Dedicated to my beloved parents
and
respected teachers who taught me.
Preface to first edition

It is a matter of great pleasure and privilege to present the first edition of "Concepts of Genetics" to meet needs of the students both for academic and competitive examinations. The "Concepts of Genetics" is written to bridge the gap of availability of proper reading and conceptual books on the branch. This book is an outcome of my vivid experience of about 24 years of teaching and guiding the students.

The architecture of the book has strategically arranged to strengthen the subjective as well as descriptive skill of the subject, which in turn become helpful to improve the confidence and problem solving skills of the students/readers. This book provides systematic, well planned, up to mark and to the point approach about genetics, which is useful for students pursuing for undergraduate and post graduate courses as well as for students preparing for medical entrance and other competitive examinations.

Each chapter of the book comprises subject matter in brief, along with point wise description, supported by suitable diagrams and examples. Text matters in the book are followed by sufficient number of objective type questions with answer. Both the texts as well as questions are presented and arranged in simple and understandable manner, which can be helpful to anyone to understand the concepts of genetics easily. This book will change the idea, attitude and concept of readers about genetics.

The book "Concepts of Genetics" incorporates Mendelian genetics, genetical terminology, gene interaction, linkage, crossing over, different types of sex determining mechanisms, haploid genetics, human inheritance including sex linked inheritance, sex limited inheritance, sex influenced inheritance, syndromes, Barr body and Lyon’s hypothesis, inborn errors, sickle cell disease, ABO blood grouping, eugenics, DNA, RNA, replication, flow of genetic information and central dogma, genetic code, transcription, teimism, translation, regulation, mutation, population genetics, genetic drift, speciation, different types of natural selection etc.

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I acknowledge the support and suggestion of my esteemed Principal Prof. Ashish Joshi, colleagues respected and dear Dr. M.D. Gupta, Dr. Gyan Prakash Verma, Dr. Balkeshwar, Dr. B.K. Mishra, Dr. Santosh, Dr. Pragyan and friends Er Birendra Singh and CA R.P. Shukla.


I extend my sincere thanks to Shri Neeraj Bharadwaj ji and his team in order to bring out this book in such a nice form. I really appreciate and admire his efforts. I am obliged to Prof Dipak Sharma and Prof Ashish Sharma of International Science Community Association for publishing this book online.

Lastly but not least, I admit that my wife Mrs. Menka Verma showed immense patience and endurance during entire period of manuscript preparation and assisted me in many ways. Besides, my special thanks to all visible and invisible powers of the nature that kept me motivated, when it was needed.

Although utmost care has been taken to make the book free from error but a few errors may creep in, for which I would like to extend due apology in advance and invite the readers for advising the author or publisher about any such discrepancies and welcome, your valuable suggestions and constructive criticisms for the up-gradation of the book.

With great regards.

Allahabad

Dr. A.K. VERMA

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Labours’ Day, 1st May 2016
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Introduction to Genetics
1. Genetics is a branch of Biology which deals with the study of heredity and variations. 

   Genetics = heredity + variations

2. Heredity lies within the species.
3. Heredity is the process of transmission of characters from parents to offspring.
4. Offspring is the product of sexual reproduction usually with biparental origin but having variations.
5. Ramet is the product of asexual reproduction with monoparental origin and it resembles the parent totally without any genetic variation. Population of ramet is called clone.
6. ‘Like begets like’ is the dogma of genetics, which means organisms breed to reproduce their own kind. It is due to heredity (inheritance) and refers to all forms of reproduction.
7. William Bateson gave the term ‘genetics’ in 1905.
8. Gregor Johann Mendel is father of genetics.
9. T.H. Morgan is father of experimental genetics.
10. Now a days genetics is described in terms of:
    (a) Forward or classical genetics i.e., from phenotype to DNA.
    (b) Reverse genetics i.e., from DNA to phenotype.
11. Human Genetics deals with the study of inheritance of characters in human. Sir Archibald Garrod (1902) is called father of human genetics and biochemical genetics because he was pioneer in the field by describing certain inborn errors in human metabolism.

Mendel and his experiment
1. Johann Mendel was born on 22nd July 1822 at Silisian, a village in Heinzenroff (Austrian Empire), which is now a part of Czech republic.
2. In 1843, he became a monk (priest) of Augustinian monastery at Brunn (Austria), where he got the monastic title ‘Gregor’ in 1849.
3. In the garden of Augustinian monastery, Mendel performed his experiments on garden pea: *Pisum sativum* (Family: Fabaceae) for about 7 years during 1856-63.
4. Conclusion of his result was read by him in 1865, which was published in a journal ‘Annual Proceedings of Natural History Society of Brunn’ in 1866.
5. Title of Mendel’s work was ‘Experiments in Plant Hybridization’.
6. Mendel worked on hawkweed: *Hieracium* (family: Asteraceae or Compositae) also but without any definite conclusion.
7. Unrecognized Mendel died in Jan 6,1884 because of kidney disorder.
8. Mendel selected garden pea as his experimental material because this plant was:
   - annual with well defined characters.
   - hermaphroditic (bisexual).
   - self pollinating.

   Because of self pollination and self fertilization, it was easy to obtain pureline with constant traits. Since this plant was self pollinating hence for cross pollination, it was necessary to remove anthers before maturity. This removal of anthers before maturity is called emasculation.

   Mendel studied the inheritance of following 7 pairs of contrasting traits in garden pea:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Characters</th>
<th>Dominant</th>
<th>Recessive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Stem length</td>
<td>tall</td>
<td>dwarf</td>
</tr>
<tr>
<td>2.</td>
<td>Flower position</td>
<td>axial</td>
<td>terminal</td>
</tr>
<tr>
<td>3.</td>
<td>Flower colour</td>
<td>violet (purple)</td>
<td>white</td>
</tr>
</tbody>
</table>
4. Pod shape
   - inflated
   - constricted

5. Pod colour
   - green
   - yellow

6. Seed shape
   - round
   - wrinkled

7. Seed colour
   - yellow
   - green

9. Typical dihybrid cross characters used by Mendel were seed shape and seed colour.

10. Starch branching enzyme (SBE-I) is present in round seeds but absent in wrinkled seeds of garden pea.

11. Mendel did not report the dihybrid cross result with stem length and pod shape (due to linkage).

12. Mendel was lucky in getting good results because genes for different characters studied by him were located on 4 different chromosomes i.e. on 1, 4, 5, 7 (Blixt and others).

   Genes for stem length, flower position and pod shape are located on chromosome no. 4, genes for flower colour and seed colour are located on chromosome no. 1, gene for pod colour on chromosome no. 5 and gene for seed shape is on chromosome no. 7.

Rediscovery of Mendel’s laws

1. Mendel’s laws were rediscovered in 1900 by following three scientists working in different countries:
   (a) Hugo de Vries (Holland)
   (b) Carl Correns (Germany)
   (c) Eric von Tschermak (Austria)

2. Hugo de Vries republished Mendel’s work in ‘FLORA’ in 1901.

3. Correns played major role in converting Mendel’s result into Mendel’s laws.

4. Mendel proposed the ‘existence of particulate unit factor’ which occurs in pair in each organism.

Mendel’s laws of inheritance (Mendelism)

- Law of dominance
- Law of segregation
- Law of independent assortment

1. Law of dominance

   When a monohybrid cross is conducted between 2 plants, in F₁ only one character appears while other character remains in hidden state. The character appears in F₁ is called dominant while other, hidden character is called recessive. The F₁ hybrid does not show any type of blending.

2. Law of segregation

   When F₁ hybrids are selfed, they segregate into F₂ in the ratio of 3 : 1. The F₁ hybrid always produces pure gametes for F₂ hence this law is also known as law of purity of gametes or law of splitting of hybrids.

   **Gametes**
   - T
   - t

   **F₁**
   - Heterozygous (hybrid) tall

   **F₂**
   - Homozygous tall
   - Heterozygous tall
   - Homozygous dwarf
   - Heterozygous dwarf

1. Phenotypic ratio (PR) - 3:1
2. Genotypic ratio (GR) - 1:2:1
3. Ratio of homozygous and heterozygous in monohybrid F₂ generation - 1:1
4. Monohybrid F₁ produces 2 types of gametes but monohybrid F₂ requires 4 types of gametes.
5. Both F₁ and F₂ do not show any type of blending.
6. Mendel observed these results through reciprocal crosses (two crosses concerning the same characteristics but with reversed sexes). For example, in one cross pollen is taken from tall plant while in other cross, pollen is taken from dwarf plant.
3. Law of independent assortment:
When a dihybrid cross is conducted between 2 plants, in F₁ generation only dominant characters appear. The dihybrid F₁ produces following 4 types of gametes:

When these F₁ are selfed, factors for each character assort out independently to the factors of other character. Dihybrid F₂ result or progeny of a cross is represented through checker board (Punnett square), which was first devised by British Geneticist R.C. Punnett.

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>GR</th>
<th>PR</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. RRTT</td>
<td>1</td>
<td></td>
<td>9 Round/tall</td>
</tr>
<tr>
<td>2. rrTT</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. RRTt</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. RrTt</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. RRtt</td>
<td>1</td>
<td></td>
<td>3 Round/dwarf</td>
</tr>
<tr>
<td>6. Rrrt</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. rrTT</td>
<td>1</td>
<td></td>
<td>3 Wrinkled/tall</td>
</tr>
<tr>
<td>8. rrTt</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. rrtt</td>
<td>1</td>
<td></td>
<td>1 Wrinkled/dwarf</td>
</tr>
</tbody>
</table>

Terminology in Genetics
1. Character and traits: Body features are called characters and variants of a character are called traits e.g., stem length is a character while tall and dwarf are traits. Genes which code for a pair of contrasting traits are the alleles.

2. Allelomorph (allele):
- This term was given by Bateson (1905/6).
- It means belonging to each other.
- It indicates alternate forms of the same gene that occupy corresponding positions upon homologous chromosomes.

3. Locus (pl.-loci): It is a specific position (location) of a gene on a chromosome.

4. Homozygous:
- This term was given by Bateson and Saunders (1902).
- If both forms/factors of a particular gene or character are identical, it is said to be homozygous e.g., TT, rr.
- Such condition occurs in pure line forms.

5. Heterozygous:
- This term was given by Bateson and Saunders (1902).
- In heterozygous condition, both factors of a pair are dissimilar e.g., Tt, Rr.
- Such condition occurs in hybrids.
6. **Hemizygous**: It is the condition in which only one allele/factor of a pair is present, as found in sex linkage or as a result of deletion.

7. **Pureline**: 
   - The term ‘pureline’ for true breeding varieties was coined by Johannsen (he also gave the term ‘gene’).
   - Generations of homozygous individuals, which produce offspring of only one type form a pure line.

8. **Genotype and phenotype**: 
   - These terms were given by Johannsen (1911).
   - The genotype refers to genetic makeup of an organism while phenotype refers to the external appearance of the organism. For example, in F₂ generation of monohybrid cross of pea plants, there are 2 types of tall plants namely; homozygous (TT) and heterozygous (Tt). Here, TT and Tt are the genotypes of tall while tall is itself their phenotype. Phenotype of each organism is controlled by its genotype interacting with the environment:

   \[
   \text{Genotype + environment} \rightarrow \text{phenotype}
   \]

9. **Phenocopy**: When two genotypes produce the same phenotype due to different environment; one is called phenocopy of other because they differ genotypically.

10. **F₁ and F₂ generations**: The F₁ means first filial generation while F₂ means second filial generation. The F₁ generation is the generation resulting immediately from a cross of the first set of parents (parental generation). The F₂ generation is the result of a cross between two F₁ hybrids.

11. **Hybridization**: Cross between unrelated forms or cross between two homozygotes differing at least in one gene or character is called hybridization and its product as hybrid.

12. **Hybrid vigour (heterosis)**: Sometimes, hybrids are seen superior or more vigour to their parents because the hybrid may have useful characters of both the parents. This superiority of hybrid over parents is called hybrid vigour.

   The process of hybrid vigour formation is called heterosis. The term ‘heterosis’ was given by American scientist G.H. Shull (1914). One example is of mule, produced by crossing a male donkey with female horse. The reverse, offspring of a male horse and a female donkey, is called a hinny. Mules and hinnies are usually sterile. These are examples of interspecific hybridization.

13. **Hybrid breakdown**: F₁ hybrid is fertile and viable but further generations are inviable or sterile.

14. **Wild and mutant alleles**: 
   - The wild allele is usually dominant, originally present and is even now the most widespread or common in the populations.
   - The mutant allele is usually recessive, less common and formed from wild allele through mutation.
   - Several mutant alleles may be present for a wild one.

15. ** Isoalleles**: These are the alleles that produce very similar phenotypic effect.

16. ** Pseudoalleles**: These are closely linked non-alleles often inherited as one gene and produce related phenotypic effect. The pseudoalleles are functionally allelic but structurally nonallelic.

17. **Multiple alleles**: 
   - If more than two alleles are present for a particular gene then these are called multiple alleles.
   - Important examples are:
     (i) coat colour in rabbit
     (ii)ABO blood group in human
   - The number of possible genotypes in multiple allelism can be calculated through following formula:

   \[
   \frac{n}{2} \times (n+1) \text{ where ‘} n \text{’ is the no. of alleles.}
   \]

   **Qns.** How many genotypes are possible in multiple allelism, if number of alleles is 4.

   **soln.** \( \frac{n}{2} \times (n+1) = \frac{4}{2} \times (4+1) = 10 \text{ Ans.} \)

18. **Lethal genes**: 
   - The genes which cause the death of bearer are called lethal genes and phenomenon of their action is called lethality. The lethality is of following types:
     (a) **Absolute lethality**: death occurs during embryonic stage. e.g., yellow lethal in mice.
     (b) **Sub lethality**: death occurs before the reproductive maturity. e.g., sickle cell disease.
     (c) ** Delayed lethality**: death occurs after reproductive maturity. e.g., Huntington chorea disease.
   - Lethal genes were first of all reported by French geneticist Cuenot (1905). He found that yellow mice never show true breeding. If yellow mouse (Yy) is crossed with another yellow mouse then yellow and brown mice appeared in the ratio of 2 : 1 (not 3 : 1) because yellow mouse never occurs in homozygous condition.
Huntington’s chorea disease in human.

MOET: 
Breed: Interspecific hybridization:

Penetrance: 

Yy

Yellow mouse

y

6

Inbreeding: Variations:

Out-crossing:

Outbreeding:

Cross-breeding:

Expressivity:

Parents (P)

Gametes

(Y)

(Y)

(Y)

(Y)

(Y)

(Dies as embryo)

Yellow

Yellow

Brown

Ratio = 2 : 1

- The lethal genes are mostly recessive and produce their lethal effect in homozygous state.
- Important examples of lethal genes are:
  - (i) Yellow lethal in mice.
  - (ii) Albino condition in snapdragon.
  - (iii) Tay sach’s disease in human.
  - (iv) Sickle cell disease in human.
  - (v) Huntington’s chorea disease in human.
- In nature, dominant lethals are rare because they kill the organisms both in homozygous and heterozygous condition. Such mutant dominant lethal gene is removed from the population in the same generation in which it arose. Some dominant lethal genes may be transmitted to the next generation because in certain cases, lethality expresses itself after the start of reproductive period (about 40 years). One such example of dominant autosomal lethal gene is Huntington’s chorea (disorganized muscular movements and progressive mental deterioration).

19. Breed: This is a group of animals related by descent and similar in most characters like general appearance, size, features etc. e.g., improved breed of cattle is Jersey and chicken is Leghorn. Sahiwal cow of Punjab is a well known Indian breed.

Inbreeding means mating between animals of the same breed while mating between animals of different breeds is called outbreeding.

20. Inbreeding: It means mating of more closely related individuals within the same breed for 4-6 generations. It increases homozygosity and is necessary to develop pureline in any animal.

Continued close inbreeding usually reduces the fertility and even productivity, which is called inbreeding depression.

21. Outbreeding: It means breeding of unrelated animals, which includes:

(a) Out-crossing: It is an outbreeding of animals within the same breed but having no common ancestors on either side of their pedigree up to 4-6 generations.

It is used for animals having below average in milk productivity, growth rate in beef cattle and to overcome inbreeding depression.

(b) Cross-breeding: It is an outbreeding of animals between different breeds. In this case, superior males of one breed are mated with superior females of another breed. Its product combines the desirable qualities of two different breeds e.g., hisardale is a new breed of sheep developed in Punjab by crossing Bikaneri and Marino rams.

(c) Interspecific hybridization: It is an outbreeding of animals between two different related species. Its product may combine the desirable qualities of both the parents and may be of considerable economic value. For example mule is a hybrid produced by cross between male donkey (Equus asinus; 2n = 62) and female horse (Equus caballus; 2n = 64). The mule and hinny both are sterile, having chromosome no. as 63.

22. MOET: This is the multiple ovulation embryo transfer technology, which is used to improve hybrid production. In this technology, cow produces 6-8 eggs (super-ovulation) through hormonal treatment. The released eggs are fertilized naturally or fertilized through artificial insemination. The zygotes at 8-32 celled stage are transferred to surrogate mother.

It has been proved good for cattle, sheep, rabbit, buffalo, mares etc. To increase herd size in a short time, high milk-yielding cow and high quality meat (lean meat with less lipid) yielding bull have been developed.

23. Expressivity: It is the degree of expression of trait controlled by a gene. A particular gene may produce different degrees of expression in different individuals.

24. Penetrance: It is the percentage of individuals that show a particular phenotype among those capable of showing it.

25. Variations: Differences shown by members of a species or offspring of the same parents are called variations. The variations are raw material for evolution.

As per degree of difference, variations are of two types:

(A) Continuous/fluctuating/plus and minus variations:

- These are small and ever present.
- These appear on both sides of an average condition, hence intermediate stage present.
- These appear as a result of random segregation during gametogenesis, crossing over and fertilization.
- Darwin considered them as major factor in evolution.
(B) Discontinuous/saltatory variations/sports / mutation:
- These are large and appear suddenly.
- Since these variations are large and appear suddenly hence intermediate stage absent.
- These appear as a result of gene mutation.
- Hugo de Vries considered them as major factor in evolution.

Types of discontinuous variations:
- (a) Meristic/quantitative: It means change in the number of body parts e.g., presence of 6 arms in star fish instead of 5, presence of only one kidney in newly born human baby.

(b) Substantive/qualitative: It means change in colour, shape and size of body or body parts e.g., Ancon sheep (with small and curved feet; occurs due to germinal mutation; first reported by Seth Wright in 1791).

Some Crosses
1. Double cross: It involves genes from 4 lines such as A, B, C and D. The parents A and B are crossed to get an F₁ hybrid. Similarly parents C and D are also crossed to get another F₁ hybrid. Now these two different types of F₁ hybrids are crossed. This is called double cross.

2. Monohybrid Cross (AA × aa): Cross involving one pair of contrasting traits is called monohybrid cross and the ratio obtained in F₂ generation is called monohybrid ratio, which is 3 : 1 (phenotype). The law of dominance and law of segregation represent the monohybrid generalization.

3. Dihybrid Cross (AABB × aabb): Cross involving 2 pairs of contrasting traits is called dihybrid cross and the ratio obtained in F₂ generation is called dihybrid ratio, which is 9 : 3 : 3 : 1 (phenotype). The law of independent assortment represents the dihybrid generalization.

4. Trihybrid Cross (AABBCC × aabbcc): Cross involving 3 pairs of contrasting traits, is called trihybrid cross and the ratio obtained in F₂ generation is called trihybrid ratio, which is 27 : 9 : 9 : 9 : 3 : 3 : 3 : 1 (phenotype).

From a trihybrid F₁ (AaBbCc), following 8 types of gametes are formed:

<table>
<thead>
<tr>
<th>A</th>
<th>ABC</th>
<th>Abc</th>
<th>abC</th>
<th>Abc</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>B</td>
<td>b</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>a</td>
<td>aBC</td>
<td>aBc</td>
<td>abC</td>
<td>abc</td>
</tr>
<tr>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
</tr>
</tbody>
</table>

Qns. How many and what types of gametes will be formed from AABbCc?

Ans. 4, A | ABC | Abc | AbC | Abc |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>B</td>
<td>b</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

Rules for Gamete Formation:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Condition of genotype</th>
<th>Types of gametes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>All genes in homozygous condition</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>One gene in heterozygous condition</td>
<td>2</td>
</tr>
<tr>
<td>3.</td>
<td>Two genes in heterozygous condition</td>
<td>4</td>
</tr>
<tr>
<td>4.</td>
<td>Three genes in heterozygous condition</td>
<td>8</td>
</tr>
<tr>
<td>5.</td>
<td>Four genes in heterozygous condition</td>
<td>16</td>
</tr>
</tbody>
</table>

5. Back cross and test cross: Cross between F₁ and parent is called back cross. When F₁ hybrid is crossed with recessive parent then it is called test cross because it is done to test the genotype of an unknown character. The test cross differentiates the heterozygous from homozygous dominant.

\[
\begin{aligned}
F_1 \times \text{dominant parent} & \quad \text{Back crosses} \\
F_1 \times \text{recessive parent} & \quad \text{test cross}
\end{aligned}
\]

Monohybrid test cross ratio :- 1:1
Dihybrid test cross ratio :- 1:1:1:1
Trihybrid test cross ratio :- 1:1:1:1:1:1:1:1
Gene Interaction

I. Intragenic or interallelic or allelic gene interaction

II. Intergenic or non-allelic gene interaction

I. Allelic gene interaction: Interaction occurs between the alleles, hence Mendelian monohybrid ratio 3:1 is modified as in:
   1. incomplete dominance
   2. co-dominance

II. Non-allelic gene interaction: In this case, interaction occurs between the non-alleles, hence Mendelian dihybrid ratio 9:3:3:1 is modified as in:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Process</th>
<th>Examples</th>
<th>Modified ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Collaborator genes</td>
<td>Comb shape in poultry</td>
<td>9:3:3:1</td>
</tr>
<tr>
<td>2</td>
<td>Dominant epistasis</td>
<td>Fruit colour in summer squash (Cucurbita)</td>
<td>12:3:1</td>
</tr>
<tr>
<td>3</td>
<td>Recessive epistasis</td>
<td>Coat colour in mice</td>
<td>9:3:4</td>
</tr>
<tr>
<td>4</td>
<td>Complementary genes</td>
<td>Flower colour in sweet pea</td>
<td>9:7</td>
</tr>
<tr>
<td>5</td>
<td>Supplementary genes</td>
<td>Grain colour in Sorghum</td>
<td>9:3:4</td>
</tr>
<tr>
<td>6</td>
<td>Inhibitory genes</td>
<td>Pigmentation in rice</td>
<td>13:3</td>
</tr>
<tr>
<td>7</td>
<td>Duplicate genes</td>
<td>Fruit shape in shepherd purse (Capsella), worked out by G.H. Shull.</td>
<td>15:1</td>
</tr>
<tr>
<td>8</td>
<td>Polygenes</td>
<td>Human skin colour (Devenport)</td>
<td>1:4:6:4:1</td>
</tr>
</tbody>
</table>

1. Incomplete/partial dominance:
   1. A process in which F₁ hybrid does not show dominant-recessive relationship and appears as an intermediate between the 2 homozygous parents, is called incomplete dominance.
   2. It was first discovered by Correns (1903) in 4 ‘O’ clock plant (Mirabilis jalapa).
   3. The F₁ hybrid is since intermediate between the 2 homozygotes hence called blending inheritance.
   4. Law of segregation (universal law of Mendel) is followed in incomplete dominance.
   5. In incomplete dominance, GR and PR remain the same i.e., 1:2:1.
   6. Important examples are:
      (i) 4 ‘O’ clock plant (Mirabilis jalapa)
      (ii) Snapdragon (Antirrhinum majus)
      (iii) Andalusian fowl

Incomplete dominance in 4 ‘O’ clock plant and Snapdragon:

- **P** RR Red × rr White
- **G** R + r
- **F₁** Rr × Rr Pink
- **F₂**

Diagram:

```
   P  RR Red × rr White
     G  R + r
     F₁ Rr × Rr Pink
       +---+---
      /   |   \
     Rr  RR Red
     /     \
    Rr Pink
    /       \
   rr White
```

Diagram:

```
   P  RR Red × rr White
     G  R + r
     F₁ Rr × Rr Pink
       +---+---
      /   |   \
     Rr  RR Red
     /     \
    Rr Pink
    /       \
   rr White
```
Incomplete dominance in Andalusian fowl:

<table>
<thead>
<tr>
<th>P</th>
<th>BB (Black)</th>
<th>×</th>
<th>bb (White)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>B</td>
<td>b</td>
<td></td>
</tr>
<tr>
<td>F₁</td>
<td>Bb × Bb (Blue)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F₂</td>
<td>Bb (Blue)</td>
<td>Bb (Blue)</td>
<td>bb (White)</td>
</tr>
</tbody>
</table>

GR = PR = 1 : 2 : 1

2. Co-dominance:
1. A process in which both alleles express themselves equally in a hybrid is called co-dominance.
2. Since both alleles express equally hence, it called mosaic inheritance.
3. Law of segregation is also followed here.
4. In co-dominance, the GR and PR remain the same i.e., 1 : 2 : 1
5. Important examples are:
   - Roan coat colour in cattle
   - AB blood group in human

3. Epistasis:
   - Bateson (1909) gave the term ‘epistasis’.
   - One gene masks the other gene.
   - The gene which suppresses the expression of other non-allelic gene is called epistatic and the other gene which is being suppressed is called hypostatic.
   - Dominance as well as incomplete dominance are allelic while epistasis is non-allelic.

4. Collaborator genes:
   - Two genes show independent expression but when come together, form a new trait.

   For example comb shape in poultry; is under the control of 2 non-allelic genes R and P.
   - R → Rose
   - P → Pea
   - RP → Walnut (new trait)
   - rpp → Single
   - This was demonstrated by Bateson and Punnett.

<table>
<thead>
<tr>
<th>P</th>
<th>RRpp (Walnut)</th>
<th>×</th>
<th>rrPP (Pea)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Rp</td>
<td>rP</td>
<td></td>
</tr>
<tr>
<td>F₁</td>
<td>RrPp × RrPp (Walnut)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F₂</td>
<td>Rp</td>
<td>Rp</td>
<td>Rp</td>
</tr>
<tr>
<td>rP</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
</tr>
<tr>
<td>Rp</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
</tr>
<tr>
<td>rp</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
</tr>
<tr>
<td>rP</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
</tr>
<tr>
<td>Rp</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
</tr>
<tr>
<td>rp</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
<td>RrPP (Walnut)</td>
</tr>
<tr>
<td>rrPp</td>
<td>Rose</td>
<td>Rose</td>
<td>Rose</td>
</tr>
<tr>
<td>rrPp</td>
<td>Pea</td>
<td>Pea</td>
<td>Pea</td>
</tr>
<tr>
<td>rrpp</td>
<td>Single</td>
<td>Single</td>
<td>Single</td>
</tr>
</tbody>
</table>

Note: In Mendelian dihybrid cross, 2 pairs of traits give rise four different combinations in the ratio of 9 : 3 : 3 : 1 but in collaborator genes, the same single trait (comb shape) produces four different phenotypes in the ratio of 9 : 3 : 3 : 1.

5. Complementary genes:
   - Two genes interact to produce a phenotype but neither is able to express the same phenotype in the absence of other.
Purple = 9  
White = 7  
Ratio = 9 : 7

For example flower colour in sweet pea (*Lathyrus odoratus*) is under the control of 2 non-allelic genes C and P

![Gene Interaction Diagram](Image)

- Precursor $\xrightarrow{C}$ Chromogen $\xrightarrow{P}$ Anthocyanin (purple)
- If C and P both are present, flower will be purple otherwise white. This was demonstrated by Bateson and Punnett.

6. **Polygenes:**

1. Two or more than two genes which influence the same single character are called polygenes.

2. Net phenotype is the additive or cumulative effect of these polygenes, which can be explained on the basis of **multiple factor hypothesis**.

3. Phenomenon of inheritance of these polygenes is called polygenic or **quantitative inheritance** which represents the **continuous variations**.

4. Kolreuter is called father of polygenic inheritance, who studied the polygenic inheritance in the height of tobacco plant.

5. Nilsson Ehle gave the experimental proof of polygenic inheritance in kernal colour of wheat grain.

6. Number of possible phenotypes in polygenic inheritance can be calculated through following formula:

$$2X + 1$$  \text{where, X is the no. of genes present.}

7. Important examples in human are:

   - intelligence
   - height
   - weight
   - behaviour
   - skin colour

**Inheritance of human skin colour:**

Human skin colour is inherited (demonstrated by C.B. Devenport) either with the help of two genes or three genes. Different phenotypes, if 2 genes involved, are as following:

<table>
<thead>
<tr>
<th>No. of dominant genes present</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Negro</td>
</tr>
<tr>
<td>3</td>
<td>Dark</td>
</tr>
<tr>
<td>2</td>
<td>Mulatto (intermediate)</td>
</tr>
<tr>
<td>1</td>
<td>Light</td>
</tr>
<tr>
<td>0</td>
<td>White</td>
</tr>
</tbody>
</table>
Negro - 1
Dark - 4
Mulatto - 6
Light - 4
White - 1
Ratio - 1 : 4 : 6 : 4 : 1

Different phenotypes, if 3 genes involved, are as following:

<table>
<thead>
<tr>
<th>No. of dominant genes present</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Black/very dark</td>
</tr>
<tr>
<td>5</td>
<td>Dark</td>
</tr>
<tr>
<td>4</td>
<td>Fairy dark</td>
</tr>
<tr>
<td>3</td>
<td>Mulatto (intermediate)</td>
</tr>
<tr>
<td>2</td>
<td>Fairy light</td>
</tr>
<tr>
<td>1</td>
<td>Light</td>
</tr>
<tr>
<td>0</td>
<td>White</td>
</tr>
</tbody>
</table>

Summary of Ratio:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Process</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Monohybrid phenotype</td>
<td>3 : 1</td>
</tr>
<tr>
<td>2</td>
<td>Monohybrid genotype</td>
<td>1 : 2 : 1</td>
</tr>
<tr>
<td>3</td>
<td>Monohybrid test cross</td>
<td>1 : 1</td>
</tr>
<tr>
<td>4</td>
<td>Dihybrid phenotype</td>
<td>9 : 3 : 3 : 1</td>
</tr>
<tr>
<td>5</td>
<td>Dihybrid genotype</td>
<td>1 : 2 : 2 : 4 : 1 : 2 : 1 : 2 : 1</td>
</tr>
<tr>
<td>6</td>
<td>Dihybrid test cross</td>
<td>1 : 1 : 1 : 1</td>
</tr>
<tr>
<td>7</td>
<td>Trihybrid phenotype</td>
<td>27 : 9 : 9 : 3 : 3 : 3 : 3 : 1</td>
</tr>
<tr>
<td>8</td>
<td>Trihybrid test cross</td>
<td>1 : 1 : 1 : 1 : 1 : 1 : 1 : 1 : 1</td>
</tr>
<tr>
<td>9</td>
<td>Incomplete dominance</td>
<td>1 : 2 : 1</td>
</tr>
<tr>
<td>10</td>
<td>Co-dominance</td>
<td>1 : 2 : 1</td>
</tr>
<tr>
<td>11</td>
<td>Lethal genes</td>
<td>2 : 1</td>
</tr>
<tr>
<td>12</td>
<td>Collaborator genes</td>
<td>9 : 3 : 3 : 1</td>
</tr>
<tr>
<td>13</td>
<td>Dominant epistasis</td>
<td>12 : 3 : 1</td>
</tr>
<tr>
<td>14</td>
<td>Recessive epistasis</td>
<td>9 : 3 : 4</td>
</tr>
<tr>
<td>15</td>
<td>Supplementary genes</td>
<td>9 : 3 : 4</td>
</tr>
<tr>
<td>16</td>
<td>Inhibitory genes</td>
<td>13 : 3</td>
</tr>
<tr>
<td>17</td>
<td>Complementary genes</td>
<td>9 : 7</td>
</tr>
<tr>
<td>18</td>
<td>Duplicate genes</td>
<td>15 : 1</td>
</tr>
<tr>
<td>19</td>
<td>Polygenes (2 genes)</td>
<td>1 : 4 : 6 : 4 : 1</td>
</tr>
<tr>
<td>20</td>
<td>Polygenic (2) test cross</td>
<td>1 : 2 : 1</td>
</tr>
<tr>
<td>21</td>
<td>Polygenes (3 genes)</td>
<td>1 : 6 : 15 : 20 : 15 : 6 : 1</td>
</tr>
</tbody>
</table>

Note: When a graph is plotted for polygenic F2 result, an inverted bell shaped curve is obtained.
Linkage : As an exception to Mendel’s law of independent assortment

1. Sutton and Boveri (1902) gave the chromosomal theory of inheritance and told that behaviour of chromosomes is parallel to the behaviour of genes and used chromosomal movement to explain the Mendel’s laws.
   According to this theory, chromosomes are the carriers/vehicles of genetic information (genes). The chromosomes are therefore unit of transmission during meiosis.

2. In general, Mendel’s law of independent assortment is applicable to only those genes which are located on different chromosomes.

3. Mendel’s last law is not applicable if several genes are located on same chromosome.

4. The genes which do not assort independently follow the linkage.

5. The linkage was first discovered by Bateson and Punnett (1905) in sweet pea (Lathyrus odoratus) as coupling and repulsion.

6. If two alleles P and L come from the same parent (PPLL), they enter the same gamete and inherited together. This is called coupling.

7. If the two alleles P and L come from different parents (PPLL x ppLL), they enter the different gametes and inherited independently. This is called repulsion.

8. In coupling state (cis arrangement), the wild or dominant alleles (e.g., A and B) are therefore located on one chromosome and their mutant or recessive alleles (e.g., a and b) are located on homologous chromosome.

   On the other hand, in repulsion state (trans arrangement), one dominant and one recessive alleles (e.g., A and b) are located on one chromosome and their respective alleles (e.g., a and B) are located on homologous chromosome.

10. This deviation from Mendel’s law was due to linkage. The behaviour of genes in relation to the above result was first described by T. H. Morgan (1910) who told that coupling and repulsion are the two aspects of the same process called linkage (term given by Morgan).

11. T. H. Morgan was an American geneticist, worked a lot on fruit fly (Drosophila melanogaster). The Drosophila (dew loving) is a dipteran insect having an average life span of about one month while it produces new adults in two weeks (life cycle). Banana medium was used as the positive control medium and plain agar was used as the negative control medium for fruit fly.

He is regarded as father of experimental genetics. He first discovered that genes are located on chromosomes and discovered and named linkage and crossing over in fruit fly. He also discovered sex linked and criss cross inheritance. He awarded Nobel Prize (1933) in the field of physiology or medicine.

Linkage and its types

1. In general, more than one genes are located on one chromosome, which are called linked genes.
2. The linked genes are arranged in linear fashion, do not assort independently and show physical association.
3. The phenomenon of inheritance of these linearly arranged linked genes is called linkage (tendency of genes to inherit together).
4. Linkage is of 2 types:
   - Complete linkage
   - Incomplete linkage
5. In complete linkage, genes are linked and cannot show crossing over and its occurrence in nature is rare, as found in male Drosophila.

6. In incomplete linkage, genes are linked but show crossing over. The occurrence of incomplete linkage means appearance of new combinations (crossing over).

Linkage group

All the linked genes on a chromosome together constitute a linkage group. The number of linkage group is equal to the haploid chromosome no. present e.g.,

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Organisms</th>
<th>Diploid ch. no.</th>
<th>Linkage group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Human</td>
<td>46</td>
<td>23</td>
</tr>
<tr>
<td>2.</td>
<td>Fruit fly</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Garden pea</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>4.</td>
<td>Bacteria and BGA</td>
<td>—</td>
<td>1</td>
</tr>
</tbody>
</table>

Crossing over (recombination)

1. The exchange of corresponding segments between non-sister chromatids (NSC) within a homologous chromosome pair is called crossing over.
2. Morgan and Castle gave the term crossing over in 1911.
3. It occurs at 4 strand stage.
4. Crossing over occurs during pachytene stage of prophase I of meiosis I.
5. The point of contact or crossing of NSC is called chiasma (pl. chiasmata).
6. The new chromatids formed as a result of crossing over are called crossovers or recombinants.
7. The crossing over produces recombination of linked genes or new combination of genes.
8. The genes which are very tightly linked show very low recombination while loosely linked genes show high recombination.
9. The crossing over is an enzyme-mediated process during which recombinase enzyme is involved.

