

# ART 1: IMPORTANT CONCEPTS FROM NCERT CLASS 10 SCIENCE CHAPTER 9 - HEREDITY AND EVOLUTION

*(Note: NCERT textbooks don't have numbered paragraphs; concepts are organized under section headings with page numbers)*

## 1. ACCUMULATION OF VARIATION DURING REPRODUCTION (Page 143)

Key Concepts:

- Variation: Differences in characteristics among individuals of a species
- In asexual reproduction, variations arise only due to inaccuracies in DNA copying (mutations) and are minimal
- In sexual reproduction, variations accumulate due to:
  - DNA copying errors during gamete formation
  - Recombination of genetic material from two parents
  - Independent assortment of chromosomes during meiosis
- Significance: Variations enable species survival under changing environmental conditions. Organisms with favorable variations survive and reproduce (natural selection)

## 2. HEREDITY - MENDEL'S EXPERIMENTS (Pages 147-150)

Mendel's Choice of Pea Plant (Page 147):

- Easy to grow with short life cycle
- Naturally self-pollinating but can be cross-pollinated manually
- Has many contrasting visible traits (e.g., tall/short, violet/white flowers)
- [ncert.nic.in](http://ncert.nic.in)
- 
- Produces large number of offspring for statistical analysis

Monohybrid Cross (Page 147):

- Cross between two pea plants differing in one pair of contrasting characters (e.g., tall × short)
- F<sub>1</sub> Generation: All offspring showed only one parental trait (tall) → Dominant trait
- F<sub>2</sub> Generation: Both parental traits reappeared in 3:1 ratio (3 tall : 1 short)
- Mendel's First Law (Law of Dominance): In a heterozygous individual, only the dominant allele expresses itself
- Mendel's Second Law (Law of Segregation): Allele pairs separate during gamete formation; each gamete receives only one allele

Dihybrid Cross (Page 150):

- Cross between plants differing in two pairs of contrasting characters (e.g., round-yellow seeds × wrinkled-green seeds)
- F<sub>2</sub> Phenotypic Ratio: 9:3:3:1 (9 round-yellow : 3 round-green : 3 wrinkled-yellow : 1 wrinkled-green)
- Mendel's Third Law (Law of Independent Assortment): Genes for different traits assort independently during gamete formation

### **3. GENETIC BASIS OF INHERITANCE (Pages 147-150)**

- Gene: Basic unit of heredity; segment of DNA that codes for a specific protein/trait
- Chromosomes: Thread-like structures in nucleus carrying genes; humans have 23 pairs (46 total)
- Alleles: Different forms of same gene (e.g., T for tall, t for short)
- Genotype vs Phenotype:
  - Genotype = Genetic constitution (e.g., TT, Tt, tt)
  - Phenotype = Observable characteristics (e.g., tall or short plant)

### **4. SEX DETERMINATION IN HUMANS (Page 156)**

- Humans have 23 pairs of chromosomes:
  - 22 pairs = Autosomes (non-sex chromosomes)
  - 1 pair = Sex chromosomes (XX in females, XY in males)
- Mechanism:
  - All eggs carry X chromosome
  - Sperms carry either X or Y chromosome (50% each)
  - Female child (XX): Formed when X-bearing sperm fertilizes egg
  - Male child (XY): Formed when Y-bearing sperm fertilizes egg
- Critical Point: Father determines sex of child (not mother) as he contributes either X or Y chromosome

### **5. EVOLUTION (Pages 156-164)**

What is Evolution?

- Cumulative change in heritable characteristics of biological populations over successive generations

Evidences of Evolution (Page 158):

a) Fossil Evidence:

- Fossils = Preserved remains/traces of ancient organisms
- Show transitional forms (e.g., Archaeopteryx - link between reptiles and birds)
- Reveal chronological sequence of life forms

b) Homologous Organs:

- Similar structure, different function (e.g., human hand, bat wing, whale flipper)
- Indicate common ancestry

c) Analogous Organs:

- Different structure, similar function (e.g., insect wing vs bird wing)
- Result of convergent evolution (similar environmental pressures)

d) Embryological Evidence:

- Similar early embryonic stages across vertebrates suggest common ancestry

e) Molecular Evidence:

- Similarities in DNA/protein sequences indicate evolutionary relationships

Speciation (Page 162):

- Formation of new species from existing ones due to:
  - Geographical isolation
  - Genetic drift
  - Natural selection acting on variations

Human Evolution (Page 163):

- All humans belong to single species *Homo sapiens*
- Physical differences (skin color, height) result from evolutionary adaptations to local environments, NOT separate evolutionary paths

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## PART 2: ORIGINAL PRACTICE QUESTIONS (Created Based on Syllabus)

### 50 ORIGINAL MCQs WITH ANSWERS & EXPLANATIONS

*(Note: These are newly created questions based on NCERT concepts, NOT copied from CBSE papers)*

Section A: Variation & Heredity (Pages 143-147)

In asexual reproduction, variations arise primarily due to:

- Crossing over during meiosis
- Inaccuracies in DNA copying
- Fusion of gametes from two parents
- Independent assortment of chromosomes

Answer: b) Inaccuracies in DNA copying

1. Explanation: Asexual reproduction involves only one parent; variations occur mainly due to mutations (errors in DNA replication). Sexual reproduction mechanisms like crossing over and independent assortment don't occur. (Ref: Page 143)

Which statement correctly explains why sexual reproduction generates more variations than asexual reproduction?

- a) It involves only one parent
- b) It produces fewer offspring
- c) It combines DNA from two different individuals
- d) It occurs only in plants

Answer: c) It combines DNA from two different individuals

2. Explanation: Sexual reproduction brings together genetic material from two parents, creating new combinations of genes in offspring. (Ref: Page 143)

A trait that appears in the  $F_1$  generation of a monohybrid cross is called:

- a) Recessive trait
  - b) Dominant trait
  - c) Intermediate trait
  - d) Hidden trait
- Answer: b) Dominant trait

3. Explanation: According to Mendel's Law of Dominance, the trait expressed in  $F_1$  generation is dominant; the unexpressed trait is recessive. (Ref: Page 147)

In Mendel's monohybrid cross between pure tall (TT) and pure short (tt) pea plants, the genotype of  $F_1$  progeny will be:

- a) TT
- b) tt
- c) Tt
- d) TTtt

Answer: c) Tt

4. Explanation: Each parent contributes one allele. Tall parent (TT) contributes T, short parent (tt) contributes t  $\rightarrow$  All  $F_1$  offspring are heterozygous Tt. (Ref: Page 147)

The phenotypic ratio in  $F_2$  generation of a monohybrid cross is:

- a) 1:1
- b) 3:1
- c) 9:3:3:1
- d) 1:2:1

Answer: b) 3:1

5. Explanation: In monohybrid cross  $F_2$  generation, 3 individuals show dominant phenotype, 1 shows recessive phenotype. (Ref: Page 147)

*(Questions 6-50 follow similar pattern covering all topics with page references)*

Section B: Sex Determination (Page 156)

Human females have which combination of sex chromosomes?

- a) XY
- b) YY
- c) XX
- d) XO

Answer: c) XX

6. Explanation: Females have two X chromosomes (XX), while males have one X and one Y chromosome (XY). (Ref: Page 156)

Who determines the sex of the child in humans?

- a) Mother only
- b) Father only
- c) Both parents equally
- d) Environmental factors

Answer: b) Father only

7. Explanation: Mother always contributes X chromosome via egg. Father contributes either X (girl) or Y (boy) via sperm, thus determining sex. (Ref: Page 156)

8. In a dihybrid cross between pure round-yellow (RRYY) and wrinkled-green (rryy) pea plants, the phenotypic ratio in  $F_2$  generation is:

- a) 3:1
- b) 1:1
- c) 9:3:3:1
- d) 1:2:1

Answer: c) 9:3:3:1

Explanation: Dihybrid cross  $F_2$  shows 9 round-yellow : 3 round-green : 3 wrinkled-yellow : 1 wrinkled-green. This demonstrates independent assortment of seed shape and color genes. (Ref: Page 150)

9. Homologous organs provide evidence for:

- a) Convergent evolution
- b) Common ancestry
- c) Acquired traits
- d) Genetic drift

Answer: b) Common ancestry

Explanation: Homologous organs (e.g., human hand, bat wing, whale flipper) have similar anatomical structure but different functions, indicating descent from a common ancestor. (Ref: Page 158)

10. Which pair represents analogous organs?

- a) Forelimbs of human and bat
- b) Wings of butterfly and bird
- c) Thorns of Bougainvillea and tendrils of cucurbit
- d) Heart of fish and heart of frog

Answer: b) Wings of butterfly and bird

Explanation: Butterfly wings (made of chitin) and bird wings (modified forelimbs with bones) have different structures but similar function (flight), showing convergent evolution. (Ref: Page 159)

11. Fossils are most commonly found in:

- a) Igneous rocks
- b) Metamorphic rocks
- c) Sedimentary rocks
- d) Volcanic rocks

Answer: c) Sedimentary rocks

Explanation: Sedimentary rocks form by deposition of sediments over time, preserving remains of organisms as fossils. Igneous and metamorphic rocks form under high heat/pressure that destroys organic remains. (Ref: Page 158)

12. The process by which new species develop from existing species is called:

- a) Mutation
- b) Speciation
- c) Hybridization
- d) Regeneration

Answer: b) Speciation

Explanation: Speciation is the evolutionary process where populations evolve to become distinct species, often due to geographical isolation, genetic drift, or natural selection. (Ref: Page 162)

13. Which factor does NOT contribute to speciation?

- a) Geographical isolation
- b) Genetic drift
- c) Natural selection
- d) Asexual reproduction

Answer: d) Asexual reproduction

Explanation: Asexual reproduction produces genetically identical offspring with minimal variation, reducing chances of speciation. Sexual reproduction with recombination promotes variation essential for speciation. (Ref: Page 162)

14. Acquired traits differ from inherited traits because acquired traits:

- a) Are passed to next generation
- b) Result from changes in DNA
- c) Develop during lifetime and are not inherited
- d) Follow Mendelian inheritance patterns

Answer: c) Develop during lifetime and are not inherited

Explanation: Acquired traits (e.g., muscle gain from exercise, loss of tail in mice) develop in response to environment but don't alter DNA, so they aren't inherited. Only DNA changes are inherited. (Ref: Page 155)

15. According to Darwin's theory, evolution occurs primarily through:

- a) Inheritance of acquired characters
- b) Natural selection acting on variations
- c) Sudden large mutations
- d) Use and disuse of organs

Answer: b) Natural selection acting on variations

Explanation: Darwin proposed that individuals with favorable variations survive environmental challenges and reproduce more successfully ("survival of the fittest"), passing advantageous traits to offspring. (Ref: Page 161)

16. Genetic drift refers to:

- a) Deliberate selection of traits by humans
- b) Change in gene frequency due to random events in small populations
- c) Migration of individuals between populations
- d) Formation of new species through isolation

Answer: b) Change in gene frequency due to random events in small populations

Explanation: Genetic drift causes random changes in allele frequencies, especially in small populations (e.g., after natural disasters), independent of natural selection. (Ref: Page 161)

17. In human beings, the sex chromosome contributed by the mother is always:

- a) X
- b) Y
- c) Either X or Y
- d) Both X and Y

Answer: a) X

Explanation: Human females have XX chromosomes, so all eggs carry one X chromosome. Males (XY) produce sperms with either X or Y chromosome. (Ref: Page 156)

18. A child born with blood group O has parents with blood groups A and B respectively. What are the possible genotypes of the parents?

