MEGA LECTURE

IB DP BIOLOGY

Theme A: Unity and Diversity

A3.1 Diversity of Organisms

Revision Notes · Standard and Higher Level

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Original notes prepared for the IB Diploma Programme Biology course (first assessment 2025)

What the syllabus requires

A3.1 asks you to think about what a species actually is, how living things vary, and how biologists identify, name and count the enormous diversity of life. Use this checklist to confirm you can do each skill before the exam.

Understanding	You should be able to...
The species concept	State the biological species concept and explain why it can be difficult to apply.
Variation	Distinguish variation between species from variation within a species, and continuous from discrete variation.
Naming organisms	Outline the binomial system of nomenclature and why a shared, standardised naming system is needed.
Chromosome number	Recognise chromosome number as a shared feature within a species, and interpret differences between species.
Genome and karyotype diversity	Describe variation in genome size and karyotype among eukaryotes.
Dichotomous keys	Construct and use a dichotomous key to identify organisms from observable features.
Measuring diversity	Explain species richness and evenness conceptually and why biodiversity matters (links to A4.2).

> **Exam note:** Most of A3.1 is common to SL and HL. Sections flagged **(HL)** in these notes go further into the limits of the species concept, the conditions that favour speciation, and the role of hybridisation. This topic connects forward to A3.2 (classification), A4.1 (evolution and speciation) and A4.2 (conservation of biodiversity).

1. What is a species?

Life is not a smooth continuum: it comes in recognisable, discrete units we call **species**. Deciding exactly where one species ends and the next begins, however, is one of the oldest problems in biology.

The biological species concept

The most widely taught definition is the **biological species concept**: a species is a group of organisms that can **interbreed** and produce **fertile offspring**. The key word is *fertile* — the offspring must themselves be able to reproduce, otherwise the two parents are not counted as the same species. Members of one species share a common **gene pool** and are reproductively isolated from other species.

This definition is powerful because it is based on a real biological process (gene flow) rather than on appearance alone. Two organisms can look very different yet belong to the same species (a Great Dane and a Chihuahua), while two organisms can look almost identical yet belong to different species.

> **Watch the wording:** “Can produce offspring” is not enough. A horse and a donkey can mate and produce a mule, but the mule is almost always sterile, so horses and donkeys are still classified as separate species. Exam mark schemes reward the words *interbreed* and *fertile offspring*.

Why the concept is difficult to apply

The biological species concept works well for most familiar animals and plants, but it breaks down in several important cases:

Difficult case	Why the concept struggles
Asexual species	Bacteria, many protists and some plants reproduce asexually, so “interbreeding” never happens. The concept simply cannot be applied to them.
Ring species	A chain of neighbouring populations that can each interbreed with the next, but the two ends of the ring cannot interbreed. There is no clear line dividing one species from another.
Hybrids	Some individuals from different species can interbreed and, occasionally, produce partly or fully fertile hybrids (for example the liger, or many plant hybrids), blurring the boundary.
Extinct species	Organisms known only from fossils cannot be tested for interbreeding, so the concept cannot be applied to them directly.
Chronospecies	A single lineage changing gradually through time. Deciding where an ancestral “species” ends and a descendant “species” begins is arbitrary, because no reproductive barrier ever existed between successive generations.

Because of these difficulties, biologists use several complementary species concepts (for example the morphological concept, based on shared physical features, and the ecological concept, based on niche). No single definition works for every organism.

2. Variation between and within species

Diversity exists at two scales. **Between species**, differences are usually large and qualitative: an oak tree, a mushroom and an elephant differ in body plan, cell type and biochemistry. **Within a species**, members share the same body plan but still differ from one another — in height, colour, blood group and countless other features. This within-species variation is the raw material on which natural selection acts (A4.1).

Continuous vs discrete variation

A crucial exam skill is classifying a characteristic as showing continuous or discrete (discontinuous) variation.

Feature	Continuous variation	Discrete (discontinuous) variation
Range of values	Any value across a range (measured on a scale)	A limited number of distinct categories (counted)
Typical examples	Human height, body mass, leaf length, milk yield, skin colour	ABO blood group, ability to roll the tongue, seed shape, sex, presence of a feature
Genetic basis	Usually many genes (polygenic), each with a small effect	Usually one or a few genes
Environmental effect	Often strongly influenced by the environment	Usually little or no environmental influence
Graph used	Histogram / bell-shaped (normal) distribution	Bar chart of separate categories

Notice the practical difference: continuous variables are **measured** and give smooth, often bell-shaped distributions; discrete variables are **counted** into clear-cut groups. When both genes and environment contribute (as for height), the variation is almost always continuous.

