1) Monohybrid Cross

Monohybrid cross is a cross of two organisms involving only one contrasting character as controlled by a pair of allelic genes.

A) Examples of monohybrid cross

1] Mendel’s Breeding Experiments on Garden pea

Cross-pollinated pure breeding with contrasting characters e.g. Tall vs dwarf.

A] Results of Breeding

- Tall plant is controlled by a dominant gene T.
- Short plant is controlled by a recessive gene t.

Parents: Tall plant x Short plant

<table>
<thead>
<tr>
<th>Parents</th>
<th>Tall plant (TT)</th>
<th>Short plant (tt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gametes</td>
<td>T</td>
<td>t</td>
</tr>
</tbody>
</table>

- F1 (all are heterozygous tall plants)

B] Explanation with genetic diagram

Self-pollination of the F1 plants:

Parents: Tt x Tt

Gametes

| Gametes | T | t | T | t |

- F2

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>Tall (TT)</th>
<th>Tall (Tt)</th>
<th>Short (tt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenotypic ratio</td>
<td>Tall : Short = 3 : 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genotypic ratio</td>
<td>TT : Tt : tt = 1 : 2 : 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If two phenotypes of the offspring resulted from a cross are in the ratio of 3:1, both parents must be heterozygous.

A Punnett Squares showing the pattern of monohybrid inheritance

<table>
<thead>
<tr>
<th>T</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>TT</td>
</tr>
<tr>
<td>t</td>
<td>Tt</td>
</tr>
</tbody>
</table>

C) Dominance and Recessiveness

a. Genetic character is determined by a pair of alleles - 2 forms, either identical (TT / tt) or different (Tt). The resulting appearance (phenotype) will be either Tall (TT / Tt) or short (tt).

b. For each character, the individual has 2 alleles, homozygous (TT / tt) or heterozygous (Tt), inherited from his parents to determine the appearance of the character.

c. In heterozygous condition, only the dominant gene (character) will express while the recessive gene (character) will not appear. It is "masked by the dominant gene".

d. The recessive gene (character) may only appear in homozygous condition.
2] Tongue-rolling in human
Those who are able to roll the tongue into a groove are tongue-rollers. Those that cannot do so are non tongue-rollers.

A] Results of Breeding
When a homozygous tongue-roller is crossed with a homozygous non tongue-roller, the offsprings are all tongue-rollers.

Parents Homozygous tongue-roller Homozygous non tongue-roller

First filial All are tongue-rollers (because tongue-rolling appears in the offspring, so it is a dominant character. Non tongue-(F1) rolling is a recessive character).

B] Explanation with genetic diagram
Let \( R \) to represent the dominant gene for tongue rolling and \( r \) the recessive gene for non tongue-rolling. Thus,

Parents Tongue-roller Non tongue-roller

\[
\begin{align*}
\text{Gametes} & \quad R & \quad r \\
\text{F1} & \quad Rr & \quad \text{(All heterozygous tongue-roller)}
\end{align*}
\]

If two heterozygous tongue-rollers cross with each other,

Parents \( Rr \times Rr \) (2N) meiosis, Mendel’s first law

\[
\begin{align*}
\text{Gametes} & \quad R & \quad r & \quad R & \quad r \\
\text{F2} & \quad RR & \quad Rr & \quad Rr & \quad rr \quad (2N)
\end{align*}
\]

Phenotypic ratio of the offspring is 3 (tongue-roller) : 1 (non tongue-roller)

Genotypic ratio of the offspring is 1 (RR) : 2 (Rr) : 1 (rr)

Probability / Proportion / Percentage of being:
Homoyzgous tongue roller \( RR = 25\% \) or \( \frac{1}{4} \)
Heterozygous tongue roller \( Rr = 50\% \) or \( \frac{1}{2} \)
Homoyzgous non-tongue roller \( rr = 25\% \) or \( \frac{1}{4} \)
Tongue roller = 75\% or \( \frac{3}{4} \)
Non-tongue roller = 25\% or \( \frac{1}{4} \)

C] Significance
Indicates the proportion / probability of offspring having a particular genotype / phenotype.
3) Some dominant and recessive characteristics in Humans

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Dominant</th>
<th>Recessive</th>
</tr>
</thead>
<tbody>
<tr>
<td>tongue rolling</td>
<td>tongue roller (RR, Rr)</td>
<td>non-roller (rr)</td>
</tr>
<tr>
<td>ear lobes</td>
<td>with ear-lobes (EE, Ee)</td>
<td>without ear-lobes (ee)</td>
</tr>
<tr>
<td>iris colour</td>
<td>brown eyes (BB, Bb)</td>
<td>blue eyes (bb)</td>
</tr>
<tr>
<td>hair colour</td>
<td>dark hair (DD, Dd)</td>
<td>red hair (dd)</td>
</tr>
<tr>
<td>skin colour</td>
<td>normal skin colour (AA, Aa)</td>
<td>albinism (aa)</td>
</tr>
<tr>
<td>right / left handed</td>
<td>right-handed (RR, Rr)</td>
<td>left-handed (rr)</td>
</tr>
<tr>
<td>blood groups</td>
<td>A, B or AB (I\textsuperscript{A}I\textsuperscript{A}, I\textsuperscript{A}I\textsuperscript{O}, ...)</td>
<td>O (I\textsuperscript{O}I\textsuperscript{O})</td>
</tr>
</tbody>
</table>

2) Test cross

A) To identify whether an individual is homozygous dominant or heterozygous dominant.