[Fig. 1: Mechanism of crossing over]
Differences between linkage and crossing over:

<table>
<thead>
<tr>
<th>S. No</th>
<th>Linkage</th>
<th>Crossing over</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>It is the tendency of genes to inherit together.</td>
<td>It is the exchange of corresponding segments between NSC within a homologous chromosomes pair.</td>
</tr>
<tr>
<td>2.</td>
<td>Chance of linkage is inversely proportional to the distance between 2 genes i.e., less is the distance between 2 genes, more will be opportunity of linkage.</td>
<td>The chance of crossing over is directly proportional to the distance between 2 genes i.e., more is the distance between 2 genes more will be the opportunity of crossing over.</td>
</tr>
<tr>
<td>3.</td>
<td>As a result of it, parental combinations (PC) are retained.</td>
<td>As a result of it, new combinations (NC) are formed.</td>
</tr>
<tr>
<td>4.</td>
<td>It plays no major role in evolution.</td>
<td>It plays a major role in evolution.</td>
</tr>
</tbody>
</table>

Recombination frequency:

1. The ability of genes to recombine is called recombination frequency, which depends upon the distance between 2 genes. This distance is described in centimorgan or map unit.

\[ \text{1 map unit distance} = 1\% \text{ crossing over} \]

2. Frequency of an allele in a given population is calculated through following formula

\[ p + q = 1 \]

\[ p^2 + q^2 + 2pq = 1 \]

Where p and q are the 2 alleles in the same population.

Linkage map

The representation of serial order of genes on a particular chromosome is called linkage map or genetic map or chromosome map. A.H. Sturtevant prepared the first linkage map.

Let us consider 3 genes A, B and C on a particular chromosome, which may be arranged as ABC or ACB or BAC. By calculating the distance between A & B, B & C and A & C, linkage map can be prepared.

Genetics of Neurospora

Pink bread mould is the common name of Neurospora crassa which is an ascomycetes saprophytic sac fungus. Neurospora was discovered by B.O. Dodge (father of Neurosporal haploid genetics) in 1920s but made famous by Beadle and Tatum in the 1940’s. Since Neurospora is extensively used in genetical studies hence it is called Drosophila of plant kingdom.

As a material for genetic research:

Neurospora crassa has following advantages for genetic research:

- It is easy to grow with a short life cycle of **10 days**.
- It has a **haploid** vegetative stage \((n = 7)\); so each gene whether dominant or recessive expresses itself and the effect of mutation can easily be seen.
- The meiotic products called 8 ascospores are arranged as ordered tetrads \((i.e., 8\) ascospores are arranged in the same order in which chromatids were on the meiotic metaphase plate) within the ascus.
- It can be grown in a culture medium called **minimal medium** which contains sugar, agar, salts and vitamin biotin etc.

The wild strain of Neurospora, which can grow in minimal medium is called **prototroph**. Its mutant strain, which has lost the ability to synthesize essential compounds is called **auxotroph**.

Life cycle:

Its hyphae or mycelia contain haploid nuclei with 7-chromosomes in each nucleus. The asexual reproduction occurs through asexual spores called conidia.

Besides reproducing asexually, this fungus also reproduces sexually through cross mating \((i.e., \text{mating occurs between two opposite strains: 'A' and 'a'. hence it is a heterothallic fungus.})\).

The haploid nuclei from hyphae of opposite strains fuse to form a diploid zygote (only diploid stage in its life cycle) in an ascus. The diploid zygote divides meiotically to form 4 haploid nuclei, each of which then undergoes mitosis. As a result, 8 haploid ascospores are formed within the ascus. These 8-ascospores are arranged linearly in the form of ordered tetrad.

First division segregation:

When there is no crossing over between centromere and a gene locus then it is called first division segregation. It is characterized by the linear arrangement of ascospores within the ascus as:

Second division segregation:

When there is a crossing over between centromere and a gene locus then it is called second division segregation. According to orientation of chromosomes at anaphase II, following would be the possible arrangement of 8-ascospores:

- AAaaaaAA or 2A:4a:2A
- aaAAAAaa or 2a:4A:2a
- AAaaAaaa or 2A:2a:2A:2a
One gene one enzyme hypothesis:
Beadle and Tatum (1941) induced nutritional or biochemical mutations in conidia of *N. crassa* and *N. sitophila* by X-rays.
They found that moulds exposed to radiation lose the ability to produce essential nutrients and such mutants stopped to grow, however growth can be restored by providing the mutated mould with a specific supplement. They reasoned that each mutation must inactivate the enzyme (protein) needed to synthesize the nutrient. Thus, one gene carries the directions for making one protein. On this basis, they proposed one gene one enzyme hypothesis and awarded Nobel Prize (1958) for the same.

The experimental proof that crossing over occurs at 4-strand stage is provided by 2 : 2 : 2 : 2 arrangement of its ascospores in ascus (reported by Lindegren 1933).

Cytoplasmic Inheritance
(Extranuclear/non-chromosomal/maternal inheritance)
1. In eukaryotes, all the genes are not located on chromosomes in nucleus but certain genes are found in cytoplasm also.
2. The genes which are located in cytoplasm are called cytoplasmic genes and phenomenon of their inheritance is called cytoplasmic inheritance.
3. It was first discovered by Correns (1909) in 4 ‘O’ clock plant.
4. Chloroplast and mitochondria are the two cytoplasmic organelles that show cytoplasmic inheritance.
5. Non-chromosomal, extra-nuclear genetic elements are called plasmids and episomes.
6. The sum total of all the extra nuclear genetic elements are called plasmon.
7. Cytoplasmic inheritance is also known as maternal inheritance because it always occurs through female parent.
8. Important examples are:
   - Plastid inheritance in 4 ‘O’ clock plant.
   - Cytoplasmic mitochondrial male sterility in maize.
   - Kappa particles in *Paramecium*.
   - Shell coiling in snail.
Sex Determination

1. Term sex is derived from a Latin word ‘sexus’ which means section or separation.
2. Male section has male gonad or testis and female section has female gonad or ovary. This type of separation of sexes is called **gonochorism**.
3. Sex determining mechanism is extensively studied in *Melandrium* among plants.
4. Different mechanisms for the determinant of sex among animals are as following:
   (i) Male haploidy or haplo-diploidy e.g., honey bee.
   (ii) Environmentally controlled sex differentiation e.g., Bonellia
   (iii) Sex reversal e.g., hen.
   (iv) Genic balance theory e.g., fruit fly
   (v) Sex chromosome mechanism:
      (a) Heterogametic females : ZW : ZZ system e.g., birds
      (b) Heterogametic males :
         ✷ XX : XO system e.g., grasshopper
         ✷ XX : XY system e.g., human

1. In Bonellia:
   1. The **Green spoonworm** (*Bonellia viridis*) is a marine worm of phylum Annelida.
   2. It is well known for displaying exceptional sexual dimorphism as the female is larger and male is microscopic and remains as parasite in the uterus of female. All the body organs of male are degenerate except the reproductive system.

3. Its larva has capability to differentiate into either sex.
4. If larva gets attached with the proboscis of female, it will differentiate into male.
5. If development of larva occurs away from the proboscis of female, it will differentiate into female.
6. The adult *Bonellia* female produces a vivid green pigment in its skin called **bonellin**, which has **biocidal** properties. The bonellin concentrated mostly in the proboscis, is highly toxic to other organisms, capable of paralyzing small animals, killing bacteria and larva of other organisms.
2. In hen:

Birds have ZW - ZZ system of sex determination. The female birds are heterogametic (ZW) while males are homogametic (ZZ). Crew reported the well known case of sex reversal in hen.

3. In fruit fly:

1. *Drosophila* is heterogametic (XY) but its Y chromosome has nothing to do with the determination of sex. It simply acts as male fertility factor because a male is sterile without it.
2. C.B. Bridges proposed genic balance theory for the determination of sex in *Drosophila*.
3. According to this theory, sex is determined by the value of X/A.
4. If X/A is 0.5, fly will be male and if it is 1, fly will be female as shown below:

<table>
<thead>
<tr>
<th>No. of X-Chromosome</th>
<th>No. of set of autosome</th>
<th>X/A</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>XX</td>
<td>2A</td>
<td>1.0</td>
<td>Female</td>
</tr>
<tr>
<td>X</td>
<td>2A</td>
<td>0.5</td>
<td>Male</td>
</tr>
<tr>
<td>XX</td>
<td>3A</td>
<td>0.67</td>
<td>Intersex</td>
</tr>
<tr>
<td>XXX</td>
<td>2A</td>
<td>1.5</td>
<td>Metafemale</td>
</tr>
<tr>
<td>X</td>
<td>3A</td>
<td>0.33</td>
<td>Metamale</td>
</tr>
</tbody>
</table>

Gynandromorph (sex mosaic):

In gynandromorph, half body parts are male and half female, commonly found in insects including butterfly and *Drosophila*.

4. In human:

1. Henking discovered an X-body in bug in 1891.
2. Mc Clung (1902) associated the X-body with the determination of sex.
3. Stevens and Wilson (1905) told the sex determining chromosomes as sex chromosomes / allosomes or heterosomes and proposed the concept of chromosomal basis of sex.
4. Tjio and Levan (1956) confirmed the diploid chromosome no. as 46.
5. In human, females are homogametic (XX) because she produces only one type of gametes while male is heterogametic (XY) because he produces 2 types of gametes as following:

   ![Diagram](image)

From the above diagrammatic representation, it is clear that:

- It is the Y- chromosome, which is responsible for the development and determination of male sex phenotype. If it is present, sex will be male otherwise female.
- The chance of being a baby male or female is equal *i.e.*, 50%. 

![Gynandromorph in Drosophila](image)
Human karyotype:

1. Human beings have 46 chromosomes, out of which 44 are autosomes and 2 sex chromosomes. Human female has XX while male has XY sex chromosomes.

2. On the basis of size, human chromosomes are of following types:
   - large
   - medium
   - small
   - smallest

3. On the basis of position of centromere, human chromosomes are of following types:
   - Acrocentric
   - Metacentric
   - Submetacentric (telocentric absent)

4. Acrocentric chromosomes are found associated with satellites but Y-chromosome has no satellite.

5. Human chromosome are arranged into following 7 groups:

<table>
<thead>
<tr>
<th>Gp.</th>
<th>Size</th>
<th>Shape/position of centromere</th>
<th>Ch. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Large</td>
<td>Submetacentric/metacentric</td>
<td>1,2,3</td>
</tr>
<tr>
<td>B</td>
<td>Large</td>
<td>Submetacentric</td>
<td>4,5</td>
</tr>
<tr>
<td>C</td>
<td>Medium</td>
<td>Submetacentric</td>
<td>6-12, X</td>
</tr>
<tr>
<td>D</td>
<td>Medium</td>
<td>Acrocentric</td>
<td>13,14,15</td>
</tr>
<tr>
<td>E</td>
<td>Small</td>
<td>Submetacentric/metacentric</td>
<td>16,17,18</td>
</tr>
<tr>
<td>F</td>
<td>Small</td>
<td>Metacentric</td>
<td>19,20</td>
</tr>
<tr>
<td>G</td>
<td>Smallest</td>
<td>Acrocentric</td>
<td>21,22,Y</td>
</tr>
</tbody>
</table>

Pedigree analysis:

1. In humans, controlled crosses cannot be made hence human is not a suitable material for genetic research. The inheritance of a trait or disease in them is therefore studied by knowing the family history. The family tree or family history is represented as pedigree.

2. The pedigree is a diagram to show the ancestral relationship and transmission of traits or diseases over several generations in human family. Galton first started to analyze the pedigree.

3. The pedigree shows the relationship between family members and indicates which individual expresses or silently carries the trait in question.

4. Different symbols used during pedigree analysis are as following:
   - ○ → normal
   - ● → affected
   - □ → normal
   - □ → affected
   - ◯ → mating
   - ◯ → mating between close relations (consanguineous mating)

5. The genetic disorders of human beings either may be dominant or recessive and either autosomal or X-linked.

6. The unusual phenotype of a recessive disorder is determined by homozygosity for a recessive allele and the unaffected phenotype is determined by the corresponding dominant allele.

   For example, phenylketonuria (PKU) is a recessive phenotype. PKU is determined by an allele ‘p’ and the normal condition by ‘P’. Therefore, sufferer of this disease is of genotype “pp” and unaffected people are either “PP” or ‘Pp’.

   Two key points are that generally the disease appears in the progeny of unaffected parents and that the affected progeny include both males and females equally. When we know that both male and female phenotypic proportions are equal, we can assume that we are dealing with autosomal inheritance (not X-linked inheritance). A typical
pedigree indicating the key point that affected children are born to unaffected parents are as following:

From above pattern, it is clear that this is an autosomal recessive inheritance, in which sufferer child must have a genotype as 'pp'. Furthermore, both the parents must have the condition heterozygous 'Pp'. Both must have a 'p' allele because each contributed one to each affected child, and both must have a 'P' allele because both the parents are phenotypically normal.

Sex Linked Inheritance

1. The sex chromosomes are basically concerned with the determination of sex but sometimes they carry certain genes for other body character also.

2. The genes which are located on sex chromosomes but not concerned with the determination of sex are called sex linked genes and phenomenon of their inheritance is called sex linked inheritance.

3. The sex linked inheritance was first discovered by T.H. Morgan in Drosophila.

4. He crossed red eyed female fly with white eyed male fly and obtained all the flies as red eyed in F1 generation.

5. When these F1 flies are intercrossed, following results obtained:

3. Among male flies, 50% red eyed and 50% white eyed.
4. Gene for eye colour is located on X-chromosome (sex linked).
5. Red eye colour is dominant over white eye colour.
6. The gene for white eye colour is transmitted from father to grandson through daughter (criss cross inheritance).

Sex linked inheritance in human

1. Some portions of both X and Y chromosomes are similar (homologous region) while remaining portions are dissimilar (differential region).

2. The genes located on homologous region of both X and Y chromosomes are called incompletely sex linked because they can show crossing over.

3. Genes located on differential region are called completely sex linked because they cannot show crossing over. The condition of such gene is always hemizygous.

4. Sex linked genes may be of following types:

1. Y-linked / holandric genes:

   The genes located on differential region of Y-chromosome are called Y-linked or holandric genes. Such genes are found only in males and are transmitted directly from father to son, e.g.,
   - gene for hypertrichosis (excessive growth of hair on ear pinna).
   - SRY (sex region on Y) gene for TDF (testis determining factor).

2. X-linked genes:

   The genes located on differential region of X-chromosomes are called X-linked genes. Such genes always follow criss-cross inheritance (from father to grandson through daugther) e.g.,
   - Colourblindness
   - Haemophilia
   - G-6PDdeficiency
   - Musculardystrophy

3. XY-linked genes:

   The genes which are located on homologous region of both X and Y chromosomes are called XY-linked genes. These are inherited like normal autosomal genes e.g.,
   - Xeroderma pigmentosa
1. **Colourblindness:**
   1. Persons unable to differentiate certain colours are called colourblind.
   2. Red green colourblindness is comparatively common, first described by Horner.
   3. Red colourblindness is called **protanopia** while green colourblindness is called **deuteranopia**.
   4. **Ishihara cards** are used to detect the colourblindness.
   5. A dominant gene ‘C’ located on differential region of X-chromosome is responsible for colour sensitive cells of retina. Its recessive allele (c) fails to do this work properly and the person becomes colourblind.

   Thus, colourblindness is caused due to a **mutant or recessive allele** located on X-chromosomes.

![Diagram of Human Inheritance: Colourblindness](image)

From above diagrammatic representation it is clear that:

1. Disease is more **frequent in males** because only one mutant/recessive allele is enough for the expression of this disease in them while 2 such alleles are necessary for the expression of this disease in females.
2. Males are never carrier.
3. Such genes are not transmitted directly from father to son.
4. Such genes are transmitted from father to grandson through daughter (**criss cross inheritance**).
5. If a male is diseased, it means his **father may be normal**, but mother either carrier or diseased.
6. If a female is diseased, it means her **father must be diseased**, but mother either carrier or diseased.

2. **Haemophilia/Bleeder’s disease/ Royal disease:**
   1. In haemophilia, **blood delays to clot** and even a minor injury may cause death of the sufferer due to excessive bleeding.
   2. It was first discovered by John Cotto while its pedigree in royal family of Europe was first described by Haldane.
   3. Haemophilia is caused due to a mutant/recessive allele located on X-chromosomes.
   4. The pattern of inheritance of haemophilia is strictly similar to that of colourblindness.
   5. Haemophilia may be of following types :
      (i) **Haemophilia A** or **Classic haemophilia:**
          It occurs due to deficiency of blood clotting factor - VIII (AHF-antihaeomophilic factor).
      (ii) **Haemophilia B** or **Christmass disease:**
           It occurs due to deficiency of blood clotting factor - IX (PTC-plasma thromboplastin component).
      (iii)**Haemophilia C** (rare and autosomal):
          It occurs due to deficiency of blood clotting factor - XI (PTA-plasma thromboplastin antecedent).

3. **G-6 PD deficiency:**

   Glucose 6-phosphate dehydrogenase enzyme is important in carbohydrate metabolism, hexose monophosphate shunt and provides stability to RBCs.

   Deficiency of this enzyme is X-linked and rare and causes severe haemolytic anaemia due to rupture of RBCs, when exposed to certain sulfa drugs, fava beans (favism) etc.

4. **Muscular dystrophy:**

   It is progressive muscular weakness caused either due to autosomal or X-linked genes. The person fails to form a protein called **dystropin**.

   Sex linked muscular dystrophy is of 2 types:
   (i) Duchenne’s muscular dystrophy (DMD) - occurs during early age.
   (ii) Becker’s muscular dystrophy (BMD) - occurs during later age.

5. **Defective enamel of teeth:**

   This is an X-linked or sex linked dominant trait. It occurs more **frequently in females** due to the presence of two X-chromosomes.
Sex Limited Genes

The genes which are located on autosomes in both the sexes but their expression is limited to the sex of the bearer, are called sex limited genes e.g.,

- gene for milk production in females.
- gene for the development of beard in males.

Sex Influenced Genes

Such genes are located on autosomes in both the sexes but their dominancy is influenced by the sex of the bearer, for e.g.,

- Short index finger in males
- Baldness pattern

The gene for baldness (B) is dominant over non-bald (b) in males because baldness expresses itself in them in heterozygous condition (Bb) as shown below:

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>Bald</td>
<td>Bald</td>
</tr>
<tr>
<td>Bb</td>
<td>Bald</td>
<td>Non-bald</td>
</tr>
<tr>
<td>bb</td>
<td>Non-bald</td>
<td>Non-bald</td>
</tr>
</tbody>
</table>

Affected chromosome no. in certain diseases

<table>
<thead>
<tr>
<th>S.No.</th>
<th>diseases</th>
<th>Chromosome no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Gaucher disease</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>Huntington disease</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Cystic fibrosis</td>
<td>7</td>
</tr>
<tr>
<td>4.</td>
<td>Sickle cell disease</td>
<td>11</td>
</tr>
<tr>
<td>5.</td>
<td>Phenylketonuria (PKU)</td>
<td>12</td>
</tr>
</tbody>
</table>
Inborn (congenital) errors in human metabolism:

These errors are caused when genic condition becomes homozygous recessive and is characterised by non-formation of certain enzymes concerned with human metabolism. These are:

1. Phenylketonuria (PKU)
2. Albinism
3. Alkaptonuria

### 1. Phenylketonuria (PKU):
- Discovered by Folling (1934).
- Characterised by accumulation of phenyl alanine or phenyl pyruvic acid in blood.
- Brain impairment and mental retardation.
- In normal condition, phenyl alanine is converted into tyrosine by an enzyme phenyl alanine hydroxylase, which is under the control of a dominant gene.
- When genic condition becomes homozygous recessive, this enzyme is not formed and the person becomes the patient of PKU.

### 2. Albinism:
- The colour of skin, hair etc. is because of melanin pigments which are synthesized from tyrosine by tyrosinase enzyme. The tyrosinase is under the control of a dominant gene ‘A’. In homozygous recessive condition (aa), this enzyme is not formed and the person becomes non-pigmented (albino).
  - i. AA → pigmented
  - ii. Aa → pigmented
  - iii. aa → non-pigmented

### 3. Alkaptonuria:
- Discovered by Garrod (1902).
- Characterized by excretion of homogentisic acid or alkapton with urine which turns black when exposed to air.
- Cartilage becomes hard and black.
- In normal condition homogenetisic acid is converted into \( \text{CO}_2 \) and \( \text{H}_2\text{O} \) under the influence of homogentisic acid oxidase enzyme, which is under the control of dominant gene.
- In homozygous recessive condition, this enzyme is not formed and alkaptonuria is caused.

Some important genetic traits

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Traits</th>
<th>Nature</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Polydactyly</td>
<td>Autosomal</td>
<td>Presence of extra fingers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dominant</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Brachydactyly</td>
<td>Autosomal</td>
<td>Palm and fingers short.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dominant</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Huntington chorea</td>
<td>Autosomal dominant</td>
<td>Disorganized muscular movements.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Progressive mental retardation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Late acting lethal disease.</td>
</tr>
<tr>
<td>4</td>
<td>Marfan syndrome</td>
<td>Autosomal dominant</td>
<td>Very long fingers (spider fingers).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Abnormal connective tissue formation.</td>
</tr>
</tbody>
</table>
5. Ability to taste the PTC  
   Autosomal dominant  
   The taste of phenyl thiocarbamide (PTC) is bitter, which can be experienced due to the presence of a dominant gene (T). Homozygous recessive condition (tt) is of non-taster.

6. Tongue rolling  
   Autosomal dominant

7. Gaucher disease  
   Autosomal recessive  
   - Defective fat metabolism.
   - Blood abnormalities, enlarged spleen, bone and neurological defects.

8. Xg blood group  
   Sex linked dominant

9. Defective enamel of teeth  
   Sex linked dominant

10. Cystic fibrosis  
    Autosomal recessive lethal  
    - Disease of pancreas, lung and liver.
    - Defective chloride transport mechanism.

11. Tay Sach’s disease  
    Autosomal recessive lethal  
    Fat deposition over nerves with poor neuromuscular control.

12. Thalassemia (sea blood)  
    Autosomal recessive lethal  
    Reduced synthesis of beta-chain of Hb (sometimes alpha-chain also).

13. Sickle cell disease  
    Autosomal recessive lethal  
    Defective beta-chain formation in Hb.

Barr Body and Lyon’s Hypothesis

1. M.L. Barr and E.G. Bertram (1949) observed a darkly stained chromatin body in the nucleus of nerve cells in cat during interphase stage which was found absent in males. It was named as X-chromatin or sex chromatin or Barr body.

2. M.F. Lyon (1961) proposed Lyon hypothesis according to which:
   - It is the inactivation of one X-chromosome which actually forms the Barr body.
   - Inactivation of one X-chromosome is a random phenomenon.
   - **The number of Barr body is one less than the number of X-chromosomes present.**
     It means human female has one Barr body (sex chromatin positive) while male none (sex chromatin negative).
   - Inactivation of one X-chromosome brings the equality in the no. of genes in both the sexes. This is called dosage compensation.

3. Barr body is demonstrated in the mucosa of buccal epithelium and hair roots. It is found in somatic cells of females only (absent in germ cells).

4. Prenatal sex and sex chromosomal abnormality can be determined by examining the presence of Barr body through a technique called amniocentesis. If Barr body is present, sex will be female otherwise male.

**Y-chromatin**

This is a brightly coloured chromatin body observed during interphase nucleus in the males of human and gorilla only.

A part of Y-chromosome is inactivated to form the Y-chromatin hence the no. of Y-chromatin is equal to the no. of Y-chromosomes present.

**Differences between X and Y chromosomes**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>X-Chromatin (Barr body)</th>
<th>Y-Chromatin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Darkly stained chromatin body.</td>
<td>Lightly stained chromatin body.</td>
</tr>
<tr>
<td>2.</td>
<td>Occurs in most of the mamilian females.</td>
<td>Occurs in the males of human and gorilla.</td>
</tr>
<tr>
<td>3.</td>
<td>One complete X-chromosome is inactivated to form the X-chromatin.</td>
<td>A part of Y-chromosome is inactivated to form the Y-chromatin.</td>
</tr>
<tr>
<td>4.</td>
<td>The no. of X-chromatin is one less than the no. of X-chromosomes present.</td>
<td>The no. of Y-chromatin is equal to the no. of Y-chromosomes present.</td>
</tr>
</tbody>
</table>

**Syndromes**

1. Human beings have 46 chromosomes out of which 44 are autosomes and 2 heterosomes.
2. When this normal no. of chromosome deviates because of non-disjunction, syndrome is caused.
3. Syndrome is a group of symptoms that appear together for a particular disease.
4. Disjunction means normal separation of chromosomes during cell division while non-disjunction is the failure of normal separation of chromosomes.
5. Syndromes are of following types:
   1. **Heterosomal syndromes**
      - Klinefelter syndrome
      - Turner syndrome
      - Jacob or criminal syndrome
   2. **Autosomal syndromes**
      - Down syndrome (Mangolism) - first syndrome discovered by Langdon Down in 1866
      - Edward syndrome
      - Patau syndrome
      - Cri-du-chat syndrome or cat cry syndrome (discoverer- Lejeune)
Sickle Cell Disease

1. Each normal haemoglobin (HbA) is composed of 2α and 2β chains. Each α-chain consists of 141 amino acids and each β-chain 146.
2. The synthesis of HbA is under the control of a dominant gene. In homozygous recessive condition, sickle celled Hb (HbS) is formed and the person dies because of lethal effect.
3. This genetic trait has following 3 genotypes:
   (a) HbA HbA: Normal Hb
   (b) HbA HbS: Sickle cell trait
   (c) HbS HbS: Sickle celled Hb (dies)
4. The α-chain of both HbA and HbS are similar. The actual difference is in β-chain where glutamic acid is replaced by valine at serial no. 6.
5. Persons with sickle cell trait (HbA and HbS) are resistant to malaria infection.
6. American Biochemist Linus Carl Pauling (Nobel Prize winner) told that sickle cell anemia is a molecular disease.
7. Sickle cell disease is examples of:
   - Pleiotropy: one gene influences more than one traits.
   - Natural Selection: In heterozygous condition, persons are resistant to malaria infection.
   - Sublethality: Death in homozygous recessive condition before the reproductive maturity.
   - Transversion/substitution/point mutation: Glutamic acid (GAA or GAG) is replaced by valine(GUA or GUG).

Philadelphia chromosome:

Nowell and Hungerford (1959) reported a deletion in 22nd chromosome in the patient of chronic leukemia. They named it as Philadelphia chromosome after the name of city.

Later, it was found that deleted part of 22nd chromosome is attached with 9th chromosome and a part of 9th chromosome was found attached with 22nd chromosome. Thus, this is the case of reciprocal translocation (between 22nd and 9th).

Alzheimer disease:

- Progressive loss of memory.
- Increasing confusion and anxiety.
- Occurs due to accumulation of a small protein called β-amyloid peptide/protein in brain.
- More common in the person affected with Down syndrome, because β-amyloid is coded by a gene located on chromosome no. 21.
- One reason may be acetylcholine also.
ABO Blood Grouping in Human

1. Human RBC has 2 types of antigens (agglutinogens) on its cell membrane: A and B.
2. Similarly, two types of antibodies (agglutinins) are found in blood plasma: ‘a’ (anti-A) and ‘b’ (anti-B).
3. Antigen ‘A’ and antibody ‘a’ are incompatible and cause self-clumping of RBCs. Similarly, antigen ‘B’ and antibody ‘b’ are incompatible and cause self-clumping of RBCs.
4. On the basis of type of antigen present on the surface of RBCs as detailed above, human has following 4 types of blood groups (popularly known as ABO blood grouping system):

<table>
<thead>
<tr>
<th>Blood group</th>
<th>Antigen present</th>
<th>Antibody present</th>
<th>Can receive from</th>
<th>Can donate to</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>b</td>
<td>A, O</td>
<td>A, AB</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>a</td>
<td>B, O</td>
<td>B, AB</td>
</tr>
<tr>
<td>AB</td>
<td>A &amp; B</td>
<td>none</td>
<td>all</td>
<td>AB</td>
</tr>
<tr>
<td>O</td>
<td>none</td>
<td>a and b</td>
<td>all</td>
<td>O</td>
</tr>
</tbody>
</table>

5. In 1900, Karl Landsteiner (Nobel Prize 1930 in the field of medicine), an Austrian doctor discovered A, B and O blood groups while blood group AB was discovered by Decastello and Sturlu in 1902.
6. Since the RBCs of people of blood group ‘O’ have no antigens hence the blood of such persons can be given to persons of all blood groups. This is the reason why blood group ‘O’ is called universal donor (actually ‘O’ negative).
7. On the other hand, people of blood group ‘AB’ have both antigens in their RBCs but no antibody in their plasma hence such persons can receive blood from persons of all blood groups. This is the reason why blood group ‘AB’ is called universal recipient. They can donate blood to persons of AB blood group only. (Rh factor has already been described in Chapter 19 ‘Circulatory System’).

Note: Fluosol is an artificial blood substitute developed in Japan and first tested in America.

Inheritance of ABO blood group

1. Multiple allelism is responsible for the inheritance of ABO blood group.
2. According to Bernstein, this genetic trait is being inherited with the help of three alleles- I^a, I^b & I^O.
3. Here, I^O is recessive while I^a and I^b are co-dominants.
4. Different possible genotypes for four blood groups are as following:

<table>
<thead>
<tr>
<th>Genotypes (6)</th>
<th>Blood groups (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I^aI^a</td>
<td>A</td>
</tr>
<tr>
<td>2. I^aI^O</td>
<td></td>
</tr>
<tr>
<td>3. I^bI^b</td>
<td>B</td>
</tr>
<tr>
<td>4. I^bI^O</td>
<td></td>
</tr>
<tr>
<td>5. I^aI^b</td>
<td>AB</td>
</tr>
<tr>
<td>6. I^OI^O</td>
<td>O</td>
</tr>
</tbody>
</table>

Q. Blood group of mother is ‘A’ and that of father is ‘B’. Find out the possible blood groups in their childrens.

Soln.

All blood groups are possible.
Eugenics

This is the science of ‘well born’ which deals with the improvement of human race by applying the principles of genetics. The term eugenics (eu = good) was given and this branch was established by Sir Francis Galton who is called father of eugenics.

Types of eugenics:

1. **Positive eugenics:** It includes all those measures which are helpful for multiplication of better and desirable (eugenic) germplasm.
2. **Negative eugenics:** It includes all those measures which are helpful in preventing the multiplication of defective and undesirable (dysgenic) germplasm.

**Dysgenics:**

It deals with the study of defective, undesirable and inferior hereditary traits.

**Euthenics:**

This is the science of ‘well living’ under which better environmental condition and ideal nurture are given to those who have already been born.

**Euphenics:**

It deals with the improvement of human genetic material through genetic engineering. It was suggested by Lederberg.

**Intelligence and IQ:**

1. Intelligence is a polygenic trait and is governed by several genes.
2. Degree of intelligence depends upon:
   - No. of such dominant genes present.
   - Environmental condition specially socio-economic.
3. Intelligence is determined by calculating the IQ value through following formula:

   \[
   \text{IQ} = \frac{\text{Mental age}}{\text{Real age or chronological age}} \times 100
   \]
Nucleic acid

1. A Swiss biologist Friedrich Miescher isolated a phosphorus containing substance from the nuclei of pus cells (WBCs), obtained from discarded bandages in 1869. He named this substance as ‘nuclein’.

2. A German pathologist Richard Altmann introduced the term ‘nucleic acid’ in 1889 to nuclein because of its acidic nature.

3. A German chemist Fischer (1880) identified 2 types of heterocyclic molecules purine and pyrimidine in nucleic acid.

4. A German biochemist Kossel (1894) identified 2 types of purines (A and G) and 2 types of pyrimidines (C and T). He received Nobel Prize in 1910.

5. Levene (1910, 1929) a Russian born biochemist working in New York told about the presence of two types of pentose sugar (deoxyribose and ribose).

   On the basis of type of pentose sugar, nucleic acid is of two types:
   (i) Deoxyribonucleic acid (DNA)
   (ii) Ribonucleic acid (RNA)

Chemical composition of nucleic acid

Nucleic acid is a polymer (polynucleotides) composed of:
   (a) Phosphoric acid
   (b) Pentose sugar
   (c) Nitrogenous bases

1. **Phosphoric acid (H₃PO₄):**
   It occurs as phosphate group in combination with sugar and is responsible for acidic nature.

2. **Pentose sugar:**
   This is 5C sugar, which is deoxyribose in DNA and ribose in RNA.

3. **Nitrogenous bases:**
   They carry genetic information and are of two types:
   (i) **Purine:** This is a 9 member double ring and contains N at 1, 3, 7 and 9 positions. These are A and G.
   (ii) **Pyrimidine:** This is a 6 member single ring and contains N at 1 and 3 positions. These are C, T and U. 5-methyl uracil is another chemical name of thymine.
Nucleosides and Nucleotides

1. A base attached with sugar through **glycosidic bond** is called nucleoside.
   \[ \text{sugar + base = nucleoside} \]

2. In a nucleoside, \(1\text{C of sugar}\) is attached with N at 9th position in purine and 1st position in pyrimidine.

   \[ \begin{align*} 
   & S^{1}\text{C—9N} \quad \text{purine} \\
   & S^{1}\text{C—1N} \quad \text{pyrimidine} 
   \end{align*} \]

3. Nucleoside attached with phosphate through ester bond is nucleotide.
   \[ \text{phosphate + sugar + base = nucleotide} \]

4. In a nucleotide, phosphate is attached with sugar at 5C.

5. A **phosphodiester bond** is present between 3C of one sugar and 5C of other sugar or between 2 adjacent nucleotides. It means two nucleotides (dinucleotides) are linked through 3'-5' phosphodiester bond.

6. The length of DNA depends upon the number of nucleotides or nucleotide pairs or base pairs (bp), which is a characteristic of an organism. For example, a bacteriophage \(\Phi\times174\) has 5386 nucleotides, bacteriophage lambda has 48502 bp, *Escherichia coli* has \(46\times10^6\) bp and haploid content of human DNA is \(3.3\times10^9\) bp.