- a)  $I^A I^A$  and  $I^B I^B$
- b)  $I^A i$  and  $I^B i$
- c)  $I^A I^B$  and  $ii$
- d)  $ii$  and  $ii$

Answer: b)  $I^A i$  and  $I^B i$

Explanation: Blood group O has genotype  $ii$ . To produce  $ii$  child, each parent must contribute 'i' allele. Parent with blood group A must be  $I^A i$  (not  $I^A I^A$ ), and parent with blood group B must be  $I^B i$  (not  $I^B I^B$ ). (Ref: Page 149 - Extension of Mendelian concept)

19. Which statement about evolution is INCORRECT?

- a) Evolution always leads to complexity
- b) Evolution occurs at population level

- c) Evolution is a slow, gradual process
- d) Evolution results from accumulation of variations

Answer: a) Evolution always leads to complexity

Explanation: Evolution doesn't necessarily lead to complexity; sometimes simplification occurs (e.g., loss of eyes in cave fish). Evolution is change in heritable characteristics over generations, not progress toward "higher" forms. (Ref: Page 163)

20. Archaeopteryx is considered a connecting link between:

- a) Fish and amphibians
- b) Reptiles and birds
- c) Amphibians and reptiles
- d) Birds and mammals

Answer: b) Reptiles and birds

Explanation: Archaeopteryx fossil shows both reptilian features (teeth, long tail) and avian features (feathers, wings), providing evidence for evolution of birds from reptiles. (Ref: Page 158)

21. The forelimb of a whale, bat, and human are examples of:

- a) Analogous organs
- b) Vestigial organs
- c) Homologous organs
- d) Adaptive radiation

Answer: c) Homologous organs

Explanation: These forelimbs have similar bone structure (humerus, radius, ulna, carpals) but different functions (swimming, flying, grasping), indicating common ancestry with divergent evolution. (Ref: Page 158)

22. Which is a vestigial organ in humans?

- a) Heart
- b) Appendix
- c) Kidney
- d) Liver

Answer: b) Appendix

Explanation: Vestigial organs are reduced/functionless remnants of structures that were functional in ancestors. Human appendix is a vestige of a larger cecum used for cellulose digestion in herbivorous ancestors. (Ref: Page 159)

23. Natural selection acts on:

- a) Genotype only
- b) Phenotype only
- c) Both genotype and phenotype
- d) Neither genotype nor phenotype

Answer: b) Phenotype only

Explanation: Natural selection acts on observable characteristics (phenotype). However, since phenotype results from genotype interacting with environment, favorable genotypes get selected indirectly. (Ref: Page 161)

24. Two isolated populations of the same species accumulate different variations over time. This may eventually lead to:

- a) Increased mutation rate
- b) Speciation
- c) Decreased genetic diversity
- d) Asexual reproduction

Answer: b) Speciation

Explanation: Geographical isolation prevents gene flow between populations. Different selective pressures and genetic drift cause accumulation of distinct variations, potentially resulting in reproductive isolation and new species formation. (Ref: Page 162)

25. Which statement correctly describes the relationship between classification and evolution?

- a) Classification is independent of evolutionary relationships
- b) Organisms with recent common ancestry are grouped together
- c) Classification is based only on physical appearance
- d) Evolutionary relationships cannot be determined from classification

Answer: b) Organisms with recent common ancestry are grouped together

Explanation: Modern classification (phylogenetic system) groups organisms based on evolutionary relationships. Closer evolutionary relationship = more recent common ancestor = placed in same taxonomic group. (Ref: Page 160)

26. In Mendel's experiments, when  $F_1$  tall plants ( $Tt$ ) were self-pollinated, the percentage of pure tall ( $TT$ ) plants in  $F_2$  generation was:

- a) 25%
- b) 50%
- c) 75%
- d) 100%

Answer: a) 25%

Explanation:  $F_1$  cross:  $Tt \times Tt \rightarrow$  Offspring:  $TT$  (25%),  $Tt$  (50%),  $tt$  (25%). Pure tall =  $TT$  = 25%. Phenotypically tall plants ( $TT + Tt$ ) = 75%. (Ref: Page 147)

27. A trait that is expressed only in homozygous condition is:

- a) Dominant trait
- b) Recessive trait
- c) Co-dominant trait
- d) Incomplete dominant trait

Answer: b) Recessive trait

Explanation: Recessive traits are masked by dominant alleles in heterozygous condition and expressed only when both alleles are recessive (homozygous recessive). (Ref: Page 147)

28. Which factor increases genetic variation in a population?

- a) Asexual reproduction
- b) Inbreeding
- c) Sexual reproduction
- d) Cloning

Answer: c) Sexual reproduction

Explanation: Sexual reproduction generates variation through crossing over, independent assortment during meiosis, and random fusion of gametes from two parents. (Ref: Page 143)

29. The theory of inheritance of acquired characters was proposed by:

- a) Charles Darwin
- b) Gregor Mendel
- c) Jean Baptiste Lamarck
- d) Alfred Wallace

Answer: c) Jean Baptiste Lamarck

Explanation: Lamarck proposed that characteristics acquired during lifetime (e.g., giraffe's long neck from stretching) are inherited by offspring. This theory was later disproved; only DNA changes are inherited. (Ref: Page 155)

30. Which provides the most direct evidence for evolution?

- a) Similarities in embryonic development
- b) Fossil record showing transitional forms
- c) Presence of vestigial organs
- d) Molecular homology in DNA sequences

Answer: b) Fossil record showing transitional forms

Explanation: Fossils provide chronological evidence of evolutionary changes, showing intermediate forms between ancestral and descendant species (e.g., Archaeopteryx between reptiles and birds). (Ref: Page 158)

31. Human beings who look different (e.g., skin color, height) belong to:

- a) Different species
- b) Different genera
- c) Same species *Homo sapiens*
- d) Different subspecies

Answer: c) Same species *Homo sapiens*

Explanation: All humans belong to single species *Homo sapiens*. Physical differences result from evolutionary adaptations to local environments over generations, not separate evolutionary lineages. (Ref: Page 163)

32. In a cross between heterozygous tall plant (Tt) and homozygous short plant (tt), the probability of getting short offspring is:

- a) 0%
- b) 25%
- c) 50%
- d) 75%

Answer: c) 50%

Explanation: Cross:  $Tt \times tt \rightarrow$  Gametes:  $T, t \times t, t \rightarrow$  Offspring:  $Tt$  (tall),  $Tt$  (tall),  $tt$  (short),  $tt$  (short). Ratio = 1:1 (50% tall, 50% short). This is a test cross. (Ref: Page 148)

33. Which statement about genes is CORRECT?

- a) Genes are made of proteins
- b) Genes are segments of DNA located on chromosomes

- c) All genes are expressed in every cell
- d) Genes are only present in reproductive cells

Answer: b) Genes are segments of DNA located on chromosomes

Explanation: Genes are functional units of heredity composed of DNA sequences located at specific positions (loci) on chromosomes. Not all genes are expressed in every cell (cell differentiation). (Ref: Page 147)

34. The process that creates new combinations of alleles during gamete formation is:

- a) Mutation
- b) Crossing over
- c) DNA replication
- d) Transcription

Answer: b) Crossing over

Explanation: During prophase I of meiosis, homologous chromosomes exchange segments (crossing over), creating new allele combinations on chromosomes, increasing genetic diversity. (Ref: Page 144 - Concept extension)

35. Which is NOT evidence for evolution?

- a) Homologous organs
- b) Fossil record
- c) Inheritance of acquired characters
- d) Molecular homology

Answer: c) Inheritance of acquired characters

Explanation: Inheritance of acquired characters (Lamarckism) is a disproved theory, not evidence for evolution. Homologous organs, fossils, and molecular similarities provide actual evidence. (Ref: Page 155)

36. When two pea plants with genotypes RrYy and RrYy are crossed, what fraction of offspring will have genotype RrYy?

- a) 1/16
- b) 2/16
- c) 4/16
- d) 9/16

Answer: c) 4/16 (or 1/4)

Explanation: Using dihybrid cross Punnett square: Rr × Rr gives 1 RR : 2 Rr : 1 rr; Yy × Yy gives 1 YY : 2 Yy : 1 yy. Probability of Rr = 2/4, Yy = 2/4. Combined probability = (2/4) × (2/4) = 4/16. (Ref: Page 150)

37. The evolutionary history of an organism is called its:

- a) Ontogeny
- b) Phylogeny
- c) Taxonomy
- d) Morphology

Answer: b) Phylogeny

Explanation: Phylogeny refers to evolutionary relationships and history of a species or group. Ontogeny is individual development from zygote to adult. (Ref: Page 160 - Concept extension)

38. Which factor can cause evolution WITHOUT natural selection?

- a) Mutation
- b) Genetic drift
- c) Gene flow
- d) All of these

Answer: d) All of these

Explanation: Evolution = change in allele frequencies over time. This can occur through natural selection, genetic drift (random changes), gene flow (migration), or mutation (new alleles), even without selective advantage. (Ref: Page 161)

39. A population of red beetles living in green bushes is mostly eaten by crows. After several generations, the population has more green beetles. This is an example of:

- a) Genetic drift
- b) Natural selection
- c) Artificial selection
- d) Mutation

Answer: b) Natural selection

Explanation: Green beetles had survival advantage (camouflage) in green environment, so they survived predation and reproduced more, passing green color trait. This is natural selection favoring adaptive variation. (Ref: Page 161)

40. Which statement about human evolution is TRUE?

- a) Humans evolved from modern chimpanzees
- b) Humans and chimpanzees share a common ancestor
- c) Human evolution followed a straight line from primitive to advanced forms
- d) Different human races evolved separately from different ancestors

Answer: b) Humans and chimpanzees share a common ancestor

Explanation: Humans didn't evolve from modern apes; both humans and chimpanzees evolved from a common ancestral primate species that lived ~6-7 million years ago. Human evolution involved branching, not linear progression. (Ref: Page 163)

41. In a family, both parents have attached earlobes (recessive trait). What is the probability that their child will have free earlobes (dominant trait)?

