# Collegedunia NCERT Formula Sheet

*Class 12 / 12th Biology — Chapter 4 (NCERT 2026-27 / Latest Edition)*

## Chapter 4: Principles of Inheritance and Variation

Mendel's Ratios | Punnett & Test Cross | ABO Genetics | Linkage & Recombination | Sex Determination | Pedigree & Disorders

**Also see for this chapter:** NCERT Solutions | Revision Notes | Exemplar Solutions

| Quantity / Ratio | Value | Where it appears |
|---|---|---|
| Monohybrid $F_2$ phenotypic ratio | $3:1$ | One-gene cross, complete dominance |
| Monohybrid $F_2$ genotypic ratio | $1:2:1$ | $TT:Tt:tt$ |
| Incomplete dominance $F_2$ ratio | $1:2:1$ (pheno = geno) | Snapdragon flower colour |
| Test cross ratio (heterozygote) | $1:1$ | $Tt \times tt$ |
| Dihybrid $F_2$ phenotypic ratio | $9:3:3:1$ | Two-gene cross, independent assortment |
| Dihybrid $F_2$ genotypic classes | $9$ genotypes | From $16$ Punnett squares |
| Number of gamete types | $2^n$ ($n$ = heterozygous loci) | Independent assortment |
| $1$ map unit (centimorgan) | $1$% recombination | Genetic map distance |
| Colour blindness frequency | $\approx 8$% males, $0.4$% females | X-linked recessive |
| Human chromosome number | $46$ ($23$ pairs) | $22$ autosome pairs $+1$ sex pair |
| Down's syndrome karyotype | $47$ (trisomy of $21$) | Aneuploidy |
| Klinefelter's / Turner's | $47,XXY$ / $45,X0$ | Sex-chromosome aneuploidy |

# 1 1. Mendel's Monohybrid Ratios (NCERT 4.1–4.2)

The inheritance of a single gene. These expressions give the predicted offspring ratios when one true-breeding parent is crossed with another and the $F_1$ is selfed — the quantitative backbone of Mendel's Law of Dominance and Law of Segregation.

**Key terms (the vocabulary every formula uses)**

**Gene**: unit of inheritance carrying information for a trait. **Allele**: one of the alternative forms of a gene (e.g. $T$ vs $t$). **Genotype**: the allelic make-up ($TT$, $Tt$, $tt$). **Phenotype**: the observable trait (tall / dwarf). **Homozygous**: identical alleles ($TT$ or $tt$). **Heterozygous**: dissimilar alleles ($Tt$). **Dominant** allele expresses in the heterozygote; **recessive** stays masked.

**Monohybrid $F_2$ phenotypic ratio**

$$\text{Dominant} : \text{Recessive} = 3 : 1$$

where the cross is $TT \times tt \rightarrow$ $F_1$ all $Tt$ (dominant); $F_1 \times F_1$ selfing $\rightarrow F_2$.

Out of every $4$ $F_2$ plants, on average **3 show the dominant** trait and **1 shows the recessive** trait. This is the single most tested ratio in the chapter (Fig. 4.3, 4.4).

**Monohybrid $F_2$ genotypic ratio**

$$TT : Tt : tt = 1 : 2 : 1$$

where $TT$ = homozygous dominant; $Tt$ = heterozygous; $tt$ = homozygous recessive.

The $3 : 1$ phenotype hides a $1 : 2 : 1$ genotype — the $3$ dominant plants are actually $1\,TT + 2\,Tt$. Tall $TT$ and tall $Tt$ look identical, so genotype cannot be read off the phenotype directly.

**Binomial form of the $F_2$ genotypes**

$$\left(\tfrac{1}{2}T + \tfrac{1}{2}t\right)^2 = \tfrac{1}{4}TT + \tfrac{1}{2}Tt + \tfrac{1}{4}tt$$

where each gamete carries $T$ or $t$ with equal frequency $\frac{1}{2}$ (Law of Segregation).

The $1 : 2 : 1$ ratio is the **binomial expansion** of $(p+q)^2$ with $p = q = \frac{1}{2}$. NCERT writes this exact expression on p. 58 — expect a "derive the ratio" board question.

**Mendel's first two laws stated**

**Law of Dominance**: characters are controlled by discrete factors occurring in pairs; in a dissimilar pair one factor dominates the other. Explains the $F_1$ uniformity and the $3 : 1$ $F_2$ ratio. **Law of Segregation**: the two alleles of a pair separate during gamete formation so that each gamete gets only one allele; alleles do not blend and are recovered unchanged in $F_2$. This law is **universal** (no known exception).

# 2 2. Test Cross & Punnett Square (NCERT 4.2)

Tools to determine an unknown genotype and to enumerate cross outcomes. The test cross resolves whether a dominant-looking individual is homozygous or heterozygous; the Punnett square is the bookkeeping grid for all gamete combinations.