### Different types of nucleosides and nucleotides in DNA (Deoxyribonucleosides and deoxyribonucleotides)

<table>
<thead>
<tr>
<th>Base with symbol</th>
<th>Nucleoside</th>
<th>Name</th>
<th>Nucleotide</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenine (A)</td>
<td>D–A</td>
<td>deoxyadenosine</td>
<td>P–D–A</td>
<td>deoxyadenosine monophosphate (dAMP)/deoxyadenylic acid</td>
</tr>
<tr>
<td>Guanine (G)</td>
<td>D–G</td>
<td>deoxyguanosine</td>
<td>P–D–G</td>
<td>deoxyguanosine monophosphate (dGMP)/deoxyguanylic acid</td>
</tr>
<tr>
<td>Cytosine (C)</td>
<td>D–C</td>
<td>deoxycytidine</td>
<td>P–D–C</td>
<td>deoxycytidine monophosphate (dCMP)/deoxycytidyl acid</td>
</tr>
<tr>
<td>Thymine (T)</td>
<td>D—T</td>
<td>deoxythymidine or thymidine</td>
<td>P–D–T</td>
<td>deoxythymidine monophosphate (dTMP/TMP) or deoxythymidyl acid</td>
</tr>
</tbody>
</table>

**Note:**
1. \(P = \text{phosphate}\)
2. \(D = \text{deoxyribose sugar}\)
3. Term ‘deoxy’ is not necessary with ‘T’

### Different types of nucleosides and nucleotides in RNA (Ribonucleosides and ribonucleotides)

<table>
<thead>
<tr>
<th>Base with symbol</th>
<th>Nucleoside</th>
<th>Name</th>
<th>Nucleotide</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenine (A)</td>
<td>R–A</td>
<td>adenosine</td>
<td>P–R–A</td>
<td>adenosine monophosphate (AMP)/adenylic acid</td>
</tr>
<tr>
<td>Guanine (G)</td>
<td>R–G</td>
<td>guanosine</td>
<td>P–R–G</td>
<td>guanosine monophosphate (GMP)/guanylic acid</td>
</tr>
<tr>
<td>Cytosine (C)</td>
<td>R–C</td>
<td>cytidine</td>
<td>P–R–C</td>
<td>cytidine monophosphate (CMP)/cytidylic acid</td>
</tr>
<tr>
<td>Uracil (U)</td>
<td>R—U</td>
<td>uridine</td>
<td>P–R–U</td>
<td>uridine monophosphate (UMP)/uridylic acid</td>
</tr>
</tbody>
</table>

**Note:**
1. \(P = \text{phosphate}\)
2. \(R = \text{ribose sugar}\)

### Important bonds in nucleic acid:

1. **Covalent bond:**
   (a) **Glycosidic bonds**: present between base and sugar.
   (b) **Phosphodiester bond**: present between 3C of one sugar and 5C of other sugar or between 2 adjacent nucleotides.
2. **Hydrogen bonds**: determine the base specificity.
   (a) 2 H-bonds between A and T
   (b) 3 H-bonds between C and G

3. **Hydrophobic bonds**: provide stability to DNA double helix. These are in fact stacking forces of stacked base pairs.

   **5’ → 3’ direction of DNA strand:**
   - Each strand of DNA has 2 ends with respect to sugar:
     (i) One end has 5’ OH group on sugar. This is called **5’ end**.
     (ii) Other end has 3’ OH group on sugar. This is called **3’ end**.
   - The direction of DNA strand is always 5’→3’ downward on left side and 5’→3’ upward on right side.
   - The direction of phosphodiester bond is 3’→5’ downward on left side and 3’→5’ upward on right side.

   ![Diagram of DNA strand and phosphodiester bond directions]

   **Chargaff’s rule of equivalence (1950):**
   Erwin Chargaff at Columbia University proposed following base pairing rules:
   1. Number of A is equal to number of T.
   2. Number of C is equal to number of G.
   3. Number of purines (50%) is equal to number of pyrimidines (50%).
   4. \[
   \frac{A + T}{G + C}\]
      molar ratio varies from species to species but constant for a particular species. It is generally high in eukaryotes (1.52 in human) and low in prokaryotes (0.93 in E.coli).
   5. It is applicable only for double stranded DNA (ds DNA).

   \[
   \begin{align*}
   A &= T \\
   G &= C \\
   A + G &= T + C
   \end{align*}
   \]

Q.1. In a dsDNA, if A is equal to 24% then find out the value of G, C and T ?

   **Soln.**
   
   \[
   \begin{align*}
   A &= 24% \\
   A + G &= 50% \\
   X &= 26% \quad (X = \text{total}) \\
   A &= T = 24% \\
   G &= C = 26% \\
   T &= 24%, \quad G = 26%, \quad C = 26%
   \end{align*}
   \]

Q.2. In a dsDNA, if C = 22% then what will be the value of A, T and G ?

   **Soln.**
   
   \[
   \begin{align*}
   C &= 22% \\
   C + T &= 50% \\
   X &= 28% \quad (X = \text{total}) \\
   A &= T = 28% \\
   G &= C = 22% \\
   T &= 28%, \quad G = 22%, \quad A = 28%
   \end{align*}
   \]

Q.3. In a dsDNA, if A = 120, T = 120, G = 80 and C = 80 then how many nucleotide pairs are possible in it ?

   **Soln.**
   
   \[
   \begin{align*}
   A &= 120 \\
   T &= 120 \\
   G &= 80 \\
   C &= 80 \\
   \text{Total} &= 400 \text{ nucleotides} \\
   \text{200 nucleotide pairs or 200 base pairs (bp)}
   \end{align*}
   \]

**Watson and Crick Model of DNA Double Helix**

Wilkins, Franklin and others (1952) studied the DNA through X-ray crystallographic diffraction technique and told that DNA is helix with a diameter of 20 Å and pitch (one round or one complete turn) of about 34 Å. The distance between 2 nucleotides is therefore 3.4 Å.

On the basis of Chargaff’s rule and Wilkins Franklin’s X-ray diffraction data, James Watson (American Geneticist) and Francis Crick (British Physicist) proposed double helical model of DNA in 1953. Watson, Crick and Wilkins were awarded Nobel Prize in 1962.
Important features of a DNA double helix are as follows:

1. DNA consists of a double helix (duplex) in which two polynucleotide chains are coiled around the same axis to form a right-handed duplex.
2. In the helix, two strands are antiparallel, i.e., both chains run in opposite directions.
3. The two strands are twisted around each other to create major and minor grooves on the surface.
4. Pentose sugar and phosphoric acid constitute the backbone of DNA. The phosphate molecules lie on the outer side while bases toward the inner side of sugar.
5. Nitrogen bases of two strands are linked through weak hydrogen bonds.
6. The purine always pairs with pyrimidine. Accordingly, A pairs with T by two hydrogen bonds and C pairs with G by three hydrogen bonds:
   \[ \text{A} \quad \text{T} \]
   \[ \text{C} \quad \text{G} \]
7. Distance between two base pairs is 3.4 Å (0.34 nm) and therefore 10 base pairs or nucleotide pairs are found in each turn as the length of one complete turn is 34 Å (= 3.4 nm).
8. Diameter of DNA duplex is 20 Å.
9. The two strands of a DNA double helix are complementary.

   It means A and T are complementary in shape and similarly C and G are also complementary.

   1st chain \[ 5' \text{A} \quad \text{T} \quad \text{C} \quad \text{G} \quad \text{A} \quad 3' \]

   Comp. chain \[ 3' \text{T} \quad \text{A} \quad \text{G} \quad \text{C} \quad \text{T} \quad 5' \]

10. The DNA duplex is held together by 2 sets of forces:

   (a) Hydrogen bonding between complementary bases.

   (b) Hydrophobic bonding or force of stacked base pairs.

---

**Q.** A dsDNA measures 34 μ. How many nucleotide pairs are possible in it?

**Soln.**

1. 1μ is equal to 10 Å

2. \[ 34 \mu = 340 \text{ Å} \]

3. 34 Å dsDNA has 10 bp

4. \[ 340 \text{ Å} = \frac{10 \times 340}{34} = 100 \text{ bp} \]

---

**Different Forms of DNA**

On the basis of direction of helix, DNA is of two types:

**I. Right handed DNA (clockwise):**

1. A - DNA with 11 bp per turn
2. B - DNA with 10 bp per turn
3. C - DNA with 9 bp per turn
4. D - DNA with 8 bp per turn

**II. Left handed DNA (anti-clockwise):**

5. Z - DNA with 12 bp per turn

Watson and Crick (1953) model of DNA duplex was right handed which is now known as B-DNA. It is the most common form of DNA.

V. Sasisekharan (Banglore) proposed **RL model** of DNA, according to which right and left handed segments alternate in B-DNA (approximately 5 bp in a repeat of 10 bp).

The Z-DNA was discovered by Andrew Wang and Alexander Rich in 1979. It is so called because sugar and phosphate backbone follows a zig-zag path in helix.
Some important differences between B and Z-DNAs are following:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Character</th>
<th>B-DNA</th>
<th>Z-DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Helical sense</td>
<td>Right handed</td>
<td>Left handed</td>
</tr>
<tr>
<td>2.</td>
<td>Sugar phosphate backbone</td>
<td>Regular</td>
<td>Zig-zag</td>
</tr>
<tr>
<td>3.</td>
<td>Diameter</td>
<td>20 Å</td>
<td>18 Å</td>
</tr>
<tr>
<td>4.</td>
<td>Helix pitch (1 turn)</td>
<td>34 Å</td>
<td>45 Å</td>
</tr>
<tr>
<td>5.</td>
<td>Distance between 2 bp</td>
<td>34 Å</td>
<td>37 Å</td>
</tr>
<tr>
<td>6.</td>
<td>Repeating unit</td>
<td>Mononucleotide</td>
<td>Dinucleotide</td>
</tr>
<tr>
<td>7.</td>
<td>Base pair per turn</td>
<td>10</td>
<td>12 (= 6 dimer)</td>
</tr>
<tr>
<td>8.</td>
<td>Rotation per base pair/angle of twist</td>
<td>360/10 = 36°</td>
<td>360/6 = 60°</td>
</tr>
</tbody>
</table>

Nucleoid and nucleosome:

1. In prokaryotes nucleus is however absent but DNA is not scattered throughout the cell. The DNA being negatively charged is held with some proteins having positive charges to form the ‘nucleoid’.

2. In eukaryotes, the negatively charged DNA is wrapped around the positively charged histone octamer to form a structure called nucleosome core. This core particle together with linker DNA and one molecule of H1 collectively constitute a complete nucleosome. A typical nucleosome contains 200 bp of DNA helix.

3. The H1 (linker histone) is involved in packaging while a histone octomer consists of 2 copies of each histone protein (H2A, H2B, H3, and H4). The histones are a set of positively charged, basic proteins rich in arginine and lysine amino acids.

4. Nucleosomes constitute the repeating unit of a structure in nucleus called chromatin and in a chromatin, these nucleosomes are seen as ‘beads-on-string’.

Properties of DNA

1. **Hydrophilic nature**: DNA is a hydrophilic molecule and it cannot pass through cell membrane.

2. **UV absorption**: Nucleic acid absorbs UV light due to conjugated aromatic nature of bases.

3. **Feulgen stain**: DNA gives positive test for this chemical due to the presence of specific pentose sugar.

4. **Viscosity and density**: DNA solutions have high viscosity and its density is almost similar to that of cesium chloride.

5. **Depurination**: Separation of purine from DNA by breaking glycosidic bonds is called depurination, which occurs when DNA is kept in strong acid such as perchloric acid (HClO₄) at more than 100°C temperature.

6. **Denaturation (melting)**: Separation of both strands of DNA by breaking H-bonds is called denaturation, which is either chemical or thermal. Chemical denaturation occurs when DNA is kept in urea.

   The mid point of temperature range over which DNA strands separate is called **melting temperature (Tm)**. Tm is low if DNA is rich in ‘A=T’ content i.e., A+T/G+C molar ratio is high, as found in eukaryotes.

   Tm is high, if DNA is rich in ‘G=C’ content i.e., A+T/G+C molar ratio is low, as found in prokaryotes.

7. **Renaturation (annealing)**: When the two DNA strands are cooled gradually, both strands base pair to reform a dsDNA. This is called renaturation.

8. **Photoreactivation**: This is a type of DNA repair, which breaks the covalent bonds between pyrimidine dimer (formed by UV rays). It includes photolyase or PR enzyme that binds the pyrimidine dimer in dark and is activated in light (mainly blue light). This enzyme breaks the covalent bonds between pyrimidine dimer and restores the normal base pairing.

9. **Promiscuous DNA**: This is the movement of DNA from chloroplast to mitochondria and from both these organelles to nucleus.

10. **Autocatalysis**: It is that property of DNA by which it catalyzes the synthesis of its own.

11. **Heterocatalysis**: It is that property of DNA by which it catalyzes the synthesis of RNA.
DNA as Genes

1. Genes are the DNA segments, composed of polynucleotides and represent the hereditary unit.
2. Johannsen (1909) gave the term 'gene' to replace the Mendelian factor.
3. Morgan first discovered that genes are located on chromosomes.
4. Locus (loci) is the location of a particular gene on chromosome.
5. Benzer gave the fine structure of gene and described it in terms of:
   - Cistron (largest) : unit of function.
   - Recon : unit of recombination (crossing over).
   - Muton (smallest) : unit of mutation.

1. Jumping genes / floating genes / mobile genetic element / insertion sequence / transposable element:
   - These are the controlling elements that move from one location to other on the same or different chromosomes.
   - These genes were first discovered by Barbara McClintock in maize in 1940 (Nobel Prize 1983).
   - Hedges and Jacob gave the term ‘transposon’ to jumping gene and reported them in bacteria.
   - Transposition requires transposase enzyme.

2. Overlapping genes:
   The genes whose nucleotide sequence overlap upto some degree are called overlapping genes e.g., control genes in E.coli and structural genes in bacteriophage φ X174.

3. Pseudogenes (false genes):
   In multicellular organisms such as fruit fly, mice, human etc. certain useless DNA sequences are found, which are called pseudogenes e.g., human α globin gene.
   The pseudogenes are therefore defective or inactive copies of currently working genes.

4. Constitutive (house keeping genes):
   The genes whose products are continuously needed by the cells for performing cellular activities are called house keeping genes e.g., gene for ATPase enzyme.

5. Oncogenes:
   - Cancer causing genes are called oncogenes.
   - Proto-oncogenes are the normal genes having the potential to develop into oncogenes.
   - Anti-oncogenes/tumor suppressor genes suppress the tumor formation.

6. Split (interrupted) genes:
   Eukaryotic genes have some coding (exon) and some non coding (intron) regions, which are called split genes.

These genes were first discovered by Roberts and Sharp in 1977 (Nobel Prize 1993).

7. Homeotic genes:
   The set of genes which determine the body plan are called homeotic genes. Gehring called them as ‘homeo box’ that occurs in fruitfly, toad, mice, human etc. If homeotic genes undergo mutation, can cause transformation of one body part into other.

8. Modifier genes:
   The genes which modify the phenotypic expression of other non-allelic genes are called modifier genes. They modify the phenotypic effect in quantitative manner.

9. Junk DNA:
   DNA that does not code for proteins or their regulation is called junk DNA. It constitutes approx. 95 percent of the human genome. It is postulated to be involved in the evolution of new genes and possibly in gene repair.

Functions of DNA

1. DNA is genetic material and responsible for heredity (through replication) and variations (through mutation and recombination).
2. The DNA is also responsible for growth, development and differentiation (through transcription and translation).

Experiments to show that DNA is genetic material

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Experiment</th>
<th>Year</th>
<th>Nature of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Griffith</td>
<td>1928</td>
<td>indirect</td>
</tr>
<tr>
<td>2.</td>
<td>Avery, MacLeod, McCarty</td>
<td>1944</td>
<td>direct and confirmed</td>
</tr>
<tr>
<td>3.</td>
<td>Hershey and Chase</td>
<td>1952</td>
<td>confirmed and best</td>
</tr>
</tbody>
</table>

1. Griffith’s experiment:
   - Griffith, an English bacteriologist, experimented with Diplococcus (Pneumococcus) pneumoniae that causes pneumonia in mammals. This bacterium occurs in two forms:
     - (a) a smooth, capsulated, virulent S III strain.
     - (b) a rough, non-capsulated, non-virulent R II strain.
   - The virulence in this bacterium depends on a polysaccharide capsule which is present in S III but absent in R II.
   - He injected these two forms into mice and obtained the following result:

<table>
<thead>
<tr>
<th>Injected form of Pneumococcus</th>
<th>Effect on mice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live R II (non virulent)</td>
<td>survived</td>
</tr>
<tr>
<td>Live S III (virulent)</td>
<td>died</td>
</tr>
<tr>
<td>Heat killed S III</td>
<td>survived</td>
</tr>
<tr>
<td>Heat killed S III and live R II</td>
<td>died</td>
</tr>
</tbody>
</table>
During post mortem, live S III strain was recovered from the body of dead mice. On the basis of above result, Griffith concluded that something is passed or transformed from heat killed S III to live R II which caused them to develop capsule and became virulent. The unknown transforming principle in this experiment failed to define the biochemical nature of genetic material.

2. Avery, MacLeod and McCarty’s experiment:
   - They purified biochemical extract (protein, DNA and RNA) from virulent S III.
   - They told that protease (protein-digesting enzyme) and RNase i.e. ribonuclease (RNA-digesting enzyme) did not affect the transformation, which means protein or RNA was not the transforming substance.
   - It was DNase i.e. deoxyribonuclease (DNA-digesting enzyme), which inhibited the transformation hence transforming substance or transforming principle is DNA (not the protein or RNA or any other substance), as shown below:

<table>
<thead>
<tr>
<th>Mixture taken</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>R II + extract from S III</td>
<td>Both R II and S III</td>
</tr>
<tr>
<td>R II + extract from S III + protease</td>
<td>Both R II and S III</td>
</tr>
<tr>
<td>R II + extract from S III + RNase</td>
<td>Both R II and S III</td>
</tr>
<tr>
<td>R II + extract from S III + DNase</td>
<td>Only R II</td>
</tr>
</tbody>
</table>

Avery, MacLeod and McCarty therefore confirmed that DNA is genetic material and determined biochemical characterization of transforming principle.

3. Hershey and Chase experiment:
   - They experimented with bacteriophage T2 and a bacterium Escherichia coli, both occur in human intestine. This phage particle is composed of DNA and protein.
   - In order to confirm that which part of phage (DNA or protein) enters the bacterium, they used radioactive sulphur (S\textsuperscript{35}) to label the protein and radioactive phosphorus (P\textsuperscript{32}) to label the DNA (because sulphur is absent in DNA and phosphorus is absent in phage protein).
   - Hershey and Chase then allowed the labelled phage particles to infect the bacterium. Only radioactive P\textsuperscript{32} was found associated with bacterial cells while S\textsuperscript{35} was left in surrounding medium.
   - When phage progeny was examined, it was found that phage progeny carried only labelled P\textsuperscript{32} and not the S\textsuperscript{35}.

Thus, it confirmed that only DNA that enters the bacterium, is genetic material. Hershey received Nobel Prize in 1969 alongwith Delbruck and Luria.
Replication of DNA

Duplication of DNA takes place by replication during S-phase of interphase of cell cycle. Three possible modes of DNA replication are as following:

1. **Conservative:**
   Both old or parental strands are conserved and two new or daughter strands are synthesized.

2. **Semiconservative:**
   Each replicated DNA duplex consists of one old or parental and one new or daughter strand. Thus, **only one strand is conserved**. This mode was proposed by Watson and Crick, which is widely accepted.

3. **Dispersive:**
   The replication of both strands occurs segmentwise hence newly formed each strand of DNA duplex contains some parental and some new segments.

**Experiments to show semiconservative mode of replication:**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Experiment</th>
<th>Year</th>
<th>Organism</th>
<th>Isotope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Meselson and Stahl</td>
<td>1958</td>
<td><em>E. coli</em></td>
<td>N15 and N14</td>
</tr>
<tr>
<td>2.</td>
<td>Cairns’</td>
<td>1963</td>
<td><em>E. coli</em></td>
<td>H3-TDR</td>
</tr>
<tr>
<td>3.</td>
<td>Taylor's</td>
<td>1958</td>
<td><em>Vicia faba</em></td>
<td>H3-TDR</td>
</tr>
</tbody>
</table>

1. **Meselson and Stahl experiment:**
   - Matthew Meselson and Franklin grew *E. coli* in a medium containing $^{15}$NH$_4$Cl ($^{15}$N is heavy isotope of nitrogen but not a radioactive isotope). This $^{15}$N was incorporated in both the strands of DNA and this DNA was **heavy (H)** in comparison to normal DNA, which has $^{14}$N and called light (L).
   - The *E. coli* with DNA strands having $^{15}$N (i.e., heavy) is transferred to a normal medium of $^{14}$NH$_4$Cl and allowed to replicate. *E. coli divides in 20 minutes.*
   - As a result (after 20 minutes in first generation) hybrid DNA molecule ($^{15}$N $^{14}$N) was obtained in which one strand is light and other strand is heavy.
   - When this hybrid DNA molecule was allowed to replicate further in the same medium of $^{14}$NH$_4$Cl, 50% **hybrid ($^{15}$N $^{14}$N) and 50% light ($^{14}$N $^{14}$N)** DNA were obtained in second generation after 40 minutes.
   - This result proves the semiconservative mode of replication.
2. Cairns’ experiment:

Dr. Cairns confirmed the semiconservative mode of replication by autoradiographic technique with *E. coli*. He used heavy isotope of hydrogen (H$_3$) to obtain radioactive thymine or tritiated thymidine (H$_3$-TDR) to label both the strands of DNA. He found the number of H$_3$-TDR labelled strands always two in 1st, 2nd, 3rd and so on generations.

3. Taylor’s experiment:

Taylor, Woods and Hughes confirmed the semi-conservative mode of replication in eukaryotes during 1957-58. They used H$_3$-TDR, autoradiography and experimented with root tips of *Vicia faba* (faba beans).

Mechanism of replication:

1. Replication of DNA is a complex process in which several enzymes and factors are involved. These together constitute the DNA replicase system or replisome.
2. *E. coli* has $4.6 \times 10^6$ bp and its replication is completed in 38 minutes.
3. Energetically, DNA replication is a very expensive process.

4. Deoxyribonucleoside triphosphate (dNTPs) performs dual functions:
   (i) to act as substrate.
   (ii) to provide energy.
5. DNA replication includes following steps:

   (a) Recognition of initiation point:
   DNA replication always starts at a specific point called initiation point (origin point). A specific initiator protein is required for recognition of this point.

   (b) Unwinding of DNA duplex:
   - This is done by breaking H-bonds by an enzyme called helicase (unwindase) with the help of ATP.
   - Topoisomerase (gyrase) cuts or nicks the DNA strands to relax the supercoiling which is followed by quick resealing of broken DNA strands.
   - Single stranded DNA binding protein (SSB) binds the nicked DNA strand and retains the DNA in single stranded condition during replication.
   - In this way a loop (bubble) is opened by separating both the DNA strands and a Y-shaped replication fork is established.

   (c) Synthesis of RNA primer:
   Synthesis of DNA strand requires the formation of an RNA primer in 5’→3’ direction by primase enzyme. DNA dependent (DNA directed) DNA polymerase III (pol. III) is the main enzyme for replication but it cannot initiate DNA strand synthesis.

   (d) Formation /elongation of new DNA strand:
   - The polymerase III is a complex enzyme, consists of 10 subunits including β subunit (copolymerase) and requires Zn and Mg ions.
   - The β subunit recognizes the site on RNA primer (3’ end) where nucleotides are to be added.
   - The parental DNA strand is called template.
   - Now the nucleotides are added at 3’ end of RNA primer with the help of polymerase III, according to base pairing rule.
   - The addition of nucleotides or elongation of DNA strand or replication of DNA occurs in 5’→3’ direction from 3’→5’ template either continuously or discontinuously.

   Accordingly, the newly synthesized DNA strands are of two types:

   (i) Leading strand is formed continuously in the direction of replication fork.
   (ii) Lagging strand is formed discontinuously in pieces in the direction opposite to replication fork. These pieces are called Okazaki fragments.
(e) Removal of RNA primer and joining of Okazaki fragments:

- Once a small piece of Okazaki fragment has been synthesized, nucleotides of RNA primer are removed one by one from 5' end by 5' → 3' exonuclease activity of DNA polymerase I (pol. I).
- The polymerase I also fills the gap left between Okazaki fragments.
- DNA repair is the function of polymerase I and polymerase II.
- 3' → 5' exonuclease activity of polymerase I and polymerase III is concerned with proofreading or editing.
- The adjacent 5' and 3' ends of Okazaki fragments are joined by DNA ligase.

Summary of proteins/enzymes needed in replication

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Protein/enzyme</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Initiator protein</td>
<td>To recognize the point of origin.</td>
</tr>
<tr>
<td>2.</td>
<td>Helicase/unwindase</td>
<td>To unwind the DNA duplex by breaking H-bonds.</td>
</tr>
<tr>
<td>3.</td>
<td>Topoisomerase (gyrase)</td>
<td>To cut and to reseal the DNA strands in order to relax the supercoiling.</td>
</tr>
<tr>
<td>4.</td>
<td>SSB</td>
<td>To retain the DNA in single stranded condition during replication.</td>
</tr>
<tr>
<td>5.</td>
<td>RNA primase</td>
<td>To synthesize RNA primer in 5' → 3' direction.</td>
</tr>
<tr>
<td>6.</td>
<td>Polymerase III (main enzyme)</td>
<td>To synthesize the DNA strand in 5' → 3' by adding nucleotides at 3' end of primer; proofreading.</td>
</tr>
</tbody>
</table>

Differences between prokaryotic and eukaryotic replication

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Character</th>
<th>Prokaryote</th>
<th>Eukaryote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>No. of initiation point</td>
<td>1</td>
<td>Many</td>
</tr>
<tr>
<td>2.</td>
<td>Cutting and resealing enzyme</td>
<td>Gyrase</td>
<td>Topoisomerase</td>
</tr>
<tr>
<td>3.</td>
<td>RNA primer length</td>
<td>Upto 50</td>
<td>Upto 9 nucleotide</td>
</tr>
<tr>
<td>4.</td>
<td>Types of polymerase</td>
<td>3; I, II and III</td>
<td>5; α, β, γ, δ, ε</td>
</tr>
<tr>
<td>5.</td>
<td>Synthesis of lagging strand</td>
<td>Polymerase-III</td>
<td>DNA polymerase α</td>
</tr>
<tr>
<td>6.</td>
<td>Synthesis of leading strand</td>
<td>Polymerase-III</td>
<td>DNA polymerase δ</td>
</tr>
<tr>
<td>7.</td>
<td>DNA repair</td>
<td>Polymerase-I and II</td>
<td>DNA polymerase β</td>
</tr>
<tr>
<td>8.</td>
<td>Proofreading</td>
<td>Polymerase-I and III</td>
<td>DNA polymerase δ</td>
</tr>
</tbody>
</table>

Note:

1. DNA polymerase γ is involved in mitochondrial DNA replication.
2. DNA replication is semiconservative, bidirectional and semidiscontinuous.
3. Drug rifampicin inhibits the replication by inhibiting RNA primer synthesis.
4. Nobel Prize of 1959 was awarded to Kornberg and Ochoa for artificial/in vitro synthesis of DNA and RNA respectively.
5. 5' → 3' exonuclease activity is found in polymerase-I.
6. 3' → 5' exonuclease activity is found in polymerase-I, II, III.
7. In eukaryotes, telomere is highly conserved both in structure and function but constant for all chromosomes of a particular species. It has highly repetitive DNA sequence to prevent the chromosome loss.
8. In progeria disease, symptoms similar to ageing appear at an early age with shortening of telomeres.
9. Severo Ochoa enzyme is needed during polymerization of RNA with defined sequences in a template independent manner. It is also known as polynucleotide phosphorylase.
Genetic code

1. Flow of genetic information:
DNA sends genetic information for protein synthesis (translation) by synthesizing mRNA (transcription). This is called central dogma of molecular biology, proposed by Crick. It is therefore one way flow of information.

Temin and Baltimore described an RNA directed DNA polymerase that synthesizes DNA from RNA. This is therefore inverse flow of information and is called central dogma reverse.

2. Definition and concept of triplet genetic code:
The genetic information is carried by 4 types of N-bases. A codon is the sequence of 3-N bases on mRNA that codes for a particular amino acid and the set of all the codons that specify 20 amino acids are called the genetic code.

The concept of triplet genetic code was given by George Gamow. Since there is four types of N-bases and 3N-bases take part in the formation of a codon hence total no. of codons will be:

\[ 4 \times 4 \times 4 = 64 \]

Triplet Genetic Code

<table>
<thead>
<tr>
<th>First Letter</th>
<th>Second Letter</th>
<th>Third Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UUU</td>
<td>Phe</td>
<td></td>
</tr>
<tr>
<td>UUC</td>
<td>UCU</td>
<td>UCU</td>
</tr>
<tr>
<td>UUA</td>
<td>UUC</td>
<td>UCC</td>
</tr>
<tr>
<td>UUG</td>
<td>Leu</td>
<td>UCA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UCG</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUC</td>
<td>Leu</td>
<td>CCC</td>
</tr>
<tr>
<td>CUA</td>
<td>CCA</td>
<td>CCA</td>
</tr>
<tr>
<td>CUG</td>
<td>CCG</td>
<td>CCG</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUG*</td>
<td>Met</td>
<td>ACC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACG</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUU</td>
<td>val</td>
<td>GCU</td>
</tr>
<tr>
<td>GUC</td>
<td>GGC</td>
<td>GCC</td>
</tr>
<tr>
<td>GUA</td>
<td>GCA</td>
<td>GCA</td>
</tr>
<tr>
<td>GUG</td>
<td>GCG</td>
<td>GCG</td>
</tr>
</tbody>
</table>

*Chain initiation codon

**Mean stop signals
3. Deciphering or cracking of Genetic Code:

It means, to determine that a particular codon codes for which amino acid. In 1961, Nirenberg (Nobel Prize winner in 1968 with Holley and Khorana) and Matthaei deciphered the first codon UUU for phenyl alanine.

They used homopolymer chain of mRNA i.e., mRNA with only one type of nitrogenous bases. By 1966, all the 64 codons had been deciphered.

4. Contribution of Dr. Khorana:

Dr. H.G. Khorana (an Indian born American Scientist) used copolymer (i.e., mRNA with more than one type of bases) UG UG UG UG ...... and deciphered UGU codon for cysteine and GUG codon for valine. He used homopolymer also.

Artificial gene was first synthesized by Dr. Khorana in 1963 (Nobel Prize 1968), which was alanine tRNA gene with 77 base pairs. Later, he also discovered a tyrosine tRNA gene with 207 bp and human leucocye interferon gene with 514 bp.

5. Second genetic code:

The genetic code determines the sequence of amino acid in a polypeptide. The second genetic code describes the mechanism through which an enzyme recognizes its tRNA and vice versa i.e., interaction between tRNA and amino acyl synthetase enzyme.

6. Second half of genetic code:

It refers to the mechanisms that govern the formation of a 3-dimensional structure from the primary structure of a protein.

7. Magic 20:

Twenty amino acids used in protein synthesis are called magic 20 by Crick. These are of 3 types:

(a) Essential/indispensable: are taken with food; not synthesized in body; 8 in number (phenyl alanine, valine, lysine, tryptophan, threonine, methionine, leucine and isoleucine).

(b) Semi-essential: are formed in slow manner in human body e.g., arginine and histidine.

(c) Non-essential/dispensable: are formed within the body and not to be supplied with diet; 10 in number (glycine, alanine, asparagine, serine, proline, aspartic acid, cysteine, glutamic acid, glutamine, and tyrosine).

Note:
- Glycine is the simplest and smallest amino acid and is involved in heme formation.
- Tryptophan is the most complex amino acid, which is involved in melatonin hormone synthesis.
- Tyrosine amino acid gives rise to melanin pigments, thyroxine, epinephrine and norepinephrine hormones.
- In strict sense, proline is not an amino acid as it does not contain NH$_2$ (but contains -NH) hence called an imino acid.

- Methionine and cysteine are sulfur containing amino acids.
- Informosomes: This term was given by Spirin. It is the association of protein and mRNA in the ratio of 4 : 1 in eukaryotes. These are stable and can remain in the cytoplasm for several days.

The amino acids, symbols, and codons

<table>
<thead>
<tr>
<th>Amino acids</th>
<th>Symbols</th>
<th>Codons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alanine</td>
<td>Ala</td>
<td>A</td>
</tr>
<tr>
<td>Cysteine</td>
<td>Cys</td>
<td>C</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>Asp</td>
<td>D</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>Glu</td>
<td>E</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>Phe</td>
<td>F</td>
</tr>
<tr>
<td>Glycine</td>
<td>Gly</td>
<td>G</td>
</tr>
<tr>
<td>Histidine</td>
<td>His</td>
<td>H</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>Ile</td>
<td>I</td>
</tr>
<tr>
<td>Lysine</td>
<td>Lys</td>
<td>K</td>
</tr>
<tr>
<td>Leucine</td>
<td>Leu</td>
<td>L</td>
</tr>
<tr>
<td>Methionine</td>
<td>Met</td>
<td>M</td>
</tr>
<tr>
<td>Asparagine</td>
<td>Asn</td>
<td>N</td>
</tr>
<tr>
<td>Proline</td>
<td>Pro</td>
<td>P</td>
</tr>
<tr>
<td>Glutamine</td>
<td>Gln</td>
<td>Q</td>
</tr>
<tr>
<td>Arginine</td>
<td>Arg</td>
<td>R</td>
</tr>
<tr>
<td>Serine</td>
<td>Ser</td>
<td>S</td>
</tr>
<tr>
<td>Threonine</td>
<td>Thr</td>
<td>T</td>
</tr>
<tr>
<td>Valine</td>
<td>Val</td>
<td>V</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>Trp</td>
<td>W</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>Tyr</td>
<td>Y</td>
</tr>
</tbody>
</table>

UUA, UUG, CUA, CUC, CUG, GUC, GCC, GCG, GCU

Characteristics of Genetic Code

1. Triplet:

The genetic code is triplet means a codon consists of a set of 3 N-bases on mRNA that codes for an amino acid. UUU was first triplet codon discovered by Nirenberg and Matthaei who are credited for discovery of genetic code. The codon UUU codes for phenyl alanine (Phe) and its one letter symbol is ‘F’.

2. Commaless:

Genetic code is commaless, means one codon is just followed by other codon and there is no any comma or additional base between two adjacent codons. The codons therefore read on mRNA in contiguous fashion.
3. **Non-overlapping:**

Genetic code is non-overlapping means the same single codon does not participate in the formation of 2 codons. It means 9 N-bases cannot take part in the formation of more than 3 codons.

4. **Non-ambiguous:**

The genetic code is non-ambiguous means the same single codon always codes for the same single amino acid. It means a particular codon can’t code more than one amino acid.

5. **Degeneracy:**

18 out of 20 amino acids are coded by more than one codon. This is explained by saying that genetic code is **degenerate or redundant type** *i.e.*, more than one codons code for a particular amino acid.

The degeneracy was first discovered by Nirenberg and Bernfield. Maximum degeneracy is shown by arginine, leucine and serine because each of them is coded by six codons. Tryptophan (trp) and methionine (met) do not show degeneracy because each one is coded by only one codon.

6. **Chain initiation codon:**

AUG is chain initiation codon as it starts the synthesis of polypeptide chain. It also codes for methionine amino acid.

Sometimes GUG (codon for valine) also works as chain initiation codon.

7. **Mean stop signals:**

3 codons do not code for any amino acid and their presence on mRNA causes the termination of protein synthesis hence called **nonsense or termination codons** (mean stop signals). These are:

<table>
<thead>
<tr>
<th>Termination codon</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAG</td>
<td>amber</td>
</tr>
<tr>
<td>UGA</td>
<td>opal</td>
</tr>
<tr>
<td>UAA</td>
<td>ochre</td>
</tr>
</tbody>
</table>

UAG was first termination codon discovered by Sydney Brenner.

8. **Universality:**

Genetic code is universal means the same single genetic code is applicable to all the living organisms however mycoplasma, certain ciliates and mitochondria are exception.

Important differences between universal and mitochondrial genetic codes are as following:

<table>
<thead>
<tr>
<th>Character</th>
<th>Universal GC</th>
<th>Mitochondrial GC</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of tRNA</td>
<td>approximately 32</td>
<td>approximately 22</td>
</tr>
<tr>
<td>Termination codons</td>
<td>3; UAG, UGA, UAA</td>
<td>4; UAG, UAA, AGA, AGG</td>
</tr>
<tr>
<td>UGA codon</td>
<td>Termination</td>
<td>Tryptophan</td>
</tr>
<tr>
<td>AGA, AGG</td>
<td>Arginine</td>
<td>Termination</td>
</tr>
</tbody>
</table>

9. **Codon and anticodon:**

Codons are found on mRNA while anticodons on tRNA and both are antiparallel. The anticodon base pairs with codon. *e.g.,*

**Codon:** 5’ GCA 3’
**Anticodon:** 3’ CGU 5’

In the diagram given here, ‘G’ is first base of codon while ‘U’ is first base of anticodon because it is convention to read DNA and RNA in 5’ → 3’ direction.

