MDCAT Biology Unit 7: Evolution, study guide with practice MCQs

What MDCAT asks

Unit 7 covers the two classical theories of how species change (Lamarck and Darwin), the modern synthesis that joins natural selection to Mendelian genetics, the lines of evidence that evolution has happened, and the way new species arise through isolation. By its curriculum weight it carries about 2 to 3 of the 81 Biology questions, split evenly between the two subtopics. Most questions are direct recall of definitions, names and standard examples, with the occasional one-step Hardy-Weinberg calculation.

B7.1 Theories of evolution

B7.1.1 Compare Lamarckism and Darwinism and explain natural selection

Evolution is the change in the inherited characteristics of a population over many generations. It is a change in a *population*, never in a single organism, and in *inherited* features, not features picked up during one lifetime.

Lamarckism (Jean-Baptiste Lamarck, 1809) was the first complete theory of evolution. It rests on two ideas:

- **Use and disuse of organs.** An organ that is used a great deal grows larger and stronger; one that is not used shrinks and may disappear. Examples: the giraffe's neck, the webbed feet of water birds, the lost limbs of snakes.
- **Inheritance of acquired characters.** Changes gained during an organism's own life are passed to its offspring.

Lamarck believed the environment creates a *need* which the organism answers. This is where the theory fails. August **Weismann** cut off the tails of mice for about twenty generations and the young were always born with full tails. His **germplasm theory** separates somatic cells, whose changes die with the individual, from germ cells, which form the gametes and alone carry inheritance. Acquired characters cannot be inherited, so Lamarckism is rejected.

Darwinism grew out of Charles Darwin's voyage on HMS *Beagle* (1831 to 1836) and his observations of finches and tortoises on the Galápagos Islands. Thomas Malthus's essay on population supplied the key: populations grow faster than their food supply, so more young are born than can survive. Alfred Russel **Wallace** reached the same conclusion independently (joint papers, 1858); *On the Origin of Species* appeared in 1859.

Natural selection is a chain of observations and deductions. Learn it in this order:

1. **Overproduction.** Every species produces far more offspring than can survive.
2. **Constancy of numbers.** Yet population size stays roughly the same from year to year.
3. **Struggle for existence.** So individuals compete for food, space, mates and safety.
4. **Variation.** Individuals of a species are not identical, and some variations are heritable.

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5. **Survival of the fittest and inheritance.** Individuals whose variations suit the environment survive and breed more, passing those variations on. Over many generations they accumulate; given time and isolation, a new species results.

The phrase "survival of the fittest" was coined by Herbert Spencer, and **fitness** has a precise meaning: the number of offspring an individual leaves that themselves survive to breed. A small animal that breeds early and often may be fitter than a large, strong one that breeds late. Darwin compared natural selection with **artificial selection** by breeders. His one gap was that he could not say where variation came from or how it was inherited; Mendel's work was unknown to him.

Point of comparison	Lamarckism	Darwinism
Why do organisms vary?	The environment creates a need; the organism responds by using or not using organs	Variation already exists by chance among the offspring of every generation
Role of the environment	Causes the change directly	Selects among existing variants; does not cause them
What is inherited	Characters acquired during life	Only heritable variations present from birth
Giraffe's neck	Each giraffe stretched its neck and passed it on	Giraffes born with longer necks fed better and bred more

B7.1.2 Describe the modern synthesis and the role of variation and mutation

After Mendel's laws were rediscovered in 1900 and Hugo de Vries described mutation, genetics and natural selection were combined into **neo-Darwinism**, the **modern synthesis** (Julian Huxley's name, 1942):

- The unit of evolution is the **population**. All the alleles of all the genes in a population form its **gene pool**, and evolution is a change in the **allele frequencies** of that pool over generations.
- Variation arises from **mutation** and **recombination**. Mutation (a change in DNA sequence, or in chromosome number or structure) is the *only* source of new alleles. Crossing over, independent assortment and random fertilisation only shuffle existing alleles into new combinations: new genotypes, not new genes.
- Mutations are random with respect to need, usually harmful or neutral, and rare, but over a large population and a long time they supply the raw material for selection. Only germ-line mutations (in cells that produce gametes) can be inherited.
- Selection acts on the **phenotype**, but what changes over the generations is allele frequency. Selection cannot see a recessive allele hidden in a heterozygote, so harmful recessive alleles persist.