- a) 0%
- b) 25%
- c) 50%
- d) 100%

Answer: a) 0%

Explanation: Attached earlobes = recessive (ee). Both parents ee → All gametes carry 'e' → All offspring ee (attached earlobes). Free earlobes (E\_) impossible without dominant allele from parents. (Ref: Page 148 - Application)

42. The wings of a bat and the wings of an insect are:

- a) Homologous structures with same origin
- b) Analogous structures with different origin
- c) Vestigial structures
- d) Result of common ancestry

Answer: b) Analogous structures with different origin

Explanation: Bat wings = modified mammalian forelimbs (bone structure); insect wings = outgrowths of exoskeleton (no bones). Different origin but similar function (flight) = analogous organs from convergent evolution. (Ref: Page 159)

43. Which process reduces genetic variation in a population?

- a) Mutation
- b) Sexual reproduction
- c) Natural selection favoring one phenotype
- d) Gene flow from other populations

Answer: c) Natural selection favoring one phenotype

Explanation: Directional selection favoring one extreme phenotype reduces variation by eliminating other variants. Mutation and gene flow increase variation; sexual reproduction maintains it. (Ref: Page 161 - Concept extension)

44. The fossil of a dinosaur found in deeper rock layers is likely:

- a) More recent than fossils in upper layers
- b) Older than fossils in upper layers
- c) From the same time period as upper layer fossils
- d) Not useful for dating

Answer: b) Older than fossils in upper layers

Explanation: In undisturbed sedimentary rock sequences, deeper layers are older (law of superposition). Fossils in deeper layers represent earlier life forms than those in upper layers. (Ref: Page 158)

45. A change in DNA sequence that creates a new allele is called:

- a) Genetic drift
- b) Mutation
- c) Recombination
- d) Speciation

Answer: b) Mutation

Explanation: Mutation is a permanent change in DNA sequence that can create new alleles. Recombination shuffles existing alleles; genetic drift changes allele frequencies randomly. (Ref: Page 144)

46. Which statement correctly describes the role of variations in evolution?

- a) Variations are always harmful
- b) Variations provide raw material for natural selection
- c) Variations occur only due to environmental changes
- d) All variations are inherited

Answer: b) Variations provide raw material for natural selection

Explanation: Genetic variations (from mutation, recombination) create diversity in populations. Natural selection acts on this variation, favoring traits suited to environment, driving evolutionary change. (Ref: Page 143)

47. When a population is drastically reduced in size (bottleneck effect), the surviving population may have:

- a) Increased genetic diversity
- b) Reduced genetic diversity
- c) No change in allele frequencies

d) Only dominant alleles

Answer: b) Reduced genetic diversity

Explanation: Population bottleneck (sudden size reduction) causes loss of many alleles by chance, reducing genetic diversity in survivors regardless of adaptive value (genetic drift). (Ref: Page 161)

48. In humans, which chromosome determines maleness?

a) X chromosome

b) Y chromosome

c) Autosome number 21

d) Both X and Y equally

Answer: b) Y chromosome

Explanation: Presence of Y chromosome triggers male development (via SRY gene). XX = female, XY = male. Y chromosome is smaller and carries fewer genes than X. (Ref: Page 156)

49. Two pea plants with round seeds are crossed. Some offspring have wrinkled seeds. What must be the genotypes of the parents?

a) RR × RR

b) RR × Rr

c) Rr × Rr

d) rr × rr

Answer: c) Rr × Rr

Explanation: Wrinkled seeds (recessive, rr) appear only if both parents carry recessive allele 'r'. Round parents producing wrinkled offspring must both be heterozygous (Rr). Cross: Rr × Rr → 3 round : 1 wrinkled. (Ref: Page 147)

50. Which provides molecular evidence for evolution?

a) Similarities in DNA sequences between species

b) Presence of homologous organs

c) Fossil record

d) Embryonic similarities

Answer: a) Similarities in DNA sequences between species

Explanation: Closely related species share more similar DNA/protein sequences than distantly related ones (e.g., human-chimpanzee DNA ~98% identical), providing molecular evidence for common ancestry. (Ref: Page 160 - Concept extension)

## 20 ORIGINAL SHORT ANSWER QUESTIONS (2-3 Marks Each)

*With Solutions, Explanations & NCERT Page References*

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1. Differentiate between inherited traits and acquired traits. Give one example of each. (2 marks)

Reference: Page 155

Solution:

| Inherited Traits                                   | Acquired Traits                                                  |
|----------------------------------------------------|------------------------------------------------------------------|
| Passed from parents to offspring through genes/DNA | Developed during lifetime due to environment/experience          |
| Result from changes in DNA                         | Do not involve DNA changes                                       |
| Example: Eye color, blood group                    | Example: Muscular body from exercise, loss of finger in accident |

Explanation: Only DNA changes are inherited. Acquired traits (like large muscles from gym) don't alter germ cells (sperm/egg), so they cannot be passed to next generation. This disproves Lamarck's theory of inheritance of acquired characters.

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2. Why are variations important for the survival of a species? Explain with an example. (2 marks)

Reference: Page 143

Solution:

Variations provide raw material for natural selection. When environment changes, individuals with favorable variations survive and reproduce, while others may die.

Example: In a population of red beetles living on green leaves, a variation producing green beetles occurs. Crows (predators) spot red beetles easily but miss green ones (camouflage). Green beetles survive, reproduce, and pass the green color trait.

Without this variation, entire population might get wiped out.

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3. State Mendel's Law of Segregation. How did he arrive at this law? (2 marks)

Reference: Page 147-148

Solution:

Law of Segregation: During gamete formation, the two alleles for a trait separate (segregate) so that each gamete receives only one allele. Fertilization restores the paired condition in offspring.

How Mendel arrived: In monohybrid cross (tall × short), F<sub>1</sub> plants were all tall (Tt).

When F<sub>1</sub> self-pollinated, F<sub>2</sub> showed 3:1 ratio with reappearance of short plants. This proved that recessive allele (t) was present but hidden in F<sub>1</sub>, and segregated during gamete formation.

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4. What are homologous organs? Give two examples. What do they indicate about evolution? (2 marks)

Reference: Page 158

Solution:

Homologous organs are structures with similar basic anatomical design and origin but different functions in different organisms.

Examples:

(i) Forelimb of human (grasping), bat (flying), whale (swimming) – all have humerus, radius, ulna, carpals

(ii) Mouthparts of cockroach (biting), butterfly (sucking), mosquito (piercing)

Evolutionary significance: They indicate common ancestry and divergent evolution – organisms evolved from same ancestor but adapted to different environments.

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5. Why is the statistical analysis of offspring important in Mendel's experiments? (2 marks)

Reference: Page 147

Solution:

Statistical analysis was crucial because:

(i) It revealed consistent mathematical ratios (3:1 in monohybrid, 9:3:3:1 in dihybrid crosses) that couldn't occur by chance

(ii) Large sample size minimized errors from random fluctuations

(iii) Ratios provided evidence for particulate inheritance (genes) rather than blending inheritance

(iv) Enabled formulation of laws of inheritance based on probability

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6. Explain why a child's sex is determined by the father and not the mother. (2 marks)

Reference: Page 156

Solution:

- Human females have XX chromosomes → all eggs carry only X chromosome
- Human males have XY chromosomes → sperms carry either X or Y chromosome (50% each)
- Fertilization possibilities:
  - X-bearing sperm + egg (X) → XX (female child)
  - Y-bearing sperm + egg (X) → XY (male child)

Since mother always contributes X, father's sperm type (X or Y) determines the child's sex.

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7. What are analogous organs? How do they differ from homologous organs? (2 marks)

Reference: Page 159

Solution:

Analogous organs: Structures with similar function but different basic structure and origin.

Example: Wings of bird (modified forelimb with bones) vs wings of insect (chitinous outgrowths).

| Feature   | Homologous Organs | Analogous Organs    |
|-----------|-------------------|---------------------|
| Structure | Similar           | Different           |
| Function  | Different         | Similar             |
| Origin    | Common ancestor   | Different ancestors |
| Evolution | Divergent         | Convergent          |

8. Define speciation. Mention two factors that can lead to speciation. (2 marks)

Reference: Page 162

Solution:

Speciation is the evolutionary process by which populations evolve to become distinct species that cannot interbreed under natural conditions.

Two factors leading to speciation:

- (i) Geographical isolation: Physical barriers (rivers, mountains) prevent gene flow between populations, allowing accumulation of different variations
- (ii) Genetic drift: Random changes in allele frequencies in small populations (e.g., after natural disaster) can lead to reproductive isolation

9. Why are fossils important in studying evolution? Give two reasons. (2 marks)

Reference: Page 158

Solution:

Fossils are important because they:

- (i) Provide chronological evidence of life forms that existed in past geological periods (deeper fossils = older organisms)
- (ii) Show transitional forms linking ancestral and descendant species (e.g., *Archaeopteryx* shows features of both reptiles and birds, proving birds evolved from reptiles)

10. A man with blood group A marries a woman with blood group O. Their child has blood group O. What are the possible genotypes of the parents? (3 marks)

Reference: Page 149 (Extension of Mendelian concept)

Solution:

- Blood group O has genotype ii (recessive)
- Child (ii) must receive 'i' allele from each parent
- Mother has blood group O → genotype must be ii
- Father has blood group A → could be I<sup>A</sup>I<sup>A</sup> or I<sup>A</sup>i

- Since child received 'i' from father, father cannot be  $I^A I^A$  (would give only  $I^A$ )
- $\therefore$  Father's genotype =  $I^A i$
- Mother's genotype =  $ii$

Cross verification:  $I^A i$  (father)  $\times$   $ii$  (mother)  $\rightarrow$  Offspring:  $I^A i$  (blood group A) or  $ii$  (blood group O) in 1:1 ratio ✓

11. What is genetic drift? When does it have maximum effect? (2 marks)

Reference: Page 161

Solution:

Genetic drift is the random change in allele frequencies in a population due to chance events, independent of natural selection.

Maximum effect occurs in:

- Small populations (e.g., after natural disasters like floods/earthquakes that kill most individuals – "bottleneck effect")
- Founder effect: When few individuals colonize a new habitat, their limited gene pool determines population's genetic makeup

In small populations, chance events can eliminate alleles rapidly, reducing genetic diversity.

12. Why did Mendel's experiments remain unrecognized for nearly 35 years after publication? (2 marks)

Reference: Page 146 (Historical context)

Solution:

Mendel's work remained unrecognized because:

- His mathematical/statistical approach was unfamiliar to biologists of that era who focused on descriptive biology
- The concept of "discrete units of inheritance" (genes) contradicted prevailing "blending inheritance" theory
- Limited communication channels in 19th century; his paper published in obscure journal of Brunn Natural History Society
- Chromosomes and DNA were unknown then; physical basis of inheritance not understood until early 1900s

13. Distinguish between natural selection and artificial selection. Give one example of each. (2 marks)

Reference: Page 161

Solution:

| Natural Selection | Artificial Selection |
|-------------------|----------------------|
|                   |                      |

|                                                                                                          |                                                                                                   |
|----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Environment selects favorable variations                                                                 | Humans selectively breed organisms with desired traits                                            |
| Leads to adaptation to natural environment                                                               | Leads to traits useful to humans                                                                  |
| Example: Peppered moth (dark variety survived better on soot-covered trees during industrial revolution) | Example: Wild cabbage bred into broccoli, cauliflower, kale, kohlrabi with different edible parts |

14. What are vestigial organs? Give two examples in humans. (2 marks)

Reference: Page 159

Solution:

Vestigial organs are reduced or functionless structures that were functional in ancestral organisms but have lost their original function during evolution.

Two examples in humans:

- (i) Appendix: Small pouch attached to large intestine; in herbivorous ancestors, it helped digest cellulose. Now largely functionless (may have minor immune role).
- (ii) Wisdom teeth (third molars): Were useful for grinding tough plant material in ancestors with larger jaws. Modern humans have smaller jaws; often impacted or unnecessary.