10. **Wobble Hypothesis:**

- Crick proposed this hypothesis to explain the **tRNA economy**, *i.e.*, to explain how one tRNA can recognize more than one codons.
- First 2 bases of codon base pair properly with the last 2 bases of anticodon.
- It is the first base of anticodon which shows some wobbling (play or dance) by which it can recognize more than one codons.
Transcription and RNA

Transcription

1. Formation of RNA from DNA is called transcription.
2. The DNA is said to be transcribed and the RNA produced is called transcript.
3. In DNA duplex, the strand which is being transcribed is called template/master strand while other strand which codes for nothing is called coding strand.
4. In viruses, template is called minus strand while coding strand is called plus strand.
5. In prokaryotes, all the three types of RNAs are synthesized by the same single DNA directed (DNA dependent) RNA polymerase (RNAP), which requires Zn and Mg ions.
6. RNAP consists of following 5 subunits or polypeptides:

<table>
<thead>
<tr>
<th>Subunit</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>2α</td>
<td>assembly of core enzyme</td>
</tr>
<tr>
<td>1β and 1β'</td>
<td>catalytic activity</td>
</tr>
<tr>
<td>σ</td>
<td>recognition of promoters</td>
</tr>
</tbody>
</table>

Core enzyme (= 2α + 1β + 1β') +σ = holoenzyme

Mechanism of transcription:

1. Replication is essentially a completive process while transcription is a selective process and includes a transcription unit.
2. The transcription unit consists of:
   I. promoter (towards the 5' end of coding strand).
   II. structural gene
   III. terminator (towards 3' end of coding strand)

Transcription includes following 3 steps:

(a) Chain initiation:
   - The holoenzyme binds the specific site on DNA called promoter which is recognised by σ factor. The promoter generally has TATAAT base sequence called TATA box.
   - GC box and CAAT box are found in the region of promoter that determine the efficiency of transcription.
   - After the recognition of promoter by σ factor, first base is attached with β subunit of RNAP and now the RNAP moves towards the 2nd base and in this way RNA chain synthesis is started.
   - Generally ‘T’ is transcribed first hence first ribonucleoside is ‘A’ (purine).
   - The RNAP uses ribonucleoside triphosphate as substrate.
Chain elongation:
After the initiation of RNA chain synthesis, core enzyme alone is enough to bind the ribonucleotides and to elongate the RNA chain in 5' → 3' direction from 3' → 5' template according to base pairing rule.

Chain termination:
When RNAP reaches the poly ‘A’ nucleotides (stop signal) on DNA then RNA chain synthesis is terminated. The stop signal is recognised by rho factor (termination factor) with the help of ATP.

In prokaryotes, the same single RNAP in general catalyzes all the three steps namely initiation, elongation and termination but in strict sense, it catalyses elongation only. It catalyzes the initiation only when initiation factor (σ) is present and catalyzes the termination only when the termination factor (p) is present.

During transcription, both the DNA strands are not copied and only a part of one strand is copied into RNA. If both strands are copied then it will produce a dsRNA which will prevent the RNA from being translated and therefore complicate the genetic information machinery.

RNAP and post transcriptional modifications in eukaryotes:
1. In eukaryotes, there are following 3 types of RNAP with clearcut division of labour:

<table>
<thead>
<tr>
<th>Type of RNAP</th>
<th>Synthesizes the</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNAP I</td>
<td>rRNA (28 S, 18 S and 5.8 S)</td>
</tr>
<tr>
<td>RNAP II</td>
<td>hnRNA (heterogeneous nuclear RNA), which is precursor of mRNA</td>
</tr>
<tr>
<td>RNAP III</td>
<td>tRNA, 5 srRNA and snRNA (small nuclear RNA)</td>
</tr>
</tbody>
</table>

2. Immediate product of transcription is called **primary transcript**, which is non-functional because it contains both exons and introns. The primary transcript of mRNA is called **hnRNA** which undergoes following processing steps in order to become an active and functional mRNA:
  - introns (non-coding segments) are removed through a process called **splicing**.
  - 7-methyl guanosine triphosphate is added at 5' end through a process called **capping**.
  - Poly ‘A’ nucleotides (adenylate residues) are added at 3' end through a process called **tailing**.

**Note:**
- **-CCA nucleotides** are added at 3' end to yield the tRNA while mRNA does not require any processing in bacteria.
- RNA was the first genetic material having catalytic activity. The RNA being a catalyst was reactive and therefore unstable. Hence more stable DNA was evolved from RNA with chemical modifications.

**Transcription inhibitors:**
- Actinomycin-D inhibits the transcription both in prokaryotes and eukaryotes.
- Rifampicin inhibits the transcription in prokaryotes.
- α-amanitin inhibits the transcription in eukaryotes.

**Differences between prokaryotic and eukaryotic transcription:**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Character</th>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Occurs in</td>
<td>Cytoplasm</td>
<td>Nucleus</td>
</tr>
<tr>
<td>2.</td>
<td>Promoters</td>
<td>TATA box or Prionbow box</td>
<td>TATA box or Hogness box</td>
</tr>
<tr>
<td>3.</td>
<td>RNAP</td>
<td>The same single RNAP synthesizes all the three types RNAs.</td>
<td>Three types of RNAP synthesize the RNAs: RNAP I → rRNA RNAP II → mRNA RNAP III → tRNA</td>
</tr>
<tr>
<td>4.</td>
<td>Composition of RNAP</td>
<td>5 subunits</td>
<td>More than 5 sub-units</td>
</tr>
<tr>
<td>5.</td>
<td>Transcriptional unit</td>
<td>Generally polycistronic</td>
<td>Always monocistronic</td>
</tr>
<tr>
<td>6.</td>
<td>Coupled transcription and translation</td>
<td>occur</td>
<td>do not occur</td>
</tr>
<tr>
<td>7.</td>
<td>Transcription inhibitor</td>
<td>Rifampicin</td>
<td>α-amanitin</td>
</tr>
</tbody>
</table>
Reverse transcription:
1. Formation of DNA from genetic RNA is called reverse transcription, as found in RSV, HIV etc.
2. Enzyme responsible for it is RNA dependent or RNA directed DNA polymerase (reverse transcriptase).
4. Rogers gave the term ‘retroposon’ for the DNA segments originated from RNA.
5. Complementary DNA or copy DNA or cDNA is a copy of RNA synthesized through reverse transcription. It is used in PCR and gene cloning.

Ribozyme:
This is an enzyme which is not a protein. This RNA enzyme was discovered by Cech and Altman in 1982 (Nobel Prize 1989). The ribozyme:
- has catalytic activity.
- can cleave/cut the RNA.
- can selectively amplify the RNA.
- can join the RNA segments.
- was important during origin of life.

Ribonucleic Acid (RNA)
The RNA is of two types:
1. Genetic RNA: RNA is the genetic material in:
   (a) Most plant viruses:
       (i) TMV-ssRNA
       (ii) Wound and tumour virus-dsRNA
   (b) Some animal viruses:
       (i) Influenza, Polio, Rous sarcoma virus (RSV), Retrovirus (HIV) - ssRNA
       (ii) Rheo virus - dsRNA
   (c) Bacteriophages: such as MS-2-ssRNA
2. Non-genetic RNA:
   - messenger RNA (mRNA)
   - transfer RNA (tRNA)/adapter RNA
   - ribosomal RNA (rRNA)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Character</th>
<th>mRNA</th>
<th>tRNA</th>
<th>rRNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Also known as</td>
<td>Nuclear RNA</td>
<td>Soluble RNA</td>
<td>Insoluble RNA</td>
</tr>
<tr>
<td>2.</td>
<td>Named by</td>
<td>Jacob and Monod</td>
<td>Hoagland</td>
<td>Kurland</td>
</tr>
<tr>
<td>3.</td>
<td>Percentage</td>
<td>5%</td>
<td>15%</td>
<td>80%</td>
</tr>
<tr>
<td>4.</td>
<td>Life span</td>
<td>Short lived</td>
<td>Long lived</td>
<td>Most stable</td>
</tr>
<tr>
<td>5.</td>
<td>Length</td>
<td>Longest but variable</td>
<td>Smallest</td>
<td>Variable</td>
</tr>
<tr>
<td>6.</td>
<td>Shape</td>
<td>Linear</td>
<td>Clover leaf-like; folded into L-form</td>
<td>Greatly coiled</td>
</tr>
<tr>
<td>7.</td>
<td>Formed in</td>
<td>Nucleus and found in cytoplasm</td>
<td>Nucleus and found in cytoplasm</td>
<td>Nucleolus and found in ribosomes.</td>
</tr>
<tr>
<td>8.</td>
<td>Contains</td>
<td>Codons</td>
<td>Anticodons</td>
<td>Bases to recognize both mRNA and tRNA</td>
</tr>
<tr>
<td>9.</td>
<td>Function</td>
<td>To determine the sequence of amino acids (aa) in polypeptide chain.</td>
<td>To recognize the mRNA by reading genetic code and to transport the aa on ribosomes after identifying them in cytoplasm.</td>
<td>To play structural and catalytic roles during translation.</td>
</tr>
</tbody>
</table>

Transfer RNA (tRNA):
1. It has to recognise mRNA by reading the genetic code and to carry the amino acid on the ribosome.
2. In order to fulfil both these purposes, its primary structure i.e., polynucleotide chain is modified into secondary structure like the shape of a clover leaf.
3. The famous clover leaf model or 2 dimensional or secondary structure of tRNA was given by Robert Holley (1965) who determined the base sequence of yeast alanine tRNA.
4. No. of nucleotides in tRNA ranges from 73 to 93.
5. tRNA also contains following **unusual** bases:
   - pseudouridine (ψ)
   - inosine (I)
   - dihydouridine (DHU)
6. **Inosine** is a modified base found only in tRNA and resembles the ‘G’.
7. Klug (Nobel Prize 1982) worked a lot on 3-D structure of tRNA. Its latest 3-D or tertiary structure was given by S.H. Kim (1973) and is **L-shaped**.

---

**Fig. 3: Clover-leaf model of tRNA**

**Fig. 4: 3-D structure of tRNA**

---

**Differences between DNA and RNA**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Character</th>
<th>DNA</th>
<th>RNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Occurrence</td>
<td>mostly in nucleus but also in chloroplasts and mitochondria.</td>
<td>Mostly in cytoplasm but also in nucleus.</td>
</tr>
<tr>
<td>3.</td>
<td>Types</td>
<td>2 types: linear and circular.</td>
<td>3 types: rRNA, mRNA, tRNA.</td>
</tr>
<tr>
<td>5.</td>
<td>Thymine and uracil bases.</td>
<td>‘T’ present but ‘U’ absent.</td>
<td>‘U’ present but ‘T’ absent.</td>
</tr>
</tbody>
</table>
**Translation (protein synthesis)**

This is a process in which genetic information carried by mRNA is converted into a polypeptide (protein) with a specific sequence of amino acids.

The cellular factory responsible for synthesizing the protein is called ribosome which takes the help of 3 types of RNAs. The mRNA acts as template, tRNA brings the amino acid and reads the genetic code while rRNA plays structural and catalytic roles. It includes following three steps:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Steps</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Initiation</td>
<td>Assembly of smaller subunit of ribosome with mRNA.</td>
</tr>
<tr>
<td>2.</td>
<td>Elongation</td>
<td>Repeated cycles of amino acid addition.</td>
</tr>
<tr>
<td>3.</td>
<td>Termination</td>
<td>Release of newly synthesized polypeptide chain.</td>
</tr>
</tbody>
</table>

**Amino Acylation of tRNA:**

- It means activation of amino acid and its attachment with tRNA.
- It occurs before the initiation of protein synthesis.
- Specific amino acyl tRNA synthetase enzyme activates the amino acid that occurs in cytoplasm with help of ATP (i.e., ATP → AMP).
- The activated amino acid gets attached with tRNA to form the amino acyl tRNA complex (charged tRNA), which moves towards the ribosome.
- The amino acyl tRNA synthetase therefore has two sites:
  (a) one site to recognise the tRNA.
  (b) other site to recognise the amino acid.

Since there are 20 amino acids hence at least 20 such enzymes are necessary.

**Chain initiation:**

- When smaller subunit of ribosome comes in contact with mRNA, translation of mRNA into polypeptide is started.
- Initiating amino acid is **methionine** which is coded by AUG (initiation codon).
- In prokaryotes, initiating amino acid is formylated methionine (fmet) and this formylation is done by transformylase enzyme.
- AUG works in association with Shine Dalgarno sequence (SD region), which has AGGAGGU base sequence.

Now an initiation complex is formed by the association of smaller subunit of ribosome, mRNA and charged initiator tRNA (1st charged tRNA). It requires GTP, 3 initiation factors (IF$_1$, IF$_2$ and IF$_3$) along with Mg ions.

After that, smaller subunit gets attached with larger subunit to form a complete ribosome.

Larger ribosomal subunit has two sites:

(a) **Donor/peptidyl P site**
(b) **Aminoacyl/acceptor A site**

- Only the charged initiator tRNA enters the ‘P’ site while all other charged tRNAs enter the ‘A’ site.
- The entrance of charged initiator tRNA (1st charged tRNA) on P site indicates the beginning of protein synthesis during which ‘P’ site is occupied and ‘A’ site is emptied.
Protein synthesis starts with N-terminal and ends with C-terminal of amino acid.

2. Chain elongation:
   Stepwise growth of polypeptide chain occurs as following:
   - Next or 2nd charged tRNA enters the ‘A’ site with the help of GTP. It requires elongation factors: EF-TU and EF-TS (u = unstable, s = stable, when heated).
   - A peptide bond is formed between two adjacent amino acids by peptidyl transferase enzyme, present in 23 srRNA of larger subunit of ribosome. It means ribosome itself acts as a catalyst.
   - Next step is translocation which requires GTP/EFG/translocase. During translocation:
     (a) entire ribosome moves one codon forward in 5’ → 3’ direction.
     (b) 1st charged tRNA is discharged from ‘P’ site.
     (c) 2nd charged tRNA comes from ‘A’ site to ‘P’ site.

   Now ‘A’ site is vacated for 3rd charged tRNA and in this way elongation of polypeptide chain goes on.

3. Chain termination:
   - The mRNA also contains untranslated regions (UTR), found between 5’ and 3’ end before the initiation codon and after the termination codon. The UTR are not translated however these are needed for efficient translation process.
   - Protein synthesis is terminated when one of the three termination codons reaches on ‘A’ site. There is no tRNA for termination codon.
   - At the end, releasing factors (RF) bind the termination codon, terminating the translation by hydrolysing the last tRNA on ‘P’ site and finally complete polypeptide is released from ribosomes.

Polysomes / polyribosomes:
When several ribosomes get attached with a common mRNA for the purpose of translation then these are called polysomes.

Energy need during translation

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Steps</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Amino acylation of tRNA (activation of amino acid)</td>
<td>ATP → AMP</td>
</tr>
<tr>
<td>2.</td>
<td>Formation of initiation complex</td>
<td>GTP → GDP</td>
</tr>
<tr>
<td>3.</td>
<td>Entry of charged tRNA on ‘A’ site</td>
<td>GTP → GDP</td>
</tr>
<tr>
<td>4.</td>
<td>Translocation</td>
<td>GTP → GDP</td>
</tr>
</tbody>
</table>

Translation inhibitors

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Antibiotics</th>
<th>Inhibit the prokaryotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tetraacycline</td>
<td>Binding of aminoacyl tRNA with ribosome.</td>
</tr>
<tr>
<td>2.</td>
<td>Streptomycin</td>
<td>Initiation of translation and proper reading.</td>
</tr>
<tr>
<td>3.</td>
<td>Chloramphenicol</td>
<td>Peptidyl transferase and peptide bond formation.</td>
</tr>
<tr>
<td>4.</td>
<td>Neomycin</td>
<td>Interaction of tRNA and mRNA.</td>
</tr>
<tr>
<td>5.</td>
<td>Erythromycin</td>
<td>Translocation of ribosomes along mRNA.</td>
</tr>
</tbody>
</table>
Regulation of Gene Expression

Expression of a particular gene in eukaryotes can be regulated at following levels:

- Transcriptional level
- Processing level
- Transportation level (transport of mRNA from nucleus to cytoplasm)
- Translational level.

In prokaryotes, gene expression is regulated at:

(a) Transcriptional level: It means regulation of transcription of mRNA from DNA.

(b) Translational level: It means regulation of initiation and rate of protein to be synthesized.

Induction and repression:

Any substance which induces protein synthesis/enzyme production is called inducer through which a particular gene is allowed to express itself. The genetic system responsible for it is called inducible system e.g., lactose operon (with 3 structural genes).

The substance which suppresses the protein synthesis is called repressor through which a particular gene is inhibited to express. The genetic system responsible for it is called repressible system e.g., tryptophan operon (with 5 structural genes).

Prokaryotic Gene Regulation:
(regulation at transcriptional level/operon model):

Famous operon model was proposed by Jacob and Monod in 1961 (Nobel Prize 1965) at Pasteur Institute Paris, while working with lactose catabolism in E.coli.

An operon consists of closely linked control genes (regulator + promoter + operator) and associated polycistronic structural genes.

Operon = regulator gene + promoter gene + operator gene + structural genes

Thus, polycistronic structural genes are regulated by promoter and regulator genes. Such arrangement is called operon e.g., lac operon, trp operon, his operon etc.

Generalized structure of an operon:

In general, an operon consists of:

1. **Regulator gene (i):** It produces repressor protein which binds the operator and inhibits (i) the transcription.
2. **Promoter gene (p):** This is a segment of DNA where RNAP binds for transcription.
3. **Operator gene (o):** This is a segment of DNA which exercises a control over transcription and acts as on off switch.
4. **Structural genes:** These are the segments of DNA that determine the primary structure of polypeptide to be synthesized.

Thus, structural genes synthesize the mRNA under the operational control of operator, which in turn controlled by regulator gene.

Structure of lac operon:

Lac (lactose) operon consists of:

- regulator gene (i)
- promoter gene (p)
- operator gene (o)
- structural genes (z, y, a)

These three structural genes code for certain enzymes necessary for lactose catabolism as following:
Functioning of an operon:

1. In the absence of an inducer:

   In the absence of an inducer, regulator gene synthesizes the repressor protein which binds the operator. The operator is therefore not free hence RNAP (RNA polymerase) cannot move. With the result no transcription and no translation.

   ![Fig. 1: Lac Operon (in the absence of inducer)](image)

2. In the presence of an inducer:

   In the presence of an inducer such as lactose (actually allolactose), inducer binds the repressor to inactivate the repressor. The inactivated repressor cannot bind the operator hence operator is free to move the RNAP. With the result transcription and translation occur, followed by the formation of necessary enzymes.

   ![Fig. 2: Lac Operon (in the presence of inducer)](image)

Lactose is therefore a substrate for enzyme β-galactosidase and it controls the switching on and off of the operon. This is the reason why it is called inducer (glucose or galactose is not the inducer).

The lac operon can also be regulated through repressor called negative regulation.

Regulation at translational level:

This is done by introducing an RNA which is complementary to mRNA. The introduced RNA forms RNA-mRNA hybrid and it prevents the mRNA from being translated.

This introduced RNA is called antisense RNA or mic RNA.

Eukaryotic gene regulation:

Regulation of gene expression in eukaryotes at transcriptional level occurs according to gene battery model proposed by Britten and Davidson in 1969.

Regulation at translational level involves the reversible protein phosphorylation proposed by E.H. Fischer and E.G. Krebs (Nobel Prize 1992).
Mutation

1. Sudden large change in genetic makeup or hereditary constitution or germplasm or DNA is called mutation by Hugo de Vries, sports by Darwin and saltatory or discontinuous variation by Bateson.

2. Mutations are generally recessive and harmful.

3. A mutation that changes a wild or original type into new type is called forward mutation and if the new type is mutated again into wild type then it is called backward or reverse mutation.

4. H.J. Muller:
   (a) first induced artificial or sex linked lethal mutation by X-rays in fruit fly in 1927.
   (b) was awarded Nobel Prize for the same in 1946.
   (c) is father of actinobiology (study of effects of radiations on living system).

5. Mutation is of two types:
   I. intragenic change/gene or point mutation
   II. intergenic change / chromosomal mutation

I. Point Mutation

   In this case, change occurs within a particular gene at a particular point. In strict sense, point mutation is considered as mutation.

   It is of two types:
   A. Substitution
   B. Frameshift / gibberish mutation

A. Substitution point mutation:

   In this case, one N-base is replaced by other and is of two sub types:

<table>
<thead>
<tr>
<th>Transition</th>
<th>Transversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) One purine is replaced by other purine and one pyrimidine is replaced by other pyrimidine.</td>
<td>(a) Purine is replaced by pyrimidine and vice versa.</td>
</tr>
<tr>
<td>(b) Four possible transitions are as following:</td>
<td>(b) 8 possible transversions are as following:</td>
</tr>
<tr>
<td>[ \begin{align*} V &amp; \rightarrow G \ V &amp; \rightarrow A \end{align*} ]</td>
<td>[ \begin{align*} A &amp; \rightarrow T \text{ or } C \ G &amp; \rightarrow T \text{ or } C \ C &amp; \rightarrow A \text{ or } G \ T &amp; \rightarrow A \text{ or } G \end{align*} ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Character</th>
<th>Transition</th>
<th>Transversion</th>
<th>Substitution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 N-base</td>
<td>1×1</td>
<td>1×2</td>
<td>1×3 = 3</td>
</tr>
<tr>
<td>1 codon (3 N-bases)</td>
<td>3×1</td>
<td>3×2</td>
<td>3×3 = 9</td>
</tr>
<tr>
<td>Genetic code (61 codons)</td>
<td>61×3</td>
<td>61×6</td>
<td>61×9 = 549</td>
</tr>
</tbody>
</table>

Note: 549 base substitutions are possible in genetic code (of 61 sense codons).

B. Frameshift point mutation:

   Addition or loss of one or more N-bases to the DNA or mRNA causes frameshift mutation because it shifts the reading frame of codons from the site of change onwards.

   If 3-N bases are added or deleted then frame shift error will not occur.

Note:

   (i) Silent mutation: If a mutation changes a codon for an amino acid into another codon that also codes for the same amino acid then it is called silent mutation. As a result, no change occurs in the protein to be synthesized.

   \[ \begin{align*} UAC & \rightarrow UAU \\ \text{tyrosine} & \rightarrow \text{tyrosine} \end{align*} \]
(ii) Missense mutation: If a mutation changes a codon that codes for an amino acid into another codon that codes for different amino acid then it is called missense mutation. As a result, defective or faulty protein will be formed.

\[ \text{UAC} \rightarrow \text{CAC} \]

tyrosine  histidine

(iii) Nonsense mutation: If a mutation changes a codon that codes for an amino acid into one of the three termination codons then it is called nonsense mutation. As a result, an incomplete protein is formed.

\[ \text{UAC} \rightarrow \text{UAG/UGA/UA} \]

termination codons

II. Chromosomal Mutation

It is of two types:
1. Structural change in chromosomes / chromosomal rearrangement.
2. Numerical change in chromosomes / ploidy.

1. Structural change:
   In this case, number of chromosomes does not change but change occurs in the number or arrangement of genes. It is of following types:
   (a) Deletion / deficiency: It is the loss of a part of chromosome, as found in Cri-du chat syndrome.

   ![Deletion Diagram]

   (b) Duplication: It is the addition of a part of chromosome hence one or more genes may be represented twice.

   ![Duplication Diagram]

   (c) Translocation: Exchange of segments between non-homologous chromosomes is called translocation which alters the linkage group. e.g., Philadelphia chromosome (exchange between 22nd and 9th chromosomes).

   ![Translocation Diagram]

   (d) Inversion: The chromosome forms a loop which breaks into 2 or more segments and the broken segments are rejoined in reversed order.

   ![Inversion Diagram]

2. Numerical change:
   It means change in the number of chromosomes but not in structure and this change is of 2 types:
   A. Aneuploidy
   B. Euploidy / polyploidy

A. Aneuploidy:
   It is the loss or gain of one or more chromosomes to the diploid no. but this no. must be less than haploid chromosome no. It occurs due to non-disjunction (failure of separation of chromosomes during cell division).

   Aneuploidy may be of following types and subtypes:

   ![Aneuploidy Diagram]

B. Polyploidy:
   1. Strasburger (1910) gave the term ‘polyploid’.
   2. In polyploids, more than 2 sets of chromosomes are found i.e., exact multiple of basic chromosome no.
   3. The primitive ancestral chromosome no. is called basic no. which is represented by ‘x’.
   4. In diploid organisms, monoploid, haploid and basic chromosome no. are the same.
   5. Haploid or gametic chromosome no. is ‘n’ while ‘2n’ is diploid or somatic chromosome no.
   6. In a hexaploid, if basic chromosome no. is 7 then different chromosome no. in following cases will be:

   \[ x = 7 \]
   \[ 6x = 42 \]
   \[ 2n = 42 \]
   \[ n = 21 \]

   7. On the basis of source of additional genome added, polyploidy is of 2 types:
   (a) Autopolyploidy
   (b) Allopolyploidy (interspecific polyploidy)

   Note:
   Genome is haploid chromosome no. found in gametes and inherited from one parent.

(a) Autopolyploidy: In this case additional genome of the same species is added. If one species has AA diploid condition then an autotriploid will contain AA ‘A’ while autotetraploid AA’AA’. Examples are reported in banana, watermelon, grapes, evening primrose etc.
**Mutation**

(b) **Alloployploidy:** In this case additional genome of different species is added hence it is also called **interspecific polyploidy.** If one species has AA diploid condition and other species has BB diploid condition then an allotriploid will contain AA ‘B’ while allottetraploid (amphidiploid) will contain AA ‘BB’.

**Example 1.** A well known example of allottetraploid is *Raphano brassica.* It is developed by crossing raddish with cabbage by Russian geneticist G.D. Karpechenko as following:


---

**Example 2.** Another example is of *Triticale* (first man made cereal) developed by Muntzing and others by crossing rye and wheat. The *Triticale* is either hexaploid or octaploid.

---

**Colchicine and its role in polyploidy:**
1. This is an alkaloid used to induce the polyploidy.
2. This chemical is extracted from seed and corm of a plant *Colchicum autumnale* (fam. Liliaceae).
3. It disturbs the spindle formation and helps in chromosome doubling.

**Mutagens**
1. These are the agents that induce mutation and are of following two types:

---

**Summary of Important Chemical Mutagens**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Chemical mutagens</th>
<th>Mutation</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Nitrous acid (HNO₃)</td>
<td>Transition</td>
<td>Oxidative deamination</td>
</tr>
<tr>
<td>2.</td>
<td>Alkylating agents</td>
<td>All types of mutation but mainly transition</td>
<td>Transfer of methyl or ethyl groups</td>
</tr>
<tr>
<td>(a)</td>
<td>Mustard gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>Methyl methane sulfonate (MMS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>Ethyl methane sulfonate (EMS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Base analogues</td>
<td>Transition</td>
<td>By changing the base pairing as they are structurally similar to bases of DNA</td>
</tr>
<tr>
<td>(a)</td>
<td>5-bromo uracil (analogue of T)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>2-amino purine (analogue of A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Acridines</td>
<td>Frameshift mutation</td>
<td>By inserting between 2 bases</td>
</tr>
<tr>
<td>(a)</td>
<td>Proflavin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>Acridine orange</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Hydroxylamine</td>
<td>Transition</td>
<td>By hydroxylating the amino group</td>
</tr>
</tbody>
</table>

2. First chemical mutagen discovered was mustard gas (sulfur mustard) by Auerbach.
3. X-rays and EMS are commonly used in plants.
4. Triploid watermelon is seedless.
5. *Datura* is a classical example of trisomy. Since it has 12 pairs of chromosomes hence there may be 12 trisomics.
6. Nitrogen bases exist in more than one alternate forms, which are called **tautomers** and this phenomenon is as **tautomeration.** This is caused by shifting and rearrangement of H-atoms from their normal position. These are called **tautomeric shifts.**
7. Different alleles of a gene arise only by mutation.
8. **Paramutation** means a change in the function of a structural gene that may last for several generations.
9. Highly mutable sites within a gene are called **hot spots** e.g., sites containing 5-methyl cytosine provide hot spot for spontaneous point mutation.
10. The genes which increase the frequency of mutation in other genes, are called **mutator genes**.

11. Haploids are better for the study of mutation because they have only one allele of a gene.

12. **Thalassemia** is an **autosomal linked recessive** blood disorder, which is characterized by reduced rate of synthesis of haemoglobin chains (alpha and beta). This causes the formation of abnormal haemoglobin molecules resulting into anaemia, which is an illness that makes a person weak and tired.

   If both parents are heterozygous (carrier for the gene) then it would be transmitted to the offspring. The defect is either due to mutation or deletion.

   There are two main types of thalassemia: alpha and beta. Beta thalassemia is the most common.

   In alpha thalassemia, production of alpha globin chain is affected. Alpha globin is made by four genes, two (closely linked genes HBA1 and HBA2) on each strand of chromosome 16. It is observed due to mutation or deletion of one or more of the four genes. The more genes affected, the less alpha globin molecules produced.

   The beta thalassemia is controlled by a single gene HBB on chromosome 11 of each parent and occurs due to mutation of one or both the genes.

   Thalassemia differs from sickle-cell anaemia in that the former is a **quantitative** problem of synthesizing too few globin molecules while the latter is a **qualitative** problem of synthesizing an incorrectly functioning globin.
Population Genetics

It deals with the study of gene frequencies in a population and represents an application of Mendelian genetics into Darwinian natural selection.

Hardy Weinberg Law

1. It was proposed by an English mathematician G.H. Hardy (1908) and German physician W. Weinberg (1909). According to this law "gene and genotype frequencies in a large and randomly mating Mendelian population remain constant or stable under certain conditions." This type of genetic stability is called genetic equilibrium or Hardy Weinberg equilibrium.

2. The evolutionary forces or agents or factors or processes that change the gene and genotype frequencies and affect the genetic equilibrium are:
   (a) Mutation
   (b) Migration
   (c) Selection
   (d) Recombination
   (e) Genetic drift

3. Absence of these factors means existence of genetic equilibrium and existence of genetic equilibrium means evolution is not taking place.

4. Evolution is possible only when genetic equilibrium disturbs or upsets i.e., one or more such factors are operating.

5. The relationship between gene and genotype frequencies can be expressed through following formula:

\[ P + q = 1 \]
\[ P^2 + q^2 + 2pq = 1 \]

Where \( p \) and \( q \) are the two alleles in the same population. This is called Hardy Weinberg formula.

Genetic Drift/ Random Drift

1. Sewall Wright gave this term.

2. It is random fluctuation in gene frequencies occurs by chance in small population from one generation to other.

3. It acts in non-directional manner.

4. It probably results from interbreeding in the populations.

5. It causes elimination of certain alleles from the population and fixation of other alleles in the population.


   (a) Bottleneck effect (Stebbins):
   Any environmental condition which kills most of the members of population and only few survive causes bottleneck effect.
   Here, only chance determines the survival but not the adaptive value.

   (b) Founder effect (Mayr):
   If some members are separated from a population and start to develop a new population then these are called founders.
   The new population therefore has less genetic variation and reduced gene pool (The sum total of all the genes present in a Mendelian population is called gene pool).

Natural Selection

1. It brings a change in gene frequencies and promotes adaptation as a product of evolution.

2. Let us consider 3 types of individuals in a population:
   (a) Smaller individuals (extreme phenotype).
   (b) Medium individuals (average or normal).
   (c) Larger individuals (extreme phenotype).
3. Natural selection is of three types:
   (a) Stabilizing selection.
   (b) Directional selection.
   (c) Disruptive selection.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Character</th>
<th>Stabilizing selection</th>
<th>Directional selection</th>
<th>Disruptive selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Phenotype favoured</td>
<td>Medium phenotype</td>
<td>Only one extreme phenotype</td>
<td>Both extreme phenotypes</td>
</tr>
<tr>
<td>2</td>
<td>Condition of environment</td>
<td>Almost unchanged</td>
<td>Changes in one direction</td>
<td>Heterogenous type with several habitats</td>
</tr>
<tr>
<td>3</td>
<td>Elimination</td>
<td>Both extreme phenotypes</td>
<td>Medium phenotype and one extreme phenotype</td>
<td>Medium phenotype</td>
</tr>
<tr>
<td>4</td>
<td>Peak produced</td>
<td>Only 1 peak in the centre</td>
<td>Only 1 peak, at one side</td>
<td>2 peaks; 1 on either side</td>
</tr>
<tr>
<td>5</td>
<td>Evolutionary change</td>
<td>Does not occur for e.g., Latimeria (living fossil)</td>
<td>Occurs progressively, e.g., Industrial melanism, DDT resistance in mosquito etc.</td>
<td>Occurs but this type of selection is rare for e.g., British land snail</td>
</tr>
</tbody>
</table>

Examples of Natural Selection

1. Industrial melanism (protective resemblance with surrounding):
   - Phenomenon of replacement of light coloured peppered moth (Biston betularia) by dark melanic species (Biston carbonaria) is called industrial melanism.
   - This had happened in England due to industrial smoke, originally reported by Ford and Fischer and then experimented by Kettelwell.
   - This is an example of natural selection, occurred due to gene mutation.
   - This is a good evidence for evolution and tells how evolution has taken place before the human eyes.

2. DDT resistance in mosquito:
   - There were two types of mosquitoes;
     (a) More DDT sensitive
     (b) Less DDT resistant
   - When DDT was not used, former dominated over later. When DDT was introduced, DDT resistant mosquitoes survived because of competitive advantage.

3. Sickle cell disease:
   - This is an example of pleiotropy, sub-lethality, point mutation and natural selection.
   - Gene for haemoglobin in homozygous dominant condition (Hb^A Hb^A) produces normal haemoglobin and normal RBCs but there is a risk of malaria.
   - Gene in homozygous recessive condition (Hb^s Hb^s) produces sickle celled Hb and RBCs and the person dies because of lethal effect.
   - Gene in heterozygous condition (Hb^A Hb^s) is called sickle cell trait and the person is resistant to malaria infection because malarial parasite cannot complete its life cycle in affected RBCs.
   - This condition is found in those areas of tropical Africa where malaria is common and heterozygous individuals survive because of competitive advantage.

4. G-6 PD deficiency:
   - Glucose-6-phosphate dehydrogenase enzyme is important in carbohydrate metabolism, hexose mono phosphate shunt and provides stability to RBCs.
   - Deficiency of this enzyme is rare but has a survival value in malaria infested area because malarial parasite cannot complete its life-cycle in affected RBCs.

5. Genetic basis of adaptation: Lederberg's replica plating experiment (1952):
   - This experiment was performed by J. Lederberg and E. Lederberg in 1952. J. Lederberg received Nobel Prize in 1958 along with Beadle and Tatum.
   - Lederberg prepared a master plate of several bacterial colonies on an agar plate.
   - They developed exact replica of this master plate on a new agar plate with the help of wooden block and velvet disc.
   - They tried to develop another replica on new agar plate having antibiotic penicillin (or streptomycin).
   - They found that most of the bacterial colonies failed to grow (antibiotic sensitive strain) while few bacterial colonies continue to grow (antibiotic resistant strain).
   - On the basis of above experiment and observation, Lederberg concluded that:
     (a) Antibiotic does not induce the new mutation to occur.
     (b) It selects only pre adaptive mutation i.e., it permitted the pre-existing mutation to express.
     (c) It supports the natural selection (Theory of Darwin).
Reproductive Isolation
1. It means ‘inability to interbreed’ and is separation of a large population into smaller units in order to:
   (a) prevent the mating between 2 members of populations of 2 species.
   (b) promote the formation of new species.
2. It along with natural selection provides direction to evolution.
3. Any factor which reduces the chance of interspecific crosses is called isolating mechanism which may be of two types:
   (i) Premating isolation:
      It includes external barriers that prevent the interspecific crosses before mating hence called premating isolation e.g.,
      - Geographical Isolation
      - Seasonal Isolation
      - Mechanical Isolation
      - Behavioural Isolation
   (ii) Postmating isolation:
      It includes internal barriers that reduce the chance of complete success of interspecific crosses after mating hence called postmating isolation e.g.,
      - Gametic mortality
      - Zygotic mortality
      - Hybrid sterility
      - Hybrid breakdown

Mimicry
1. It is the superficial resemblance of an organism to other organism or any object for the purpose of offence and defence e.g., Indian dead leaf butterfly (Kallima).
2. The organism which shows mimicry is called mimic and the other organism or object which is being copied is called model.
3. Bates gave the term mimicry which is a type of adaptation.
4. Mimicry is of two types:
   (a) Batesian mimicry: One edible or palatable species looks like other non-edible species. Here only one species is benefitted.
   (b) Mullerian mimicry: Two non-edible and harmful species resemble each other to provide sufficient warning to predators. Here, both species are equally benefitted.