Other agents also change allele frequencies: **gene flow** (migration), **genetic drift** (random change in small populations, as in a *bottleneck* or the *founder effect*) and **non-random mating**. Selection may be **stabilising** (the average favoured, as in human birth weight), **directional** (one extreme favoured, as in antibiotic resistance) or **disruptive** (both extremes favoured).

The **Hardy-Weinberg principle** (1908) is the yardstick against which evolution is measured: in a large population with random mating and no mutation, migration or selection, allele and genotype

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frequencies stay constant from generation to generation, so the population is in **genetic equilibrium** and is not evolving. If p is the frequency of the dominant allele and q of the recessive allele:

$p + q = 1$ and $p^2 + 2pq + q^2 = 1$

where p^2 is the frequency of homozygous dominants, $2pq$ of heterozygotes and q^2 of homozygous recessives. Because only the recessive phenotype has a certain genotype, calculations start from q^2: take its square root to find q, subtract from 1 to find p, then find what is asked. A population that departs from these frequencies is evolving.

Hardy-Weinberg condition	If it is broken, the agent of evolution is
Population is very large	Genetic drift (bottleneck, founder effect)
Mating is random	Non-random mating
No mutation	Mutation: the only source of new alleles
No migration in or out	Gene flow
No selection; all genotypes breed equally	Natural selection (stabilising, directional or disruptive)

MDCAT trap: the environment never "makes" a variation. The commonest wrong answer in this unit is any option saying organisms change *because they need to*, *in order to* survive, or *in response to* a new condition. That is Lamarck. In Darwinian and neo-Darwinian thinking the order is fixed: (1) random variation or mutation is present first, by chance, with no regard to usefulness; (2) the environment selects among the variants that already exist; (3) the survivors breed and the favoured allele becomes commoner. Bacteria do not "develop" resistance when an antibiotic is given; the drug kills the sensitive cells and the already-resistant ones multiply. Two further checks: fitness is reproductive success, not strength; only germ-line mutations are inherited.

Worked example (B7.1): a Hardy-Weinberg calculation. Albinism is caused by a recessive allele and affects about 1 person in 10,000 in a large, randomly mating population. What fraction of the population are carriers?

1. Albino individuals are homozygous recessive, so $q^2 = 1/10{,}000 = 0.0001$.
2. $q = \sqrt{0.0001} = 0.01$, so $p = 1 - 0.01 = 0.99$.
3. Carriers are heterozygotes: $2pq = 2 \times 0.99 \times 0.01 = 0.0198$, about 0.02.

Answer: roughly 2% of people, or 1 in 50, carry the allele although only 1 in 10,000 shows it. A rare recessive allele hides in heterozygotes, so selection against the homozygote removes it only very slowly.

B7.2 Evidence and speciation

B7.2.1 Describe evidence for evolution: fossils, comparative anatomy, embryology, biochemistry

Several independent lines of evidence show that living species have descended, with modification, from common ancestors. MDCAT expects you to name each line, its standard example and what it

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shows.

1. Fossils (palaeontology). A fossil is any preserved remain, impression or trace of a past organism, usually in **sedimentary rock**. Sediments settle in layers (strata), so in undisturbed rock the deeper the layer, the older the fossil (**relative dating**). **Absolute dating** uses the half-life of radioactive isotopes (carbon-14, half-life about 5,730 years, for remains younger than about 50,000 years; potassium-argon for ancient rocks). The record shows simple forms in the oldest rocks and complex forms later, and it contains **transitional forms** with features of two groups:

- ***Archaeopteryx*** (about 150 million years old) had feathers and wings like a bird but teeth, clawed fingers and a long bony tail like a reptile: a connecting link between reptiles and birds.
- The **horse series** runs from the dog-sized, several-toed, leaf-browsing *Eohippus* through *Mesohippus*, *Merychippus* and *Pliohippus* to the modern *Equus*, with one hoofed toe per foot and high-crowned grass-grinding teeth.