1) The unknown is crossed with a homozygous recessive; e.g. using the dwarf garden pea (tt) cross with the unknown genotype Tall plant:

Parents: T? x t

Gametes: T ? t

F1: T? T? ?t

2) If ALL the offspring are tall, then ? is T. The unknown is homozygous dominant TT. If short plants appear in F1, then ? is t. The unknown is heterozygous dominant Tt.

B) To identify which phenotype is the dominant character

1) Cross two homozygous individuals of different phenotype. The resulting offspring are all heterozygous.

2) The expressed phenotype (allele) is dominant.
B. Solving problems involving Monohybrid Inheritance

1) Pedigree

A) Identify the nature of character (recessive or dominant).
B) Identify the genotype of individuals within the pedigree. Calculate the probability of having such character.
C) Predict the genotype / phenotype of offsprings. Calculate the probability of having such character.

Study the following problems: (Explain your answer with/without using genetic diagram).
1] What is the genotype of individual 1?
2] Which one (brown eye or blue eye) is the dominant character?
3] How can you determine the genotype of individual 9?
4] What is the probability of individual 5 and 9 to be brown eyed?
5] What is the probability of the possible phenotypes and genotypes offsprings of individual 9, if she married with
   A] a blue-eyed man.  
   B] a heterozygous brown-eyed man  
   C] a homozygous brown-eyed man

2) Given: genotype / phenotype of parent
Deduce: genotype / phenotype of offspring + probability

Given: A homozygous normal pigmented man (AA) married with an albinic woman (aa). The presence of black pigment (melanin) in the skin is controlled by a dominant gene A. The absence of melanin in skin (albinism) is controlled by a defective recessive gene a.

Deduction:
1] Results of Breeding

<table>
<thead>
<tr>
<th>Parent</th>
<th>Normal skin (pure breeding) x Albinism (pure breeding)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offspring (F1)</td>
<td>All normal skin pigmentation</td>
</tr>
</tbody>
</table>

2] Explanation with genetic diagram

```
<table>
<thead>
<tr>
<th>Parents</th>
<th>Normal skin pigmentation x Albinism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gametes</td>
<td>A x a</td>
</tr>
<tr>
<td>F1</td>
<td>Aa (all are normal skin pigmentation)</td>
</tr>
</tbody>
</table>
```
The phenotype of all offspring is normal skin pigmentation.
The genotype of all offspring is Aa
The probabilities are:
Homozygous normal pigment AA = 0% or 0
Heterozygous normal pigment Aa = 100% or 1
Homozygous albinism aa = 0% or 0
Normal pigmentation = 100% or 1
Albinism = 0% or 0

If two individuals having genotype Aa cross with each other.

<table>
<thead>
<tr>
<th>Parents</th>
<th>Aa x Aa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamete</td>
<td>A a A a</td>
</tr>
<tr>
<td>F2</td>
<td>AA Aa Aa aa</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phenotypic ratio</th>
<th>normal skin pigmentation : albinism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genotypic ratio</td>
<td>1 : 2 : 1</td>
</tr>
</tbody>
</table>

The phenotypes of the offspring are normal skin pigmentation and albinism.
The genotypes of the offspring are AA, Aa and aa.
The probabilities are:
Homozygous normal pigment AA = 25% or $\frac{1}{4}$
Heterozygous normal pigment Aa = 50% or $\frac{1}{2}$
Homozygous albinism aa = 25% or $\frac{1}{4}$
Normal pigmentation = 75% or $\frac{3}{4}$
Albinism = 25% or $\frac{1}{4}$

3) Given: Results of certain crosses
Deduce: the phenotype and/or genotype of the parents

Ex.1 - Fur colour
Deduce the genotypes of the parents from which both parents show the dominant character and one / some of the offspring show the recessive character.

**Given:** In guinea pigs, black fur is dominant over brown fur. The fur colour is controlled by a pair of alleles. Two black guinea were mated giving three brown and one black offspring.

**Deduction:**
1] The brown offspring must be homozygous recessive. Therefore, they must receive one recessive allele from each parent.
2] Since both of the parents should have a dominant allele for being black, their genotypes must be heterozygous.