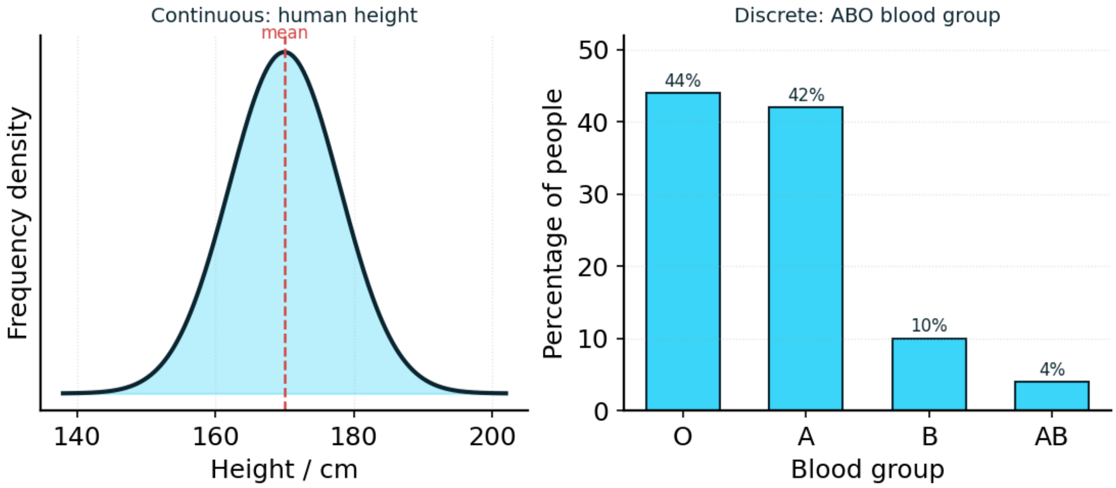

Figure 1. Continuous variation (human height) forms a smooth bell-shaped distribution shown with a histogram; discrete variation (ABO blood group) falls into a few separate categories shown with a bar chart.

> **Skill:** To decide which type a trait shows, ask two questions — "Can I measure it on a continuous scale, or does it fall into separate boxes?" and "Would a histogram or a bar chart show it best?" Continuous → histogram; discrete → bar chart.

3. Identifying and naming organisms

With millions of species described, biologists need a single, universal system for naming them. Common names are unreliable: one organism can have many local names, and the same name can refer to different organisms in different places (a "robin" in Europe is a different bird from a "robin" in North America).

Binomial nomenclature

The solution, formalised by Carl Linnaeus, is **binomial nomenclature**: every species is given a two-part Latinised scientific name.

- The first part is the **genus** (a group of closely related species); it begins with a capital letter.
- The second part is the **specific epithet**, identifying the particular species; it begins with a lower-case letter.
- The whole name is written in *italics* (or underlined when handwritten), e.g. *Homo sapiens*, *Panthera leo*, *Quercus robur*.
- After the first mention, the genus may be abbreviated to its initial, e.g. *H. sapiens*.

Because the system is standardised and internationally agreed, a scientist anywhere in the world knows exactly which organism is meant. The rules for how these names are assigned, and how organisms are grouped into larger categories, are developed fully in the next topic, **A3.2 Classification and cladistics**.