**Test cross ratio**

$$\text{Unknown dominant} \times tt \;\Rightarrow\; \begin{cases} \text{all dominant} & \Rightarrow \text{unknown is } TT \\ 1 \text{ dom} : 1 \text{ rec} & \Rightarrow \text{unknown is } Tt \end{cases}$$

where the tester is always the **homozygous recessive** ($tt$).

A test cross crosses the dominant-phenotype individual with the recessive parent. A $\mathbf{1:1}$ **ratio in the progeny** proves the parent was heterozygous; uniform dominant progeny proves it was homozygous (Fig. 4.5).

**Punnett square gamete count**

$$\text{Cells in square} = (\text{gamete types of } \mathrm{P}_1) \times (\text{gamete types of } \mathrm{P}_2)$$

e.g. monohybrid $Tt \times Tt$: $2 \times 2 = 4$ cells; dihybrid $RrYy \times RrYy$: $4 \times 4 = 16$ cells.

The Punnett square is a graphical grid (Reginald Punnett) that lists every possible **fusion of gametes**. Each interior cell is one equally likely zygote — count cells to read off ratios.

**Number of distinct gametes from a genotype**

A genotype heterozygous at $n$ independent loci produces $\mathbf{2^n}$ types of gametes. $Tt \Rightarrow 2^1 = 2$; $RrYy \Rightarrow 2^2 = 4$; heterozygous for $4$ loci $\Rightarrow 2^4 = 16$ gamete types. Directly answers NCERT Exercise Q3.

## 3 3. Exceptions to Dominance (NCERT 4.2.2)

Cases where the simple $3:1$ phenotype does not appear because the heterozygote is not identical to a homozygous parent. The genotype ratio stays $1:2:1$ in every case — only the mapping to phenotype changes.

**Incomplete dominance $\mathrm{F}_2$ ratio**

$$\text{Phenotypic ratio} = \text{Genotypic ratio} = 1:2:1$$

e.g. snapdragon: Red ($RR$) : Pink ($Rr$) : White ($rr$) $= 1:2:1$.

The heterozygote shows an **intermediate phenotype** (pink) because $R$ is not completely dominant over $r$. The $\mathbf{3:1}$ phenotype collapses onto the $\mathbf{1:2:1}$ genotype, so each genotype is now visibly distinct.

**Co-dominance — ABO blood groups**

$$I^A = I^B > i \qquad (I^A, I^B \text{ co-dominant; both dominant over } i)$$

where gene $I$ has three alleles $I^A$, $I^B$, $i$; each diploid carries any **two**.

In co-dominance **both alleles express fully** in the heterozygote — $I^AI^B$ produces **both** A and B sugars, giving blood group AB. Allele $i$ produces no sugar, so it is recessive to both.

**ABO genotype → phenotype map**

| Genotype | Blood group |
|---|---|
| $I^AI^A$ or $I^Ai$ | A |
| $I^BI^B$ or $I^Bi$ | B |
| $I^AI^B$ | AB |
| $ii$ | O |

**Six** genotypes collapse into **four** phenotypes (A, B, AB, O). This is also the standard NCERT example of **multiple alleles** — three alleles for one gene at the population level.

**Pleiotropy and multiple alleles**

**Multiple alleles**: a single gene with more than two allelic forms in the population (e.g. $I^A, I^B, i$); an individual still carries only two. **Pleiotropy**: one gene controlling **multiple phenotypic traits** through one metabolic pathway — NCERT example *phenylketonuria* (one mutated phenylalanine hydroxylase gene → mental retardation *and* reduced pigmentation). Starch synthesis in pea ($BB > Bb > bb$ grain size) shows dominance is phenotype-dependent, not an absolute property of an allele.

## 4 4. Dihybrid Cross & Independent Assortment (NCERT 4.3)

The inheritance of two genes together. These ratios follow from Mendel's Law of Independent Assortment: the segregation of one gene pair is independent of another, so the dihybrid ratio factorises into the product of two monohybrid ratios.

**Dihybrid $F_2$ phenotypic ratio**

$$9 : 3 : 3 : 1$$

for the cross $RRYY \times rryy \rightarrow$ $F_1$ $RrYy \rightarrow$ $F_2$ (round yellow : round green : wrinkled yellow : wrinkled green).

$9$ show **both dominant** traits, $3+3$ show **one dominant + one recessive**, $1$ shows **both recessive**. The classic NCERT seed-shape $\times$ seed-colour cross (Fig. 4.7).

**$9{:}3{:}3{:}1$ as a product of monohybrid ratios**

$$(3\text{ Round} : 1\text{ Wrinkled}) \times (3\text{ Yellow} : 1\text{ Green}) = 9 : 3 : 3 : 1$$

because each gene pair independently gives a $3 : 1$ ratio.