2. Comparative anatomy.

- **Homologous organs** share the same basic plan and embryonic origin but may serve different functions. The **pentadactyl limb** (one upper bone, two lower bones, wrist bones, five digits) appears in the human arm, bat wing, whale flipper, horse foreleg and frog leg. The similarity is inherited from a common ancestor: **divergent evolution**.
- **Analogous organs** have the same function but different plan and origin: the wing of a bird (a forelimb with bones) and the wing of an insect (a fold of the body wall); the eye of an octopus and the eye of a vertebrate; the spine of a cactus (a leaf) and the thorn of a rose (a stem outgrowth). They arise when unrelated groups face the same selection pressure: **convergent evolution**, not relationship.
- **Vestigial organs** are reduced structures that no longer perform their ancestral function: in humans the appendix, coccyx (tail bones), wisdom teeth, ear muscles and body hair. They are leftovers of descent.

3. Comparative embryology. The early embryos of all vertebrates, from fish to humans, look alike: each has a notochord, a dorsal hollow nerve cord, a post-anal tail and a row of **gill pouches** in the neck region. In fish the pouches become gill slits; in mammals they are remodelled into parts of the jaw, middle ear and neck glands. The resemblance is strongest early and the groups diverge as development continues, as descent from a common vertebrate ancestor predicts. Haeckel's biogenetic law, "ontogeny recapitulates phylogeny", is quoted in FSc texts but overstates this: embryos resemble the *embryos* of ancestors, not their adult forms.

4. Biochemistry (molecular evidence). All living things share the same basic chemistry: DNA and RNA, an almost universal genetic code, the same twenty amino acids and ATP as energy currency, which points to common origin. More precisely, the **amino acid sequence** of a protein found in many species can be compared: the fewer the differences, the more recent the common ancestor. The classic protein is **cytochrome c** (a respiratory-chain protein of about 104 amino acids): human and chimpanzee sequences are identical, the rhesus monkey differs by one amino acid, and the differences grow through other mammals, birds, fishes and yeast. Haemoglobin and DNA hybridisation (how tightly DNA strands from two species pair) give the same order. Because mutations collect at a roughly steady rate, such comparisons also act as a **molecular clock**.

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Line of evidence	Standard example	What it shows
Fossils	*Archaeopteryx*; horse series from *Eohippus* to *Equus*	Order of appearance; transitional forms
Homologous organs	Pentadactyl limb of human, bat, whale, horse, frog	Common ancestry; divergent evolution
Analogous organs	Bird wing and insect wing; octopus eye and human eye	Convergent evolution, not relationship
Vestigial organs	Appendix, coccyx, wisdom teeth, ear muscles	Leftovers of ancestral structures
Embryology	Gill pouches, notochord and tail in all early vertebrate embryos	Common vertebrate ancestor
Biochemistry	Cytochrome c sequence; universal genetic code; DNA hybridisation	Degree of relationship; fewer differences means closer

B7.2.2 Explain isolation and speciation and give examples of evolution in action

A **species** is a group of natural populations whose members can interbreed and produce **fertile** offspring, and which are reproductively isolated from other such groups (Ernst Mayr's biological species concept). Both halves matter: horse and donkey can interbreed, but the mule is sterile, so they remain two species. The concept cannot be applied to asexual organisms or fossils, where structure is used instead.

Speciation is the formation of a new species from an existing one. The usual route, **allopatric speciation**, has four stages:

1. A single population with one gene pool.
2. A **geographical barrier** (a river, a mountain range, rising sea level, colonisation of an island) splits it into two populations with no gene flow between them.
3. Each population collects its own mutations and faces different selection pressures, so the gene pools diverge.
4. Eventually the differences prevent interbreeding even if the barrier disappears: **reproductive isolation** has been reached and there are two species.

Speciation without a barrier, **sympatric speciation**, is rare in animals but common in plants through **polyploidy**: chromosome doubling makes the offspring unable to breed with the parent species in one step, as in bread wheat. When one ancestral species gives rise to many species adapted to different ways of life, the pattern is **adaptive radiation**: Darwin's finches on the Galápagos (more than a dozen species from one mainland ancestor, differing chiefly in beak size and shape for seeds, insects or cactus) and the marsupials of Australia.

Isolating mechanisms are grouped by whether they act before or after fertilisation.

Isolating mechanism	Acts	How it works	Example
Geographical	Prezygotic	Physical barrier; populations never meet	Squirrels on opposite rims of the Grand Canyon

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Ecological (habitat)	Prezygotic	Same area, different habitats	Lion (grassland) and tiger (forest)
Seasonal (temporal)	Prezygotic	Breed or flower at different times	Pines shedding pollen in different months
Behavioural	Prezygotic	Courtship signals not recognised	Firefly flash patterns; bird songs
Mechanical	Prezygotic	Reproductive parts do not fit	Insect genitalia; flowers built for different pollinators
Hybrid sterility	Postzygotic	Hybrid lives but cannot breed	Mule (horse × donkey)

Evolution in action. In short-lived organisms under strong selection, natural selection can be watched within years.