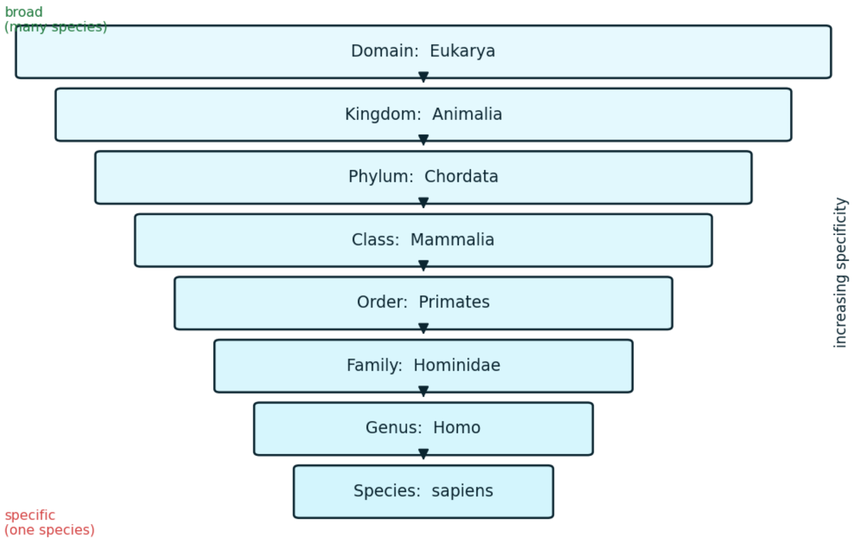

Figure 2. The Linnaean hierarchy from domain down to species, becoming more specific at each level, with Homo sapiens as the worked example.

> **Common error:** Writing the specific epithet with a capital letter, or forgetting the italics. Both lose marks. *Homo Sapiens* is wrong; *Homo sapiens* is correct.

4. Chromosome number as a shared characteristic

Members of the same species normally share the same **diploid chromosome number (2n)** — the number of chromosomes found in each of their body cells. This shared number is one reason members of a species can interbreed successfully: their chromosomes can pair up correctly during meiosis. Humans, for example, all have 46 chromosomes (23 pairs).

Different species usually have different chromosome numbers, as the table shows. Note that chromosome number is a characteristic *of the species*, not of the individual — it does not vary from one healthy individual to another.

Organism	Scientific name	Diploid number (2n)
Human	*Homo sapiens*	46
Chimpanzee	*Pan troglodytes*	48
Domestic dog	*Canis familiaris*	78
Domestic cat	*Felis catus*	38
House mouse	*Mus musculus*	40
Fruit fly	*Drosophila melanogaster*	8
Mosquito	*Culex pipiens*	6
Bread wheat	*Triticum aestivum*	42
Rice	*Oryza sativa*	24

Organism	Scientific name	Diploid number (2n)
Adder's-tongue fern	*Ophioglossum reticulatum*	about 1260

Chromosome number is not a measure of complexity

It is tempting to assume that “more complex” organisms have more chromosomes, but the data flatly contradict this. A human (2n = 46) has fewer chromosomes than a dog (2n = 78), and vastly fewer than an adder's-tongue fern, which has over 1000. The fruit fly, an animal with a nervous system, eyes and wings, manages with just 8. Chromosome number reflects how a species' genetic material happens to be packaged, not how sophisticated the organism is.

> **Key idea:** Chromosome number is a reliable label for a species, but it is **not** an indicator of evolutionary advancement or complexity. Never write “more chromosomes = more advanced.”

5. Diversity of genomes and karyotypes

The **genome** is the whole of an organism's genetic information — the complete set of DNA in one cell. Across eukaryotes, genomes vary enormously, both in the number of chromosomes and in the total amount of DNA they contain.

Karyotypes

A **karyotype** is the number and appearance of all the chromosomes in the nucleus of a body cell, arranged as matching pairs by size and banding pattern. Karyotypes let biologists compare species and detect abnormalities in chromosome number (for example an extra copy of chromosome 21). Because the karyotype is characteristic of a species, it is another way of describing the diversity between species.

Genome size variation

Genome size is usually measured as the total number of DNA base pairs. The range among eukaryotes spans several orders of magnitude:

Organism	Approximate genome size (base pairs)
Yeast (*Saccharomyces cerevisiae*)	about 1.2×10^{7}
Fruit fly (*Drosophila melanogaster*)	about 1.4×10^{8}
Human (*Homo sapiens*)	about 3.2×10^{9}
Marbled lungfish (*Protopterus aethiopicus*)	about 1.3×10^{11}
Japanese canopy plant (*Paris japonica*)	about 1.5×10^{11}

Strikingly, genome size does not correlate with organism complexity either. Some flowering plants and amphibians have genomes tens of times larger than the human genome. Much of this extra DNA is **non-coding** (it does not code for proteins), so a large genome does not mean a large number of genes. This mismatch between genome size and apparent complexity is sometimes called the C-value paradox.

> **Link:** The human genome contains ≈ 3.2 billion base pairs but only around 20 000 protein-coding genes. Most of the genome is regulatory or non-coding DNA — a point developed further when you study gene expression.

6. Dichotomous keys

A **dichotomous key** is a tool for identifying an unknown organism. It is a series of numbered steps, each offering **two** contrasting choices ("di-" means two). Each choice either names the organism or directs you to another step, until an identification is reached.