Speciation
Formation of a new species from pre-existing species is called speciation, which may be of following types:
1. Phyletic speciation:
   It is the formation of new species from pre-existing species but the parent species dies e.g., evolution of Mesohippus from Eohippus.
   Evolution of new species through change in single lineage is called anagenesis or phyletic evolution.
2. Gradual speciation:
   It is the slow transformation of an isolated population into new species through the accumulation of small continuous variation generation after generation. This is an example of adaptive radiation e.g., Darwin's finches.
   Formation of two species from a single ancestral species is called cladogenesis or divergent evolution.
3. Rapid or fast or instant speciation:
   It occurs through mutation and polyploidy.

Patterns of speciation
1. Allopatric speciation:
   Formation of new species occurring in different geographical areas is called allopatric speciation. It requires geographical isolation and is common among animals.
2. Sympatric speciation:
   Formation of new species occurring in same or overlapping geographical areas, is called sympatric speciation. It requires reproductive isolation and is common among plants.
3. Parapatric speciation:
   Two populations with adjacent geographical areas are called parapatic. It is an intermediate condition of allopatric and sympatric speciation and requires the reproductive isolation.
1. Term ‘genetics’ was given by
   (a) Mendel  (b) Bateson  
   (c) Morgan  (d) Johannsen

2. Genetics deals with the study of:
   (a) Cell biology and Eugenics  
   (b) Heredity and Mendelism  
   (c) Mendelism and Evolution  
   (d) Heredity and Variations

3. Who is the father of genetics?
   (a) Mendel  (b) Bateson  
   (c) Morgan  (d) Garrod

4. ‘Like begets like’ is due to:
   (a) Heredity  (b) Eugenics  
   (c) Morphology  (d) Evolution

5. What is the dogma of genetics?
   (a) Heredity  (b) Omnis vivum ex ovo  
   (c) Like begets like  (d) Omnis cellula e cellula

6. Heredity lies within a:
   (a) Species  (b) Genus  
   (c) Class  (d) Kingdom

7. An asexually produced organism inheriting all the characters of its parent is called:
   (a) Clone  (b) Offspring  
   (c) Hybrid  (d) Variety

8. In biparental reproduction, the offspring shows
   (a) differences from both the parents:  
   (b) no change from the maternal parent  
   (c) no change from the paternal parent  
   (d) mixtures of characters from both the parents

9. The term offspring is used for young ones resulting from:
   (a) Sexual reproduction  
   (b) Asexual reproduction  
   (c) Vegetative reproduction  
   (d) Cloning

10. An offspring:
    (a) resembles the ramet  
    (b) is not produced through sexual reproduction  
    (c) is identical to either parent  
    (d) must have variations

11. Siblings:
    (a) have different parents (b) have same parents  
    (c) are genetically similar (d) are identical twins

12. Mendel was born in:
    (a) 18th century  (b) 19th century  
    (c) 20th century  (d) 21st century

13. Mendel died because of:
    (a) Liver disease  (b) Heart attack  
    (c) Kidney disorder  (d) Cancer

14. Experimental plant of Mendel was:
    (a) Sweet pea  (b) Garden pea  
    (c) Maize  (d) Evening primrose

15. Besides, *Pisum sativum*, Mendel also worked upon a plant named:
    (a) Maize  (b) Sweet pea  
    (c) Hawkweed  (d) Evening primrose

16. Hawkweed (*Hieracium*) belongs to the family:
    (a) Malvaceae  (b) Cruciferae  
    (c) Compositae  (d) Solanaceae

17. Mendel had selected garden pea as his experimental material because besides being an annual showing a number of contrasting characters and easy to cultivate, it had the following advantages:
    (a) Bisexual and self-pollinating  
    (b) Bisexual and cross-pollinating  
    (c) Unisexual and cross-pollinating  
    (d) Unisexual and self-pollinating

18. Removal of anthers during hybridization experiments is called:
    (a) Emasculation  (b) Bagging  
    (c) Heterosis  (d) Hybrid
19. Emasculation is a part of:
   (a) clonal selection  (b) hybridization  
   (c) self pollination (d) pure line selection

20. In emasculation, anthers are removed:
   (a) after pollination  (b) after maturity  
   (c) during maturity  (d) before maturity

21. Mendel performed his experiments during the year:
   (a) 1856-1863  (b) 1876-1886  
   (c) 1956-1964  (d) 1843-1849

22. Mendel published works of hybridization in year:
   (a) 1866  (b) 1876  
   (c) 1966  (d) 1843

23. Mendel conducted his experiments for:
   (a) 6 years  (b) 7 years  
   (c) 9 years  (d) 8 years

24. Which one of the following traits of garden pea studied by Mendel was a recessive feature:
   (a) Axial flower position  (b) Green seed colour  
   (c) Green pod colour  (d) Round seed shape

25. Yellow colour in garden pea is not:
   (a) recessive for seed colour  (b) dominant for seed colour  
   (c) recessive for pod colour  (d) inherited through hereditable genes

26. Which character studied by Mendel in garden pea was dominant?
   (a) Wrinkled seed shape  (b) Green pod colour  
   (c) Green seed colour  (d) Terminal flower position

27. Diploid chromosome number in pea is:
   (a) 8  (b) 10  
   (c) 7  (d) 14

28. Who discovered that the genes for different characters studied by Mendel were located on 4 of the 7 pairs chromosomes in garden pea?
   (a) Morgan  (b) Bateson  
   (c) Blixt  (d) de Vries

29. Mendel's 7 pairs of contrasting traits in garden pea are actually located on following set of chromosomes:
   (a) 1, 4, 5, 7  (b) 1, 4, 5, 6  
   (c) 1, 4, 5, 3  (d) 1, 2, 4, 5

30. All of the following characters of garden pea are located on chromosome no. 4 except:
   (a) Pod colour  (b) Pod shape  
   (c) Stem length  (d) Flower position

31. The genes for flower colour and seed colour in pea plant are located on the chromosome pair:
   (a) 1  (b) 4  
   (c) 5  (d) 7

32. Out of 7 pairs of contrasting traits in garden pea, how many traits are actually located on chromosome no. 4?
   (a) 3  (b) 1  
   (c) 4  (d) 2

33. Starch branching enzyme (SBE-I) is responsible for which of the following trait of pea plant?
   (a) Round seed  (b) Wrinkled seed  
   (c) Grey coat colour of seed  (d) White coat colour of seed

34. Mendel's work was republished in the year:
   (a) 1840  (b) 1884  
   (c) 1900  (d) 1901

35. The forgotten work of Mendel was rediscovered by three biologists from the following countries:
   (a) Holland, France and England  (b) Holland, Austria and England  
   (c) Germany, France and England  (d) Germany, Holland and Austria

36. Who republished Mendel's work in Flora?
   (a) Carl Correns  (b) Hugo de Vries  
   (c) T.H. Morgan  (d) Tschermak

37. Who proposed the concept of particulate unit factor?
   (a) Correns  (b) Mendel  
   (c) Morgan  (d) Bateson

38. The scientist who converted Mendel's work into laws of heredity was:
   (a) Carl Correns  (b) Hugo de Vries  
   (c) Tschermak  (d) Morgan

39. How many types of gametes are formed by a plant with a genotype AaBB?
   (a) 1  (b) 2  
   (c) 3  (d) 4

40. How many different kinds of gametes can be produced by an organism of the genotype AaBBCc?
   (a) 3  (b) 4  
   (c) 8  (d) 9

41. Female AaBb is crossed to male AAbb. The gametes shall be:
   (a) Female AB and ab, male AA and bb  
   (b) Female Aa and Bb, male AA and bb  
   (c) Female AB,Ab, aB and ab, male Ab  
   (d) Female AA,bb,AB and ab, male Ab

42. How many different types of gametes can be formed by F1 progeny, resulting from the cross AABBCC × aabbcc?
   (a) 4  (b) 8  
   (c) 27  (d) 64

43. If an organism produces 32 types of gametes, its genotype should be heterozygous for:
   (a) 4 genes  (b) 5 genes  
   (c) 8 genes  (d) 16 genes

44. How many different types of gametes are needed for F2 from AaBb genotypes?
45. Which of the following composition represent gamete?
(a) Gg  (b) Ggl
(c) Gl  (d) GgLl

46. A human male produces sperms with the genotypes AB, Ab, aB and ab pertaining to two diallelic characters in equal proportions. What is the corresponding genotype of this person?
(a) AABb  (b) AABB
(c) AaBb  (d) AaBB

47. How many different types of gametes are needed for a typical dihybrid and trihybrid F2 respectively?
(a) 2 and 4  (b) 4 and 8
(c) 8 and 16  (d) 12 and 16

48. Which of these is homozygous recessive?
(a) Ss  (b) SS
(c) ss  (d) s

49. A gamete normally contains:
(a) One allele of a gene  (b) Two alleles of a gene
(c) All alleles of a gene  (d) Many alleles of a gene

50. How many types of gametes will be produced by individuals of AABbcc genotype?
(a) Two  (b) Four
(c) Six  (d) Nine

51. Mendel reasoned that an individual has how many factors for every character?
(a) One  (b) Two
(c) Three  (d) Four

52. Mendel also reasoned that gametes contain how many factors for each character?
(a) Only one  (b) Two
(c) Three  (d) Four

53. During the formation of the gametes, genetic factors:
(a) Segregate  (b) Duplicate many times
(c) Disappear  (d) Combine or fuse

54. The members of each allelic pair separate during:
(a) Meiosis  (b) Mitosis
(c) Fertilization  (d) Either meiosis or mitosis

55. The law of independent assortment states that:
(a) Each pair of factors segregate independently of other pairs
(b) All possible combinations of factors can occur in the gametes
(c) Both (a) and (b) are true
(d) Genetic traits are independent of the genes on the chromosome

56. Mendel’s idea that pairs of characters separate during gamete formation is called the law of:
(a) Particulate inheritance  (b) Dominance
(c) Segregation  (d) Independent assortment

57. Which Mendel’s law states that a random assortment of maternally and paternally derived chromosomes in meiosis results in gametes that have different combinations of these genes?
(a) Particulate inheritance  (b) Dominance
(c) Segregation  (d) Independent assortment

58. Mendel’s laws are explained by:
(a) Chromosome behaviour in mitosis  (b) Chromosome behaviour in meiosis
(c) Cytokinesis in mitosis and meiosis  (d) Mendel’s laws have not been explained

59. Mendel’s last law is:
(a) Segregation  (b) Dominance
(c) Polygenic inheritance  (d) Independent assortment

60. “Gametes are never hybrids” is the statement of:
(a) Law of Dominance  (b) Law of Segregation
(c) Law of Random fertilization  (d) Law of Independent assortment

61. Mendel failed to get linkage because:
(a) genes of 7 types of traits selected by him were located on 4 different chromosomes and behaved independently
(b) genes selected by him were discrete and stable
(c) genes selected by him were located on seven non homologous chromosomes.
(d) he studied crossing over

62. On the basis of Independent assortment and physical basis of inheritance what actually assorts independently?
(a) Sister chromatids  (b) Homologous chromosomes
(c) Heterologous chromosomes  (d) Genes on the chromosomes

63. In which generation the segregation of allelic phenotypes take place?
(a) F0  (b) F1
(c) F2  (d) F3

64. When an allele fails to express itself in the presence of other allele, former is said to be:
(a) Recessive  (b) Dominant
(c) Co-dominant  (d) Incompletely dominant
65. An allele is said to be dominant if it is expressed:
(a) in heterozygous combination
(b) only in homozygous combination
(c) both in homozygous and heterozygous combinations
(d) in hemizygous combinations

66. Universal law of Mendel is:
(a) Law of segregation
(b) Law of independent assortment
(c) Law of dominance
(d) All of the above

67. In a monohybrid cross, the genotypic ratio of F2 is:
(a) 3 : 1
(b) 1 : 2 : 1
(c) 4 : 0
(d) 1 : 1 : 1 : 1

68. What is the ratio of homozygous and heterozygous plants in monohybrid F2 generation?
(a) 3 : 1
(b) 1 : 2 : 1
(c) 4 : 0
(d) 1 : 1 : 1 : 1

69. What is the most common outcome in the F2 generation of a cross between a tall plant and a dwarf plant?
(a) 1 tall : 1 dwarf
(b) 3 tall : 1 dwarf
(c) 1 tall : 2 medium : 1 dwarf
(d) All tall

70. F2 generation is produced by:
(a) Crossing F1 progeny with one of the parents
(b) Selfing the progeny of two individual parents
(c) Selfing the parents
(d) Recessive cross between individual parents

71. The offspring resulting from a cross between two pure homozygous recessives would be:
(a) 100% homozygous recessive
(b) 75% homozygous recessive and 25% heterozygous dominant
(c) 50% homozygous recessive and 50% homozygous dominant genes on the chromosomes
(d) 75% homozygous recessive and 25% homozygous dominant

72. If a cross is made between AA and aa, the nature of F1 progeny will be genotypically:
(a) aa phenotypically A
(b) Aa phenotypically a
(c) AA phenotypically a
(d) Aa phenotypically A

73. Resistance to a fungus in pea plants is conferred by gene ‘h’ which is completely recessive to its allele ‘H’ for susceptibility. If a resistant female plant is crossed with a homozygous susceptible male what would be order of genotype in pistillate (female) parent, staminate parent, male gametes and egg:
(a) Hh ; HH ; H : h
(b) hh ; Hh ; h ; h
(c) hh; HH; H; h
(d) Hh; HH; h; H

74. A dwarf pea plant is treated with gibberellin, which makes it tall. This plant is crossed with genetically pure tall plant. Phenotypic ratio in F2 generation shall be?
(a) 3 tall: 1 dwarf
(b) 50% tall: 50% dwarf
(c) All tall
(d) All dwarf

75. Consider a monohybrid cross between a pure tall plant and a dwarf plant. In F2 generation of this cross 4000 seedlings were produced. How many seedlings will be dwarf?
(a) 0
(b) 1000
(c) 2000
(d) 3000

76. In garden pea, when a plant having pure yellow pod is crossed with another plant having pure green pod then F1 will be:
(a) All green
(b) All yellow
(c) 50% green
(d) 50% yellow

77. Percentage of heterozygous individuals obtained from selfing Rr individuals is:
(a) 25
(b) 75
(c) 50
(d) 100

78. In a cross 45 tall and 14 dwarf plants were obtained. Genotypes of the parents are:
(a) TT × TT
(b) Tt × Tt
(c) TT × Tt
(d) TT × tt

79. How many types of phenotypes are possible in F2 generations as a result of a monohybrid cross?
(a) 2
(b) 4
(c) 3
(d) 1

80. What would be the no. of homozygous dominant genotypes in a dihybrid F2 generation out of 16?
(a) One
(b) Two
(c) Three
(d) Four

81. Which of the following is an example of a dihybrid cross?
(a) AABb × aabb
(b) AaBb × AaBB
(c) aabb × AABB
(d) aabb × aabb

82. Which of the following phenotypic results are expected from a dihybrid cross?
(a) 1 : 1 : 1 : 1 ratio
(b) 9 : 3 : 3 : 1 ratio
(c) All dominant for both traits
(d) All recessive for both traits

83. Consider the cross AaBb × AaBb. If the alleles for both genes exhibit complete dominance, what genotypic ratio is expected in the resulting offspring?
(a) 1 : 1 : 1 : 1
(b) 3 : 6 : 3 : 1 : 2 : 1
(c) 9 : 3 : 3 : 1
(d) 1 : 2 : 2 : 4 : 1 : 2 : 1

84. When two hybrids with the genetic constitution RrTt and rrtt are crossed, the phenotypic ratio of the offsprings will be?
(a) 1 : 2 : 1
(b) 1 : 1 : 1 : 1
(c) 7 : 1 : 1 : 7
(d) 1 : 1
85. When a pure strain of tall plants with round peas is crossed with a pure strain of short plants with wrinkled peas, then what proportion of the \( F_1 \) generation will be short with wrinkled peas?
   (a) 1/16  
   (b) 1/8  
   (c) 1/4  
   (d) zero

86. When two hybrids \( rrTt \) and \( RrTt \) are crossed, the phenotype ratio of offspring shall be?
   (a) 3:1  
   (b) 1:1:1:1  
   (c) 1:1  
   (d) 9:3:3:1

87. How many types of phenotypes are possible in \( F_2 \) generations as a result of dihybrid cross?
   (a) 2  
   (b) 4  
   (c) 3  
   (d) 1

88. If a dwarf plant with terminal flowers produced 100 tall plants with axial flowers and 100 tall offspring with terminal flowers. The possible genotype of other parent is:
   (a) TTAA  
   (b) TtAA  
   (c) TTAa  
   (d) TtAa

89. A homozygous plant with axial flower position and wrinkled seed is crossed with another homozygous plant having terminal flowers position and round seed. The \( F_1 \) offspring obtained by this above cross is crossed with a plant having terminal flower position and wrinkled seed. Find out the phenotypic ratio in \( F_2 \) generation:
   (a) 9:3:3:1  
   (b) 1:2:1  
   (c) 1:4:6:4:1  
   (d) 1:1:1:1

90. A plant with \( AaBb \) composition, on self pollination results in which of the following genotypic frequencies:

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>( AABB )</td>
<td>1</td>
</tr>
<tr>
<td>( AAbb )</td>
<td>4</td>
</tr>
<tr>
<td>( AaBb )</td>
<td>1</td>
</tr>
<tr>
<td>( aaBb )</td>
<td>2</td>
</tr>
<tr>
<td>( aabb )</td>
<td>1</td>
</tr>
</tbody>
</table>

91. From a cross \( AABb \times aaBb \), the genotypes \( AaBb : Aabb \) will be obtained in the following ratio:
   (a) 1:1:1:1  
   (b) 1:2:1:0  
   (c) 0:3:1:0  
   (d) 1:1:1:0

92. In a dihybrid cross \( AABb \times aabb \), \( F_2 \) progeny of aaBB, AABb, AaBB and aaBb occurs in the ratio of:
   (a) 1:4:1:1  
   (b) 9:3:3:1  
   (c) 4:2:2:1  
   (d) 1:4:2:2

93. In a dihybrid cross, yellow is dominant over green and round seed is dominant over the wrinkled. They were crossed and a typical Mendelian dihybrid ratio of 9:3:3:1 was obtained. There were 1600 members in the progeny. How many of them are likely to be wrinkled?
   (a) 100  
   (b) 400  
   (c) 300  
   (d) 600

94. In a dihybrid cross \( AABB \times aabb \), \( F_2 \) progeny of \( AABB \), \( AABb \), \( AaBB \) and \( aaBb \) occurs in the ratio of:
   (a) 1:1:1:1  
   (b) 9:3:3:1  
   (c) 1:2:2:1  
   (d) 1:2:2:4

95. Dominant gene for tallness is \( T \) and for yellow colour is \( Y \). A plant heterozygous for both the traits is selfed, then the ratio of pure homozygous dwarf and green offspring to pure homozygous tall and yellow offspring would be:
   (a) 3:1  
   (b) 1:16  
   (c) 1:1  
   (d) 1:7

96. In a plant, red fruit (\( R \)) is dominant over yellow fruit (\( r \)) and tallness (\( T \)) is dominant over shortness (\( t \)). If a plant with \( RRrrTt \) genotype is crossed with a plant that is \( rrrttt \):
   (a) 50% will be tall with red fruit  
   (b) 75% will be tall with red fruit  
   (c) 25% will be tall with red fruit  
   (d) All the offspring will be tall with red fruit

97. A double heterozygous tall plant with yellow colour seed (cotyledon) is selfed. The ratio of dwarf plants with green cotyledons is:
   (a) 1/16  
   (b) 1/4  
   (c) 1/6  
   (d) 2/16

98. In a typical dihybrid cross, if one character is fixed then other character shows a ratio of:
   (a) 3:1  
   (b) 1:1  
   (c) 1:1:1:1  
   (d) 9:3:3:1

99. Ratio of homozygous dominant and homozygous recessive for both characters in a typical dihybrid cross is:
   (a) 3:1  
   (b) 9:3:3:1  
   (c) 1:1:1:1  
   (d) 1:1

100. How many percentage of individuals are found in a dihybrid \( F_2 \) generation having both characters in heterozygous condition?
   (a) 25%  
   (b) 50%  
   (c) 75%  
   (d) 100%

101. When a tall plant with round seeds (\( TTRR \)) crossed with a dwarf plant with wrinkled seeds (\( ttrr \)), the \( F_1 \) generation consists of tall plants with round seeds. What would be the proportion of dwarf plant with wrinkled seeds in \( F_2 \)?
   (a) 0  
   (b) 1/2  
   (c) 1/4  
   (d) 1/16

102. When \( AABB \) and \( aabb \) are crossed, in \( F_2 \) generation the \( AaBb \) will be:
   (a) 1/16  
   (b) 2/16  
   (c) 8/16  
   (d) 4/16

103. Select the correct statement from the ones given below with respect to dihybrid cross:
   (a) Genes far apart on the same chromosome show very few recombinations
Selected Objective Questions

(b) Genes loosely linked on the same chromosome show similar recombinations as the tightly linked ones
(c) Tightly linked genes on the same chromosome show very few recombinations
(d) Tightly linked genes on the same chromosome show higher recombinations

104. In Mendel’s experiment with garden pea, a cross is conducted between round seeded tall plant and a wrinkled seeded dwarf plant. What would be the expected phenotypes in F₂ generation of this cross?
(a) 3R:1W
(b) 3T : 1D
(c) 9RT:3RD:3WT:1WD (d) All of these

105. A trihybrid cross is made between two yeast, both having genotypes AaBbCc. What proportion of the offsprings will be of genotype aabbcc:
(a) 0
(b) 1/4
(c) 1/16
(d) 1/64

106. If the number of heterozygous gene pairs involved in a particular cross is three, the phenotypic ratio obtained in their F₂ generation would be:
(a) 9:3:3:1
(b) 27:9:9:3:3:3:3:1
(c) 27:9:9:9:3:3:3:1
(d) 1:2:2:4:1:2:1:1

107. A self-fertilizing trihybrid plant forms:
(a) 4 different gametes and 16 different zygotes
(b) 8 different gametes and 27 different zygotes
(c) 8 different gametes and 29 different zygotes
(d) 8 different gametes and 64 different zygotes

108. How many phenotypic classes are expected from the test cross of AaBbCcDd?
(a) 2
(b) 4
(c) 6
(d) 16

109. Trihybrid test cross ratio is:
(a) 1 : 1 : 1 : 1
(b) 1 : 1 : 1 : 1 : 1 : 1
(c) 27 : 9 : 9 : 9 : 3 : 3 : 3 : 3 : 1
(d) 1 : 2 : 2 : 4 : 1 : 2 : 1 : 1 : 1

110. A tall red-flowered pea plant after crossing with a dwarf white-flowered plant yields only tall red flowered plants. A test cross shall give a ratio of:
(a) 1 : 1
(b) 3 : 1
(c) 1 : 2 : 4 : 6 : 4 : 2 : 1
(d) 1 : 1 : 1 : 1

111. A test cross is carried out to:
(a) determine whether two species or varieties will breed successfully
(b) determine the genotype of a plant at F₂
(c) predict whether two traits are linked
(d) assess the number of alleles of a gene

112. The genotype of a plant showing the dominant phenotype can be determined by:
(a) Dihybrid cross
(b) Pedigree analysis
(c) Back cross
(d) Test cross

113. A back cross is F₁ ×:
(a) F₁
(b) Dominant parent
(c) Recessive parent
(d) Any parent

114. Which of the following crosses is a test cross?
(a) Unknown × AA
(b) Unknown × aa
(c) Unknown × Aa
(d) Unknown × unknown

115. A cross between homozygous recessive and heterozygous plant is:
(a) Dihybrid cross
(b) Monohybrid cross
(c) Test cross
(d) Back cross

116. A test cross distinguishes between:
(a) Two homozygous forms
(b) A homozygous dominant and the heterozygous form
(c) Two heterozygous forms
(d) A homozygous recessive and a heterozygous form

117. Which cross is used to determine heterozygosity or homozygosity of parents?
(a) Test cross
(b) Back cross
(c) Dihybrid cross
(d) Monohybrid cross

118. Tall red flowered pea plant is crossed to dwarf white flowered plant yields only tall red flowered plant. Test cross ratio is:
(a) 1 : 1
(b) 3 : 1
(c) 1 : 1 : 1 : 1
(d) 1 : 2 : 4 : 6 : 4 : 2 : 1

119. A common test to find the genotype of a hybrid is by:
(a) Studying the sexual behaviour of F₁ progeny
(b) Crossing of one F₁ progeny with male parent
(c) Crossing of one F₂ progeny with male parent
(d) Crossing of one F₂ progeny with female parent

120. In order to find out the different types of gametes, produced by a pea plant having the genotype AaBb, it should be crossed to a plant with the genotype:
(a) aaBB
(b) AaBb
(c) AABB
(d) aabb

121. Genes located on different chromosomes assort independently during meiosis, giving a test cross ratio of:
(a) 9 : 3 : 3 : 1
(b) 7 : 1 : 1 : 7
(c) 1 : 1 : 1 : 1
(d) 1 : 1

122. The ratio 1 : 1 : 1 : 1 is obtained from a cross between the parents:
(a) RRYY × rryy
(b) RRYy × rYy
(c) Rryy × Rryy
(d) Rr Yy × rryy

123. A plant with a genotype AaBb is crossed with a plant having genotype aabb. The genotype of progeny will be:
(a) AaBb, AaBb
(b) aabb, aaBb
(c) aaBB, AABb
(d) AaBb, AaBb, aabb, aabb

124. A test cross of AaBbCc produces how many phenotypes?
(a) 16
(b) 4
(c) 8
(d) 12
125. Test cross in plants or in *Drosophila* involves crossing:
(a) between 2 genotypes with dominant trait
(b) the F₁ hybrid with a double recessive genotype
(c) between two F₁ hybrids
(d) between 2 genotypes with recessive trait

126. An organism with two identical alleles for a given trait is:
(a) Dominant  (b) Homozygous
(c) Segregating  (d) Heterozygous

127. In which of the following the two members of the allelic pair in the zygote are the same?
(a) Homozygous  (b) Heterozygous
(c) Codominant  (d) Dominant

128. An organism with two different alleles is:
(a) Homozygous for that trait
(b) Heterozygous for that trait
(c) Homologous for the alleles
(d) Heterologous for the alleles

129. In which of the following the members of the allelic pair are different:
(a) Homozygous  (b) Recessive
(c) Allelopathic  (d) Heterozygous

130. The condition in which only one allele of a pair is present, is referred to as:
(a) Homozygous
(b) Heterozygous
(c) Hemizygous
(d) Incomplete dominance

131. Hemizygous condition is:
(a) When one gene is present of a homologous set
(b) When multiple alleles
(c) When only one gene is expressed and other remains suppressed
(d) Lethal to organism

132. Alternate forms of a gene having the same position on a pair of chromosomes and affecting the same trait are called:
(a) Loci  (b) Alleles
(c) Mutations  (d) Genotypes

133. Wild types are:
(a) Common
(b) Rare and occurs in forests
(c) Non existing at present
(d) Extinct genes

134. A cross involving two crosses concerning the same characteristics but with reversed sexes is known as:
(a) Test cross  (b) Reciprocal cross
(c) Back cross  (d) Dihybrid cross

135. Which term was given by Johannsen?
(a) Genetics  (b) Gene
(c) Homozygous  (d) Heterozygous

136. Phenotype of an organism is the result of:
(a) Genotype and environment interactions
(b) Mutations and linkages
(c) Cytoplasmic effects and nutrition
(d) Environmental changes and sexuality

137. Pure line breed refers to:
(a) Homozygosity only
(b) Heterozygosity only
(c) Heterozygosity and linkage
(d) Homozygosity and independent assortment

138. Alleles are:
(a) Homologous chromosomes
(b) Alternate forms of a particular gene
(c) Linked genes
(d) Chromatids that have crossed over

139. Isoalleles are:
(a) Similar alleles with different expression
(b) Alleles with very similar phenotype
(c) Different genes with similar expression
(d) Lethal genes

140. Non alleles that produce related phenotypic effects are:
(a) Isoalleles  (b) Pseudoalleles
(c) Multiple alleles  (d) Wild alleles

141. Pseudoalleles are:
(a) 2-closely placed genes with nearly similar expression
(b) Forms of same allele
(c) Mutations in different genes producing alleles with similar effect
(d) Alleles producing similar effect under changed conditions

142. Pseudoalleles are:
(a) Functionally allelic but structurally non allelic
(b) Structurally allelic but functionally non allelic
(c) Isoalleles
(d) Unable to express in progeny

143. Alleles that produce related phenotypic effects are called:
(a) Pseudoalleles  (b) Isoalleles
(c) Wild alleles  (d) Multiple alleles

144. Cross involving genes from 4 lines is called:
(a) Out cross  (b) Reciprocal cross
(c) Double cross  (d) Dihybrid cross

145. When two genotypes produce the same phenotype due to environmental difference, then each one is known as:
(a) phenotype
(b) phenocopy
(c) progeny
(d) offspring

146. Primary source of allelic variation is:
(a) Recombination
(b) Independent assortment
(c) Mutation
(d) Polyploidy
147. Hybridization means:
(a) Removal of stamens  
(b) Mixing parental characters  
(c) Production of large-sized grains  
(d) Study of pollination habit

148. Intermediate gradations are found in:
(a) Continuous variations  
(b) Discontinuous variations  
(c) Mutations  
(d) Gene interaction

149. Who for the first time reported the Ancon sheep with small and curved feet as substantive variation:
(a) Sewall Wright  
(b) Haldane  
(c) Dobzhansky  
(d) Seth Wright

150. Superiority of hybrid over parents is called:
(a) Gigantism  
(b) Heterosis  
(c) Hybrid vigour  
(d) Hybridized progeny

151. When two unrelated individuals or lines are crossed, the performance of F1 hybrid is often superior to both its parents. This phenomenon is called:
(a) Splicing  
(b) Metamorphosis  
(c) Heterosis  
(d) Transformation

152. Which of the following is an example of hybrid vigour?
(a) Mule  
(b) Horse  
(c) Donkey  
(d) Neopilina

153. The percentage of individuals that show a particular phenotype among those capable of showing is called:
(a) expressivity  
(b) penetrance  
(c) heterosis  
(d) phenocopy

154. Inbreeding is carried out in animal husbandry because it
(a) increases vigour  
(b) improves the breed  
(c) increases heterozygosity  
(d) increases homozygosity

155. The group of animals related by descent and similar in most characters is called a:
(a) breed  
(b) race  
(c) species  
(d) hybrid

156. A well known Indian breed developed through artificial selection and domestication from ancestral cows is:
(a) Leghorn  
(b) Sahiwal  
(c) Jersy  
(d) Bikaneri

157. Which one of the following is an improved breed of chicken?
(a) Jersy  
(b) Sahiwal  
(c) Bikaneri  
(d) Leghorn

158. Which one of the following is a new breed of sheep?
(a) Sahiwal  
(b) Hisardale  
(c) Murrah  
(d) Jersy

159. Hisardale is a new breed developed:
(a) in Punjab  
(b) by cross-breeding  
(c) as sheep  
(d) all of these

160. Which one of the following is developed by crossing of Bikaneri and Marino rams:
(a) Murrah  
(b) Jersy  
(c) Leghorn  
(d) Hisardale

161. Mule is obtained by crossing:
(a) male donkey and female horse  
(b) female donkey and male horse  
(c) donkey and horse  
(d) two mules

162. Hinny is obtained by crossing:
(a) male donkey and female horse  
(b) female donkey and male horse  
(c) donkey and horse  
(d) two mules

163. Both mule and hinny:
(a) are sterile  
(b) have 63 chromosomes  
(c) are examples of interspecific hybridization  
(d) all of the above

164. Inbreeding depression:
(a) decreases the fertility  
(b) reduces the productivity  
(c) is caused due to continued close inbreeding  
(d) all of the above

165. Inbreeding depression:
(a) increases the fertility  
(b) enhances the productivity  
(c) is caused due to continued close inbreeding  
(d) is removed by cross breeding

166. Which Mendelian idea is depicted by a cross in which the F1 generation resembles both the parents?
(a) law of dominance  
(b) inheritance of one gene  
(c) co-dominance  
(d) incomplete dominance

167. In a red and white-flowered cross of Mirabilis jalapa, F2 generation has red, pink and white-flowered plants in the ratio of:
(a) 2 : 1 : 1  
(b) 1 : 1 : 2  
(c) 1 : 2 : 1  
(d) 1 : 0 : 1

168. A blue fowl obtained from mating between black and white fowls, is self-crossed. The F2 ratio is:
(a) 1 black : 2 white : 1 blue  
(b) 1 black : 2 blue : 1 white  
(c) 2 black : 1 white : 1 blue  
(d) all blue

169. Incomplete dominance occurs when:
(a) chromosomes are deleted
170. Phenotype of a hybrid is in between the two heterozygotes is due to:
(a) Co-dominance
(b) Incomplete dominance
(c) Complete dominance
(d) Lethal genes

171. Blending inheritance is shown by:
(a) Mendelian monohybrid cross
(b) Co-dominance
(c) Incomplete dominance
(d) Lethal genes

172. In incomplete dominance, modified allele is responsible for the production of:
(a) less efficient enzyme
(b) a non-functional enzyme
(c) no enzyme at all
(d) all of the above

173. Which plant was used by Carl Correns to demonstrate the incomplete dominance:
(a) Pea plant
(b) Lathyrus odoratus
(c) Mirabilis jalapa
(d) Mustard

174. In Mirabilis jalapa, when red coloured flowers were crossed with white flowers, pink colour flowers were obtained. It was due to:
(a) Epistasis
(b) Crossing over
(c) Complete dominance
(d) Incomplete dominance

175. The phenotypic and genotypic ratios resemble in F₂ generation in case of:
(a) Independent assortment
(b) Qualitative inheritance
(c) Segregation of factors
(d) Incomplete dominance

176. Co-dominance is when:
(a) Both alleles express themselves together
(b) One allele expresses itself while other remain hidden
(c) One gene expresses partially
(d) All genes themselves together

177. If both alleles express equally in a hybrid, it is called:
(a) Lethal gene
(b) Incomplete dominance
(c) Complete dominance
(d) Co-dominance

178. In which of the following process genotypic and phenotypic ratio remain the same?
(a) Polygenes
(b) Co-dominance
(c) Lethal genes
(d) Monohybrid cross

179. Roan coat colour in cattle is an example of:
(a) mosaic inheritance and partial-dominance
(b) mosaic inheritance and co-dominance
(c) blending inheritance and co-dominance
(d) epistasis and Mendelian inheritance

180. Albino condition in snapdragon is due to:
(a) Lethal genes
(b) Supplementary genes
(c) Epistatic genes
(d) New genes

181. A gene whose phenotypic effect kills the bearer is called:
(a) Pleiotropic
(b) Supplementary
(c) Complementary
(d) Lethal

182. Cuenot crossed 2 yellow coloured mice which never breed true and received 2 yellow and 1 brown. It was due to:
(a) Cumulative genes
(b) Epistatic genes
(c) Supplementary genes
(d) Lethal genes

183. A gene when present in homozygous form causes the death of bearer and disturbs phenotypic ratio from 3 : 1 to 2 : 1 is:
(a) Lethal gene
(b) Pleiotropic gene
(c) Epistatic gene
(d) Duplicate gene