- **Industrial melanism in the peppered moth** (*Biston betularia*). Before industrialisation the pale, speckled form rested unseen on lichen-covered bark and the rare dark (melanic) form was picked off by birds. Soot killed the lichens and blackened the trunks, and by the end of the nineteenth century the dark form made up almost the whole population around Manchester while the pale form stayed common in clean countryside. Kettlewell's release-and-recapture experiments in the 1950s confirmed that birds take whichever form stands out. After clean-air laws the pale form recovered. The dark allele was always present; only the direction of selection changed.
- **Antibiotic resistance.** Among millions of bacteria a few carry a chance mutation (or a plasmid) that lets them survive a drug. The drug kills the rest, the survivors multiply, and within years the resistant strain dominates. Insecticide resistance in mosquitoes, and the sickle-cell allele kept common by malaria (heterozygote advantage), follow the same logic.

MDCAT trap: homologous is about origin, analogous is about the job. Students swap these two words constantly. Ask one question: "*do the structures share the same basic plan and embryonic origin?*" If yes, they are homologous, whatever their functions (a bat's wing and a whale's flipper look nothing alike, yet share the pentadactyl plan). If they merely do the same job with different plans, they are analogous (a bird's wing has bones; an insect's wing has none). Homologous means common ancestry and divergent evolution; analogous means convergent evolution. Two related slips: a vestigial organ is *reduced*, not necessarily useless; and "deeper rock is older" holds only for undisturbed strata.

Worked example (B7.2): are horses and donkeys one species? A horse has 64 chromosomes and a donkey 62. They mate readily and produce the mule, a healthy animal that is almost always sterile. Are horse and donkey one species, and which isolating mechanism applies?

1. Apply the definition: a species must interbreed *and* give fertile offspring. Horse and donkey pass the first test but fail the second.
2. The mule has 63 chromosomes, which cannot pair properly in meiosis, so it makes almost no viable gametes.
3. The barrier operates after the zygote has formed, so it is postzygotic, specifically hybrid sterility.

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Answer: horse and donkey are separate species kept apart by hybrid sterility, a postzygotic mechanism. The mule itself is not a species, because a species must be able to reproduce; the same applies to the liger and other sterile hybrids.

Practice MCQs

1. The idea that characters acquired by an organism during its lifetime are passed on to its offspring was proposed by:
   A. Charles Darwin
   B. Jean-Baptiste Lamarck
   C. August Weismann
   D. Alfred Russel Wallace
2. A student writes: "Giraffes have long necks because their ancestors kept stretching to reach high leaves and passed the longer necks to their young." This explanation is:
   A. Darwinian, because it mentions a struggle for food
   B. Neo-Darwinian, because it involves inheritance
   C. Lamarckian, because it relies on use and inheritance of acquired characters
   D. Mendelian, because it concerns a single character
3. In Darwin's theory the "fittest" individual in a population is the one that:
   A. leaves the largest number of offspring that survive to breed
   B. is largest and strongest
   C. lives longest
   D. changes most quickly when the environment changes
4. Which of the following is the only process that introduces a completely new allele into a gene pool?
   A. Crossing over in prophase I
   B. Independent assortment in metaphase I
   C. Random fertilisation
   D. Mutation
5. In a large, randomly mating population in Hardy-Weinberg equilibrium, 16% of individuals show a recessive phenotype. What percentage of the population is heterozygous for the gene?
   A. 16%
   B. 36%
   C. 48%
   D. 60%
6. Which pair of structures is homologous?
   A. Wing of a bird and wing of a housefly
   B. Flipper of a seal and foreleg of a cat
   C. Eye of an octopus and eye of a human
   D. Spine of a cactus and thorn of a rose
7. The amino acid sequence of cytochrome c in three species is compared with the human sequence. Species X differs at 1 position, species Y at 12 and species Z at 20. Which species shares the most recent common ancestor with humans?
   A. Species X

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B. Species Y
C. Species Z
D. It cannot be decided without comparing DNA