Rules for a good key

- Each step has exactly two mutually exclusive alternatives.
- Use clear, observable features (shape, number, presence or absence) rather than vague or variable ones ("large", "pretty").
- Avoid features that change with age, season or environment where possible.
- Each organism should be reachable by one, and only one, path through the key.

Worked example: building and using a key

Suppose we must identify five small animals: an **earthworm**, a **spider**, a **housefly**, a **centipede** and a **snail**. First list a distinguishing feature for each, then split the group step by step.

Step	Choice	Go to / Identify
1	a. Body has jointed legs	go to 2
	b. Body has no jointed legs	go to 5
2	a. Three pairs of legs (six legs)	Housefly
	b. More than three pairs of legs	go to 3
3	a. Four pairs of legs (eight legs)	Spider
	b. Many pairs of legs (one per body segment)	Centipede
5	a. Body inside a coiled shell	Snail
	b. Long, soft, segmented body with no shell	Earthworm

To use the key, start at step 1 and follow the choices. An unknown animal with a soft segmented body and no shell: step 1 gives "no jointed legs" (→ step 5); step 5 gives "no shell" → **earthworm**. An animal with six legs: step 1 → step 2 → **housefly**. Notice each organism is reached by a single unambiguous route.

> **Exam tip:** When building a key, always start with a feature that splits the group roughly in half, and use presence/absence or countable features. "Has legs / has no legs" is a far better first split than "big / small."

7. Measuring biodiversity

Biodiversity is the variety of life in a given area. It has several levels — the diversity of species, of genes within a species, and of ecosystems — but at this stage we focus on the diversity of species within a community. Two components together describe it.

Component	Meaning	Simple illustration
Species richness	The number of different species present in the area.	A wood with 12 tree species is richer than one with 4.
Species evenness	How evenly the individuals are spread among those species (their relative abundance).	100 individuals split 25/25/25/25 is more even than 97/1/1/1.

A community is considered more diverse when it has both high richness (many species) and high evenness (no single species overwhelmingly dominating). Because both matter, ecologists combine them into a single figure using a **diversity index**, a calculation you will meet in **A4.2 Conservation of biodiversity**.

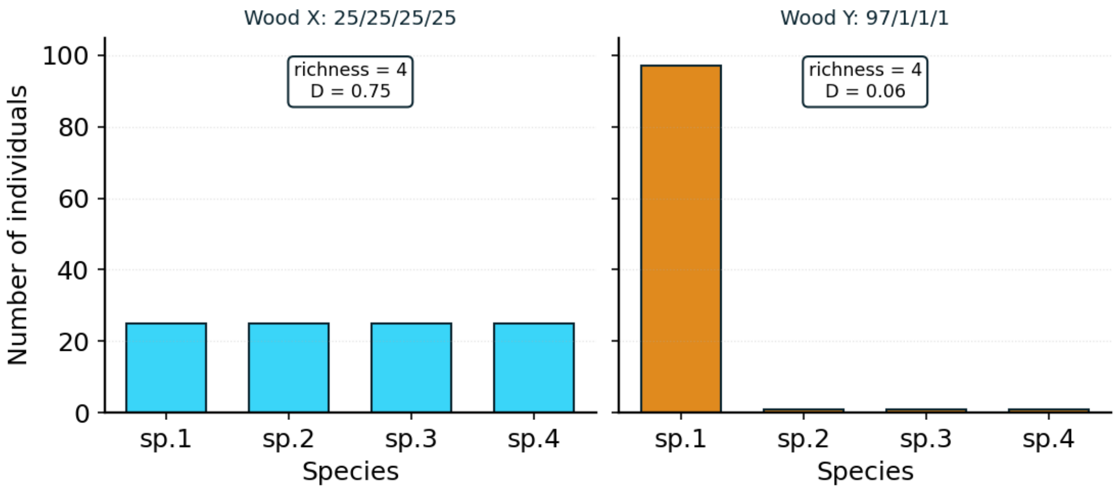

Figure 3. Two woods with equal species richness (4) but different evenness. Simpson's diversity index D = 1 minus the sum of squared proportions is far higher for the even Wood X (D = 0.75) than the dominated Wood Y (D = 0.06).