**Law of Independent Assortment**: each pair segregates independently, so combined ratios **multiply**. This product rule lets you predict any specific phenotype fraction without drawing the full $16$-cell square.

**Gamete types in a dihybrid**

$$RrYy \;\rightarrow\; RY,\ Ry,\ rY,\ ry \quad (\text{each } \tfrac{1}{4} = 25\%)$$

giving $4 \times 4 = 16$ Punnett cells, $9$ genotypes and $4$ phenotypes in $F_2$.

Four equally frequent gamete classes arise because $R/r$ assorts **independently** of $Y/y$. The

$F_2$ genotypic ratio is $1{:}2{:}2{:}4{:}1{:}2{:}1{:}2{:}1$ across $9$ classes.

**Probability shortcut for a specific phenotype**

Use the product rule: P(round *and* green) $= \frac{3}{4} \times \frac{1}{4} = \frac{3}{16}$; P(wrinkled *and* green) $= \frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$. Far faster than the full square for NCERT Exercise Q7-type problems.

**Chromosomal Theory of Inheritance (NCERT 4.3.2)**

**Sutton & Boveri (1902–03)**: genes (Mendel's "factors") sit on chromosomes; the **pairing and separation of homologous chromosomes during meiosis** exactly parallels the segregation and independent assortment of alleles. This united Mendelian genetics with cell biology. Verified experimentally by **T. H. Morgan** using *Drosophila melanogaster*.

## 5 5. Linkage & Recombination (NCERT 4.3.3)

What happens when two genes lie on the *same* chromosome — they no longer assort independently. Recombination frequency quantifies how often they are separated and is the basis of genetic mapping.

**Recombination frequency**

$$\text{RF} = \frac{\text{number of recombinant offspring}}{\text{total offspring}} \times 100\%$$

where recombinants carry **non-parental** allele combinations.

RF measures how often linked genes are separated by crossing over. **Tightly linked** genes $\Rightarrow$ low RF (e.g. Morgan's $y$ & $w$: $1.3\%$); **loosely linked** $\Rightarrow$ high RF (e.g. $w$ & $m$: $37.2\%$). Max RF $= 50\%$ (= independent assortment).

**Genetic map distance**

$$1 \text{ map unit (centimorgan, cM)} = 1\% \text{ recombination}$$

where map distance $\propto$ recombination frequency between two loci.

Alfred **Sturtevant** used RF as a measure of the **physical distance** between genes to build the first linkage map. Greater RF $\Rightarrow$ genes farther apart on the chromosome.

**Linkage vs. recombination in one line**

**Linkage**: physical association of genes on the same chromosome — parental gamete types dominate, $F_2$ deviates strongly from $9{:}3{:}3{:}1$. **Recombination**: generation of non-parental combinations by crossing over during meiosis I. The two are inversely related: **strong linkage** $\Rightarrow$ **low recombination**.

## 6 6. Sex Determination (NCERT 4.4)

The chromosomal basis of sex. NCERT covers four systems — XO, XY, ZW and the haplodiploid honey-bee mechanism — each with a fixed ratio or chromosome rule worth memorising for NEET.

**Human / Drosophila XY system**

$$\text{Female} = XX \qquad \text{Male} = XY \qquad \text{(male heterogamety)}$$

sperm: $50\%$ carry $X$, $50\%$ carry $Y$; all ova carry $X$.

The **sperm decides the sex** of the child. $X$-sperm $\to$ female (XX); $Y$-sperm $\to$ male (XY). Probability of a male or female child is exactly $50\%$ **each pregnancy**, independent of the mother.

**XO, ZW and honey-bee systems**

| | | |
|---|---|---|
| XO (grasshopper) | Female $XX$, Male $XO$ | male heterogamety; no Y |
| ZW (birds) | Female $ZW$, Male $ZZ$ | female heterogamety |
| Haplodiploid (honey bee) | Female $2n{=}32$, Male $n{=}16$ | female from fertilised egg; male (drone) from unfertilised egg |

Male honey bees (drones) are **haploid**, develop by **parthenogenesis**, produce sperm by **mitosis**, have **no father** but a grandfather.

**Male vs. female heterogamety**

**Male heterogamety** = the male makes two kinds of gametes (humans XY, grasshopper XO). **Female heterogamety** = the female makes two kinds (birds ZW). NEET frequently swaps "ZW = male is different" — in ZW it is the **female** ($ZW$) that is heterogametic.

## 7 7. Mutation (NCERT 4.5)

Heritable change in DNA that creates new variation. NCERT distinguishes point mutations from large chromosomal and ploidy changes; the sickle-cell substitution is the model example.

**Point mutation — sickle-cell anaemia**

$$\text{GAG} \longrightarrow \text{GUG} \qquad \text{(single base substitution)}$$

$$\text{Glu} \longrightarrow \text{Val} \quad \text{at codon } 6$$

on the $\beta$-globin chain of haemoglobin ($\text{Hb}^A \to \text{Hb}^S$).

