together, the **niche** .

Predator and prey cycle with a delay: hares rise, lynx follow, hares fall, lynx starve – a lag of about a quarter cycle.



Succession begins when pioneer species colonise bare ground; each stage changes the soil and microclimate, enabling the next, until the **climax community** stabilises. Measuring abundance uses quadrats and transects (random sampling for estimates, systematic along a gradient) and capture-mark-recapture for animals ($N \approx$ first catch $\times$ second catch/marked recaptures).

Climate change: evidence, causes, effects

Evidence comes from direct temperature records, ice cores (trapped air giving ancient CO_2), tree rings (**dendrochronology**) and pollen layers in peat. The **enhanced greenhouse effect** : outgoing long-wave radiation is absorbed by CO_2, methane and nitrous oxide and re-emitted downward. The gases differ – methane is potent but short-lived; CO_2 lasts centuries; nitrous oxide combines both – so policy weighs **global warming potential** against lifetime.

Extrapolating a trend beyond its data is a judgement, not a fact: state the assumption (the trend continues) and its weakness. Effects already examined: shifting rainfall and species ranges, and – close to this course – temperature's effect on enzyme rates in cold-blooded organisms and whole ecosystems.

Worked check. Methane's warming potential is about 28× CO_2's per kg, but it lasts ~12 years against centuries. A one-tonne methane leak matters 28× a one-tonne CO_2 leak this decade, but fades while the CO_2 persists – the arithmetic of "warming potential vs cumulative load".

Evolution and speciation

Evolution is a change in **allele frequency** . It needs variation (mutation, meiosis) and a filter: **directional selection** shifts the mean when the environment moves; **stabilising selection** trims the extremes in a stable one. Drift changes frequencies by chance in small populations; gene flow (migration) mixes them back.

Speciation needs isolation: **allopatric** (a physical barrier – allopatric = different homeland) or **sympatric** (reproductive isolation in the same place – behavioural, temporal or genetic). Isolated populations diverge until they can no longer interbreed.

Culturing microorganisms

Aseptic technique protects you and the culture: flame the loop to red heat, flame bottle necks, lift lids briefly, secure plates and use approved teaching cultures under the school's incubation and disposal procedures. Lower incubation temperatures reduce some risks but do not guarantee that pathogens cannot multiply. Measure growth by direct cell count (haemocytometer), **turbidity** in broth, or viable counts by **dilution plating** (colony count $\times$ dilution factor $\div$ volume plated, giving colony-forming units per unit volume).

The growth curve: **lag** (enzymes synthesising), **log** (exponential doubling), **stationary** (deaths = divisions), **death** . The exponential constant:

$$k = \frac{\log_{10} N_t - \log_{10} N_0}{0.301 \times t}$$

Worked check. From 2×10^4 to 1.6×10^7 cells in 5 hours: log difference = 2.903; $k = 2.903/(0.301 \times 5) = 1.93$ generations per hour – a doubling time of about 31 minutes.

Pathogens and the body's barriers

Bacteria: cell wall, plasmids, ribosomes, circular DNA, some with capsule and flagellum. Viruses: nucleic acid (DNA or RNA) in a **capsid** , some with an envelope – no organelles, no metabolism of their own; they hijack host cells. **Mycobacterium tuberculosis** infects lungs, surviving inside macrophages; **HIV** infects T helper cells and can weaken immune defence. Untreated HIV increases the risk of active TB, including reactivation of an existing infection; reactivation is not inevitable.

Barriers come first: skin, mucus and cilia, stomach acid, lysozyme in tears, and the clotting cascade sealing wounds.

The immune response

Non-specific: inflammation (vasodilation and fluid leak bringing phagocytes), phagocytosis, interferon. Specific – **antigens** trigger it:

- **Humoral** : B effector cells → plasma cells → **antibodies** ; **B memory cells** B remain for the faster, stronger secondary response.
- **Cellular** : T helper cells coordinate, **T killer cells** T destroy infected cells, T memory cells persist.