15. In a monohybrid cross between pure breeding tall (TT) and dwarf (tt) pea plants, what will be the phenotype and genotype ratio in F<sub>2</sub> generation? (2 marks)

Reference: Page 147

Solution:

F<sub>1</sub> generation: All Tt (tall phenotype)

F<sub>2</sub> generation (from Tt × Tt):

| Genotype  | TT   | Tt   | tt    |
|-----------|------|------|-------|
| Ratio     | 1    | 2    | 1     |
| Phenotype | Tall | Tall | Dwarf |

- Genotypic ratio: 1 TT : 2 Tt : 1 tt
- Phenotypic ratio: 3 Tall : 1 Dwarf

16. How do embryological studies provide evidence for evolution? (2 marks)

Reference: Page 159 (Concept extension)

Solution:

Embryos of different vertebrates (fish, salamander, turtle, chicken, pig, cow, rabbit, human) show striking similarities in early stages:

(i) All have gill slits and tails during development

(ii) These structures persist in fish but disappear/reduce in terrestrial vertebrates

This suggests common ancestry – all vertebrates evolved from fish-like ancestors, retaining embryonic features even when not needed in adult form ("ontogeny recapitulates phylogeny" – partially true).

---

17. Why is evolution considered a slow process? Can it ever be rapid? Explain. (3 marks)

Reference: Page 161-162

Solution:

Evolution is generally slow because:

(i) Requires accumulation of small variations over many generations

(ii) Natural selection acts gradually on existing variations

(iii) Speciation typically takes thousands to millions of years

However, evolution can be rapid in:

(i) Microorganisms: Short generation time (e.g., bacteria develop antibiotic resistance in years)

(ii) Strong selective pressure: Pesticide resistance in insects develops within decades

(iii) Polyploidy in plants: Instant speciation via chromosome doubling (single generation)

But for complex animals like mammals, evolution remains predominantly slow.

---

18. A couple has four daughters. What is the probability that their fifth child will be a daughter? Give reason. (2 marks)

Reference: Page 156

Solution:

Probability = 50% (or  $1/2$ )

Reason: Sex determination is independent for each conception:

- Mother always contributes X chromosome via egg
- Father contributes X (50%) or Y (50%) via sperm
- Each fertilization event has 50% chance of XX (female) and 50% chance of XY (male)

Previous children's sexes do not affect probability for next child (independent events).

---

19. What is the significance of the 9:3:3:1 ratio obtained in Mendel's dihybrid cross? (2 marks)

Reference: Page 150

Solution:

The 9:3:3:1 phenotypic ratio in F<sub>2</sub> generation of dihybrid cross proves:

- (i) Law of Independent Assortment: Genes for different traits (e.g., seed shape and color) segregate independently during gamete formation
  - (ii) New combinations arise: Offspring show combinations not present in parents (e.g., round-green and wrinkled-yellow seeds from round-yellow × wrinkled-green parents)
  - (iii) Traits are inherited as discrete units (genes), not blended
- 

20. All human beings belong to a single species despite physical differences. Justify this statement. (3 marks)

Reference: Page 163

Solution:

All humans belong to single species *Homo sapiens* because:

- (i) Interbreeding capability: Humans from different continents/ethnicities can marry and produce fertile offspring (no reproductive isolation)
  - (ii) Genetic similarity: Human DNA is 99.9% identical across all populations; differences in skin color, height etc. involve very few genes
  - (iii) Recent common ancestry: All modern humans evolved from African ancestors ~200,000 years ago; physical differences resulted from adaptations to local environments (e.g., skin color adaptation to UV intensity), not separate evolutionary paths
  - (iv) No subspecies classification: Unlike some animals (e.g., tiger subspecies), humans show continuous variation without distinct biological boundaries
- 

## 20 ORIGINAL LONG ANSWER QUESTIONS (5 Marks Each)

*With Detailed Solutions, Diagrams & NCERT Page References*

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1. Explain Mendel's monohybrid cross experiment with the help of a Punnett square. State and explain the two laws of inheritance derived from this experiment. (5 marks)

Reference: Pages 147-148

Solution:

Mendel's Monohybrid Cross Experiment:

Mendel crossed pure breeding tall pea plants (TT) with pure breeding dwarf plants (tt).

Step 1 – Parental (P) Cross:

TT (tall) × tt (dwarf)

↓

All F<sub>1</sub> offspring: Tt (tall phenotype)

Step 2 – F<sub>1</sub> Self-pollination:

Tt (tall) × Tt (tall)

Punnett Square for F<sub>2</sub> Generation:

|   | T  | t  |
|---|----|----|
| T | TT | Tt |
| t | Tt | tt |

F<sub>2</sub> Results:

- Genotypes: 1 TT : 2 Tt : 1 tt
- Phenotypes: 3 Tall : 1 Dwarf (75% tall, 25% dwarf)
- Key observation: Dwarf trait (absent in F<sub>1</sub>) reappeared in F<sub>2</sub>

Two Laws Derived:

(i) Law of Dominance:

- When two contrasting alleles are present together, only one (dominant) expresses itself in phenotype
- The other allele (recessive) remains hidden but is not lost
- In F<sub>1</sub>, T (tall) dominated over t (dwarf); in F<sub>2</sub>, recessive trait reappeared

(ii) Law of Segregation:

- Allele pairs separate during gamete formation; each gamete receives only one allele
- F<sub>1</sub> plants (Tt) produced two types of gametes: 50% with T, 50% with t
- Random fusion during fertilization produced 3:1 phenotypic ratio in F<sub>2</sub>
- This disproved blending inheritance theory

Significance: Established genes as discrete units of inheritance transmitted unchanged across generations.

---

2. Describe the mechanism of sex determination in human beings with the help of a flow chart. Why is it scientifically incorrect to blame mothers for the birth of daughters? (5 marks)

Reference: Page 156

Solution:

Mechanism of Sex Determination in Humans:

Chromosomal Basis:

- Humans have 23 pairs (46) chromosomes
- 22 pairs = Autosomes (same in males & females)

- 1 pair = Sex chromosomes
  - Females: XX
  - Males: XY

Flow Chart of Sex Determination:

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21

Why blaming mothers for daughters is scientifically wrong:

1. Mother's contribution is fixed: All eggs carry only X chromosome. Mother has no control over sex chromosome in her gametes.
2. Father determines sex:
  - Father produces two types of sperms: 50% with X, 50% with Y
  - If X-sperm fertilizes egg → XX (daughter)
  - If Y-sperm fertilizes egg → XY (son)
  - Sex of child depends entirely on which type of sperm (X or Y) from father fertilizes the egg
3. Probability is equal: Each conception has 50% chance of boy and 50% chance of girl – a matter of chance, not maternal "fault"
4. Social implication: Blaming mothers reflects scientific illiteracy and perpetuates gender discrimination. Education about biological mechanism is essential for gender equality.

---

3. (a) What are homologous organs? Give three examples.

(b) What are analogous organs? Give three examples.

(c) How do these organs provide evidence for evolution? (5 marks)

Reference: Pages 158-159

Solution:

(a) Homologous Organs:

Structures with similar anatomical design and embryonic origin but different functions in different organisms, indicating common ancestry.

Three examples:

1. Forelimbs of vertebrates:

- Human hand (grasping)
- Bat wing (flying)
- Whale flipper (swimming)
- *All have same bone pattern:* Humerus → Radius/Ulna → Carpals → Metacarpals → Phalanges

2. Mouthparts of insects:

- Cockroach (biting/chewing)
- Butterfly (sucking nectar)
- Mosquito (piercing/sucking blood)
- *All derived from same basic structure*

3. Thorns of Bougainvillea and tendrils of cucurbit:

- Both modifications of axillary buds
- Thorns for protection, tendrils for climbing

(b) Analogous Organs:

Structures with similar function but different basic structure and origin, resulting from adaptation to similar environments (convergent evolution).

Three examples:

1. Wings of bird vs wings of insect:

- Bird wing: Modified forelimb with bones, covered by feathers
- Insect wing: Outgrowth of exoskeleton (chitin), no bones
- *Both used for flight*

2. Eyes of octopus vs eyes of mammals:

- Octopus eye: Evolved independently in molluscs
- Mammal eye: Evolved in vertebrates
- *Both provide vision but different embryonic origin*

3. Flippers of penguin (bird) vs flippers of dolphin (mammal):

- Penguin flipper: Modified wing
- Dolphin flipper: Modified forelimb
- *Both for swimming but different evolutionary origin*

(c) Evidence for Evolution:

| Organ Type | Evolutionary Process | Evidence Provided                                                                                                                                          |
|------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Homologous | Divergent evolution  | Proves common ancestry – organisms inherited similar structure from ancestor, then modified for different functions as they adapted to different niches    |
| Analogous  | Convergent evolution | Shows adaptation to environment – unrelated organisms independently evolved similar solutions to similar environmental challenges (e.g., flight, swimming) |

Conclusion: Homologous organs reveal evolutionary relationships (phylogeny), while analogous organs demonstrate power of natural selection in shaping adaptations.

---

#### 4. Explain the various evidences that support the theory of evolution. (5 marks)

Reference: Pages 158-160

Solution:

Five Major Evidences Supporting Evolution:

(i) Fossil Evidence (Page 158):

- Fossils = Preserved remains/traces of ancient organisms in sedimentary rocks
- Significance:
  - Show chronological sequence: Deeper rock layers contain older fossils
  - Reveal transitional forms linking ancestral and descendant groups
    - *Example:* Archaeopteryx – fossil with reptilian features (teeth, long bony tail) AND avian features (feathers, wings) → proves birds evolved from reptiles
  - Document extinction and appearance of new species over geological time

(ii) Homologous Organs (Page 158):

- Structures with similar anatomy but different functions (e.g., human hand, bat wing, whale flipper)
- Indicate common ancestry and divergent evolution
- Same basic design modified for different environments

(iii) Analogous Organs (Page 159):

- Structures with similar function but different structure (e.g., bird wing vs insect wing)
- Demonstrate convergent evolution – unrelated organisms independently evolve similar adaptations to similar environmental pressures

(iv) Vestigial Organs (Page 159):

- Reduced/functionless structures that were functional in ancestors
- Examples in humans: Appendix (digestive function in herbivores), wisdom teeth, tail bone (coccyx), body hair (goosebumps)
- Evidence of evolutionary history – structures retained even after losing function

(v) Molecular Evidence (Page 160 - Concept extension):

- DNA/protein sequence similarities indicate evolutionary relationships
  - Humans & chimpanzees: ~98% DNA similarity → recent common ancestor (~6-7 mya)
  - Humans & mice: ~85% similarity → more distant common ancestor
- Universal genetic code across all life forms supports common origin of life

Conclusion: Multiple independent lines of evidence – paleontological, anatomical, embryological, and molecular – consistently support evolution as the unifying theory of biology.

---

5. What is speciation? Explain three different ways by which speciation can occur. (5 marks)

Reference: Page 162

Solution:

Speciation Definition:

Speciation is the evolutionary process by which populations of the same species become reproductively isolated and evolve into distinct species that cannot produce fertile offspring under natural conditions.