Ex.2 - Chlorophyll production
Given: In maize, chlorophyll production is controlled by a pair of alleles. The dominant allele G enables chlorophyll production while the recessive allele g causes inability to produce chlorophyll. In an experiment, two green maize plants were crossed and 510 seeds were collected. The seeds were then allowed to germinate in the presence of light. 382 seeds developed into green seedlings while 128 developed into pale yellow ones.
Deduce the genotypes of the parents. Explain your answer.

**Deduction:**
1] The pale yellow offspring must be homozygous recessive. Therefore, they must have received one recessive allele from each parent.
2] Since both of the parents should have a dominant allele for being green, their genotypes must be heterozygous.
Ex.3 - Corn cob
Deduce the genotypes (and phenotypes) of the parents from which the two phenotypes in the offsprings are approximately in the ratio of 3:1.

Given: A maize plant was self-pollinated and cobs bearing both purple and yellow corn grains were produced. The number of purple grains and yellow grains on one side of a cob were 53 and 18 respectively.

The colour of grain is controlled by a single pair of alleles, deduce the genotype and phenotype of the parent plant.

Deduction:
1] The purple grains and yellow grains are in a 3:1 ratio (53 : 18 = 3:1).
2] According to Mendel's Law of inheritance, the parent must be heterozygous and purple grain is the dominant character.
3] Therefore the phenotype of the parent must be purple grain (i.e. the parent plant was developed from a purple grain).

Ex.4 – Pea plant
Deduce the genotypes of the parents from which the phenotypes of the parents and the offsprings are the same.

Given: A green pea plant was self-pollinated and all offspring produce green leaves. Assuming that leaf colour is controlled by a pair of alleles, deduce the genotype of the pea plant.

Deduction:
1] Since all the offspring have the same phenotype as their parent, the parent plant must be homozygous.

Ex.1 – Fur colour of rat:
Deduce the dominant / recessive allele of a character from parent both have the same phenotype but the offspring have different phenotypes.

Given: Fur colour of rats is controlled by a pair of alleles. In a breeding experiment, two grey rats were mated and the female gave birth to 3 grey and 5 black rats. Which is the recessive character, grey or black colour? Explain your answer.

Deduction:
1] Black is recessive because:
2] Both parents have grey fur therefore each of them must possess at least one grey allele.
3] Some of their offspring have black fur showing that at least one of the parents must also possess at least one black allele.
4] At least one of the parents is heterozygous.
5] In heterozygous condition, the recessive allele is masked.
6] Therefore the black allele is recessive.

OR
In heterozygous condition, only the dominant allele is expressed. Therefore the grey allele is dominant.
Ex. 2 – Tongue rolling:

Given: In man, the ability to roll tongue is determined by a pair of alleles.

Deduction:
1] The ability to roll tongue is dominant.
2] Both parents are tongue rollers therefore each of them must possess at least one tongue-rolling allele.
3] Some of their children are non-rollers showing that at least one of the parents must also possess at least one non-rolling allele.
4] At least one of the parents is heterozygous.
5] In heterozygous condition, only the dominant allele will be expressed.
6] Therefore the tongue-rolling allele is dominant.

Ex. 2 – Fruit fly:

Deduce the dominant / recessive allele / character from the parents have different phenotypes but the offspring have the same phenotype.

Given: Wing length of fruit flies is controlled by a pair of alleles. In a breeding experiment, long-winged flies were crossed with short-winged flies, all the F1 flies were long-winged. Which of the parents shows the dominant character? Explain your answer.

Deduction:
1] Some offspring must have received a long-winged allele and a short-winged allele from their parents / some offspring must be heterozygous.
2] All offspring have long wings.
3] Therefore, the long-winged allele must be dominant over the short-winged allele.
   OR
   The short-winged allele must be masked by the long-winged allele.
B. Sex Determination in Man

1) In human beings, the 23rd pair of chromosome determine the sex and is named as the Sex Chromosomes.

<table>
<thead>
<tr>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Female Chromosomes" /></td>
<td><img src="image2" alt="Male Chromosomes" /></td>
</tr>
</tbody>
</table>

2) It is distinguished by its shape / size as
   A) X chromosome - larger or longer carries more genes.
   B) Y chromosome - smaller or shorter carries fewer genes.

3) A male has XY combination in the sex chromosome while a female has XX. The expression of Y chromosome is essential for the formation of male sex organ and the sexual characteristics of a male. Some genes stored in X chromosome are vital for survival e.g. haemophilia, colour blindness. “Defective gene” in X could be fatal.