The standard Y-shaped antibody has four polypeptide chains (two heavy, two light) and two matching antigen-binding sites. Each site includes a **variable region** whose shape helps determine antigen specificity. Immunity splits two ways: **active** (your own antibodies – natural infection or vaccination) vs **passive** (given antibodies – mother to baby, antiserum); natural vs artificial in each. Vaccination works at the scale of populations too (**herd immunity**) – but pathogens evolve back: the evolutionary race.

Worked check. A vaccine's second dose produces antibody levels ten times the first and within days rather than weeks: clonal selection finds the memory B cells, which divide rapidly into plasma cells – the secondary response the primary response built.

Antibiotics and hospital-acquired infections

Bacteriostatic antibiotics stop bacterial growth; **bactericidal** ones kill. Resistance arises by mutation and spreads by selection whenever exposure kills the susceptible and spares the resistant – unnecessary antibiotic exposure favours selection, so antibiotics should be used only when clinically indicated and as prescribed. Hospital-acquired infections thrive where vulnerable patients, invasive devices and resistant strains meet; hand hygiene, sterile procedure and isolating carriers break the chain.

Decomposition, PCR, profiling and time of death

Decomposers recycle carbon and nitrogen – the ecosystem's waste system. The **polymerase chain reaction** cycles denaturation (95 °C), primer annealing (50–60 °C) and extension (72 °C), ideally doubling the target DNA each cycle: in this simplified model, one starting copy gives 2^n copies after n cycles. Actual amplification efficiency can be lower. **Gel electrophoresis** drags negatively charged DNA fragments through gel – short fragments run furthest. The **profile** of band positions supports comparisons between samples and investigation of family relationships.

Time of death narrows by four clocks: body temperature (falls ~1 °C per hour, modified by size, clothing, air), **rigor mortis** (sets then passes), decomposition degree, and insect succession on the body – each stage's arrivals time-stamp the interval.

Worked check. A body found at 22 °C core temperature in a 15 °C room: $(37 - 22)/(1\ °\text{C per hour}) \approx 15$ hours – but state the assumptions (still air, average build) before trusting it.

Check yourself

1. Name the products of the light-dependent reactions used by the Calvin cycle.
2. A crop fixes 60 000 kJ m^{-2} yr^{-1} and respirers 20 000. Calculate NPP and the energy reaching a third trophic level at 10 % transfer each step.
3. Explain why the action spectrum is evidence that chlorophyll carries out photosynthesis.
4. Distinguish directional and stabilising selection with one example of each.
5. Give two reasons a food chain rarely exceeds five trophic levels.
6. A culture grows from 5×10^3 to 4×10^6 in 6 hours. Calculate k and the doubling time.
7. Explain why a second vaccine dose raises antibody titre far faster than the first.
8. State the difference between bacteriostatic and bactericidal, and why the distinction matters for a patient with a weak immune system.
9. Three PCR cycles from one double-stranded template: how many copies?
10. A body's core is 30 °C. Estimate the time since death under standard assumptions and name one factor that would extend the true interval.

Answers: 1 ATP and reduced NADP; 2 NPP = 40 000; third level = 400 kJ $m^{-2}yr^{-1}$ (10 % of 4 000); 3 wavelengths chlorophyll absorbs best are the wavelengths that drive photosynthesis best; 4 directional – antibiotic resistance shifting the mean; stabilising – human birth weights; 5 energy lost at each step to respiration/heat/egestion, so little remains; producers also lose to respiration before the first transfer; 6 log difference 2.903, $k = 2.903/(0.301 \times 6) = 1.61$ h^{-1}, doubling $\approx$ 37 min; 7 memory B cells persist; the second encounter selects clones that divide rapidly into plasma cells – the secondary response; 8 bacteriostatic stops growth (im-

mune system must clear), bactericidal kills outright – a weak immune system needs bactericidal support; 9 $2^3 = 8$ copies; 10 $(37 - 30)/1 = 7$ hours; heavy clothing or a warm room slows cooling, so true time is longer.