Why diversity matters

- **Resilience:** diverse ecosystems tend to recover better from disturbance, because different species can take over lost functions.
- **Ecosystem services:** pollination, nutrient cycling, water purification and climate regulation all depend on many interacting species.
- **Genetic resources:** wild diversity is a reservoir of genes for medicines, crop improvement and future adaptation.
- **Ethical and cultural value:** many argue that species have intrinsic worth and that humans have a duty to conserve them.

> **Look ahead:** A diversity index gives a single number so that two habitats can be compared objectively, and so that the same habitat can be monitored over time to detect the effects of human activity. The mathematics belongs to A4.2.

8. Difficulties, speciation and hybridisation (HL)

At Higher Level you are expected to reason more deeply about *why* the species concept is hard to apply and how new species form.

Limits of the species concept (HL)

The biological species concept assumes a clear reproductive barrier, but nature provides many intermediate cases. Populations may be **partly** reproductively isolated — able to interbreed occasionally but rarely doing so, or producing hybrids of reduced fertility. In such cases, whether to call them one species or two is a judgement, not a fact. Ring species make this especially clear: reproductive isolation accumulates gradually around the ring, so there is no single point at which “one species” becomes “two.” This shows that species boundaries can be genuinely fuzzy because **speciation is a gradual process**.

Conditions that favour speciation (HL)

Speciation — the formation of new species — is favoured when gene flow between populations is reduced and the populations then diverge:

- **Isolation:** a barrier stops interbreeding. It may be geographical (a mountain, river or ocean — allopatric speciation) or occur within the same area through behavioural, temporal or ecological barriers (sympatric speciation).
- **Different selection pressures:** the separated populations experience different environments, so natural selection pushes them in different directions.
- **Time and small population size:** given enough generations, mutation, natural selection and genetic drift accumulate differences until the populations can no longer interbreed.
- **Reproductive isolation becoming permanent:** once the populations can no longer produce fertile offspring even if reunited, speciation is complete.

Hybridisation and its role (HL)

Hybridisation is interbreeding between members of different species (or genetically distinct populations). Its outcomes vary and shape the diversity of life in important ways:

Outcome of hybridisation	Consequence
Sterile hybrid	Genes do not flow between the species (e.g. the mule); the two species stay distinct.
Fertile hybrid	Genes can flow between the parent species, which may blur or even merge them, or create new variation on which selection can act.
Polyploid hybrid (esp. plants)	Chromosome doubling can restore fertility and instantly produce a new, reproductively isolated species — an important route to new plant species, including many crops.
Hybrid zones	Regions where two species meet and interbreed; studying them reveals how strong reproductive barriers really are.

Hybridisation therefore cuts both ways: it can break down the boundaries between species, but through polyploidy it can also generate entirely new species. This is a further reason the neat biological species concept does not capture the full messiness of real populations. Speciation and its mechanisms are explored in detail in **A4.1**.

> **HL exam focus:** Be ready to explain, with an example, why a named case (ring species, a fertile plant hybrid, or a polyploid crop) challenges the biological species concept, and to link reduced gene flow to divergence and speciation.

9. Skills, pitfalls and practice

Skills practice

Skill 1 — using a dichotomous key

Use the key in Section 6 to identify an animal that has a coiled external shell and no jointed legs.

Step 1: it has no jointed legs → go to step 5.

Step 5: it has a body inside a coiled shell → **Snail**.

The identification uses only clear, observable features, and just one path leads to the answer.

Skill 2 — continuous or discrete?

Classify each characteristic: (a) the number of petals on buttercup flowers, (b) the mass of apples from an orchard, (c) human ABO blood group.

(a) Counted in whole numbers with distinct values → **discrete**.

(b) Measured on a continuous scale, giving a bell-shaped spread → **continuous**.

(c) Falls into a few clear categories (A, B, AB, O) → **discrete**.

Skill 3 — applying the species concept

A lion (*Panthera leo*) and a tiger (*Panthera tigris*) can breed in captivity to produce a “liger.” Female ligers are sometimes fertile, but males are sterile. Are lions and tigers the same species by the biological species concept?

Under a strict reading they are separate species: they are largely reproductively isolated in the wild and the hybrid's fertility is greatly reduced (males sterile). The partial fertility of females, however, shows why this is a borderline case that the concept handles awkwardly — exactly the kind of difficulty examined at HL.

Skill 4 — interpreting chromosome-number data

A student states: "The potato has 2n = 48 and humans have 2n = 46, so potatoes are more complex than humans." Evaluate this claim.