4) At meiosis, the 2 sex chromosomes separate in the same way as the others.
   A) All the ova will contain an X chromosome (1 type of gamete, ONLY X)
   B) Half of the sperms will contain an X chromosome while the other half will contain a Y chromosome. (2 types of gamete, either X or Y)

5) If the X-bearing sperm fertilizes an ovum, the zygote will be XX and give rise to a girl. If a Y-bearing sperm fertilizes the ovum, the zygote will be XY and develop into a boy. The possibility for having a boy or girl for each birth is 50%.

   ![Diagram](image3)

   Phenotypic ratio: girl : boy = 1 : 1
2. Variation
   A. Significance of Variation
      1) In the natural environment, there is **unavoidable competition** for various **resources**
         (e.g. food, water, living space (and mate)) within a population of organisms.
      2) **Variations** among individuals of the same species may allow the those with **advantageous**
         characteristics to **survive better and reproduce** (i.e. Natural Selection). >> **Adaptive Variation**
      3) Sexual reproduction (+ migration and mutation) enriches the variations (**"gene pool"**) of the
         population and ensure some individuals will **adapt** to the changing environment (new habitats) =>
         **successfully survive and reproduce** of those **best fitted** in the long run.  Mutation + natural selection > **Evolution** of the species.
      4) If the population could not adapt to the changing environment it would be in **danger of extinction**.
   
   3. Genetic Disorder
      A. Down Syndrome
         1) Affected persons are mentally and physically retarded.
         2) Women aged over 45 have a higher chance of giving birth to children with the syndrome.
         3) The ovum and the resulting zygote may have an extra chromosome No. 21.

   B. Colour Blindness
      1) Affected persons, suffering from red-green colour blindness, cannot distinguish between red and green colours.
      2) An abnormal recessive allele located on the X-chromosome give rise to the disorder, therefore more common in males*. A higher percentage of men are colour-blind in a population.

   C. G6PD (Glucose-6-Phosphate Dehydrogenase) Deficiency
      1) an enzyme deficiency of the red blood cells
      2) leads to haemolytic anaemia (abnormal rupture of red blood cells) after exposure to certain compounds* such as those in broad bean.
      3) An abnormal recessive allele located on the X-chromosome gives rise to the disorder, therefore more common in males*.

   The Y chromosome of male does not carry any genes for such characters. Therefore, the recessive allele on the X-chromosome in the male can express itself in the absence of the dominant allele. Female, with 2 X-chromosomes, will normally be the carrier of the defective gene but will not suffer from the genetic disorder.

   The use of naphthalene in schools has been prohibited as naphthalene is suspected to cause haemolytic anaemia in pupils with G6PD deficiency.
4. Biotechnology (Genetic Engineering)

A. Human Genome Project
1) The project was started in 1990 to identify and decode all the genes in human DNA.
2) The main area of application of the genome study is for medical purpose.
3) There are many associated ethical problems such as:
   A) Who can use the data?
   B) Should genes be manipulated to improve genetic make-up?
   C) Will privacy be respected?
   D) Will people with bad genetic make-up be discriminated against?

B. Cloning (The making of “Dolly”)
1) The nucleus of a body cell of an adult is taken out as the clone.
2) The nucleus of an unfertilized ovum is removed and discarded.
3) The clone (donor nucleus) is inserted into the ovum without nucleus. (recipient cell)
4) The resulting hybrid cell divides mitotically in optimum condition.
5) The mass of cells (embryo) is put into the uterus of a female.
6) A baby is born after the gestation period.

C. Genetically Modified (GM) Foods
1) They are foods or food additives that are manufactured by gene modification techniques.
2) Plants or animals modified genetically for food production usually grow faster and larger by the addition of growth genes.
3) Crops are more resistant to unfavourable conditions by the addition of resistance genes of drought, cold or heat, and pest (herbivorous insects).
4) New food strains with unique nutrient(s) and flavour can be manufactured by incorporating genes into different plants and animals.
5) Problems arisen:
   A) Being an untested technology, nobody really knows if GM foods do pose a risk to health.
B) Many GM foods are now sold in the markets without notifying the consumers. Consumers should have the right to make a choice between GM foods and natural foods. Food labelling is very important for chasing the occurrence of health problems.

C) GM foods cannot solve hunger problems.

D) GM organisms may interact with natural ones leading to unknown consequences.

D. Recombination of DNA

1) Production of Human Insulin

A) The human gene for the production of insulin is identified and cut out using special restriction enzymes.

B) A small circular DNA called plasmid is removed from a bacterium such as E. coli.

C) The human insulin gene is inserted into the plasmid using special enzymes (DNA Ligase).

D) The plasmid is put into a bacterial cell.

E) The bacterial cell grows and multiplies rapidly in optimum condition to produce a lot of bacteria containing the insulin gene.

F) A large quantity of insulin can be produced.

G) Many other human hormones (e.g. HGH), enzymes (e.g. Factor VIII) and vaccines can be produced to treat a wide range of disorders.