Three Mechanisms of Speciation:

(i) Allopatric Speciation (Geographical Isolation):

- Process: Physical barrier (river, mountain range, ocean) divides population into isolated subpopulations
- Mechanism:
  - No gene flow between isolated groups
  - Different environmental pressures cause natural selection to favor different variations in each group

- Genetic drift causes random changes in small isolated populations
- Over time, accumulated genetic differences lead to reproductive isolation
- Example: Darwin's finches on Galápagos Islands – ancestral finch species colonized different islands; isolated populations evolved different beak shapes adapted to local food sources, becoming distinct species

(ii) Sympatric Speciation (Without Geographical Barrier):

- Process: New species forms within same geographical area as parent population
- Mechanisms:
  - Polyploidy (common in plants): Chromosome doubling creates instant reproductive barrier (e.g., tetraploid plant cannot breed with diploid parent)
  - Habitat differentiation: Subpopulation exploits new niche within same area (e.g., feeding on different host plant)
  - Sexual selection: Mate preferences diverge within population
- Example: *Tragopogon* plant species formed in North America within 80 years via polyploidy after introduction from Europe

(iii) Parapatric Speciation (Partial Isolation):

- Process: Populations occupy adjacent habitats with limited interbreeding in contact zone
- Mechanism:
  - Environmental gradient (e.g., soil toxicity) creates selection pressure
  - Individuals at extremes adapt to local conditions
  - Reduced fitness of hybrids in intermediate zone reinforces divergence
- Example: *Anthoxanthum odoratum* (grass) evolved tolerance to mine tailings; mine-tolerant and non-tolerant populations now show reproductive isolation despite growing side-by-side

Key Requirement for All Speciation: Evolution of reproductive isolation mechanisms – prezygotic (temporal, behavioral, mechanical isolation) or postzygotic (hybrid inviability/sterility).

---

6. (a) What are acquired traits? Why are they not inherited?

(b) What are inherited traits? How are they transmitted?

(c) Explain with an example why the inheritance of acquired traits is not possible. (5 marks)

Reference: Page 155

Solution:

(a) Acquired Traits:

- Characteristics developed by an organism during its lifetime in response to environment, use/disuse of organs, or experiences

- Examples:
  - Large muscles from weight training
  - Knowledge/skills learned (riding bicycle)
  - Loss of body part in accident (amputated finger)
  - Darkened skin from sun exposure

Why not inherited:

Acquired traits do not involve changes in DNA sequence of germ cells (sperm/egg). Only genetic information in germ cells is transmitted to offspring. Somatic (body) cell changes don't affect germ cells.

(b) Inherited Traits:

- Characteristics passed from parents to offspring through genes (DNA segments)
- Result from variations in DNA sequence (alleles) present in germ cells
- Transmission mechanism:
  - During sexual reproduction, each parent contributes one set of chromosomes via gametes
  - Gametes form by meiosis – chromosome number halved (23 in humans)
  - Fertilization restores diploid number (46 in humans)
  - Offspring receives 50% genetic material from each parent → expresses inherited traits

(c) Example Demonstrating Non-inheritance of Acquired Traits:

Weismann's Mouse Tail Experiment:

- August Weismann cut tails of mice for 22 consecutive generations
- Observation: Every new generation was born with normal-length tails
- Explanation:
  - Tail removal affected only somatic cells of parents
  - DNA in germ cells (sperm/egg) remained unchanged
  - Offspring developed from zygote with intact "tail-development" genes
  - Therefore, acquired trait (taillessness) was not inherited

Modern molecular explanation:

- DNA in germ cells is protected in gonads (testes/ovaries)
- Environmental effects on body don't alter germ cell DNA sequence (except mutagens like radiation)
- Central dogma: Information flows DNA → RNA → Protein, not Protein → DNA
- Thus, changes in proteins/body structures cannot rewrite DNA code in germ cells

Conclusion: Only DNA mutations in germ cells are inherited. This disproves Lamarck's theory of inheritance of acquired characters and supports Darwinian evolution via natural selection acting on genetic variations.

---

7. Explain Darwin's theory of natural selection with a suitable example. How does it differ from Lamarck's theory? (5 marks)

Reference: Pages 155, 161

Solution:

Darwin's Theory of Natural Selection (Page 161):

Four Postulates:

1. Overproduction: Organisms produce more offspring than can survive (limited resources)
2. Variation: Individuals in population show heritable variations in traits
3. Struggle for existence: Competition for food, space, mates; predation; environmental challenges
4. Differential survival/reproduction: Individuals with favorable variations survive better and reproduce more ("survival of the fittest") → advantageous traits accumulate in population over generations

Example – Peppered Moth (*Biston betularia*) in Industrial England:

- Pre-industrial era:
  - Light-colored moths camouflaged on lichen-covered tree trunks
  - Dark (melanic) moths easily spotted and eaten by birds
  - Light form predominated (>90%)
- Industrial revolution:
  - Soot from factories darkened tree trunks; lichens died
  - Light moths became conspicuous → heavily predated
  - Dark moths now camouflaged → survived and reproduced more
- Result: Within 50 years, dark form frequency increased to >90%
- Key point: Variation (dark color) existed before pollution; environment *selected* existing variant – no new trait acquired during lifetime

Darwin vs Lamarck – Critical Differences:

| Feature             | Darwin's Natural Selection     | Lamarck's Inheritance of Acquired Characters         |
|---------------------|--------------------------------|------------------------------------------------------|
| Source of variation | Pre-existing random variations | Variations arise during lifetime in response to need |

|                     |                                                                                  |                                                                            |
|---------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Mechanism           | Environment <i>selects</i> favorable variants                                    | Organism <i>acquires</i> traits by use/disuse                              |
| Inheritance         | Only DNA changes inherited                                                       | Acquired traits inherited                                                  |
| Example explanation | Giraffe ancestors had neck length variation; long-necked survived drought better | Giraffes stretched necks to reach leaves; offspring inherited longer necks |
| Scientific validity | Supported by evidence                                                            | Disproved (Weismann's experiment)                                          |

Conclusion: Darwin correctly identified natural selection acting on random genetic variations as evolutionary mechanism. Lamarck incorrectly proposed inheritance of environmentally induced changes.

---

8. Describe the process of fossil formation. Why are fossils found more commonly in sedimentary rocks? Explain how fossils help in determining the age of rocks. (5 marks)

Reference: Page 158

Solution:

Process of Fossil Formation (Fossilization):

Step 1 – Death and Rapid Burial:

- Organism dies near water body (river, lake, ocean)
- Body quickly buried by sediments (sand, mud) → prevents complete decomposition by scavengers/bacteria

Step 2 – Decomposition and Mineralization:

- Soft tissues decay; hard parts (bones, teeth, shells) remain
- Groundwater seeps through sediments, depositing minerals (silica, calcite) into pores of hard parts
- Original material gradually replaced by minerals → forms rock-like fossil (petrification)

Step 3 – Lithification:

- Overlying sediments compress lower layers
- Sediments harden into sedimentary rock (sandstone, shale, limestone) with fossil embedded

#### Step 4 – Exposure:

- Geological uplift or erosion exposes fossil at surface for discovery

#### Why Fossils Found Mainly in Sedimentary Rocks:

| Rock Type   | Formation Process                       | Fossil Preservation                           |
|-------------|-----------------------------------------|-----------------------------------------------|
| Sedimentary | Deposition of sediments in water bodies | ✓ Excellent – gentle burial preserves remains |
| Igneous     | Cooling of molten magma/lava            | ✗ None – extreme heat destroys organic matter |
| Metamorphic | Transformation under heat/pressure      | ✗ Rare – recrystallization destroys fossils   |

#### Dating Rocks Using Fossils (Relative Dating):

##### (i) Law of Superposition:

- In undisturbed sedimentary rock sequence, lower layers are older than upper layers
- Fossils in deeper layers represent earlier life forms

##### (ii) Index Fossils:

- Fossils of organisms that existed for short geological period but were widespread
- Presence indicates specific time period
- *Example: Ammonites* (extinct cephalopods) indicate Mesozoic Era (252-66 mya)

##### (iii) Faunal Succession:

- Fossil assemblages succeed each other in predictable order globally
- Allows correlation of rock layers across continents

Limitation: Provides relative age (older/younger), not absolute age. Absolute dating requires radiometric methods (e.g., carbon-14, potassium-argon).

- 
9. (a) What is genetic drift? Explain with an example.  
(b) How does genetic drift differ from natural selection?  
(c) When does genetic drift have maximum effect? (5 marks)

Reference: Page 161

Solution:

(a) Genetic Drift Definition & Example:

Definition: Random change in allele frequencies in a population from one generation to next due to chance events, independent of adaptive value of alleles.

Example – Beetle Population Bottleneck:

- Original population: 20 red beetles (RR/Rr) + 20 green beetles (rr) → equal frequency of R and r alleles
- Catastrophe (flood) randomly kills 38 beetles, leaving only 2 survivors: both green (rr)
- Next generation: All offspring green (rr) – red allele (R) completely lost
- Key point: Loss of R allele was random (not because red color was disadvantageous); could have equally lost green allele by chance

(b) Genetic Drift vs Natural Selection:

| Feature                | Genetic Drift                                                      | Natural Selection                                   |
|------------------------|--------------------------------------------------------------------|-----------------------------------------------------|
| Cause                  | Random sampling error (chance)                                     | Environmental pressure                              |
| Direction              | Non-adaptive; can fix harmful alleles or eliminate beneficial ones | Adaptive; increases frequency of beneficial alleles |
| Effect on fitness      | May decrease population fitness                                    | Increases population fitness                        |
| Population size effect | Strongest in small populations                                     | Effective in all population sizes                   |
| Predictability         | Unpredictable outcome                                              | Predictable direction (toward adaptation)           |
| Example                | Loss of rare allele after earthquake                               | Dark moths increase in polluted areas               |

(c) When Genetic Drift Has Maximum Effect:

1. Small Population Size:

- Sampling error magnified when few individuals contribute to next generation
  - Formula: Magnitude of drift  $\propto 1/(2N)$  where  $N$  = population size
  - In population of 10, drift 100× stronger than in population of 1000
2. Population Bottleneck:
- Sudden drastic reduction in population size (natural disaster, disease)
  - Surviving gene pool unrepresentative of original population
  - *Example:* Northern elephant seals hunted to ~20 individuals in 1890s; now recovered to 30,000 but with extremely low genetic diversity
3. Founder Effect:
- New population established by few colonizers (founders)
  - Founders carry only subset of original population's genetic diversity
  - *Example:* Amish population in Pennsylvania – high frequency of Ellis-van Creveld syndrome (dwarfism) due to few founders carrying recessive allele

Evolutionary Significance: Genetic drift can cause rapid evolutionary change in small/isolated populations, potentially leading to speciation even without natural selection.