The claim is wrong. Chromosome number reflects how genetic material is packaged, not organism complexity. Species with more chromosomes are not more advanced — dogs (2n = 78) are not "more complex" than humans. Chromosome number is a useful label for a species but says nothing about complexity.

Common pitfalls

- Defining a species as organisms that produce *any* offspring — the offspring must be **fertile**.
- Assuming more chromosomes or a larger genome means a more complex or advanced organism. Neither correlates with complexity.
- Treating the biological species concept as universal — it fails for asexual, extinct, ring and hybridising species.
- Confusing continuous with discrete variation, or drawing a bar chart for continuous data (use a histogram).
- Capitalising the specific epithet or forgetting italics in a scientific name.
- Building a key with overlapping or vague choices, so an organism could follow more than one path.

Quick reference

Idea	Statement
Biological species concept	A group that can interbreed to produce **fertile** offspring; members share a gene pool.
Why it fails	Asexual, ring, hybrid, extinct species and chronospecies cannot be neatly classified this way.
Continuous variation	Measured; many genes + environment; histogram / normal distribution.
Discrete variation	Counted into categories; one or few genes; bar chart.
Binomial name	*Genus species* — genus capitalised, epithet lower case, whole name italicised.
Chromosome number	Shared within a species (e.g. human 2n = 46); differs between species; **not** a measure of complexity.
Genome / karyotype	Total DNA and full chromosome set; vary hugely among eukaryotes; size ≈ unrelated to complexity.
Dichotomous key	Stepwise pairs of contrasting, observable features leading to one identification.
Biodiversity	Species richness (how many) + evenness (how balanced); combined in a diversity index (A4.2).

Test yourself

Attempt all eight, then check against the worked answers.

1. State the biological species concept, making clear the property the offspring must have.

2. A mule is produced when a horse breeds with a donkey. Explain why horses and donkeys are still classified as separate species.

3. Classify each as continuous or discrete variation, giving a reason: (a) shoe size, (b) number of digits on a hand, (c) leaf surface area.

4. Write the scientific name of the domestic cat, *Felis catus*, and identify the genus and the specific epithet. State two rules for writing it correctly.

5. Humans have 2n = 46 and the adder's-tongue fern has over 1000 chromosomes. Explain what this shows about the relationship between chromosome number and complexity.

6. Using the key in Section 6, identify an animal with eight jointed legs, and list the steps you followed.

7. Two woods each contain 100 trees. Wood X has 25 trees of each of 4 species; Wood Y has 97 of one species and 1 each of 3 others. Which wood is more diverse, and why? Refer to richness and evenness.

8. (HL) Explain how geographical isolation can lead to the formation of a new species.

Answers

1. A species is a group of organisms that can interbreed to produce **fertile** offspring (offspring that can themselves reproduce). Members share a common gene pool.

2. A horse and a donkey can mate and produce a mule, but the mule is sterile, so no fertile offspring is produced. As the biological species concept requires fertile offspring, the two are classified as separate species (there is no gene flow between them).

3. (a) Shoe size — based on a continuous measurement of foot length, so underlying variation is **continuous** (though rounded to sizes). (b) Number of digits — counted in whole numbers, distinct categories → **discrete**. (c) Leaf surface area — measured on a continuous scale → **continuous**.

4. *Felis catus*. Genus = *Felis*; specific epithet = *catus*. Rules (any two): the genus is capitalised and the epithet is lower case; the whole name is written in italics (or underlined when handwritten); after first use the genus may be abbreviated to *F. catus*.

5. It shows there is **no relationship** between chromosome number and complexity. A fern with over 1000 chromosomes is not more complex than a human with 46; chromosome number reflects how genetic material is packaged, not how advanced the organism is.

6. Step 1: has jointed legs → step 2. Step 2: more than three pairs of legs → step 3. Step 3: four pairs (eight legs) → **Spider**.

7. **Wood X** is more diverse. Both woods have the same species richness (4 species), but Wood X has far greater **evenness** — its individuals are spread equally among the species, whereas Wood Y is dominated by one species. Higher evenness at equal richness means greater diversity.

8. (HL) A physical barrier (e.g. a river or mountain) separates a population so gene flow between the two parts stops. The separated populations experience different environments and therefore different selection pressures; mutation, natural selection and genetic drift cause them to diverge over many generations. Eventually the populations differ so much that they can no longer interbreed to produce fertile offspring even if reunited — a new species has formed (allopatric speciation).