8. Fossils of *Archaeopteryx* show feathers and wings together with teeth, clawed fingers and a long bony tail. This fossil is important mainly because it:
A. is the oldest fossil ever found
B. proves that birds descended from mammals
C. shows that reptiles evolved from birds
D. is a transitional form linking reptiles and birds

9. Two closely related species of frog live in the same pond. One breeds in early spring and the other in late summer, so they never interbreed. The isolating mechanism is:
A. geographical isolation
B. mechanical isolation
C. seasonal (temporal) isolation
D. hybrid sterility

10. In an industrial town the dark form of the peppered moth made up 95% of the population. Clean-air laws then removed the soot, lichens regrew and tree trunks became pale again. Over the following decades the frequency of the dark allele is expected to:
A. stay the same, because the allele is dominant
B. rise, because dark moths are now rare and therefore favoured
C. fall, because the clean air causes dark moths to mutate back to pale
D. fall, because pale moths are now better hidden from birds and leave more offspring

Answer key

1. **B.** Inheritance of acquired characters is Lamarck's idea; Weismann disproved it, and Darwin and Wallace proposed natural selection.
2. **C.** "Stretching" is use of an organ and "passed to their young" is inheritance of an acquired character: both are Lamarck's mechanisms, not Darwin's.
3. **A.** Fitness means reproductive success, the number of offspring surviving to reproduce, not size, strength or lifespan.
4. **D.** Crossing over, independent assortment and random fertilisation only recombine alleles that already exist; mutation alone creates new ones.
5. **C.** $q^2 = 0.16$ so $q = 0.4$ and $p = 0.6$; heterozygotes are $2pq = 2 \times 0.6 \times 0.4 = 0.48$, that is 48%.
6. **B.** Seal flipper and cat foreleg are both pentadactyl limbs with the same bones and origin; the other pairs do the same job with different plans and origins, so they are analogous.
7. **A.** The fewer the amino acid differences, the more recent the common ancestor; protein sequence comparison is valid evidence in its own right.
8. **D.** *Archaeopteryx* mixes reptile and bird features, exactly what a transitional form between the two groups should look like.
9. **C.** The populations share a habitat and could physically mate, but their breeding seasons do not overlap: a prezygotic, seasonal (temporal) barrier.
10. **D.** Selection has reversed: on pale bark the pale moths are camouflaged and the dark ones

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> are eaten, so the dark allele declines. Clean air does not cause mutations, and dominance does not keep an allele common.

Before the test: 12 facts to recite

1. Evolution is a change in the inherited features of a population over generations: a change in allele frequencies in a gene pool.
2. Lamarck: use and disuse of organs, and inheritance of acquired characters. Rejected by Weismann's germplasm theory: only germ cells carry inheritance.
3. Darwin's chain: overproduction → constancy of numbers → struggle for existence → variation → survival of the fittest → inheritance of favourable variations.
4. Malthus gave Darwin the struggle for existence; Wallace reached the same theory independently; *On the Origin of Species*, 1859.
5. Fitness is the number of offspring that survive to breed, not strength or size.
6. Mutation is the only source of new alleles; crossing over, independent assortment and random fertilisation only make new combinations. Only germ-line mutations are inherited.
7. Hardy-Weinberg: $p + q = 1$ and $p^2 + 2pq + q^2 = 1$, valid only in a large, randomly mating population with no mutation, migration or selection. Always start from q^2.
8. Fossils: deeper undisturbed strata are older; *Archaeopteryx* links reptiles and birds; the horse series runs from *Eohippus* to *Equus*.
9. Homologous: same plan and origin, different function, divergent evolution (pentadactyl limb). Analogous: same function, different origin, convergent evolution (bird and insect wings). Vestigial: reduced, original function lost (appendix, coccyx).
10. Early vertebrate embryos all have gill pouches, a notochord and a tail. In cytochrome c, human and chimpanzee are identical; the fewer the differences, the closer the relationship.
11. A species can interbreed to give fertile offspring; the mule is sterile, so horse and donkey are separate species (hybrid sterility, postzygotic). Allopatric speciation: geographical barrier → divergence → reproductive isolation.
12. Evolution in action: industrial melanism in the peppered moth, antibiotic resistance in bacteria, adaptive radiation of the Galápagos finches. In every case the variation came first and the environment only selected.

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