184. Recessive lethal genes are:
(a) Killers in homozygous state
(b) Causative for appearance of ancestral traits
(c) Genes present on different chromosomes but influencing single trait
(d) Dominant in nature

185. What is the phenotypic ratio, if one character in a dihybrid cross shows incomplete dominance?
(a) 3 : 6 : 1 : 2 : 3 : 1
(b) 1 : 6 : 15 : 20 : 15 : 6 : 1
(c) 27 : 9 : 9 : 9 : 3 : 3 : 3 : 1
(d) 8 : 4 : 2 : 1 : 1

186. Polygenes are:
(a) genes which control continuously variable characters like height, weight, intelligence etc.
(b) multiple copies of a single gene
(c) always linked genes
(d) pseudogenes

187. The ratio 9 : 7 is produced due to:
(a) complementary genes
(b) supplementary genes
(c) lethal genes
(d) epistatic genes

188. If one allele of one gene masks the expression of an allele of another gene, then it is called:
(a) Epistasis
(b) Codominance
(c) Suppression
(d) Inactivation

189. In a genetic cross having recessive epistasis, F₂ phenotypic ratio would be:
(a) 9 : 6 : 1
(b) 15 : 1
(c) 9 : 3 : 4
(d) 12 : 3 : 1
190. In case of inhibitory genes, the Mendelian dihybrid ratio 9:3:3:1 is modified as:
(a) 9 : 3 : 3 : 1  
(b) 9 : 3 : 4  
(c) 1 : 4 : 6 : 4 : 1  
(d) 13 : 3

191. Appearance of walnut comb in poultry in a cross between pure pea comb and rose comb animals is due to:
(a) Duplicate genes  
(b) Complementary genes  
(c) Additive genes  
(d) Collaborative genes

192. What is the phenotypic ratio in collaborative genes?
(a) 9 : 3 : 3 : 1  
(b) 9 : 3 : 4  
(c) 1 : 4 : 6 : 4 : 1  
(d) 15 : 1

193. Gene interaction in which either of dominant gene is enough to give rise to same phenotypic effect is
(a) Complementary gene  
(b) Duplicate gene  
(c) Epistatic gene  
(d) Supplementary gene

194. 9:3:3:1 ratio is modified in complementary genes as:
(a) 5:1  
(b) 9:7  
(c) 13:3  
(d) 15:1

195. If dominant C and P genes are essential for the development of purple colour in sweet pea flowers then what would be the ratio of white and purple colour in a cross of Cc Pp x CC pp:
(a) 2 : 6  
(b) 9 : 7  
(c) 3 : 5  
(d) 1 : 1

196. In Lathyrus odoratus, two white flowered strains are crossed then in F1 generation purple flowered plants are obtained. Determine the genotypes of parents and offspring:
(a) Cc Pp x ccPP and CcPp  
(b) CC PP x ccpp and CcPp  
(c) CCPp x CcPP and CcPP  
(d) CCpp x ccPP and CcPp

197. In Lathyrus odoratus, the cross between two purple flowered plants gave a white flowered progeny refers to:
(a) Segregation  
(b) Complementary gene  
(c) Co-dominance  
(d) Incomplete dominance

198. If two or more than two non-allelic genes affect the same character, then it is called:
(a) Pleiotropy  
(b) Epistasis  
(c) Double cross  
(d) Polygenic inheritance

199. Genes whose combined action affects one particular character are known as:
(a) Oncogenes  
(b) Polygenes  
(c) Dominant genes  
(d) Pleiotropic genes

200. Experimental evidence for polygenic inheritance was first provided by:
(a) Malthus  
(b) Nilsson-Ehle  
(c) Kolreuter  
(d) Mendel

201. Inheritance of skin colour in human beings is determined by cumulative genes. This hypothesis was proposed by:
(a) Morgan and Benzer  
(b) Nilssen Ehle  
(c) C.B. Davenport  
(d) Bateson and Punnett

202. Which is connected with multiple phenotypes?
(a) Epistasis  
(b) Pleiotropy  
(c) Mutations  
(d) Polygenic inheritance

203. In case of polygenic inheritance, the Mendelian dihybrid ratio 9:3:3:1 is modified as:
(a) 9 : 3 : 3 : 1  
(b) 9 : 3 : 4  
(c) 1 : 4 : 6 : 4 : 1  
(d) 15 : 1

204. Which of the following are controlled by quantitative inheritance?
(a) Skin colour and intelligence  
(b) Human blood group and haemophilia  
(c) Haemophilia and skin  
(d) Colourblindness and height

205. Which one of the following is an example of polygenic inheritance?
(a) Skin colour in humans  
(b) Flower colour in Mirabilis jalapa  
(c) Production of male honey bee  
(d) Pod shape in garden pea

206. Inheritance of skin colour in humans is an example of:
(a) Polygenic inheritance  
(b) Codominance  
(c) Chromosomal aberration  
(d) Point mutation

207. Which one of the following represents the continuous variations?
(a) Polygenic inheritance  
(b) Monogenic inheritance  
(c) Saltatory behaviour  
(d) Mutation

208. When a graph is plotted for the polygenic F2 result, the curve obtained will be:
(a) Sigmoid  
(b) Linear  
(c) Bell shaped  
(d) Urn shaped

209. The common distribution of phenotypes for polygenic traits is a pattern of:
(a) 3 : 1  
(b) 9 : 3 : 3 : 1  
(c) All or nothing  
(d) A bell shaped curve

210. Polygenic traits probably include:
(a) Skin colour  
(b) Height  
(c) Behavior  
(d) All of these

211. In a quantitative inheritance, when homozygous wheat variety of red kernels is crossed with a homozygous white kernelled wheat then F1 is obtained. Find out the phenotypic ratio, if above
119. F₁ is crossed with a homozygous wheat variety of white kernels?
(a) 3:1  (b) 1:2:1
(c) 1:4:6:4:1  (d) 1:1:1:1

212. In quantitative inheritance, when a negro is crossed with white then mulatto is obtained in F₁ generation. If above F₁ mulatto is crossed with white then what ratio would be obtained?
(a) 1 : 2 : 1  (b) 3 : 1
(c) 9 : 3 : 3 : 1  (d) 1 : 2 : 2 : 4

213. What will the number of linkage groups in a cell having 2n=20?
(a) 15  (b) 40
(c) 10  (d) 4

214. Combined form of coupling and repulsion is called
(a) crossing over  (b) mutation
(c) linkage  (d) disjunction

215. Drosophila melanogaster (fruit fly) is a suitable for genetical studies because:
A. It can be grown on simple synthetic medium in lab.
B. Life cycle is short (about 2 weeks)
C. A single mating produces large number of progenies.
D. Visible sexual dimorphism and many types of genetical variations can be easily observed.
(a) A, C, D  (b) A, B, C, D
(c) B, C, D  (d) A, B, C

216. Who gave the term ‘linkage’?
(a) Morgan  (b) Bateson
(c) Sutton  (d) Stevens

217. Linkage was discovered by:
(a) Mendel in Pisum sativum
(b) Beadle in Neurospora crassa
(c) Bateson in Lathyrus odoratus
(d) Morgan in Drosophila melanogaster

218. First attempt to show linkage in plants was performed in:
(a) Pisum sativum
(b) Oenothera lamarckiana
(c) Lathyrus odoratus
(d) Zea mays

219. Tendency of genes to be inherited together is known as:
(a) Dominance  (b) Linkage
(c) Crossing over  (d) Translocation

220. When two or more characters do not assort independently in F₂ generation, it indicates that characters are:
(a) Lethal  (b) Dominant
(c) Linked  (d) Recessive

221. Chromosomal theory of inheritance was proposed by:
(a) Bateson and Punnett (b) Sutton and Boveri (c) T.H. Morgan (d) Tjio and Levan

222. Who told that chromosomes are the carriers of genes or genetic information?
(a) Bateson and Punnett
(b) Mendel and Blixt
(c) Sutton and Boveri
(d) Wilson and Stevens

223. The relationship between the behaviour of chromosomes and the behavior of mendelian factors was first recognized by W.S. Sutton and T. Boveri in:
(a) 1890  (b) 1902
(c) 1869  (d) 1938

224. All alleles on the same chromosome are said to form a:
(a) Segregation group  (b) Conjugation group
(c) Differentiation group  (d) Linkage group

225. An exception to Mendel’s law is:
(a) Independent assortment
(b) Linkage
(c) Purity of gametes
(d) Law of segregation

226. If there is complete linkage in F₂ generation
(a) Parental and recombinant types appear in equal ratio
(b) Recombinants are less than parental types
(c) Recombinants are more than parental types
(d) There will only be parental types

227. Two genes R and Y are located very close on the chromosomal linkage map of maize plant. When RRYY and rryy genotypes are hybridized, the F₂ segregation will show:
(a) Segregation in 3:1 ratio
(b) Higher number of the parental types
(c) Higher number of the recombinant types
(d) Segregation in the expected 9:3:3:1 ratio

228. The strength of linkage is inversely proportional to distance between the:
(a) Chromomeres  (b) Telomeres
(c) Genes  (d) Chromatids

229. When a cluster of genes show linkage behaviour they:
(a) do not show a chromosome map
(b) show recombination during meiosis
(c) do not show independent assortment
(d) induce cell division

230. Lack of independent assortment of 2 genes A and B in fruit fly is due to:
(a) Recombination  (b) Linkage
(c) Crossing over  (d) Repulsion

231. The number of linkage groups corresponds to:
(a) Tetraploid structure

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(b) General structure of organism
(c) Diploid number of chromosomes
(d) Haploid number of chromosomes

232. How many linkage group is present in fruit fly ?
   (a) 4  
   (b) 7  
   (c) 11  
   (d) 22

233. Chiasma represents the site of :
   (a) homologous chromosome
   (b) crossing over
   (c) pachytene
   (d) diakinesis

234. During gamete formation, the enzyme recombinase participates during :
   (a) prophase-I  
   (b) prophase-II
   (c) metaphase-I  
   (d) anaphase-II

235. Which one of the following is an enzyme-mediated process and involves the enzyme recombinase ?
   (a) emasculation  
   (b) linkage
   (c) cheese making  
   (d) crossing over

236. The phenomenon of exchange of corresponding segments between homologous chromosomes is called :
   (a) Linkage  
   (b) Recombination
   (c) Crossing over  
   (d) Segregation

237. When two genes are situated very close to each other in a chromosome :
   (a) The percentage of crossing over between both is high
   (b) The percentage of crossing over between both is very low and hardly any cross overs are detected
   (c) The percentage of linkage is very low
   (d) The chance of linkage and crossing over both are high

238. Crossing over occurs at :
   (a) One strand stage  
   (b) Two strand stage
   (c) Three strand stage  
   (d) Four strand stage

239. Genetic recombination is caused by :
   (a) Fertilization and mitosis
   (b) Fertilization and meiosis
   (c) Mitosis and meiosis
   (d) None of the above

240. Crossing over that results in genetic recombination in higher organisms occurs between :
   (a) Non-sister chromatids of a bivalent
   (b) Two daughter nuclei
   (c) Two different bivalents
   (d) Sister chromatids of a bivalent

241. Crossing over produces
   (a) Synapsis of linked genes
   (b) Linkages of dominant genes
   (c) Expression of recessive genes
   (d) Recombination of linked genes

242. T.H. Morgan received Nobel Prize of 1933 in the field of :
   (a) Genetics  
   (b) Chemistry
   (c) Biology  
   (d) Physiology

243. Crossing over occurs in :
   (a) Mitotic cells  
   (b) Meiotic cells
   (c) Amitotic cells  
   (d) Mutating cells

244. In which phase of meiosis crossing over takes place? 
   (a) Prophase I  
   (b) Metaphase I
   (c) Prophase II  
   (d) Anaphase II

245. During meiosis crossing over occurs at :
   (a) Zygotene  
   (b) Pachytene
   (c) Leptotene  
   (d) Diakinesis

246. Crossing over involves
   (a) Addition of chromosomes
   (b) Deletion of chromosomes
   (c) Exchange of genetic material
   (d) Duplication of chromosomes

247. Crossing over takes place between
   (a) Two chromosomes
   (b) Two homologous chromosomes
   (c) Two nonhomologous chromosomes
   (d) None of these

248. Crossing over involves
   (a) Chiasmata  
   (b) Recombination
   (c) Termination  
   (d) All of these

249. Crossing over is advantageous because it brings about
   (a) Linkage  
   (b) Stability
   (c) Variations  
   (d) Inbreeding

250. The name for a chromosome map unit is :
   (a) centiMorgan  
   (b) milliMendel
   (c) centiStern  
   (d) centiSutton

251. Genetic map is one that :
   (a) Shows the stages during cell division
   (b) Shows the distribution of various species in a region
   (c) Establishes sites of the genes on a chromosomes
   (d) Establishes the various stages in gene evolution

252. Linkage depends upon :
   (a) Distribution of genes on chromosomes
   (b) Number of genes on chromosome
   (c) Number of DNAs in chromosomes
   (d) Distance between two genes on chromosome

253. Determination of percentage of crossing over between two linked genes is important in :
   (a) Maintaining heterozygosity in population
   (b) Indicating relative position of genes in chromosomes
   (c) Fixation of heterosis in organisms
   (d) Explaining the phenomenon of coupling and repulsion
254. Suppose the recombination frequency between genes A and B is 9%; between A and C is 18% and between B and C is 27%. What is the sequence of these genes on the chromosome?
(a) BAC (b) ABC (c) ACB (d) Data insufficient

255. The recombination frequencies between the genes A and B; A and C; B and C are 9%, 17% and 26% respectively. The sequence of genes A, B, C on the chromosome is:
(a) ABC (b) ACB (c) BAC (d) Data insufficient

256. The organelles responsible for cytoplasmic or extranuclear inheritance among eukaryotes are:
(a) Chloroplasts and mitochondria (b) Chloroplasts and Golgi complex (c) Ribosomes and Golgi complex (d) Ribosomes and chloroplasts

257. When certain character is inherited only through the female parent, it represents the case of:
(a) Incomplete dominance (b) Cytoplasmic inheritance (c) Mendelian nuclear inheritance (d) Multiple plastid inheritance

258. Male sterility in maize usually occurs by:
(a) Chloroplast (b) Mitochondria (c) Ribosomes (d) Nucleus

259. Male sterility in maize is due to:
(a) Chloroplast of female parent (b) Chloroplast of male parent (c) Mitochondria of male parent (d) Mitochondria of female parent

260. Cytoplasmic male sterility is passed down:
(a) Paternally (b) Paternally (c) Biparentally (d) Through vector

261. One of the parents of a cross has a mutation in its mitochondria. In this cross, that parent is taken as a male. During segregation of F2 progenies that mutation is found in:
(a) None of the progenies (b) All the progenies (c) 50% of the progenies (d) 25% of the progenies

262. In which mode of inheritance do you expect more maternal influence among the offspring?
(a) X-linked (b) Autosomal (c) Cytoplasmic (d) Y-linked

263. In cytoplasmic inheritance, characters are transmitted:
(a) Paternally (b) Morphologically (c) Maternally (d) Biparentally

264. Cytoplasmic genes were first observed in:
(a) Pisum sativum (b) Neurospora crassa (c) Mirabilis jalapa (d) Lathyrus odoratus

265. Genes located on mitochondrial DNA:
(a) show biparental inheritance (b) are not inherited like nuclear genes (c) always inherited from the male parent (d) show maternal inheritance

266. Only diploid stage in the life cycle of pink bread mould is:
(a) Ascospore (b) Zygote (c) Gamete (d) Adult mould

267. Haploids are able to express both recessive and dominant alleles/mutations because there are:
(a) Many alleles for each gene (b) Two alleles for each gene (c) Only one allele for each gene in the individual (d) Only one allele in a gene

268. In Neurospora, 2A : 4a : 2A arrangement of 8 ascospores represents:
(a) Ist division segregation (b) IInd division segregation (c) Linkage (d) Cytoplasmic inheritance

269. An auxotroph is:
(a) Plant capable of synthesizing its own carbohydrates (b) Plant showing quick bending response to sunlight (c) A mutant having lost the ability to synthesize one or more nutrients (d) An organism dependent on another for nutritional requirements

270. Wild type of Neurospora crassa which can synthesize all essential metabolites from raw materials is called:
(a) prototroph (b) auxotroph (c) heterotroph (d) autotroph

271. Beadle and Tatum did not:
(a) work on Neurospora crassa (b) proposed one gene one enzyme hypothesis (c) induce sex linked nutritional mutation (d) receive Nobel Prize of 1958

272. Formation of 8 ascospores instead of four in Neurospora indicates the completion of:
(a) One meiosis (b) One mitosis (c) Mitosis followed by meiosis (d) Meiosis followed by mitosis

273. Which arrangement of ascospores in Neurospora does not represent second generation segregation?
(a) aaaaaAAA (b) AAaaaAaa (c) AAaaaAA (d) aaAAAAaa
274. The evidence that crossing over occurs at four strand stage and not at two-strand stage of the chromosomes comes from:
(a) 2:2:2:2 arrangement of ascospores in Neurospora
(b) Studies on meiosis in maize
(c) 4:4 arrangement of ascospores in Neurospora
(d) Studies on linkage maps of chromosomes in Drosophila

275. Nutritional mutation in Neurospora is induced by:
(a) Beadle and Tatum
(b) Lindegren
(c) Bateson and Punnett
(d) Morgan and Bridges

276. One gene one enzyme relationship was established for the first time in:
(a) Escherichia coli
(b) Diplococcus pneumoniae
(c) Neurospora crassa
(d) Salmonella typhimurium

277. Which of the following fungus has been extensively used as an experimental material in the study of genetics?
(a) Pisum
(b) Neurospora
(c) Drosophila
(d) All of these

278. Drosophila completes its life cycle in about:
(a) 2 weeks
(b) 3 weeks
(c) 1 week
(d) 4 weeks

279. The male of grasshoppers and bugs possess two sets of autosomes and:
(a) Only Y-chromosomes
(b) Only X-chromosomes
296. Environmental control of sex determination is seen in:
(a) *Drosophila*  
(b) *Bonellia*  
(c) *Melandrium*  
(d) *Apis indica*

297. Sex reversal is characteristic of:
(a) *Drosophila*  
(b) Hen  
(c) Man  
(d) Bees

298. Who confirmed the diploid chromosome number in human as forty six?
(a) Tjio and Lejeune  
(b) Tjio and Garrod  
(c) Tjio and Levan  
(d) Garrod and McClung

299. Allosomes are:
(a) Bead like structures on chromosomes  
(b) Sex chromosomes  
(c) Centromeres  
(d) Heterochromatic regions

300. When released from ovary, human egg contains:
(a) XY-chromosomes  
(b) One X-chromosome  
(c) Two-X-chromosomes  
(d) One Y-chromosome

301. A couple has five daughters but no son. The probability of son as the sixth child will be:
(a) 0%  
(b) 25%  
(c) 50%  
(d) 100%

302. A family has 9 girls. The probability of son at 10th birth is:
(a) 50%  
(b) 100%  
(c) 25%  
(d) 75%

303. Probability of four sons to a couple is:
(a) 1/4  
(b) 1/8  
(c) 1/16  
(d) 1/32

304. Who confirmed the diploid chromosome number in human as forty six?
(a) Tjio and Lejeune  
(b) Tjio and Garrod  
(c) Tjio and Levan  
(d) Garrod and McClung

305. Human chromosomes are arranged in:
(a) 5 groups  
(b) 6 groups  
(c) 7 groups  
(d) 8 groups

306. To make a karyotype, chromosomes are photographed during:
(a) Interphase  
(b) Fertilization  
(c) Mitotic metaphase  
(d) Meiotic metaphase

307. Satellites in human are associated with:
(a) Acrocentric chromosomes  
(b) Telocentric chromosomes  
(c) Metacentric chromosomes  
(d) Submetacentric chromosomes

308. X and Y chromosomes are grouped in:
(a) C and G groups respectively  
(b) A and B groups respectively  
(c) D and G groups respectively  
(d) E and F groups respectively

309. A single recessive trait which can express its effect should occur on:
(a) any chromosome  
(b) any autosome  
(c) X chromosome of male  
(d) X chromosome of female

310. SRY gene is located on:
(a) Autosome  
(b) X-chromosome  
(c) Y-chromosome  
(d) Sex chromosome

311. The recessive genes located on X-chromosome in human are always:
(a) Lethal  
(b) Sub-lethal  
(c) Expressed in males  
(d) Expressed in females

312. Sex linked characters are usually:
(a) Lethal  
(b) Recessive  
(c) Dominant  
(d) Pleiotropic

313. Criss-cross inheritance occurs for the genes found on:
(a) Autosomes  
(b) Y-chromosome  
(c) X-chromosome  
(d) Both (b) and (c)

314. Most sex linked genes are found on:
(a) X chromosome  
(b) Y chromosome  
(c) Both are equal  
(d) Autosomes

315. Who gave the experimental proof for sex linkage?
(a) Johannsen  
(b) Lederberg  
(c) Haldane  
(d) Morgan

316. Sex linked inheritance was first discovered by:
(a) Garrod  
(b) Bridges  
(c) Galton  
(d) Morgan

317. If red eyed fly is mated with white eyed fly, the ratio of red to white eyed in F2 would be:
(a) 3 : 1  
(b) 2 : 2  
(c) 2 : 1  
(d) 1 : 3

318. Sex-linked characters have one distinct features:
(a) Only present on X-chromosome  
(b) May be present on Y-chromosome  
(c) Never follows criss cross inheritance  
(d) Always follow criss cross inheritance

319. Hypertrichosis or hairy ears is a sex-linked character associated with the?
(a) XX chromosomes  
(b) XY chromosomes  
(c) Y chromosome  
(d) X chromosome

320. Genes present on Y-chromosome are called:
(a) Basic genes  
(b) Polygenes  
(c) Pleiotropic genes  
(d) Holandric genes

321. Hypertrichosis (a condition with excessive growth of hair on ear pinna) is an example of holandric gene. If a man with hairy ears marries a normal woman, then what percentage of their daughters would be expected to have hairy ears:
(a) 100%  
(b) 50%  
(c) 25%  
(d) 0%
322. A man with certain disease marries a normal woman. They have eight children out of which 5 are sons and 3 daughters. All the daughters suffer from their father’s disease but none of the sons are affected. Which mode of inheritance do you suggest for this disease?
(a) Sex linked recessive  
(b) Sex linked dominant  
(c) Autosomal dominant  
(d) Sex limited recessive

323. A man and a women, who do not show any apparent signs of a certain inherited disease, have seven children (2 daughters and 5 sons). Three of the sons suffer from the given disease but none of the daughters are affected. Which of the following mode of inheritance do you suggest for this disease:
(a) Autosomal dominant  
(b) Sex-linked dominant  
(c) Sex-limited recessive  
(d) Sex-linked recessive

324. G-6PD deficiency disease is a/an :
(a) Sex linked recessive trait  
(b) Sex linked dominant trait  
(c) Autosomal dominant trait  
(d) Autosomal recessive trait

325. G-6-P dehydrogenase deficiency is associated with haemolysis of:
(a) Lymphocytes  
(b) RBCs  
(c) Platelets  
(d) Leucocytes

326. Which protein is required for the transfer of nerve impulse to calcium strong regions of the muscle that lacking in muscular dystrophy?
(a) Phenylalanine  
(b) Dystrophin  
(c) Tyrosine  
(d) Insulin

327. Dystrophin protein is not formed in patient of:
(a) Down syndrome  
(b) Muscular dystrophy  
(c) Nervous dystrophy  
(d) Defective enamel of teeth

328. Duchenne’s muscular dystrophy is a:
(a) Dominant sex-linked disorder  
(b) Recessive sex-linked disorder  
(c) Dominant autosomal disorder  
(d) Recessive autosomal disorder

329. Which of the following diseases are more frequent in females than males?
(a) Haemophilia  
(b) G-6 PD deficiency  
(c) Defective enamel of teeth  
(d) Becker’s muscular dystrophy

330. Which one is sex linked dominant trait?
(a) Duchenne muscular dystrophy  
(b) Becker’s muscular dystrophy  
(c) G-6 PD deficiency  
(d) Defective enamel of teeth

331. Mr. Kapoor (XY) is heterozygous for one autosomal gene pair Bb. He carries a recessive X-linked gene ‘d’. What proportion of his sperms will contain ‘bd’?
(a) 0  
(b) 1/2  
(c) 1/3  
(d) 1/4

332. Which disease is an XY linked in humans?
(a) Hypertrichosis  
(b) Xeroderma pigmentosa  
(c) Erythroblastosis  
(d) Gynandromorphism

333. Haemophilia is more common in males because it is a:
(a) recessive trait carried by X chromosome  
(b) dominant trait carried by X chromosome  
(c) recessive character carried by Y chromosomes  
(d) dominant character carried by Y chromosome

334. In haemophilia, blood:
(a) Fails to clot  
(b) Delays to clot  
(c) Corpuscles are absent  
(d) Is colourless

335. Haemophilia is a condition where there is:
(a) No production of haemoglobin in the blood  
(b) No clotting of blood  
(c) A failure in the immune mechanism of blood  
(d) A delay in the clotting of blood

336. Christmas disease occurs because of deficiency of blood clotting factor:
(a) VII  
(b) VIII  
(c) IX  
(d) XI

337. Which of the following types of haemophilia is autosomal in nature?
(a) Haemophilia A  
(b) Haemophilia B  
(c) Haemophilia C  
(d) All are sex linked

338. Ishihara cards are used to detect:
(a) Haemophilia  
(b) Colour blindness  
(c) Albinism  
(d) Syndromes

339. A ‘normal’ woman whose father was haemophilic marries a normal man. The offspring shall be:
(a) All normal  
(b) All sons haemophilic  
(c) All daughters haemophilic  
(d) Some sons are haemophilic

340. If a haemophilic man marries a normal lady then the offspring will be:
(a) All haemophilic  
(b) All normal  
(c) Haemophilic daughters  
(d) Haemophilic sons

341. A colourblind daughter is born when:
(a) Mother is carrier and father is normal  
(b) Mother is carrier and father is colourblind  
(c) Mother is normal and father is colourblind  
(d) Mother is colourblind and father is normal
342. Red-green colourblindness in humans is governed by sex-linked recessive gene. A normal woman whose father was colourblind marries a colourblind man. What proportion of their daughters is expected to be colourblind?
(a) 1/4  (b) 1/2  (c) 1/3  (d) All

343. A haemophilic man marries a normal homozygous woman. What is the probability that their son will be haemophilic?
(a) 100%  (b) 50%  (c) 25%  (d) 0%

344. A male human is heterozygous for autosomal genes A and B and is also hemizygous for haemophilic gene h. What proportion of his sperms will be abh?
(a) 1/4  (b) 1/8  (c) 1/16  (d) 1/32

345. Colourblind daughters will be born if:
(a) Mother is colourblind
(b) Only father is colourblind
(c) None are colourblind
(d) Both are colourblind

346. If husband and wife both are normal in vision but fathers of both were colour blind, the probability of their first daughter to be colour blind is:
(a) 100%  (b) 50%  (c) 0%  (d) 25%

347. The haemophilia is found in males of a family. A girl from this family married a boy who suffered from this disease. They had two sons and two daughters. The possibility of the disease being passed on to the sons or daughters is:
(a) 25%  (b) 50%  (c) 75%  (d) 100%

348. If a colourblind woman marries a normal visioned man, their sons will be:
(a) All colourblind
(b) All normal visioned
(c) One-half colourblind and one-half normal
(d) Three fourths colourblind and one-fourth normal

349. A female child will definitely be haemophilic, if:
(a) her father is haemophilic and her mother is normal
(b) her mother carries alleles for haemophilia on both the X-chromosomes
(c) her mother is a carrier and her father is haemophilic
(d) both of her parents are also haemophilic

350. Which of the following type of progeny could be produced by a normal homozygous female and a haemophilic male?:
(a) Normal males and normal females
(b) Normal males and carrier females
(c) Haemophilic males and normal females
(d) Haemophilic males and carrier females

351. The occurrence of affected individuals in every generation in a family suggests trait:
(a) An autosomal dominant
(b) An autosomal recessive
(c) Either dominant or recessive
(d) Sex linked

352. Sex limited genes located on:
(a) X-chromosome  (b) Y-chromosome  (c) Autosomes  (d) Sex chromosomes

353. Autosomal recessive traits are:
(a) Albinism, phenylketonuria and alkaptonuria
(b) Albinism, alkaptonuria and haemophilia
(c) Phenylketonuria, red green colour blindness and muscular dystrophy
(d) Huntington chorea, polydactyly and albinism

354. Pattern baldness, moustaches and beard in human males are examples of:
(a) Sex linked traits
(b) Sex limited traits
(c) Sex differentiating traits
(d) Sex determining traits

355. A bald headed (Bb) man marries a non-bald woman (Bb), their progeny if all are females, the probable bald to non-bald ratio in their progeny would be:
(a) 1 : 1  (b) 3 : 1  (c) 1 : 3  (d) 3 : 1

356. The number of Barr body in a cell with Turner syndrome will be:
(a) 1  (b) 3  (c) 2  (d) 0

357. Sex chromatin was discovered by:
(a) Barr and Bertram  (b) Bateson and Punnett  (c) Garrod and Mendel  (d) Shull and Kolreuter

358. The number of Barr body is:
(a) Equal to no. of X-chromosome present
(b) One less than the number of X-chromosomes present
(c) One more than the number of X-chromosomes present
(d) Equal to no. of Y-chromosome present

359. Barr body is found in human:
(a) Somatic cells of males
(b) Germinal cells of males
(c) Gametes
(d) Somatic cells of females

360. Dosage compensation through Lyon’s hypothesis means inactivation of:
(a) half Y-chromosome in males
(b) both X-chromosomes in females
(c) one X-chromosome in females so that equality occurs in the genes of two sexes
361. Barr body is studied in:
(a) Prophase nuclei of human female
(b) Interphase nuclei of human female
(c) Prophase nuclei of human male
(d) Interphase nuclei of human male

362. Lyon's hypothesis deals with:
(a) Rh factor incompatibility
(b) Centromere position
(c) Counting of genes
(d) Number of Barr bodies

363. Y-chromatin is formed as a result of inactivation of:
(a) One complete Y-chromosome in males
(b) One complete X-chromosome in females
(c) A part of Y-chromosome in males
(d) Autosomes in males

364. Other names of Barr body is/are:
(a) X-chromatin
(b) Sex chromatin
(c) Y-chromatin
(d) Both (a) and (b)

365. Barr body is found in the nucleus during:
(a) Interphase in cell of female mammal
(b) Interphase in cell of male mammal
(c) Prophase in cell of female mammal
(d) Prophase in cell of male mammal

366. Group of symptoms that appear together for a particular disease is called:
(a) Syndrome
(b) Polygenes
(c) Pleiotropy
(d) Variations

367. Klinefelter syndrome results from the fusion of:
(a) an X egg and a YY sperm
(b) an XY egg and an X sperm
(c) an XX egg and a Y sperm
(d) an XX egg and a YY sperm

368. Down syndrome is caused by the presence of extra chromosome number in:
(a) X
(b) Y
(c) 21
(d) 22

369. The risk of Down syndrome offspring is more if mothers age exceeds:
(a) 20 years
(b) 35 years
(c) 45 years
(d) 50 years

370. Individual with Turner syndrome is:
(a) Normal female
(b) Normal male
(c) A female with rudimentary ovaries and undeveloped breasts
(d) A male with rudimentary testes and penis

371. A disease caused by an autosomal primary non-disjunction is:
(a) Turner syndrome
(b) Down syndrome
(c) Klinefelter syndrome
(d) PKU

372. XO chromosome abnormality is:
(a) Down syndrome
(b) Turner syndrome
(c) Klinefelter syndrome
(d) Edward syndrome

373. Edward syndrome, Patau syndrome and Down syndrome are caused by changes in:
(a) Autosomes
(b) Sex chromosomes
(c) Nutrition
(d) Both (a) and (b)

374. Mental retardation in man associated with sex chromosomal abnormality is usually due to:
(a) Increase in X-complement
(b) Decrease in X-complement
(c) Large increase in Y-complement
(d) Moderate increase in Y-complement

375. Mongoloid condition is due to:
(a) Monosomy
(b) Nullisomy
(c) Allisomy
(d) Trisomy

376. Webbed neck is characteristic of:
(a) XXX
(b) XO
(c) XY
(d) XXXY

377. Which of the following syndromes are characterized by 47 chromosomes?
(a) Klinefelter syndrome
(b) Turner syndrome
(c) Cri-du-chat syndrome
(d) All of these

378. In Mongolism, a patient possesses:
(a) 46 chromosomes
(b) 47 chromosomes
(c) 45 chromosomes
(d) 44 chromosomes

379. Extra 18th autosomal chromosome results in:
(a) Edward syndrome
(b) Patau syndrome
(c) Down syndrome
(d) Turner syndrome

380. Which one is related to heart diseases?
(a) Turner syndrome
(b) Edward syndrome
(c) Cushing syndrome
(d) Patau syndrome

381. The infant produces voice-like mewing of cat because of lack of a part of 5th autosome. This happens in:
(a) Patau syndrome
(b) Cri-du-chat syndrome
(c) Edward syndrome
(d) Down syndrome

382. A women with 47 chromosomes due to three copies of chromosome 21 is characterized by:
(a) Down syndrome
(b) Triploidy
(c) Turner syndrome
(d) Super femaleness

383. Epicanthal fold is associated with:
(a) Down syndrome
(b) Klinefelter syndrome
(c) Cri-du-chat syndrome
(d) Turner syndrome

384. Gynaecomastia is:
(a) Development of embryo
(b) Descending of testis into scrotum
(c) Failure of kidney to form urine
(d) Development of breast in males

385. Who discovered cat cry syndrome?
(a) Levan
(b) Lejeune
(c) Huxley
(d) Hungerford
386. Sloping forehead, cleft palate and hare-lip are the symptoms of:
   (a) Patau syndrome (b) Edward syndrome (c) Down syndrome (d) Point mutation

387. Which of the following diseases is due to deletion of chromosome?
   (a) Cat cry syndrome (b) Patau syndrome (c) Edward syndrome (d) Down syndrome

388. The “cri-du-chat” syndrome is caused by change in chromosome structure involving:
   (a) Deletion (b) Duplication (c) Inversion (d) Translocation

389. Which of the following has normal sex chromosomes?
   (a) Down syndrome (b) Klinefelter syndrome (c) Turner syndrome (d) Super female

390. Philadelphia chromosome is found in the patient suffering from:
   (a) PKU (b) Hepatitis (c) Albinism (d) Myelocytic leukaemia

391. Nowell and Hungerford described a deletion in chromosome 22nd. They named this deleted chromosome 22nd as Philadelphia chromosome. It was observed in the patient of chronic:
   (a) Thalassemia (b) Hepatitis (c) Leukemia (d) Albinism

392. Deleted part of 22nd chromosome in Philadelphia chromosome is attached with:
   (a) 8th chromosome (b) 9th chromosome (c) 7th chromosome (d) 6th chromosome

393. In humans, Philadelphia chromosome is formed by reciprocal translocation between chromosomes:
   (a) 9 and 21 (b) 9 and 22 (c) 9 and 20 (d) 20 and 10

394. Two carriers of albinism have four children. One of their children is albino and the remaining three are normally pigmented. What is the probability that their next child will be albino:
   (a) 0% (b) 25% (c) 75% (d) 100%

395. Albinism in humans is due to:
   (a) Multiple allelism (b) Recessive alleles (c) Dominant allele (d) Polygenic effect

396. An inborn error of metabolism which eventually affects mental development is:
   (a) Albinism (b) Phenylketonuria (c) Anaemia (d) Bleeder’s disease

397. The absence of pigment in the eyes, hair and skin is referred to as:
   (a) Albinism (b) Colour blindness (c) Night blindness (d) Phenylketonuria

398. Homogentisic acid is excreted with urine, if person is sufferer of:
   (a) PKU (b) Alkaptonuria (c) Muscular dystrophy (d) Albinism