---

10. Explain how evolution has occurred in human beings. Are different human races different species? Justify your answer. (5 marks)

Reference: Page 163

Solution:

Human Evolution – Key Stages:

(i) Primate Ancestry:

- ~65 mya: First primates evolved after dinosaur extinction
- Arboreal (tree-dwelling) mammals with grasping hands, forward-facing eyes

(ii) Hominin Divergence:

- ~6-7 mya: Lineage leading to humans split from lineage leading to chimpanzees/bonobos (our closest living relatives; share ~98% DNA)
- Early hominins (e.g., *Sahelanthropus*) showed bipedalism (walking upright)

(iii) Genus *Homo* Evolution:

- ~2.5 mya: *Homo habilis* – first stone tool makers
- ~1.8 mya: *Homo erectus* – migrated out of Africa to Asia/Europe; controlled fire
- ~300,000 ya: *Homo sapiens* (anatomically modern humans) evolved in Africa

(iv) Migration and Adaptation:

- ~70,000 ya: Modern humans migrated from Africa to rest of world

- Populations adapted to local environments:
  - Skin color: Darker near equator (protection from UV); lighter at higher latitudes (vitamin D synthesis)
  - Body shape: Stocky in cold climates (Bergmann's rule – reduce heat loss); slender in tropics (dissipate heat)
  - Lactose tolerance: Evolved independently in pastoral populations (Europe, Africa) after animal domestication

Are Different Human Races Different Species? NO – Justification:

1. Biological Species Concept:
  - Species = group of organisms that can interbreed and produce fertile offspring under natural conditions
  - Humans from all continents/ethnicities can marry and produce fully fertile children → single biological species
2. Genetic Evidence:
  - All humans share 99.9% identical DNA sequence
  - Genetic variation *within* any population (~85-90%) exceeds variation *between* populations (~10-15%)
  - "Racial" traits (skin color, hair type) controlled by very few genes among ~20,000 human genes
3. No Reproductive Isolation:
  - No biological barriers to reproduction between populations
  - Continuous gene flow throughout human history (migration, trade, conquest)
4. Recent Common Ancestry:
  - All living humans descend from African population ~200,000 years ago
  - Physical differences evolved recently (<70,000 years) as adaptations to local environments
  - Not sufficient time for speciation (typically requires millions of years)
5. Social Construct:
  - "Race" categories vary across cultures/history (e.g., US "one-drop rule" vs Brazilian continuum)
  - No discrete genetic boundaries – human variation is clinal (gradual change across geography)

Conclusion: Human "races" are not biological subspecies but socially constructed categories based on superficial physical differences resulting from recent local adaptations. All humans belong to single species *Homo sapiens* with shared evolutionary history and equal biological potential.

---

11. (a) What is a dihybrid cross?

(b) Explain Mendel's dihybrid cross experiment with seed shape and seed color in pea plants. Show the phenotypic ratio in F<sub>2</sub> generation.

(c) State the law derived from this experiment. (5 marks)

Reference: Page 150

Solution:

(a) Dihybrid Cross Definition:

A cross between two individuals differing in two pairs of contrasting traits/characters (e.g., seed shape AND seed color).

(b) Mendel's Dihybrid Cross Experiment:

Parental (P) Generation:

- Pure breeding Round-Yellow seeds (RRYY) × Wrinkled-Green seeds (rryy)

F<sub>1</sub> Generation:

- All offspring: RrYy (Round-Yellow phenotype)
- Round (R) dominant over wrinkled (r); Yellow (Y) dominant over green (y)

F<sub>1</sub> Self-pollination: RrYy × RrYy

Gamete Formation (Independent Assortment):

Each parent produces 4 types of gametes with equal probability:

RY, Ry, rY, ry (1:1:1:1 ratio)

Punnett Square (4×4) for F<sub>2</sub> Generation:

|           | <b>RY</b> | <b>Ry</b> | <b>rY</b> | <b>ry</b> |
|-----------|-----------|-----------|-----------|-----------|
| <b>RY</b> | RRYY      | RRYy      | RrYY      | RrYy      |
| <b>Ry</b> | RRYy      | RRyy      | RrYy      | Rryy      |
| <b>rY</b> | RrYY      | RrYy      | rrYY      | rrYy      |
| <b>ry</b> | RrYy      | Rryy      | rrYy      | rryy      |

F<sub>2</sub> Phenotypic Analysis:

- Round-Yellow: 9 (RRYY, RRYy, RrYY, RrYy)
- Round-Green: 3 (RRyy, Rryy)
- Wrinkled-Yellow: 3 (rrYY, rrYy)
- Wrinkled-Green: 1 (rryy)

Phenotypic Ratio: 9 : 3 : 3 : 1

Key Observation:

New combinations appeared that were not present in parental generation:

- Round-Green seeds (parent P had only Round-Yellow)
- Wrinkled-Yellow seeds (parent P had only Wrinkled-Green)
- Proved traits for seed shape and color are inherited independently

(c) Law of Independent Assortment:

"During gamete formation, alleles for different traits segregate independently of one another."

- Genes located on different chromosomes assort independently during meiosis I
- Creates new combinations of alleles in gametes → increases genetic diversity
- Basis for variation essential for evolution

Exception: Genes located close together on same chromosome show linkage (do not assort independently) – discovered after Mendel.

12. Explain the role of variations in evolution. How do variations originate during sexual reproduction? (5 marks)

Reference: Pages 143-144

Solution:

Role of Variations in Evolution:

1. Raw Material for Natural Selection:
  - Without variations, all individuals identical → no differential survival when environment changes
  - Variations provide options for selection to act upon
2. Adaptation to Changing Environments:
  - Environmental changes (climate, predators, food sources) favor individuals with specific variations
  - *Example:* Drought favors plants with deeper roots; antibiotic use favors resistant bacteria
3. Speciation:
  - Accumulation of different variations in isolated populations leads to reproductive isolation
  - Eventually forms new species
4. Survival of Species:
  - Species with high genetic variation more likely to have some individuals survive catastrophic changes
  - Low variation → vulnerability to extinction (e.g., cheetahs)

Origin of Variations During Sexual Reproduction (Page 144):

(i) DNA Copying Errors (Mutations):

- During DNA replication before meiosis, occasional mistakes occur (1 error per  $10^9$  bases)

- Creates new alleles not present in parents
- Ultimate source of all genetic variation

(ii) Crossing Over (Recombination):

- During Prophase I of meiosis, homologous chromosomes exchange segments
- Creates new combinations of alleles on same chromosome
- *Example:* Chromosome with alleles AB/ab → after crossing over → Ab/aB

(iii) Independent Assortment:

- During Metaphase I, homologous chromosome pairs align randomly at equator
- For humans (23 chromosome pairs),  $2^{23} = \sim 8$  million possible gamete combinations from single individual

(iv) Random Fertilization:

- Any sperm (1 of  $\sim 8$  million types) can fertilize any egg (1 of  $\sim 8$  million types)
- Zygote possibilities:  $8 \text{ million} \times 8 \text{ million} = \sim 70$  trillion genetically unique offspring from same parents!

Comparison: Sexual vs Asexual Reproduction

| Feature                | Sexual Reproduction                                             | Asexual Reproduction             |
|------------------------|-----------------------------------------------------------------|----------------------------------|
| Variation source       | Multiple (crossing over, independent assortment, random fusion) | Only mutations                   |
| Variation amount       | High                                                            | Very low                         |
| Evolutionary advantage | Rapid adaptation to changing environments                       | Efficient in stable environments |
| Example                | Humans, flowering plants                                        | Bacteria, Hydra, potato tubers   |

Conclusion: Sexual reproduction generates abundant variations through multiple mechanisms, providing essential raw material for natural selection and long-term evolutionary success of species.

---

13. (a) What are sex chromosomes? How many sex chromosomes are present in human beings?

(b) Draw a flow chart showing determination of sex in humans.

(c) In a family with four sons, what is the probability that the fifth child will be a son? Explain. (5 marks)

Reference: Page 156

Solution:

(a) Sex Chromosomes:

- Pair of chromosomes that determine biological sex of an individual
- Differ in morphology and gene content from autosomes (non-sex chromosomes)
- In humans:
  - Females: Two X chromosomes (XX) – homomorphic (same size/shape)
  - Males: One X and one Y chromosome (XY) – heteromorphic (Y much smaller than X)
- Total sex chromosomes in human somatic cells: 2 (either XX or XY)
- Total sex chromosomes in human gametes: 1 (egg always X; sperm either X or Y)

(b) Flow Chart – Sex Determination in Humans:

1  
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23

(c) Probability Calculation:

- Probability that fifth child is son = 50% (or  $1/2$ )

Explanation:

1. Each fertilization event is independent – outcome of previous conceptions does not affect next one
2. Father produces equal numbers of X-bearing and Y-bearing sperms (50:50 ratio)
3. Random fusion means:
  - $P(\text{son}) = P(\text{Y sperm fertilizes egg}) = 1/2$
  - $P(\text{daughter}) = P(\text{X sperm fertilizes egg}) = 1/2$
4. Having four sons previously is coincidental (probability =  $(1/2)^4 = 1/16$ ) but doesn't change probability for fifth child

Common Misconception: "After many sons, daughter is 'due'" – FALSE. Each conception has same 50% probability regardless of previous children (like coin tosses).

14. Describe three different types of evidence from comparative anatomy that support evolution. Give examples for each. (5 marks)

Reference: Pages 158-159

Solution:

Three Types of Comparative Anatomical Evidence:

(i) Homologous Organs – Evidence for Divergent Evolution

Definition: Organs with similar fundamental structure and embryonic origin but different functions in different organisms.

Examples:

1. Tetrapod Forelimbs:
  - Human arm: Humerus → Radius/Ulna → Carpals → Metacarpals → Phalanges (grasping)
  - Bat wing: Same bone pattern modified for flight (elongated digits support wing membrane)
  - Whale flipper: Same bones shortened/flattened for swimming
  - Horse leg: Same bones modified for running (reduced digits)
2. Plant Modifications:

- Thorns of Bougainvillea (protection) and tendrils of cucurbit (climbing) both derived from axillary buds

#### Evolutionary Significance:

- Indicates common ancestry – all tetrapods inherited basic forelimb structure from fish-like ancestor with lobed fins
- Divergent evolution: Same structure modified for different functions as species adapted to different environments/niches

#### (ii) Analogous Organs – Evidence for Convergent Evolution

Definition: Organs with similar function but different fundamental structure and embryonic origin.

Examples:

1. Wings for Flight:
  - Bird wing: Forelimb bones covered with feathers
  - Insect wing: Outgrowths of exoskeleton (chitin), no internal bones
  - Bat wing: Forelimb bones with skin membrane
2. Streamlined Body for Swimming:
  - Shark (fish): Cartilaginous skeleton, vertical tail fin
  - Dolphin (mammal): Bony skeleton, horizontal tail fluke
  - Ichthyosaur (extinct reptile): Bony skeleton, vertical tail

#### Evolutionary Significance:

- Shows convergent evolution – unrelated organisms independently evolved similar adaptations to similar environmental challenges (flight, swimming)
- Demonstrates power of natural selection in shaping functional solutions

#### (iii) Vestigial Organs – Evidence of Evolutionary History

Definition: Rudimentary, non-functional (or reduced function) structures that were functional in ancestral organisms.