399. Enzyme lacking in alkaptonuria is homogentisic acid:
   (a) Oxidase (b) Hydroxylase (c) Transaminase (d) Tyrosinase

400. Which one of the following is not an inborn errors in human metabolism?
   (a) PKU (b) Alkaptonuria (c) Tyrosinosis (d) Nightblindness

401. Albinism is a congenital disorder resulting from the lack of the enzyme:
   (a) Tyrosinase (b) Catalase (c) Catheptase (d) Oxidase

402. Enzyme lacking in PKU is phenyl alanine:
   (a) Oxidase (b) Hydroxylase (c) Transaminase (d) Tyrosinase

403. A normal woman marries an albino man. They have both albino and normal children. The woman is:
   (a) Homozygous recessive (b) Homozygous dominant (c) Heterozygous normal (d) Homozygous normal

404. Phenylketonuria is an inherited disease which is characterized by:
   (a) Elimination of sugar in urine (b) Increased occurrence of phenylalanine in blood and tissues (c) Decreased occurrence of phenylalanine in blood and tissues (d) Elimination of homogentisic acid in urine

405. Both father and mother have allele for PKU but are phenotypically normal. What is the probability that their child will have the disease?
   (a) 0.25 (b) 0.50 (c) 0.75 (d) 1.00

406. Which of the following is not the symptoms of alkaptonuria?
   (a) Darkening of cartilage of ear (b) Darkening of urine (c) Deposition of alkapton causing arthritis (d) Brain tumor

407. Phenylketonuria is:
   (a) Sex linked dominant trait (b) Sex linked recessive trait (c) Autosomal dominant trait (d) Autosomal recessive trait
408. Phenylketonuria is an example of a genetic disease in which?
(a) A single enzyme is not functional
(b) Inheritance is sex linked
(c) Two parents without the disease cannot have a child with the disease
(d) Mental retardation always occurs, regardless of treatment

409. Blackening of urine when exposed to air is a metabolic disorder in human beings, is due to:
(a) Tyrosine
(b) Phenylalanine
(c) Homogentisic acid
(d) Valine replacing glutamine

410. Which inborn error is characterized by brain impairment and mental retardation?
(a) Albinism
(b) Phenylketonuria
(c) Alkaptonuria
(d) Tyrosinosis

411. Chloride transport mechanism is not working properly in:
(a) Thalassemia
(b) Cystic fibrosis
(c) Polydactyly
(d) Tongue rolling

412. Two phenotypically normal individuals have an affected child. What can we conclude about the parents?
(a) They both carried the allele of disease
(b) They are not the parents of the child
(c) They are affected
(d) No conclusions can be drawn

413. A late acting dominant disorder is:
(a) Tay Sach’s disease
(b) Polydactyly
(c) Huntington’s chorea
(d) Phenylketonuria

414. Late acting lethal disease is:
(a) Yellow lethal in mice
(b) Albino condition in snapdragon
(c) Tay sach disease
(d) Huntington Chorea disease

415. Huntington’s chorea is characterized by:
(a) Rapid muscle movement
(b) Disordered muscle movement and mental deterioration
(c) Weak eye sight and hearing power
(d) Inability to speak

416. Hemolytic jaundice is caused due to a dominant gene but only ten per cent of the people actually develop the disease. A heterozygous man marries a homozygous normal woman. What proportion of the children would be expected to develop the hemolytic disease:
(a) 1/5
(b) 1/10
(c) 1/15
(d) 1/20

417. To taste the phenyl thio carbamide (PTC) is a genetic trait. Some people experience its paper on tongue as bitter and other as tasteless. If “T” stands for dominant gene then find out the non-taster:
(a) TT
(b) Tt
(c) tt
(d) All of these

418. Which one of the following is a chromosomal disease of pancreas?
(a) Tay Sach’s disease
(b) Huntington’s chorea
(c) Cystic fibrosis
(d) Gynaeomastia

419. In human beings, brown eye (B) is dominant over blue eye (b). A brown eyed couple has a blue eyed child. What is the possible genotype of the couple?
(a) Bb × bb
(b) Bb × Bb
(c) BB × bb
(d) BB × Bb

420. Defective fat metabolism with enlarged spleen, bone and neurological defects are the symptoms which autosomal recessive disease?
(a) Thalassemia
(b) Gaucher disease
(c) Mongolism
(d) Cystic fibrosis

421. Which one of the following autosomal dominant disorder in human is characterized by ‘spider fingers’ and abnormal connective tissue formation?
(a) Mongolism
(b) Edward Syndrome
(c) Tyrosinosis
(d) Marfan Syndrome

422. Progressive loss of memory with anxiety and confusion are the symptoms of:
(a) Gaucher disease
(b) Sickle cell disease
(c) Thalassemia
(d) Alzheimer disease

423. Which one of the following protein is deposited in human brain, if person is sufferer of Alzheimer disease?
(a) Dystrophin
(b) beta amyloid
(c) Actinin
(d) Thermogenin

424. What happens in thalassemia?
(a) Defective synthesis of α - chain of Hb
(b) Defective synthesis of β - chain of Hb
(c) Reduced synthesis of β - chain of Hb
(d) Hb is not synthesized

425. Huntington’s chorea is caused by a dominant gene mutation in the chromosome?
(a) 4th
(b) 12th
(c) 7th
(d) X

426. Sickle cell haemoglobin contains which amino acid at 6th position of beta chain:
(a) Valine
(b) Glutamic acid
(c) Serine
(d) Tyrosine

427. Sickle cell anaemia is caused by the substitution of:
(a) glutamic acid by valine at 6th position of beta chain
(b) valine by glutamic acid at 6th position of beta chain
(c) glutamic acid by valine at 6th position of alpha chain
(d) valine by glutamic acid at 6th position of alpha chain

428. The most striking example of point mutation is found in a disease called:
(a) Nightblindness  (b) Turner syndrome
(c) Down syndrome  (d) Sickle cell anaemia

429. In sickle cell anaemia which got changed:
(a) alpha chain  (b) beta-chain
(c) Both (a) and (b)  (d) None of these

430. Sickle cell disease is not an example of:
(a) Transversion  (b) Substitution
(c) Pleiotropy  (d) Nondisjunction

431. In pleiotropy:
(a) One gene influences many traits
(b) Many genes influence one trait
(c) Genes are lethal
(d) Persons are sterile

432. Person with which one of the following genetic constitution is resistant to malaria infection:
(a) HbA HbA  (b) HbA HbS
(c) HbS HbS  (d) All of these

433. Pleiotropy occurs when a gene has:
(a) A complementary gene elsewhere
(b) A small effect on one trait
(c) Reversible effect on the phenotype
(d) Many effects on the phenotypes

434. A person may have one gene for adult Hb and one gene for sickle cell Hb. This heterozygous condition is called:
(a) Genome  (b) Gene trait
(c) Sickle cell trait  (d) Anaemia

435. People who carry an allele for normal haemoglobin and an allele for sickle cell are resistance to malaria. They are example of:
(a) Heterozygote advantage
(b) Diploidy
(c) Out breeding
(d) Recessive superiority

436. Sickle cell anaemia and Huntington's chorea are:
(a) Virus-related diseases
(b) Bacteria-related diseases
(c) Congenital disorders
(d) Pollutant-induced disorders

437. Sickle cell disease is caused due to disorder associated with chromosome number:
(a) 11  (b) 12
(c) 13  (d) 14

438. Where is the chromosome for alpha thalassemia?
(a) 10  (b) 11
(c) 15  (d) 16

439. Affected chromosome number in beta thalassemia is:
(a) 10  (b) 11
(c) 15  (d) 16

440. Thalassemia is a/an:
(a) sex linked recessive disease
(b) autosomal recessive disorder
(c) case of deletion in a part of X-chromosome
(d) nutritional defect

441. Thalassemia is characterized by:
(a) reduced rate of synthesis of alpha or beta chain of haemoglobin
(b) synthesizing an incorrectly functioning globin
(c) hyper formation of haemoglobin chain
(d) tumor formation

442. Thalassemia differs from sickle-cell anaemia because:
(a) thalassemia is a quantitative problem
(b) thalassemia is a qualitative problem
(c) thalassemia synthesizes an incorrect protein
(d) thalassemia is non-genetic

443. The child of 'O' group has 'B' group father. The genotype of the father will be:
(a) I^o I^o  (b) I^b I^o
(c) I^o I^b  (d) I^b I^b

444. If mother has 'O' blood group, child also has 'O' group. What will be the blood group of father?
(a) O  (b) A
(c) B  (d) A, B, O

445. Multiple alleleism controls the inheritance of:
(a) Blood group  (b) PKU
(c) Sickle cell anaemia  (d) Colour blindness

446. If child is of 'O' group, which group can not be present in any of his parents:
(a) O  (b) AB
(c) A  (d) B

447. A man with blood group A marries a woman having blood group AB. Which of the following types in the progeny of this couple would show that the man is heterozygous?
(a) Type O  (b) Type A
(c) Type B  (d) Type AB

448. A child of a mother with blood group A and father with blood group AB may have any one of the following blood groups except:
(a) A  (b) B
(c) AB  (d) O

449. A child with mother of 'A' group and father of 'AB' group, will not have the following blood group:
(a) A  (b) B
(c) AB  (d) O

450. Improvement of genetic characters and present generation on the basis of nutrition and training is:
Study of improvement of human race by providing ideal ‘nurture’ is called:
(a) euthenics (b) eugenics (c) euphenics (d) genetics

Euthenics means improvement of human race by:
(a) curing genetic disorders (b) gene manipulations (c) deleting lethal genes (d) providing suitable environment

Undesirable traits of human are studied in:
(a) Eugenics (b) Dysgenics (c) Euphenics (d) Euthenics

Improvement of human race with the help of genetic engineering is called:
(a) Euthenics (b) Euphenics (c) Genetics (d) Neurology

The inbreeding between closely related organisms:
(a) Reduces variations (b) Increases variations (c) Reduces dominance (d) Enhances speciation

Heterozygosity protects which of the following from natural selection:
(a) Recessive alleles (b) Dominant alleles (c) Multiple factors (d) Genomes

To find IQ of an individual, we:
(a) Multiply chronological age by mental age (b) Divide mental age by chronological age (c) Divide chronological age by mental age (d) Multiply mental age by age of parents

Marriages in close blood relatives result into deformed babies because of receiving:
(a) Dominant alleles (b) Two copies of same recessive allele (c) A deleted piece of DNA from mother (d) Two copies of dominant alleles

Term ‘nuclein’ was given by:
(a) Altmann (b) Levene (c) Kossel (d) Meischer

Deoxyribonucleic acid (DNA) is:
(a) Neutral (b) Strongly acidic (c) Alkaline (d) Weakly acidic

DNA is:
(a) hydrophilic (b) hydrophobic (c) neutral (d) salty

DNA fragments are:
(a) negatively charged molecules that can move to anode (b) negatively charged molecules that move to cathode (c) hydrophobic molecules that cannot be fragmented by restriction endonuclease enzyme (d) positively charged and hydrophilic molecules

Circular DNA molecules occur in:
(a) Viruses (b) Bacteria only (c) Bacteria and chloroplasts only (d) Bacteria, chloroplasts and mitochondria

Density of DNA molecule is determined with the help of:
(a) CaCl₂ (b) KMnO₄ (c) CsCl (d) HClO₄

Hydrogen bonds occur between which of the following constituents of DNA?
(a) sugar and base (b) phosphate and base (c) complementary (d) phosphate and sugar

5-methyl uracil is:
(a) found in RNAs (b) a double ring structure (c) found both in DNA and RNA (d) another chemical name of thymine

Which one of the following types of bonds provides stability to DNA double helix?
(a) Hydrogen bonds (b) Glycosidic bonds (c) Hydrophobic bonds (d) Phosphodiester bonds

The two strands of DNA are held together by:
(a) Peptide bonds (b) S-S bonds (c) Phosphodiester bonds (d) Hydrogen bonds

At which place of pentose sugar, a base is attached to form a nucleoside?
(a) C₃ (b) C₂ (c) C₁ (d) C₄

The carbon atoms of the pentose sugar involved in phosphodiester bond formation in DNA and RNA are:
(a) C₂ and C₅ (b) C₂ and C₃ (c) C₃ and C₅ (d) C₄ and C₅

Number of carbon in a ring of deoxyribose sugar is:
(a) Four (b) Five (c) Six (d) Three

Thymine is a:
(a) Purine (b) Enzyme (c) Pyrimidine (d) Vitamin

If a highly purified sample of plant DNA is dissolved in distilled water, the pH of the resulting solution will be:
(a) Basic (b) Acidic (c) Neutral (d) Highly basic

Which of the following elements is not present in a nitrogenous base?
(a) P (b) N (c) C (d) H

In a nucleic acid, bond between phosphate and hydroxyl group of sugar is a/an:
(a) H-bond (b) ester bond (c) glycosidic bond (d) hydrophobic bond
476. Which of the following bond is present between phosphate and hydroxyl group of sugar in a nucleic acid molecule?
   (a) Ester bond   (b) Glycosidic bond   (c) Hydrogen bond   (d) Peptide bond

477. Adenine + Pentose + Phosphate form:
   (a) Adenosine   (b) Adenyllic acid   (c) Adenosine diphosphate   (d) Adenosine triphosphate

478. Z-DNA:
   (a) was not discovered by Wang and Rich (1979)   (b) has 12 base pair per turn   (c) does not have zig-zag sugar phosphate backbone   (d) has 36° angle of twist/rotation per base pair

479. Double hydrogen bonds occur in DNA between:
   (a) A and T   (b) U and T   (c) A and G   (d) C and T

480. Three hydrogen bonds occur in DNA between:
   (a) A and T   (b) U and T   (c) C and G   (d) C and T

481. Which of the following scientists demonstrated that in DNA, $A = T$ and $C = G$?
   (a) Chargaff   (b) Griffith   (c) Watson   (d) Wilkins

482. The fact that a purine base always pairs with a pyrimidine base through hydrogen bonds leads to, in the DNA double helix:
   (a) The antiparallel nature   (b) The semiconservative nature   (c) Uniform width throughout DNA   (d) Uniform length in all DNA

483. DNA duplex shows:
   (a) left handed and parallel coiling   (b) left handed and antiparallel coiling   (c) right handed and parallel coiling   (d) right handed and antiparallel coiling

484. Who proposed the double helical model of DNA?
   (a) Sasishekaran   (b) Wang and Rich   (c) Nirenberg   (d) Watson and Crick

485. Watson, Crick and Wilkins got Nobel Prize in Medicine/Physiology in the year:
   (a) 1959   (b) 1962   (c) 1968   (d) 1950

486. Which one of the following is most common form of DNA in the cells?
   (a) A-DNA   (b) B-DNA   (c) C-DNA   (d) Z-DNA

487. RL model of DNA was given by:
   (a) Andrew Wang   (b) Alexender Rich   (c) Sasishekaran   (d) Sinsheimer

488. DNA strand are antiparallel because of:
   (a) H-bonds   (b) Disulphide bonds   (c) Phosphate bonds   (d) Phosphodiester bonds

489. Double helical model of DNA was proposed in the year:
   (a) 1953   (b) 1962   (c) 1950   (d) 1990

490. To determine the three-dimensional structure of DNA, Watson and Crick took the help of:
   (a) Tissue culture   (b) X-ray diffraction   (c) Autoradiography   (d) Electrophoresis

491. The number of nucleotide pairs in a complete pitch of Z-DNA is:
   (a) 10   (b) 11   (c) 12   (d) 13

492. Wilkins X-ray diffraction showed the diameter of the DNA helix as:
   (a) 10 Å   (b) 20 Å   (c) 30 Å   (d) 40 Å

493. In a dsDNA, if C is equal to 24% then find out the values of A, G and T respectively:
   (a) 24, 24, 26   (b) 26, 24, 24   (c) 24, 26, 24   (d) 26, 24, 26

494. Double stranded DNA virus with 10,000 base pairs has nucleotides:
   (a) 10,000   (b) 20,000   (c) 40,000   (d) 30,000

495. If cytosine is 18% in an organism’s DNA then what will be the percentage of adenine?
   (a) 32%   (b) 18%   (c) 72%   (d) 36%

496. Chargaff’s rule is applicable to:
   (a) Single stranded RNA   (b) Double stranded DNA   (c) Single stranded DNA and RNA

497. Which one of the following ratio is generally constant for a given species?
   (a) $T + C/G + A$   (b) $G + C/A + T$   (c) $A + C/T + G$   (d) $A + G/C + T$

498. In DNA if 10% of guanine is present, how much thymine is present?
   (a) 10%   (b) 20%   (c) 40%   (d) 80%

499. AGCT are nitrogenous bases of DNA. The pairing is:

500. Biochemical characterization of transforming principle was first done by:
   (a) Avery, MacLeod and McCarty   (b) Hershey and Chase   (c) Griffith   (d) Meselson and Stahl
501. Who performed the transformation experiments in bacteria?
(a) Pasteur   (b) Griffith  
(c) MacLeod   (d) Meselson

502. Transformation experiment was first performed on:
(a) Escherichia coli   (b) Salmonella typhi  
(c) Pasteurella pestis   (d) Diplococcus pneumoniae

503. Who proved that DNA is the basic genetic material?
(a) James Watson   (b) Frederick Griffith  
(c) Hershey and Chase   (d) Sutton and Boveri

504. A bacteriophage with radioactive DNA and protein when infects a bacterium the radioactivity inside the bacterium will be located:
(a) In DNA   (b) In protein  
(c) Both in DNA and protein  (d) In all parts of bacterial cell only

505. The ratio of proteins and mRNA in informosome usually:
(a) 1 : 4   (b) 4 : 1  
(c) 3 : 1   (d) 1 : 2

506. A single enzyme is specified by a single
(a) nucleosome   (b) gene  
(c) nucleotide   (d) chromosome

507. A functional unit of gene which specifies one polypeptide in protein synthesis is known as:
(a) Muton   (b) Recon  
(c) Cistron   (d) Codon

508. Which one of the following is smallest?
(a) Gene   (b) Cistron  
(c) Recon   (d) Muton

509. A pseudogene has:
(a) Homology with functional gene   (b) Homology with product of normal gene  
(c) Analogy with functional gene   (d) Analogy with product of normal gene

510. The segment of DNA which participates in crossing over is known as:
(a) Muton   (b) Recon  
(c) Cistron   (d) Replicon

511. The genes which determine the body plan are called:
(a) Modifier genes   (b) Constitutive genes  
(c) Homeotic genes   (d) Cytoplasmic genes

512. Location of a gene on chromosome is called its:
(a) locus   (b) hot spot  
(c) receptor   (d) bead

513. Which of the following got Nobel Prize for discovering jumping genes?
(a) Jacob and Monod   (b) Khorana  
(c) Beadle and Tatum   (d) Barbara McClintock

514. In split genes, the coding sequences are called:
(a) Exons   (b) Introns  
(c) Cistrons   (d) Operons

515. Information pieces of split genes are:
(a) Exons   (b) Introns  
(c) Pseudogenes   (d) Cistrons

516. Junk DNA refers to:
(a) replicating sequences   (b) coding sequences  
(c) non-coding sequences   (d) decoding sequences

517. Transposons are:
(a) Jumping genes   (b) House-keeping genes  
(c) Transporting genes   (d) Stationary genes

518. All eukaryotic genes contain two kinds of base sequences. Which of these plays an important role in protein synthesis?
(a) Exons   (b) Introns  
(c) Both (a) and (b)   (d) Junk DNA

519. Portion of gene which is transcribed but not translated is:
(a) exon   (b) intron  
(c) cistron   (d) codon

520. The intervening sequences of ‘gene’ are known as:
(a) introns   (b) exons  
(c) codons   (d) cistrons

521. What are those structures that appear as ‘beads - on -string’ in the chromosomes when viewed under electron microscope?
(a) Nucleosomes   (b) Base pairs  
(c) Genes   (d) Nucleotides

522. The histone protein that attaches to DNA strands between nucleosomes is:
(a) H1   (b) H2A  
(c) H2B   (d) H4

523. A nucleosome contains:
(a) 200 bp of DNA   (b) Histone octamer  
(c) H1   (d) All of these

524. In prokaryotes, DNA occurs:
(a) as scattered condition   (b) within a well defined nucleus  
(c) as nucleoid with basic protein   (d) in association with acidic protein

525. In 1957, Meselson and Stahl concluded from their studies that:
(a) DNA replicates conservatively   (b) DNA replicates semiconservatively  
(c) DNA replicates dispersively   (d) DNA does not replicate

526. Replication is continuous in:
(a) the leading strand   (b) the lagging strand
(c) the strand where Okazaki fragments are present
(d) both the strands

527. DNA replication needs:
   (a) RNA primer  (b) DNA template
   (c) dNTPs       (d) All of these

528. Function of deoxyribonucleoside triphosphate is to:
   (a) provide energy  (b) provide stability
   (c) act as substrate  (d) both (a) and (c)

529. DNA duplication occurs in:
   (a) G1 phase       (b) G2 phase
   (c) S phase        (d) Interphase

530. DNA is genetic material and is responsible for heredity because of its:
   (a) Replication  (b) Transcription
   (c) Mutation       (d) Translation

531. Topoisomerase is involved in:
   (a) Producing RNA primer
   (b) Joining of DNA segments
   (c) Producing nick in DNA
   (d) Separation of DNA strands

532. The element required by DNA polymerase is:
   (a) Ca++        (b) Mg++
   (c) K+          (d) Cu++

533. The telomeres of eukaryotic chromosomes consist of short sequences of:
   (a) Cytosine rich repeats (b) Adenine rich repeats
   (c) Guanine rich repeats (d) Thymine rich repeats

534. Telomerase is an enzyme which is a:
   (a) Repetitive DNA  (b) RNA
   (c) Simple protein  (d) Ribonucleoprotein

535. The G-rich strand of telomere is synthesized by an enzyme telomerase, which is a/an:
   (a) DNA       (b) Polysaccharide
   (c) RNA       (d) Ribonucleoprotein

536. Enzyme responsible for mitochondrial DNA replication:
   (a) Polymerase III (b) DNA polymerase γ
   (c) Polymerase I  (d) DNA polymerase β

537. The 5’ end of each Okazaki fragment has:
   (a) ACC         (b) Ribonucleotide
   (c) AUG         (d) Deoxyribonucleotide

538. Isotopes used for proving semiconservative mode replication are:
   (a) N14 and P31  (b) N14 and C14
   (c) N14 and N15  (d) C14 and P31

539. Semiconservative mode of DNA replication in eukaryotes was demonstrated by:
   (a) Taylor, Woods and Hughes
   (b) Watson and Crick
   (c) Meselson and Stahl
   (d) Khorana

540. If tritiated thymidine (H3-TDR) is present in both DNA strands then what would be the number of molecules of DNA having H3-TDR after 3 replications?
   (a) 2            (b) 4
   (c) 6            (d) 8

541. In vitro synthesis of RNA and DNA was carried out respectively by:
   (a) Kornberg and Nirenberg
   (b) Ochoa and Kornberg
   (c) Nirenberg and Khorana
   (d) Ochoa and Nirenberg

542. The direction of DNA replication is:
   (a) 5’ end → 3’ end
   (b) 3’ end → 5’ end
   (c) Amino terminus to carboxyl terminus
   (d) Carboxyl terminus to amino terminus

543. Okazaki fragments are:
   (a) Short DNA fragments on the lagging strand
   (b) Short DNA fragments on the leading strand
   (c) The DNA fragment produced due to radiation action
   (d) RNA primers required for initiation of DNA synthesis

544. Which of the following scientists was awarded Nobel Prize in 1959 for in vitro synthesis of polynucleotides:
   (a) Ochoa          (b) Nirenberg
   (c) Kornberg       (d) Khorana

545. The enzyme which is responsible for breaking and resealing a strand of DNA during replication is:
   (a) Ligase        (b) Topoisomerase
   (c) Helicase     (d) Endonuclease

546. During replication of a bacterial chromosome DNA synthesis starts from a replication origin site and:
   (a) Is facilitated by telomerase
   (b) Moves in one direction of the site
   (c) Moves in bi-directional way
   (d) RNA primers are involved

547. During replication, proofreading or editing activity of DNA polymerase-I is due to its:
   (a) 3’ → 5’ exonuclease activity
   (b) 5’ → 3’ exonuclease activity
   (c) polymerization activity
   (d) overall endonuclease activity

548. Principal enzyme needed during replication of DNA is DNA polymerase-III, which is actually a/an:
   (a) DNA dependent DNA polymerase
   (b) DNA dependent RNA polymerase
   (c) RNA dependent DNA polymerase
   (d) Taq DNA polymerase

549. During replication new DNA strand is synthesized in:
   (a) 5’ → 3’ direction from 3’ → 5’ template
   (b) 5’ → 3’ direction from 5’ → 3’ template
(c) 3’ → 5’ direction from 5’ → 3’ template
(d) 3’ → 5’ direction from 3’ → 5’ template

550. DNA polymerase-I is not concerned with:
(a) DNA repair
(b) synthesis of leading strand
(c) Proofreading
(d) removal of RNA primer

551. Semiconservative mode of replication of DNA was first demonstrated in:
(a) Escherichia coli
(b) Streptococcus pneumoniae
(c) Dalmonella typhimurium
(d) Drosophila melanogaster

552. Which one of the following disease is extremely rare, severe and has a very low incidence and occurs in one per eight million live births, wherein symptoms resembling aspects of ageing are manifested at an early age with shortening of telomeres?
(a) Progeria
(b) Kwashiorkor
(c) Cancer
(d) Schizophrenia

553. Single stranded DNA binding proteins are important for this function:
(a) Prevent single stranded DNA from rewinding
(b) Protect single stranded DNA from enzymatic action
(c) Prevent double helical DNA from unwinding
(d) Prevent double helical DNA from becoming triple helix

554. Okazaki fragments are used to elongate the
(a) leading strand toward the replication fork
(b) lagging strand toward the replication fork
(c) leading strand away from the replication fork
(d) lagging strand away from the replication fork

555. Nuclease enzyme which begins its attack from a free end of a polynucleotide is called
(a) kinase
(b) endonuclease
(c) exonuclease
(d) polymerase

556. Discontinuous synthesis of DNA occurs in one strand, because
(a) DNA molecule being synthesised is very long
(b) DNA dependent DNA polymerase catalyses polymerisation only in one direction (5’ to 3’)
(c) it is a more efficient process
(d) DNA ligase has to have a role

557. Actual synthesis of DNA in a bacterium is the function of
(a) polymerase I
(b) polymerase II
(c) polymerase III
(d) ligase

558. Okazaki fragments are used to elongate the
(a) leading strand toward the replication fork
(b) lagging strand toward the replication fork
(c) leading strand away from the replication fork
(d) lagging strand away from the replication fork

559. The flow of information from DNA to mRNA and then to proteins is called:
(a) transcription
(b) translation
(c) genetic code
(d) central dogma

560. AUG is found:
(a) only in mRNA
(b) only in tRNA
(c) in RNA
(d) in DNA

561. In genetic code,:
(a) ambiguity occurs
(b) codons have overlapping nature
(c) mean stop signals code for rare amino acid
(d) mRNA codons read in contiguous fashion

562. Central dogma of molecular biology was modified with the discovery of:
(a) Ligase
(b) RNA polymerase
(c) DNA polymerase
(d) Reverse transcriptase

563. Which one of the following does not follow the central dogma of molecular biology?
(a) Mucor
(b) Chlamydomonas
(c) HIV
(d) Pea

564. The one aspect which is not a salient feature of genetic code, is its being:
(a) Ambiguous
(b) Universal
(c) Specific
(d) Degenerate

565. Wobble hypothesis was proposed by:
(a) M. Nirenberg
(b) J.D. Watson
(c) F.H.C. Crick
(d) H.J. Muller

566. Crick called ‘magic-20’ to:
(a) 20 genetically engineered antibiotics
(b) 20 important nucleotides
(c) 20 most significant codons of mRNA
(d) 20 different amino acids used during protein synthesis

567. Considering the four nucleotides A, T, C and G then the number of base substitutions that can occur in amino acid codons are:
(a) 535
(b) 549
(c) 265
(d) 268

568. Khorana was awarded with Nobel Prize for:
(a) Artificial gene synthesis
(b) Deciphering genetic code
(c) Nucleotide sequence of tRNA
(d) Discovery of transposon

569. Genetic code determines:
(a) Sequence of amino acids in polypeptide
(b) Constancy of internal environment
(c) The structural pattern
(d) The variations

570. Wobble hypothesis establishes:
(a) Peptide chain formation
(b) Economy in tRNA molecules
(c) Initiation of polypeptide chain
(d) Termination of polypeptide chain

571. Which one of the following codons has no tRNA?
(a) UGC  (b) UAU  (c) UGU  (d) UGA

572. Which of the following bases of codon are important according to Crick’s wobble hypothesis?
(a) Last two  (b) Only first  (c) First two  (d) Only last

573. First termination codon discovered was:
(a) UAG  (b) UGA  (c) UAA  (d) All the 3 are discovered at the same time

574. Artificial synthesis of genes for alanine tRNA and tyrosine tRNA was done by:
(a) Khorana  (b) Kornberg  (c) Nirenberg  (d) Crick

575. The first codon UUU discovered by Nirenberg and Matthaei codes for:
(a) Phenylalanine  (b) Tyrosine  (c) Tryptophan  (d) Arginine

576. Genetic code is degenerate type because:
(a) Codons degenerate very quickly  (b) One amino acid is coded by more than one codons  (c) One codon codes for several amino acids  (d) It is present in all organisms

577. An anticodon of tRNA can recognize more than one codon of mRNA. It is:
(a) Wobble hypothesis  (b) Template hypothesis  (c) Gene flow hypothesis  (d) Richmond and Lang effect

578. How many types of anticodons or tRNAs are present in mitochondrial genetic code?
(a) 22  (b) 61  (c) 64  (d) Less than 61

579. Usually triplet codons are read in the:
(a) 3’ to 5’ direction  (b) 5’ to 3’ direction  (c) Any direction  (d) None of these

580. In yeast and mammalian mitochondria, UGA represents:
(a) Tryptophan  (b) Methionine  (c) Arginine  (d) Lysine

581. Which one of the following base of anticodon shows the wobbling?
(a) First base  (b) Second base  (c) Third base  (d) Wobbling is shown by codon not by anticodon

582. Inosine is a modified base, resembles the ‘G’ occurs in:
(a) DNA  (b) mRNA  (c) Codon  (d) tRNA

583. Which one of the following pair of amino acids are not concerned with degeneracy?
(a) Tryptophan and methionine  (b) Leucine and proline  (c) Lysine and phenyl alanine  (d) Histidine and cysteine

584. Find out the pair of semi essential amino acids:
(a) Arginine and histidine  (b) Leucine and proline  (c) Histidine and glutamic acid  (d) Tyrosine and Aspartic acid

585. In strict sense, which one of the following amino acid is actually an imino acid?
(a) Isoleucine  (b) Threonine  (c) Proline  (d) Serine

586. The codon for anticodon 3’ UUA 5’ is:
(a) 3’UUA5’  (b) 3’AAU5’  (c) 3’UUA5’  (d) 3’TTA5’

587. Genetic code was discovered by:
(a) Holley and Ochoa  (b) Holley, Nirenberg and Khorana  (c) Nirenberg and Matthaei  (d) Watson and Crick

588. Genetic code of nuclear and mitochondrial DNA is:
(a) Similar  (b) Different  (c) Not worked out so far  (d) DNA is not found in mitochondria

589. Which of the following is the simplest amino acid?
(a) Tyrosine  (b) Asparagine  (c) Glycine  (d) Alanine

590. The number of triplet codons having all the three bases same in 64 triplet codons is:
(a) 2  (b) 4  (c) 6  (d) 8

591. Ribosomal RNA is actively synthesized in:
(a) Nucleoplasm  (b) Ribosomes  (c) Lysosomes  (d) Nucleolus

592. Which one of the following is not an anticodon found in tRNA?
(a) UCU  (b) AUC  (c) CGA  (d) GCU

593. Which one of the following also acts as a catalyst in a bacterial cell?
(a) hnRNA  (b) 23 srRNA  (c) 5 srRNA  (d) snRNA

594. Which one of the following is called adapter molecule?
(a) rRNA  (b) mRNA  (c) tRNA  (d) rDNA
595. Acidic characters of DNA and RNA are due to:
   (a) Purine bases  (b) Sugar molecules
   (c) Pyrimidine bases  (d) Phosphate group

596. The difference between RNA and DNA is due to:
   (a) Base only  (b) Sugar and base
   (c) Phosphates and base  (d) Sugar and phosphate

597. Theodor Otto Diener discovered a:
   (a) bacteriophage  (b) free infectious DNA
   (c) infectious protein  (d) free infectious RNA

598. Which type of RNA contains unusual bases?
   (a) mRNA  (b) tRNA
   (c) rRNA  (d) All of these

599. Clover leaf model of tRNA was given by:
   (a) Khorana  (b) Nirenberg
   (c) Holley  (d) Klug

600. Which purine base is found in RNA?
   (a) Uracil  (b) Guanine
   (c) Thymine  (d) Cytosine

601. How many bases are present in an anticodon loop of transfer RNA?
   (a) 7  (b) 3
   (c) 5  (d) 8-12

602. Shine Dalgarno sequence occurs in:
   (a) DNA  (b) mRNA
   (c) rRNA  (d) tRNA

603. Shine-Dalgarno sequence is:
   (a) Found at the 3' end of a prokaryotic gene
   (b) Found in 16S rRNA
   (c) Complementary to an mRNA sequence
   (d) Located upstream of the AUG initiation codon of a prokaryotic mRNA

604. RNA does not occur in:
   (a) Chromosome  (b) Plasmalemma
   (c) Ribosome  (d) Nucleous

605. Which one of the following reads the genetic code?
   (a) mRNA  (b) hnRNA
   (c) rRNA  (d) tRNA

606. According to clover leaf secondary structure of tRNA, it does not contain:
   (a) 7 bases in anticodon loop
   (b) 7 bases in thymine loop
   (c) 10 bases in DHU loop
   (d) -CCA nucleotides at 5' end

607. Acceptor arm of a transfer RNA has:
   (a) -CCA at 3'end  (b) -CCA at 5’ end
   (c) poly A nucleotides  (d) 8-12 nucleotides

608. Latest and most accepted L-shaped 3-dimensional model of the tRNA was proposed by:
   (a) Aaron Klug  (b) S.H. Kim
   (c) H.G. Khorana  (d) Robert Holley

609. Which of the following occurs in mRNA but not in tRNA?
   (a) ACU  (b) AUC
   (c) AUU  (d) All of the above

610. The amino acid attaches to the tRNA at its:
   (a) 3'– end  (b) 5’–end
   (c) Anticodon site  (d) DHU loop

611. Transcription refers to the:
   (a) transfer of DNA sequence into RNA
   (b) formation of DNA from RNA
   (c) formation of protein
   (d) polymerisation of RNA in cell-free system

612. Generally only one strand of DNA is transcribed. This strand is called:
   (a) ‘A’ strand  (b) ‘B’ strand
   (c) sense strand  (d) template strand

613. For transcription RNA polymerase attaches to the:
   (a) regulator  (b) cofactor
   (c) repressor  (d) promoter

614. Which of the following RNA polymerase catalyzes the formation of transfer RNA in eukaryotes?
   (a) RNA polymerase I
   (b) RNA polymerase II
   (c) RNA polymerase I and III
   (d) RNA polymerase III

615. Removal of RNA polymerase III from nucleoplasm will affect the synthesis of:
   (a) mRNA  (b) rRNA
   (c) tRNA  (d) hnRNA

616. If one strand of DNA has the nitrogenous base sequence as ATCTG, what would be the complementary RNA strand sequence?
   (a) AACGT  (b) ATCGU
   (c) TTAGU  (d) UAGAC

617. Which one of the following is not a part of a transcription unit in DNA?
   (a) A promoter  (b) the structural gene
   (c) the inducer  (d) A terminator

618. The process of formation of RNA from DNA is called:
   (a) Transcription  (b) Translation
   (c) Replication  (d) Regulation

619. The transcription of DNA to a molecule of messenger RNA occurs:
   (a) on the ribosomes
   (b) in the cytosol
   (c) in the nucleus
   (d) only during cell division

620. During transcription:
   (a) Both the strands are copied
   (b) Only one strand is copied
   (c) A part of only one strand is copied
   (d) A dsRNA is synthesized

621. In eukaryotes, snRNA is synthesized by RNA polymerase:
(a) I  (b) II  
(c) III  (d) taq polymerase

622. If the uracil content is exhausted, the following process will immediately stop:
(a) Reverse transcription  (b) Transcription  
(c) Replication  (d) Translation

623. The promoter is:
(a) A factor involving in translational process  
(b) Associated with repressor in an inducible operon  
(c) A sequence located at the 3’ end of a gene  
(d) The binding site for RNA polymerase

624. During transcription, a promoter is located towards:
(a) 5’ end of coding strand  (b) 3’ end of coding strand  
(c) 5’ end of template strand  (d) mid of DNA duplex

625. TATA box found in prokaryotic DNA is concerned with:
(a) Transcription  (b) Replication  
(c) Translation  (d) Proofreading

626. In eukaryotes, rRNA, mRNA and tRNA are synthesized respectively by RNA polymerase:
(a) I, II and III  (b) α, β and γ  
(c) II, III and I  (d) III, II and I

627. Which one of the following works as stop signals during transcription?
(a) Rho factor  (b) Poly C nucleotides  
(c) Poly G nucleotides  (d) Poly A nucleotides

628. During transcription, recognition of promoters and chain termination are done respectively by:
(a) Sigma and rho factors  (b) Alpha and beta factors  
(c) Rho and sigma factors  (d) Core enzyme and holoenzyme

629. The DNA template for RNA synthesis has the following order of bases, TGCTTCGA. What will be the order of bases in mRNA:
(a) TCGAAGCT  (b) AGGAAGCU  
(c) UGCUAGCT  (d) ACGAAGCU

630. Reverse transcriptase is:
(a) RNA dependent RNA polymerase  (b) DNA dependent RNA polymerase  
(c) DNA dependent DNA polymerase  (d) RNA dependent DNA polymerase

631. Who discovered reverse transcription?
(a) Beadle and Tatum  (b) Temin and Baltimore  
(c) Har Govind Khorana  (d) Watson and Crick

632. Transcription takes place in:
(a) Matrix  (b) Cytosol  
(c) Nucleus  (d) Cytoplasm

633. In eukaryotes, RNA polymerase-I catalyses:
(a) tRNA synthesis  (b) rRNA synthesis  
(c) mRNA synthesis  (d) Initiation in transcription

634. In eukaryotes after transcription of mRNA, some of its nucleotides are removed before it is translated into polypeptide. The nucleotides which are removed from mRNA are called:
(a) Exons  (b) Upstream sequences  
(c) Unusual bases  (d) Introns

635. Teminism is the same as:
(a) Translation  (b) DNA synthesis  
(c) Transcription  (d) Reverse transcription

636. Types of RNA polymerase required in nucleus for RNA synthesis in eukaryotes:
(a) 1  (b) 2  
(c) 3  (d) 4

637. In 3-dimensional view, the tRNA is:
(a) L-shaped  (b) S-shaped  
(c) Y-shaped  (d) T-shaped

638. Which form of RNA has a structure resembling a clover leaf?
(a) hnRNA  (b) mRNA  
(c) tRNA  (d) rRNA

639. During transcription, if the nucleotide sequence of the DNA strand that is being coded is ATACG, then the nucleotide sequence in the mRNA would be:
(a) TCTGG  (b) UAUGC  
(c) UATGC  (d) TATGC

640. During transcription holoenzyme RNA polymerase binds to a DNA sequence and the DNA assumes a saddle-like structure at that point. What is the sequence called:
(a) CAAT box  (b) GGTT box  
(c) AAAT box  (d) TATA box

641. Which one of the following makes use of RNA as a template to synthesize DNA?
(a) Reverse transcriptase  (b) DNA dependent RNA polymerase  
(c) DNA polymerase  (d) RNA polymerase

642. The mode of action of a steroid hormone involves:
(a) binding to a cell membrane receptor  (b) binding to calmodulin  
(c) covalent modification of enzyme activity  (d) modifying gene transcription

643. Removal of introns and joining the exons in a defined order in a transcription unit is called:
(a) talling  (b) transformation  
(c) capping  (d) splicing

644. Splicing is meant for eliminating:
(a) Recons  (b) Mutons  
(c) Exons  (d) Introns
645. Synthesis of RNA molecule is terminated by a signal recognized by:
(a) Alpha factor (b) Gamma factor
(c) Delta factor (d) Rho factor

646. In eukaryotic cell transcription, RNA splicing and RNA capping take place inside the:
(a) Nucleus (b) Dictyosomes
(c) ER (d) Ribosomes

647. Transcription unit in DNA does not include:
(a) promoter (b) terminator
(c) inducer (d) structural gene

648. Removal of introns and joining of exons in a defined order during transcription is called:
(a) slicing (b) splicing
(c) looping (d) tailing

649. Removal of RNA polymerase II from nucleoplasm will affect the synthesis of:
(a) mRNA (b) tRNA
(c) snRNA (d) rRNA

650. Severo Ochoa enzyme, needed during polymerization of RNA with defined sequences in a template independent manner, is also known as:
(a) Taq polymerase (b) Polynucleotide phosphorylase
(c) Transformylase (d) RNA polymerase

651. Which one is different from rest three:
(a) cDNA (b) Complementary DNA
(c) Copy DNA (d) Chimeric DNA

652. Complementary DNA (= cDNA) is a copy of:
(a) DNA formed by DNA polymerase
(b) DNA formed by RNA polymerase
(c) RNA formed by reverse transcriptase
(d) RNA formed by transposition

653. cDNA probes are copied from the messenger RNA molecules with the help of:
(a) Restriction enzymes (b) Reverse transcriptase
(c) DNA polymerase (d) Adenosine deaminase

654. cDNA stands for:
(a) Circular DNA (b) Complementary DNA
(c) Coiled DNA (d) Cytoplasmic DNA

655. cDNA is made from a:
(a) tRNA template (b) mRNA template
(c) rRNA template (d) DNA template

656. A large cluster of ribosomes is called:
(a) megasome (b) microsome
(c) oligosome (d) polyribosome

657. Nonsense codon is responsible for:
(a) elongation of polypeptide (b) termination of protein synthesis
(c) putting a wrong amino acid (d) hydrolysis of GTP

658. Initiation of polypeptide chain takes place through:
(a) methionine (b) lysine
(c) leucine (d) glycine

659. The process of translation relates to:
(a) DNA synthesis (b) RNA synthesis
(c) ribosome synthesis (d) protein synthesis

660. RNA that picks up specific amino acid from amino acid pool of cytoplasm to carry it to ribosome during protein synthesis is:
(a) mRNA (b) tRNA
(c) rRNA (d) gRNA

661. Site for protein synthesis is:
(a) Nucleus (b) Cytosol
(c) Ribosome (d) Lysosome

662. To initiate translation, the mRNA first binds to the:
(a) Smaller ribosomal sub-unit (b) Larger ribosomal sub-unit
(c) Whole ribosome (d) Transfer RNA

663. Which one of the following is not involved in the formation of initiation complex during protein synthesis?
(a) mRNA (b) first charged tRNA
(c) smaller subunit of ribosome (d) larger subunit of ribosome

664. The process of formation of protein from DNA through mRNA is called:
(a) Transcription (b) Translation
(c) Replication (d) Regulation

665. The process of translation requires the presence of:
(a) mRNA, tRNA and ribosomes (b) mRNA, ribosomes and RNA polymerase
(c) DNA, mRNA and RNA polymerase (d) chromatin, DNA and amino acids

666. Which one cannot be synthesized from DNA directly?
(a) mRNA (b) tRNA
(c) rRNA (d) Protein

667. As per template theory, amino acid first combines with:
(a) tRNA (b) DNA
(c) rRNA (d) mRNA

668. Which of the following RNAs picks up specific amino acid from amino acid pool in the cytoplasm to ribosome during protein synthesis?
(a) mRNA (b) rRNA
(c) tRNA (d) All of these

669. A sequence of how many nucleotides in an mRNA makes a codon for an amino acid:
(a) One (b) Two
(c) Three (d) Four
670. If the number of amino acids in a polypeptide chain is 200, what will be the number of nucleotides in its cistron?
(a) 600  (b) 300  (c) 400  (d) 200

671. Enzyme peptidyl transferase helps in:
(a) Shifting of ribosomes on mRNA
(b) Transferring amino group from one amino acid to another
(c) Removal of tRNA after formation of peptide bond between amino acids
(d) Catalyzing bonding between adjacent amino acids

672. The genes that are responsible for growth, development and differentiation in an organism work through the regulation of:
(a) Translocation
(b) Transformation
(c) Transduction and translation
(d) Transcription and translation

673. The first step in the biosynthesis of polypeptide is catalyzed by:
(a) Initiation factors
(b) Aminoacyl-tRNA synthetase
(c) Peptidyl transferase
(d) Terminal transferase

674. The enzyme aminoacyl synthetase facilitates:
(a) Joining 2 adjacent amino acid on ribosomes
(b) Adoption of amino acid by a tRNA of its type
(c) Insertion of aminoacyl-tRNA into the ribosome sites
(d) Transfer of aminoacyl-tRNA from the ribosomal A-site to P-site

675. Polyosome is formed by:
(a) several ribosomes attached to a single mRNA
(b) many ribosomes attached to a strand of ER
(c) a ribosome with several subunits
(d) ribosomes attached to each other in a linear arrangement

676. During which one of the following processes of protein synthesis, energy is not required?
(a) aminoacylation of tRNA
(b) formation of initiation complex
(c) entry of charged tRNA on A-site
(d) release of newly synthesized polypeptide chain

677. An mRNA has certain untranslated regions (UTR), found:
(a) between initiation and termination codons
(b) between 5’ end and termination codon
(c) between 3’ end and initiation codon
(d) before the initiation and after the termination codons

678. In bacteria:
(a) mRNA requires processing
(b) transcription and translation take place in separate compartments
(c) translation can begin much before the mRNA is fully transcribed
(d) RNA polymerase shows division of labour

679. In *Escherichia coli*, lac operon is induced by:
(a) i-gene  (b) promoter gene
(c) lactose  (d) β-galactosidase

680. Lac operon is:
(a) a set of overlapping genes
(b) repressible operon
(c) inducible operon
(d) arabinose operon

681. A gene that takes part in synthesis of polypeptide is:
(a) regulator gene  (b) promoter gene
(c) operator gene  (d) structural gene

682. An operon is a:
(a) cistron
(b) protein
(c) gene
(d) group of structural genes and control genes

683. Sequence of structural genes of lac operon is:
(a) y, z, a  (b) z, y, a
(c) a, y, z  (d) a, z, y

684. In lac operon system, i stands for:
(a) inducer  (b) isolator
(c) insertion  (d) inhibitor

685. Repressor molecules are produced by:
(a) Regulator gene  (b) Promoter gene
(c) Inducer gene  (d) Structural gene

686. The operator gene of lac operon is “turned on” when lactose molecules bind to:
(a) mRNA  (b) Promoter site
(c) Repressor  (d) Operator gene

687. Genes involved in turning on or off the transcription of a set of structural genes are called:
(a) Redundant genes  (b) Operator genes
(c) Regulatory genes  (d) Polymorphic genes

688. In *E.coli*, the lac operon gets switched on when:
(a) Lactose is present and it binds to RNA polymerase
(b) Lactose is present and it binds to the repressor
(c) Repressor binds to operator
(d) RNA polymerase binds to the operator

689. Which is not produced by *E.coli* in the medium of lactose?
(a) Thiogalactoside transacetylase
(b) Lactose dehydrogenase
(c) Lactose permease
(d) p-galactosidase
Selected Objective Questions

690. Jacob and Monod studied lactose metabolism in *Escherichia coli* and proposed operon concept, which is applicable to:
(a) All prokaryotes
(b) All prokaryotes and some eukaryotes
(c) All prokaryotes and all eukaryotes
(d) All prokaryotes and some protozoans

691. In operon model, RNA polymerase binds to:
(a) Regulator gene
(b) Operator gene
(c) Structural gene
(d) Promoter gene

692. Fischer and Krebs got Nobel Prize of 1992 for their discovery of:
(a) Krebs cycle
(b) Reversible protein phosphorylation as biological regulatory mechanism
(c) Reverse transcription
(d) Prokaryotic regulation mechanism of gene expression

693. Which one of the following is the correct sequence of genes within an operon?
(a) Regulator, promoter, operator, structural
(b) Regulator, operator, promoter, structural
(c) Structural, operator, regulator, promoter
(d) Promoter, operator, structural, regulator

694. Segment of a DNA molecule determining the amino acid sequence of a protein is known as:
(a) Operator gene
(b) Regulator gene
(c) Structural gene
(d) Modifier gene

695. In *Escherichia coli*, lac operon is induced by:
(a) Lactose
(b) Permease
(c) Promoter gene
(d) β-galactosidase

696. “Gene-Battery model” of gene expression in eukaryotes is proposed by:
(a) Jacob and Monod
(b) Britten and Davidson
(c) Beadle and Tatum
(d) Kornberg and Ochoa

697. In lac operon system lac gene-i codes for:
(a) Inducer
(b) Repressor
(c) Promoter
(d) β-galactosidase

698. *E. coli* cells with a mutated z gene of the lac operon cannot grow in medium containing only lactose as the source of energy because:
(a) In the presence of glucose, *E. coli* cells do not utilize lactose
(b) They cannot transport lactose from the medium into the cell
(c) The lac operon is constitutively active in these cells
(d) They cannot synthesize functional β-galactosidase

699. Beadle and Tatum work on genetics of *Neurospora* or biochemical mutations resulted in the development of a new science called:
(a) Biochemical genetics
(b) Dendrochronology
(c) Genetic engineering
(d) Biotechnology

700. The lac operon consists of:
(a) One regulatory gene and three structural genes
(b) Two regulatory genes and two structural genes
(c) Three regulatory genes and three structural genes
(d) Four regulatory genes only

701. In the operon system, the repressor protein can bind only with the:
(a) Structural genes
(b) Regulator gene
(c) Operator gene
(d) Promoter gene

702. What is the ultimate source of genetic variability?
(a) mutation
(b) migration
(c) genetic drift
(d) selection

703. Mutations can be induced with:
(a) Ethylene
(b) Gamma radiations
(c) Infra red radiations
(d) IAA

704. Beadle and Tatum induced mutation in *Neurospora* by:
(a) γ-rays
(b) UV-rays
(c) X-rays
(d) Chemical mutagen

705. A base pair change:
(a) results in new species
(b) always alter protein function
(c) always causes amino acid replacement
(d) does not necessarily change the phenotype

706. Which base is responsible for hot spots for spontaneous point mutation?
(a) Adenine
(b) 5-bromouracil
(c) Guanine
(d) 5-methyl cytosine

707. Most of the mutations are:
(a) Dominant
(b) Harmful
(c) Useful
(d) recessive and harmful

708. Which is base analogue of adenine?
(a) 5-bromo uracil
(b) 2-amino purine
(c) Nitrous acid
(d) Bromo deoxyuracil

709. If the DNA codons are ATG ATG ATG and a cytosine base is inserted at the beginning, which of the following will occur:
(a) A nonsense mutation
(b) CATGAATGATG
(c) CAT GAT GAT G
(d) C ATG ATG ATG

710. Point mutation involves:
(a) insertion
(b) duplication
(c) deletion
(d) change in a base pair

711. How many gametes contain a dominant mutation if 1/15,000 babies show the new phenotype?
(a) 1/15,000
(b) 1/20,000
(c) 1/30,000
(d) 1/45,000

712. Which discoveries resulted in a Nobel Prize?
(a) X-rays induced sex linked lethal mutations
(b) Cytoplasmic inheritance
Recombination of linked genes
(d) Genetic engineering

713. Transition type of mutation is caused when:
(a) GC is replaced by TA
(b) AT is replaced by CG
(c) CG is replaced by GC
(d) AT is replaced by GC

714. Sickle cell disease is the replacement of glutamic acid by valine amino acid in the beta globin protein results due to the single base substitution at 6th codon of the gene from:
(a) GAG to GUG  (b) AAU to CCC  
(c) UUU to UAC  (d) GCA to GGA

715. The insertion or deletion of a base pair into the genetic code will cause a frame shift mutation unless the number of base pairs inserted or deleted is:
(a) Seven  (b) Just one  
(c) Two  (d) Three

716. A mutation that changes a codon specifying one amino acid to another codon that specifies another amino acid is called:
(a) Silent mutation  (b) Frameshift mutation
(c) Nonsense mutation  (d) Missense mutation

717. In a mutational event, when adenine is replaced by guanine, it is a case of:
(a) Transcription  (b) Transversion
(c) Translation  (d) Frame shift mutation

718. After a mutation at a genetic locus the character of an organism changes due to the change in:
(a) DNA replication  (b) Protein synthesis pattern
(c) RNA transcription pattern  (d) Protein structure

719. Colchicine interferes with:
(a) organization of spindle  (b) chromosome replication
(c) chromosome condensation  (d) incorporation of nitrogenous bases

720. Euploidy is best explained as:
(a) one chromosome less than the haploid set  (b) one chromosome more than the haploid set
(c) one chromosome more than the diploid set  (d) exact multiples of a haploid set of chromosome

721. A polyploid derived from F1 hybrid between 2 species is:
(a) autodiploid  (b) allopolyplaid
(c) autopolyploid  (d) autoallopolyploid

722. *Triticale*, the first man-made cereal crop, has been obtained by crossing wheat with:
(a) Rye  (b) Barley
(c) Sugarcane  (d) Pearl millet

723. In the octoploid wheat, the haploid (n) and basic (x) number of chromosomes are:
(a) n = 28 and x = 28  (b) n = 28 and x = 14
(c) n = 28 and x = 7  (d) n = 7 and x = 28

724. In a hexaploid wheat, the haploid (n) and basic (x) chromosome numbers are:
(a) n = 21 and x = 21  (b) n = 21 and x = 14
(c) n = 21 and x = 7  (d) n = 7 and x = 21

725. The chromosomal doubling in making polyploid plants is carried out by using:
(a) Colchicine treatment  (b) PEG
(c) EMS  (d) NAA

726. Loss of one single chromosome creates a condition called:
(a) trisomy  (b) nullisomy
(c) monosomy  (d) haploid

727. Which pairs is a chromosomal aberration?
(a) duplication and transduction  (b) duplication and transversion
(c) duplication and translocation  (d) all of these

728. Attachment of a chromosomal fragment resulting in addition of one or more genes to a chromosome is called:
(a) inversion  (b) deletion
(c) translocation  (d) duplication

729. When a segment of a chromosome breaks and later rejoins after 180° rotation, it is known as:
(a) deletion  (b) duplication
(c) inversion  (d) translocation

730. Which one can change linkage group?
(a) transfer  (b) translocation
(c) inversion  (d) crossing over

731. The exchange of chromosome segments between nonhomologous chromosomes is called:
(a) transfer  (b) translocation
(c) deletion  (d) translation

732. Which of the following chromosomal mutation are most likely to take place when homologous chromosomes are undergoing synapsis?
(a) Deletion and duplication  (b) Inversion and deletion
(c) Translocation and deletion  (d) Inversion and translocation

733. Chromosome complement with 2n - 1 is:
(a) Monosomy  (b) Nullisomy
(c) Trisomy  (d) Tetrasomy

734. Haploid organisms have:
(a) no enzyme  (b) no genotype
(c) only one allele of gene  (d) no phenotype

735. Haploids are more suitable for mutation studies than the diploids. This is because the:
(a) haploids are reproductively more stable than diploids
(b) mutagens penetrate in haploids more effectively than in diploids
(c) haploids are more abundant in nature than diploids
(d) all mutations, whether dominant or recessive are expressed in haploids.

736. Mutations can be considered as one of the raw materials of evolution because they:
(a) contribute to new variations in organisms
(b) are usually related to the environment in which they appear
(c) are usually beneficial to the organism in which they appear
(d) usually cause species of organisms to become extinct.

737. When gene pool of a population is constant then it called that population is at?
(a) genetic equilibrium (b) declining level (c) growing stage (d) upset condition.

738. Gene pool of a population tends to remain stable if the population is large, without large scale mutations and without migration but with:
(a) Random mating
(b) Moderate environmental changes
(c) Genetic drift
(d) Natural selection.

739. Change in gene frequency of a population means:
(a) Evolution is in progress
(b) Hardy Weinberg equilibrium is not achieved
(c) There may be a selection, migration or mutation
(d) All of the above.

740. A population is in Hardy-Weinberg equilibrium for a gene with only two alleles. If the gene frequency of an allele A is 0.7, the genotype frequency of Aa is:
(a) 0.21 (b) 0.42 (c) 0.36 (d) 0.7

741. If the frequency of an allele ‘B’ in a given population is 0.64 then find out the frequency of other allele ‘b’ in the same:
(a) 0.64 (b) 0.37 (c) 0.53 (d) 0.36

742. A population is in Hardy-Weinberg equilibrium for a gene with only 2 alleles. If the gene frequency of an allele D is 0.6 then the genotype frequency of carriers would be:
(a) 0.24 (b) 0.42 (c) 0.36 (d) 0.48

743. Hardy and Weinberg principle explains:
(a) Genetic equilibrium (b) Non-random mating (c) Evolutionary force (d) All of these

744. Hardy-Weinberg equilibrium operates in the absence of:
(a) Recombination (b) Mutation (c) Natural selection (d) All of these

745. Evolution is possible only when the Hardy-Weinberg equilibrium is:
(a) Upset (b) Maintained (c) Stationary (d) First upset then constant

746. Total genes and their alleles in a population is called:
(a) Gene pool (b) Founder effect (c) Gene flow (d) Genetic drift

747. Which one of the following factor does not affect Hardy-Weinberg’s equilibrium?
(a) Gene migration
(b) Natural Selection
(c) Genetic drift
(d) Replication of genetic material

748. According to Hardy-Weinberg law, sum total of all allelic frequencies is:
(a) 1 (b) 2 (c) 3 (d) 4

749. Who gave the term “genetic drift”?
(a) Huxley (b) Sewall Wright (c) Seth Wright (d) Hugo de Vries

750. Genetic drift (Sewell Wright effect) is a:
(a) directed process (b) random process (c) coevolutionary process (d) uniform process

751. Genetic drift operates in:
(a) Small population (b) Moderate sized population (c) Large population (d) Panmictic population

752. Genetic drift is:
(a) an orderly change in gene frequency (b) the appearance of recessive alleles (c) a random fluctuation of gene frequency (d) appeared in an directional manner

753. Which of the following evolutionary forces does not act in directional manner?
(a) Selection (b) Migration (c) Recombination (d) Genetic drift

754. Genetic drift appears:
(a) in the same generation (b) in the appearance of recessive genes (c) from one generation to another (d) in a directional manner

755. What is the major effect of genetic drift?
(a) Change in gene pool (b) Loss of genetic variability (c) Directional change (d) Bottle neck

756. The genetic drift causes/brings:
(a) Heterozygous gene pairs from homozygous
(b) Genetic variability
(c) Elimination of certain alleles and fixation of other alleles in the population
(d) Co-evolution i.e., evolution of one species in response to other and vice versa

757. The chance of elimination of genes from a small population is an example of:
(a) Speciation  (b) Adaptation
(c) Genetic drift  (d) Selection pressure

758. One of the following is called Sewall Wright effect:
(a) Gene pool  (b) Isolation
(c) Genetic drift  (d) Gene flow

759. Match the following evolution concepts in List-I with List-II and select the correct answer using the codes given below the lists:

List-I  List-II
A. Mutation  1. changes in population’s allele frequencies due to chance alone
B. Gene flow  2. differences in survival and reproduction among various individuals
C. Natural selection  3. immigration, emigration change allele frequencies
D. Genetic drift  4. source of new alleles
(a) A=1, B=2, C=3, D=4  (b) A=4, B=2, C=3, D=1
(c) A=5, B=1, C=4, D=2  (d) A=4, B=3, C=2, D=1

760. The spread of genes from one breeding population to another by migration which may result in change in gene frequency is:
(a) Gene flow  (b) Genetic drift
(c) Gene frequency  (d) Genetic erosion

761. Which one of the following evolutionary mechanisms acts to slow down the evolution of reproductive isolation?
(a) Mutation  (b) Gene flow
(c) Natural selection  (d) Genetic drift

762. Gene flow is the:
(a) Transfer of genes between genetically distinct but inbreeding population
(b) Transfer of genes from females to males of an organism
(c) Transfer of genes from outside to chromosomes
(d) Transfer of genes from sperms to eggs

763. “Differential reproduction” is just another way of saying:
(a) variation  (b) mutation
(c) genetic drift  (d) natural selection

764. Which of the following natural process is likely to hasten organic evolution?
(a) Overproduction  (b) Reproductive isolation
(c) Favourable environment  (d) Abundant genotypic variations

765. What is the unit of natural selection?
(a) Population  (b) Individual
(c) Species  (d) Family

766. What is useful for natural selection?
(a) Recombination  (b) Pre-adaptive mutation
(c) Variation  (d) Post-adaptive mutation

767. Which of the following process brings a change in gene frequency in a population to promote the adaptation as a product of evolution?
(a) Speciation  (b) Mimicry
(c) Natural selection  (d) Isolation

768. Which of the following is correct?
(a) Natural selection is not the basis for evolutionary change
(b) Natural selection discriminates variations
(c) Natural selection is essential for evolution
(d) Natural selection is the exclusive cause of all types of hereditary variations

769. Read the following statements carefully about natural selection:
A. Adaptive ability is inherited.
B. Adaptive ability has a genetic basis.
C. Fitness is the end result of the ability to adapt and get selected by nature.

Find out the appropriate answer:
(a) Only B  (b) Only A and C
(c) A, B and C  (d) All are incorrect

770. The appearance of DDT resistant variety of mosquito amongst the sensitive ones as a result of increased use of this chemical is an example of:
(a) Disruptive selection  (b) Stabilizing selection
(c) Directional selection  (d) Artificial selection

771. The natural selection that acts against change in the form and keeps the population constant through time is:
(a) Directional  (b) Disruptive
(c) Stabilizing  (d) Non-acting

772. In which type of natural selection, nature selects only intermediate phenotype with the production of only one peak at centre:
(a) Directional  (b) Disruptive
(c) Stabilizing  (d) All of these

773. The appearance of dark coloured peppered moths amongst the light coloured ones as a result of increased industrial pollution is an example of:
(a) Disruptive selection  (b) Stabilizing selection
(c) Directional selection  (d) Point mutation

774. Which of the following types of natural selection is rare?
(a) Stabilizing  (b) Disruptive
(c) Directional  (d) Artificial

775. Stabilizing selection favours:
(a) Both extreme forms of a trait
Directional selection favours
(a) Only one extreme form of a trait
(b) Both extreme forms of a trait
(c) Intermediate form of a trait
(d) Environmental differences

In which type of natural selection nature selects only one extreme phenotype with the production of only one peak towards one side:
(a) Directional
(b) Disruptive
(c) Stabilizing
(d) All of these

In stabilizing selection:
(a) only one peak is formed at the centre
(b) only one peak is formed towards left side
(c) only one peak is formed towards right side
(d) two peaks are formed on each side

Which type of natural selection is shown by the diagram given below?

(a) Disruptive selection
(b) Stabilizing selection
(c) Directional selection
(d) Artificial selection

Birds with average-sized wings survived in a severe storm more successfully than with longer or shorter wings. It illustrates:
(a) stabilizing selection
(b) gene flow
(c) diversifying selection
(d) founder effect

Who gave experimental evidence for selection and genetic basis of adaptation in bacteria using replica plating technique?
(a) Louis Pasteur
(b) Lederberg
(c) Strasburger
(d) Darwin

Master plate in replica plating experiment contained:
(a) Drug resistant bacteria
(b) Sterile colony of bacteria
(c) Different colonies of fertile bacteria
(d) Viruses, bacteria and antibiotics

Replica plating experiment of Joshua Lederberg and Esther Lederberg:
(a) Supports the natural selection theory
(b) Proves genetic basis of adaptation
(c) States that adaptation is selection of pre-existing variations and not due to new mutation
(d) All are correct

Lederberg gave the proof in support of genetic basis of adaptation in the year:
(a) 1952
(b) 1872
(c) 1953
(d) 1892

The experiment of which of the following shows that nature selects the pre-adaptive mutation?
(a) Lederberg
(b) Dobzhansky
(c) Bates
(d) Darwin

Which of the following is used by J.Lederberg and E. Lederberg in their experiment?
(a) viruses
(b) antibiotics
(c) birds
(d) hormones

In Lederberg’s replica plating experiment what shall be used to obtain streptomycin resistant strain?
(a) Only minimal medium
(b) Only complete medium
(c) Minimal medium and streptomycin
(d) Complete medium and streptomycin

Replacement of light coloured Biston betularia by dark Biston carbonaria in industrial melanism is due to a:
(a) Gene mutation
(b) Change in chromosome number
(c) Genetic drift
(d) Geographical isolation

Higher frequency of melanic British moths and DDT resistance in mosquitoes are cited as examples for:
(a) Genetic drift
(b) Point mutation
(c) Natural selection
(d) Arrival of the fittest

Industrial melanism and sickle cell anaemia support:
(a) Natural selection
(b) Induced mutation
(c) Isolation
(d) Geographical isolation

Natural selection is not exemplified by:
(a) industrial melanism
(b) sickle cell anaemia
(c) DDT resistance in mosquito
(d) rudimentary eyes in cave dwellers

Industrial melanism is an example of:
(a) Drug resistance
(b) Darkening of skin due to smoke from industries
(c) Protective resemblance with the surroundings
(d) Defensive adaptation of skin against ultraviolet radiation

Glucose-6-phosphate dehydrogenase deficiency (useful for natural selection) in human is associated with haemolysis of:
(a) lymphocytes
(b) leucocytes
(c) platelets
(d) RBCs

The continued occurrence of sickle-cell anaemia in some parts of Africa with falciparum malaria is due to:
(a) Disruptive selection
(b) Gene flow between populations
(c) Continual mutation
(d) Survival rate of heterozygous individuals
795. In favism, deficiency of which one of the following has survival value in malaria infested areas?
(a) RBCs  (b) WBCs  (c) Antibiotics  (d) G-6 PD enzyme

796. Scientific study of mimicry was carried out by:
(a) Bates  (b) Muller  (c) Darwin  (d) Huxley

797. Some organisms escape detection from enemies by resembling other organisms. This is called:
(a) Homology  (b) Artificial selection  (c) Mimicry  (d) Natural selection

798. Indian dead leaf butterfly (Kallima) is well known for:
(a) Speciation  (b) Isolation  (c) Mimicry  (d) Variation

799. The edible mimic animal appears like non-edible model. Here, former species gets benefit of protection. This is an example of:
(a) Mullerian mimicry  (b) Batesian mimicry  (c) Aggressive mimicry  (d) Concealing mimicry

800. Two non-palatable poisonous species resemble each other for increasing warning effect to predators. This is:
(a) Mullerian mimicry  (b) Adaptation  (c) Batesian mimicry  (d) Isolation

801. Resemblance of an animal with environment for defence and offence is called:
(a) camouflage  (b) shot gun  (c) mimicry  (d) adaptation

802. Reproductive isolation is:
(a) Inability to interbreed  (b) Ability of interbreed  (c) Breeding in isolation  (d) Intraspecific breeding

803. The role of isolation in evolution is to:
(a) Preserve the identity of a species  (b) Formation of new species  (c) Causes natural selection  (d) Open the gene pool

804. An example of reproductive isolation is:
(a) Mule  (b) Bonella  (c) Dinosaurs  (d) Archaeopteryx

805. When the members of one population do not breed at the same time of the year as the members of another population, it is called:
(a) Sexual isolation  (b) Habitat isolation  (c) Seasonal isolation  (d) Geographic isolation

806. Species that do not interbreed in nature are said to be:
(a) sterile  (b) hybrids  (c) reproductively isolated  (d) geographically isolated

807. Individuals of different species living in the same area may be prevented from interbreeding by responding to different mating dances. This is called:
(a) temporal isolation  (b) ecological isolation  (c) behavioural isolation  (d) mechanical isolation

808. All of the following are post zygotic isolating mechanisms except:
(a) Gametic mortality  (b) Zygotic mortality  (c) Seasonal isolation  (d) Geographical isolation

809. Which is not a prezygotic isolation mechanism?
(a) Hybrid sterility  (b) Seasonal isolation  (c) Ecological isolation  (d) Geographical isolation

810. For the formation of new species, geographical isolation is required by populations having:
(a) overlapping geographical areas  (b) same geographical areas  (c) adjacent geographical areas  (d) different geographical areas

811. The most important character for speciation is:
(a) Reproductive isolation  (b) Ethological isolation  (c) Behavioural isolation  (d) Geographical isolation

812. Speciation process comes under:
(a) Isolation  (b) Megaevolution  (c) Microevolution  (d) Macroevolution

813. Populations with adjacent geographical ranges are known as:
(a) Sympatric  (b) Allopatric  (c) Parapatric  (d) Deme

814. The origin of species from pre-existing species is:
(a) isolation  (b) mutation  (c) speciation  (d) polyploidy

815. A new species can be developed by:
(a) Mutation and isolation  (b) Isolation and competition  (c) Mutation and competition  (d) Variation and competition

816. For food, light and space, the greatest competition is between two:
(a) Closely related species of the same niche  (b) Closely related species of different niche  (c) Unrelated species of the same niche  (d) Unrelated species of the different niche
## Answers of Selected Objective Questions

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Dr. A. K. Verma completed his schooling from Govt. Inter College Faizabad. He is first divisioner graduate (B.Sc.) from University of Lucknow of 1989 batch. He did M.Sc. in Zoology from KNIPSS Sultanpur in 1992 and received Chancellor’s Gold Medal, as he secured first position. He was awarded Doctorate degree (Ph.D.) by Dr. RML Avadh University, Faizabad under the supervision of Dr. A.K. Singh (Professor, Department of Zoology, BHU-Varanasi).

Dr. Verma is young, dynamic, most popular and energetic faculty of the field. Due to his keen interest in teaching, he opted his career in teaching and guiding the students preparing for medical entrance examinations at Allahabad since 1992-1993 and continued till 2012-2013. He is highly dedicated and devoted to this field and under his able guidance, generous encouragement and motivational behaviour, thousands of students have fulfilled their dreams of becoming a Doctor. He is actively involved in providing nonstop personal affectionate guidance, immense co-operation, motivational, sympathetic and moral support to students of state of Uttar Pradesh based at Allahabad, for last 24 years.

Dr. Verma taught Zoology to undergraduate classes of B.Sc. I, II and III at CMP Degree College, University of Allahabad for many years to the absolute satisfaction of students. Now he is class one gazetted officer in Provincial Higher Education Services Uttar Pradesh and is deeply and actively involved in teaching Zoology to students of both undergraduate (B.Sc. I, II and III) as well as post graduate classes (M.Sc. I and II). He has published 20 Research papers in reputed International, refereed/peer reviewed & indexed journals and 2 in National level proceedings. He also attended and presented research papers in a number of National as well as International conferences/seminars/workshops/Orientation programme/Refresher course.

Dr. A.K. Verma is honoured/awarded fellowship of five prestigious International professional societies and is life member of more than one dozen professional societies. He has already written "A HANDBOOK OF ZOOLOGY" of 644 pages, which has been popularized throughout the country since 2012. He is editor-in-chief of International Journal of Zoology Studies (ISSN: 2348-5914) and executive editors of Bioherald : An International Journal of Biodiversity & Environment (ISSN: 2248-9061) as well as International Journal of Pure and Applied Zoology (ISSN: 2320-9585). Moreover, he is editorial board members of about one dozen International journals.