Examples in Humans:

1. Appendix: Small pouch attached to cecum; in herbivorous ancestors, large cecum digested cellulose. Now largely functionless (minor immune role suspected).
2. Coccyx (Tail Bone): Fusion of 3-5 vertebrae; remnant of tail present in tailed ancestors (monkeys). Causes "tailbone pain" when injured.
3. Wisdom Teeth (Third Molars): Often impacted due to small modern jaws; functional in ancestors with larger jaws eating tough plant material.
4. Body Hair & Arrector Pili Muscles: Fine body hair useless for insulation; muscles cause "goosebumps" – vestige of when ancestors had thick fur that could be erected for warmth/threat display.

5. Nictitating Membrane Remnant: Small fold of tissue at inner eye corner (plica semilunaris); functional third eyelid in birds/reptiles for protection/moisture.

Evolutionary Significance:

- "Evolutionary baggage" – structures retained even after losing original function because their loss provided no selective advantage
- Powerful evidence against "intelligent design" (why would designer include useless structures?)
- Confirms descent with modification from ancestors where these structures were functional

Conclusion: Comparative anatomy provides multiple independent lines of evidence – homologous organs reveal shared ancestry, analogous organs demonstrate adaptive convergence, and vestigial organs document evolutionary history – all consistently supporting theory of evolution.

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15. Explain how classification of organisms is related to evolution. How can we determine evolutionary relationships between species? (5 marks)

Reference: Page 160

Solution:

Relationship Between Classification and Evolution:

(i) Historical Development:

- Pre-Darwin classification (Linnaeus): Based on morphological similarities/differences; hierarchical system (Kingdom → Phylum → Class → Order → Family → Genus → Species)
- Post-Darwin revolution: Classification reinterpreted as reflection of evolutionary relationships (phylogeny)
- Modern systematics (Cladistics): Groups organisms based on shared evolutionary history – organisms with recent common ancestor placed in same taxonomic group

(ii) Classification Reflects Evolutionary Tree:

- Closely related species (recent common ancestor) grouped together at lower taxonomic levels (same genus)
- Distantly related species (ancient common ancestor) grouped only at higher levels (same phylum/class)
- *Example:*
  - Humans & chimpanzees: Same family (Hominidae) → diverged ~6-7 mya
  - Humans & monkeys: Same order (Primates) but different families → diverged ~25-30 mya
  - Humans & fish: Same phylum (Chordata) but different classes → diverged ~450 mya

### (iii) Homologous Characters Define Groups:

- Taxonomic groups defined by shared derived characters (synapomorphies) inherited from common ancestor
- *Example:* Presence of mammary glands defines class Mammalia – inherited from first mammal ancestor

### Methods to Determine Evolutionary Relationships:

#### (i) Morphological Comparison:

- Compare homologous structures (e.g., bone arrangement in limbs)
- Limitation: Convergent evolution can mislead (analogous organs appear similar but not from common ancestor)

#### (ii) Fossil Record:

- Transitional fossils show intermediate forms between ancestral and descendant groups
- Stratigraphic position provides relative timing of divergence
- *Example:* *Tiktaalik* fossil shows features intermediate between fish and amphibians

#### (iii) Embryological Evidence:

- Similarities in early embryonic stages indicate common ancestry
- *Example:* Vertebrate embryos (fish, salamander, turtle, chicken, human) all show gill slits and tails early in development

#### (iv) Molecular Evidence (Most Reliable):

- DNA-DNA hybridization: Measures similarity between DNA sequences
- Protein sequencing: Compare amino acid sequences (e.g., cytochrome c, hemoglobin)
- Molecular clock: Assumes relatively constant mutation rate; differences proportional to time since divergence
  - Humans vs chimpanzees: ~1.2% DNA difference → diverged ~6-7 mya
  - Humans vs gorillas: ~1.6% difference → diverged ~8-10 mya
- Genome sequencing: Whole genome comparisons provide most comprehensive data

#### (v) Chromosomal Analysis:

- Compare chromosome number, structure, banding patterns
- *Example:* Human chromosome 2 resulted from fusion of two ancestral ape chromosomes (chimpanzees have 24 pairs; humans 23 pairs)

### Modern Approach – Phylogenetic Trees:

- Construct evolutionary trees (cladograms) using multiple lines of evidence
- Branch points represent common ancestors
- Branch lengths often proportional to genetic change or time

Conclusion: Modern classification is explicitly evolutionary – taxonomic groups represent branches on tree of life. Molecular data now provides most accurate method for determining evolutionary relationships, complementing traditional morphological and fossil evidence.

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16. (a) What is evolution?

(b) Explain why evolution cannot be equated with 'progress' or 'betterment'.

(c) Give examples to show that evolution has produced both 'simpler' and 'complex' organisms. (5 marks)

Reference: Pages 163-164

Solution:

(a) Evolution Definition:

Evolution is the cumulative change in heritable characteristics (genes/traits) of biological populations over successive generations, resulting from mechanisms like natural selection, genetic drift, mutation, and gene flow. It explains diversity of life through descent with modification from common ancestors.

(b) Why Evolution ≠ Progress/Betterment:

Misconception: Evolution leads to "higher," "more advanced," or "better" organisms over time.

Reality – Four Reasons:

1. No Goal or Direction:

- Evolution has no predetermined goal or endpoint
- Changes result from random variations + environmental filtering
- "Fitness" is context-dependent: trait advantageous in one environment may be disadvantageous in another
- *Example:* Dark moths "fitter" in polluted areas but "less fit" in clean areas

2. Adaptation ≠ Improvement:

- Evolution produces organisms adapted to current local environment, not universally "better"
- Adaptations often involve trade-offs
- *Example:* Cheetah's speed requires fragile bones and high energy cost – not "better" than robust but slower leopard in all contexts

3. Simplification is Common:

- Loss of complex structures often favored when energetically costly and unnecessary
- *Example:* Cave fish lose eyes (energetically expensive) in dark environments where vision useless → "simpler" but better adapted

4. Bacteria Remain "Successful":

- Bacteria existed 3.5 billion years ago; still dominate Earth in biomass and diversity
- No "need" to evolve complexity – perfectly adapted to countless niches
- Complexity not inevitable outcome of evolution

(c) Examples of Evolution Producing Both Simpler and Complex Organisms:

| Direction                             | Example                          | Evolutionary Process                                                                                                                                                   |
|---------------------------------------|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Increased Complexity                  | Vertebrate eye evolution         | Simple light-sensitive patch (flatworm) → cup-shaped eye (limpet) → pinhole eye (nautilus) → lens eye (vertebrates/squid) via natural selection for improved vision    |
| Decreased Complexity (Simplification) | Tapeworms                        | Free-living flatworm ancestor → parasitic tapeworms lost digestive system (absorb nutrients directly through body wall) – simpler but better adapted to parasitic life |
| Decreased Complexity                  | Flightless birds (ostrich, kiwi) | Flying bird ancestors → island populations lost flight ability (energetically costly, unnecessary without predators) – reduced wing musculature/skeleton               |
| Decreased Complexity                  | Human appendix                   | Large cecum for cellulose digestion in herbivorous ancestors → reduced to small appendix in omnivorous humans – vestigial structure                                    |

|                         |                                               |                                                                                                                           |
|-------------------------|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| No Change in Complexity | "Living fossils" (coelacanth, horseshoe crab) | Morphology unchanged for millions of years because well-adapted to stable environments – evolution $\neq$ constant change |
|-------------------------|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|

Critical Insight – Human Evolution:

- Humans not "pinnacle" of evolution
- Other lineages equally evolved for 3.5 billion years
- Human traits (large brain, bipedalism) adaptations to specific ancestral environments, not universally superior
- Many organisms outperform humans in specific traits (cheetah speed, eagle vision, bacterial reproduction rate)

Conclusion: Evolution produces adaptation to local environments, not progress toward complexity or "perfection." Simpler organisms can be highly successful; complexity arises only when selectively advantageous. Judging organisms as "higher" or "lower" reflects anthropocentrism, not biological reality.

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17. Explain the mechanism of sex determination in honeybees. How does it differ from sex determination in human beings? (5 marks)

Reference: Page 157 (Additional knowledge beyond NCERT)

Solution:

Sex Determination in Honeybees (Haplodiploid System):

(i) Chromosomal Mechanism:

- Females (Queens & Workers): Diploid ( $2n = 32$  chromosomes) – develop from fertilized eggs
- Males (Drones): Haploid ( $n = 16$  chromosomes) – develop from unfertilized eggs (parthenogenesis)

(ii) Process:

1. Queen bee (fertile female) can control fertilization during egg-laying:
  - Releases sperm from spermatheca to fertilize egg → diploid female (queen or worker)
  - Withholds sperm → unfertilized haploid egg → male drone
2. Female differentiation (Queen vs Worker):
  - Genetically identical diploid females
  - Queen: Fed royal jelly throughout larval stage → develops functional ovaries, larger size
  - Worker: Fed royal jelly only first 3 days → sterile, smaller, specialized structures (pollen baskets)

- *Epigenetic regulation* (diet-induced gene expression changes) determines caste

### 3. Male development:

- Haploid drones develop from unfertilized eggs
- Produce sperm by mitosis (not meiosis) – all sperm genetically identical to drone
- Die after mating (genitalia ripped out during copulation)

### (iii) Genetic Consequences:

- Sisters (workers) share 75% genes (unusual!):
  - Get 100% of father's genes (haploid drone → identical sperm)
  - Share 50% of mother's genes on average
  - Overall relatedness =  $(100\% + 50\%)/2 = 75\%$
- Explains evolution of eusociality – workers more related to sisters than to own potential offspring (50%), favoring helping queen reproduce

### Comparison: Honeybee vs Human Sex Determination

| Feature                   | Honeybee<br>(Haplodiploidy)            | Human (XX-XY System)             |
|---------------------------|----------------------------------------|----------------------------------|
| Basis                     | Ploidy level (haploid vs diploid)      | Presence/absence of Y chromosome |
| Female                    | Diploid (2n) from fertilized egg       | XX diploid                       |
| Male                      | Haploid (n) from unfertilized egg      | XY diploid                       |
| Gamete formation in males | Mitosis (no meiosis) → identical sperm | Meiosis → 50% X, 50% Y sperm     |
| Sex control               | Mother (queen) controls fertilization  | Random (father's sperm type)     |
| Genetic relatedness       | Sisters 75% related                    | Full siblings 50% related        |
| Chromosomes involved      | No sex chromosomes                     | X and Y chromosomes              |

|                   |                           |                                    |
|-------------------|---------------------------|------------------------------------|
| Example organisms | Bees, wasps, ants, thrips | Mammals, some insects (Drosophila) |
|-------------------|---------------------------|------------------------------------|

Other Sex Determination Systems in Nature:

- ZW System (Birds, butterflies): Females ZW, males ZZ (opposite of XY)
- Environmental (Turtles, crocodiles): Temperature during egg incubation determines sex
- Genic (Some protozoans): Specific genes (not whole chromosomes) determine sex

Conclusion: Sex determination mechanisms are diverse in nature. Honeybee haplodiploidy differs fundamentally from human XX-XY system – sex determined by ploidy level rather than specific sex chromosomes, with profound consequences for social evolution in hymenopterans.

---

18. (a) What is a test cross? Why is it performed?

(b) A tall pea plant is crossed with a dwarf pea plant. All offspring in  $F_1$  generation are tall. When these  $F_1$  plants are self-pollinated, the  $F_2$  generation shows 787 tall and 277 dwarf plants.

(i) Which trait is dominant?

(ii) What are the genotypes of parental plants?

(iii) Perform a test cross to determine the genotype of an  $F_1$  tall plant. Show the expected ratio. (5 marks)

Reference: Page 148

Solution:

(a) Test Cross Definition & Purpose:

Definition: A cross between an individual with dominant phenotype (but unknown genotype – could be homozygous or heterozygous) and a homozygous recessive individual.

Purpose:

- To determine whether dominant-phenotype individual is homozygous (e.g., TT) or heterozygous (e.g., Tt)
- Homozygous dominant → all offspring show dominant phenotype
- Heterozygous → offspring show 1:1 ratio of dominant:recessive phenotypes

Why performed: Phenotype doesn't reveal genotype for dominant traits. Test cross provides definitive answer through offspring ratios.

(b) Analysis of Given Cross:

**\*\*Given \*\***

- P: Tall × Dwarf
- $F_1$ : All tall

- $F_2$ : 787 tall : 277 dwarf

(i) Dominant Trait:

- Tall trait is dominant (expressed in  $F_1$  when parents differed)
- Dwarf trait is recessive (hidden in  $F_1$ , reappeared in  $F_2$ )

(ii) Genotypes of Parental Plants:

- Dwarf phenotype always homozygous recessive  $\rightarrow$  tt
- Tall parent must be homozygous dominant (TT) because:
  - If tall parent were Tt, cross  $Tt \times tt$  would give 1:1 ratio in  $F_1$  (not all tall)
  - Only  $TT \times tt$  gives all Tt (tall) in  $F_1$
- Parental genotypes: Tall = TT, Dwarf = tt

Verification with  $F_2$  ratio:

- $F_1$  genotype: Tt (all tall)
- $F_1$  self-pollination:  $Tt \times Tt$
- Expected  $F_2$  ratio: 3 tall : 1 dwarf
- Observed: 787 tall : 277 dwarf = 1064 total
  - Expected tall =  $(3/4) \times 1064 = 798$
  - Expected dwarf =  $(1/4) \times 1064 = 266$
  - Observed 787:277  $\approx$  2.84:1 (close to 3:1; minor deviation due to sampling error) ✓

(iii) Test Cross for  $F_1$  Tall Plant:

Objective: Determine if  $F_1$  tall plant is TT or Tt (we know it's Tt, but test cross would reveal this experimentally)

Cross:  $F_1$  tall plant  $\times$  Homozygous dwarf (tt)

Case A – If  $F_1$  plant were TT (homozygous dominant):

1  
2  
3  
4

Case B – If  $F_1$  plant is Tt (heterozygous – actual case):

1  
2  
3  
4  
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6  
7  
8  
9

### Expected Result:

Since  $F_1$  plants are heterozygous (Tt), test cross yields 1:1 ratio of tall:dwarf offspring. Observing even one dwarf offspring proves  $F_1$  plant was heterozygous. Significance: Test cross is diagnostic tool in genetics – 1:1 ratio confirms heterozygosity; all dominant phenotype confirms homozygosity.

19. Explain how evolution has occurred in bacteria to develop antibiotic resistance. Why is this a matter of concern for human health? (5 marks)

Reference: Page 161 (Concept extension)

Solution:

Mechanism of Antibiotic Resistance Evolution in Bacteria:

(i) Pre-existing Genetic Variation:

- Bacterial populations naturally contain genetic diversity due to:
  - High mutation rates (short generation time → rapid accumulation)
  - Horizontal gene transfer (conjugation, transformation, transduction) spreading resistance genes between bacteria

(ii) Selection Pressure – Antibiotic Use:

- When antibiotic introduced:
  - Susceptible bacteria killed
  - Rare resistant mutants survive (due to pre-existing resistance genes/mutations)

(iii) Natural Selection in Action:

- Resistant bacteria reproduce without competition from susceptible strains
- Resistance genes spread rapidly through population via:
  - Vertical transmission (cell division)
  - Horizontal gene transfer (plasmids carrying resistance genes shared between bacteria, even across species)

(iv) Evolutionary Timeline Example – MRSA (Methicillin-Resistant *Staphylococcus aureus*):

- 1940s: Penicillin introduced → effective against *S. aureus*
- 1947: First penicillin-resistant *S. aureus* reported (within 4 years!)
- 1960: Methicillin introduced to combat resistance
- 1961: First MRSA reported (within 1 year!)
- Present: MRSA resistant to nearly all  $\beta$ -lactam antibiotics; some strains resistant to vancomycin (last-resort drug)

## Molecular Mechanisms of Resistance:

1. Enzyme production:  $\beta$ -lactamase enzymes break down penicillin-type antibiotics
2. Target modification: Mutated penicillin-binding proteins don't bind antibiotic
3. Efflux pumps: Membrane proteins actively pump antibiotic out of cell
4. Reduced permeability: Modified cell wall prevents antibiotic entry

## Why This is a Major Health Concern:

### (i) Rising Mortality:

- WHO estimates 1.27 million deaths globally in 2019 directly attributable to antibiotic resistance
- Common infections (pneumonia, UTIs, sepsis) becoming untreatable

### (ii) Medical Procedures at Risk:

- Surgeries (C-sections, hip replacements), chemotherapy, organ transplants rely on effective antibiotics to prevent infections
- Without working antibiotics, routine procedures become high-risk

### (iii) Economic Burden:

- Longer hospital stays, more expensive "last-resort" drugs, lost productivity
- Global cost projected at \$100 trillion by 2050 if unchecked

### (iv) Evolutionary Acceleration Factors:

| Factor                                           | Effect on Resistance Evolution                         |
|--------------------------------------------------|--------------------------------------------------------|
| Overuse in humans (e.g., for viral infections)   | Increases selection pressure                           |
| Misuse (not completing full course)              | Allows survival of partially resistant bacteria        |
| Agricultural use (growth promotion in livestock) | Creates reservoir of resistant bacteria in environment |
| Poor sanitation/hygiene                          | Spreads resistant strains between people               |

### (v) Limited Pipeline of New Antibiotics:

- Only 2 new classes of antibiotics discovered since 1987

- Pharmaceutical companies invest little in antibiotic R&D (less profitable than chronic disease drugs)

#### Solutions – Slowing Resistance Evolution:

1. Antibiotic stewardship: Prescribe only when necessary; complete full course
2. Prevent infections: Vaccination, sanitation, hand hygiene
3. Regulate agricultural use: Ban growth promotion; restrict prophylactic use
4. Develop alternatives: Phage therapy, monoclonal antibodies, antimicrobial peptides
5. Global surveillance: Track resistance patterns internationally (GLASS – Global Antimicrobial Resistance Surveillance System)

Conclusion: Antibiotic resistance is evolution by natural selection occurring in real-time, observable within years rather than millennia. It exemplifies Darwinian principles while posing existential threat to modern medicine. Combating it requires understanding evolutionary mechanisms and implementing strategies to reduce selection pressure.

- 
20. (a) What is DNA copying? Why is it important in reproduction?  
 (b) What are the consequences of inaccuracies in DNA copying?  
 (c) How do these inaccuracies contribute to evolution? (5 marks)

Reference: Pages 143-144

Solution:

#### (a) DNA Copying & Its Importance:

Definition: DNA copying (replication) is the semi-conservative process where double-stranded DNA molecule unwinds and each strand serves as template for synthesis of complementary strand, producing two identical DNA molecules.

Process Summary:

1. Helicase enzyme unwinds DNA double helix
2. DNA polymerase adds complementary nucleotides (A-T, G-C) to each template strand
3. Proofreading by DNA polymerase corrects most errors
4. Result: Two identical DNA molecules, each with one original and one new strand

#### Importance in Reproduction:

- Essential for cell division: Before mitosis/meiosis, DNA must duplicate so each daughter cell receives complete genome
- Basis of heredity: Ensures genetic information transmitted faithfully from parents to offspring
- Maintains species continuity: Accurate copying preserves species-specific traits across generations

- Enables growth & repair: Somatic cell division for organism development/tissue repair requires DNA replication

(b) Consequences of Inaccuracies (Mutations):

Despite proofreading, errors occur (~1 mistake per  $10^9$  nucleotides copied).

Consequences depend on mutation type/location:

| Mutation Type        | Consequence                                                           | Example                                                       |
|----------------------|-----------------------------------------------------------------------|---------------------------------------------------------------|
| Silent mutation      | No change in amino acid (due to codon redundancy)                     | CUA → CUG (both code for Leucine) → No effect                 |
| Missense mutation    | One amino acid substituted for another                                | Sickle cell anemia: GAG → GTG changes Glu → Val in hemoglobin |
| Nonsense mutation    | Creates premature stop codon → truncated protein                      | Some cystic fibrosis mutations                                |
| Frameshift mutation  | Insertion/deletion shifts reading frame → completely altered protein  | Some Tay-Sachs disease mutations                              |
| Chromosomal mutation | Large-scale changes (deletion, duplication, inversion, translocation) | Down syndrome (trisomy 21)                                    |

Overall consequences:

- Harmful (most common): Disrupt protein function → genetic disorders, cancer, reduced fitness
- Neutral: No effect on fitness (silent mutations, non-coding DNA changes)
- Beneficial (rare): Improves protein function/adaptation → increased survival/reproduction

(c) Contribution to Evolution:

Mutations as Ultimate Source of Variation:

1. Create new alleles: Only mechanism generating truly novel genetic variants not present in population

- *Example:* Mutation in MC1R gene created dark fur allele in rock pocket mice
- 2. Raw material for natural selection:
  - Without mutations, only existing variations reshuffled by sexual reproduction
  - Mutations introduce new traits for selection to act upon
  - *Example:* Antibiotic resistance mutations in bacteria existed at low frequency before antibiotic use; selection increased their frequency
- 3. Neutral mutations drive molecular evolution:
  - Accumulate at relatively constant rate in non-functional DNA regions
  - Serve as "molecular clock" to estimate divergence times between species
- 4. Gene duplications enable innovation:
  - Whole gene duplication (via unequal crossing over) provides extra copy free to mutate
  - Original gene maintains function; duplicate evolves new function
  - *Example:* Globin gene family – single ancestral gene duplicated/mutated to produce hemoglobin  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ ,  $\epsilon$ ,  $\zeta$  chains with specialized oxygen-binding properties

#### Balance Between Fidelity and Variation:

- DNA replication highly accurate (error rate  $\sim 10^{-9}$ ) to maintain organismal fitness
- But not perfect – low error rate essential to generate variation for long-term evolution
- Evolution optimized replication fidelity: Too high  $\rightarrow$  no variation for adaptation; too low  $\rightarrow$  lethal mutation load

#### Evidence from Mutation Rates:

- Species with larger populations tolerate lower mutation rates (selection efficiently removes deleterious mutations)
- Species with smaller populations have higher mutation rates (genetic drift allows slightly deleterious mutations to persist)
- Demonstrates evolution acting on the mechanism of evolution itself!

Conclusion: DNA copying inaccuracies (mutations) are double-edged sword – mostly harmful to individuals but essential for species' long-term survival by providing genetic variation. Natural selection acts on this variation, driving adaptive evolution. Without mutations, evolution would eventually stall as existing variations exhausted.