A **single base-pair change** (point mutation) swaps one amino acid and converts normal Hb to sickle Hb. Under low $O_2$, $\text{Hb}^S$ polymerises and the RBC bends into a **sickle shape**. Autosomal recessive.

**Types of genetic change (NCERT 4.5)**

**Point mutation**: change in a single base pair (e.g. sickle-cell). **Frame-shift mutation**: insertion or deletion of base pairs shifting the reading frame. **Aneuploidy**: gain/loss of a single chromosome (failure of chromatid segregation) — e.g. Down's, Turner's. **Polyploidy**: gain of a whole chromosome set (failure of cytokinesis), common in plants. **Mutagens**: agents that induce mutation, e.g. UV radiation, chemicals.

## 8 8. Genetic Disorders (NCERT 4.6)

Mendelian (single-gene) disorders and chromosomal disorders, plus pedigree analysis — the tool used to trace inheritance in humans where controlled crosses are impossible.

**X-linked recessive — colour blindness**

$$\text{Affected: } \approx \mathbf{8\%} \text{ males, } \quad \approx \mathbf{0.4\%} \text{ females}$$

gene on the X chromosome; males ($XY$) need only **one** defective allele, females ($XX$) need **two**.

Far commoner in males because they are **hemizygous** for X. A carrier mother ($X^cX$) gives each son a **50%** chance of being colour blind. Haemophilia follows the same X-linked recessive pattern (Queen Victoria pedigree).

**Chromosomal disorders — karyotypes**

| | | |
|---|---|---|
| Down's syndrome | $47$, trisomy of $21$ | extra chr. $21$; described by Langdon Down |
| Klinefelter's syndrome | $47,\ XXY$ | masculine + gynaecomastia; sterile |
| Turner's syndrome | $45,\ X0$ | female, rudimentary ovaries; sterile |

Normal human cell $= 46$ chromosomes. **Trisomy** = one extra ($2n+1$); **monosomy** = one missing ($2n-1$). All three arise from **non-disjunction** during gamete formation.

**Mendelian disorders & pedigree analysis**

**Mendelian disorders** (single-gene): haemophilia, cystic fibrosis, sickle-cell anaemia, colour blindness, phenylketonuria, thalassaemia. They may be **autosomal** or **sex-linked**, **dominant** or **recessive**. **Pedigree analysis** represents a trait's inheritance across family generations using standard symbols (Fig. 4.13) — it reveals whether a trait is dominant/recessive and autosomal/sex-linked. **Thalassaemia** (autosomal recessive) is *quantitative* (too few globin chains) whereas sickle-cell is *qualitative* (wrong globin).

**Read the Full Revision Notes** 

## 9 9. Worked Number Patterns (NEET Quick-Recall)

The handful of ratio computations that recur in NEET MCQs and CBSE board numericals, condensed so they can be reproduced without re-deriving.

**Carrier & cross probabilities**

$$Aa \times Aa \Rightarrow \tfrac{1}{4}\,AA : \tfrac{1}{2}\,Aa : \tfrac{1}{4}\,aa$$

$$\text{P(carrier among dominant offspring)} = \frac{2}{3}$$

where the affected $aa$ class is excluded when only dominant-phenotype offspring are considered.

Among the **phenotypically dominant** $F_2$ ($3$ out of $4$), the ratio $AA : Aa$ is $1 : 2$, so $\frac{2}{3}$ **are heterozygous carriers**. A staple of genetic-counselling MCQs.

**Blood-group cross example**

$$I^Ai \times I^Bi \;\Rightarrow\; I^AI^B,\; I^Ai,\; I^Bi,\; ii \;=\; AB : A : B : O$$

ratio $1 : 1 : 1 : 1$ — all four blood groups possible from heterozygous A $\times$ heterozygous B parents.

Directly answers NCERT Exercise Q12 (child is O from father A, mother B): parents must be $I^Ai$ and $I^Bi$; the $ii$ child has group O. Shows co-dominance *and* multiple alleles in one cross.

## 10 10. Quick Reference — Formula & Ratio Index

| Quantity | Value / Formula | When to use |
|---|---|---|
| Monohybrid $F_2$ phenotype | $3 : 1$ | One gene, complete dominance |
| Monohybrid $F_2$ genotype | $1 : 2 : 1$ | $TT : Tt : tt$ |
| Binomial form | $(\frac{1}{2}T + \frac{1}{2}t)^2$ | Deriving 1:2:1 |
| Incomplete dominance | $1 : 2 : 1$ (pheno) | Snapdragon, intermediate $F_1$ |
| Test cross | $1 : 1 \Rightarrow$ heterozygote | Find unknown genotype |
| Punnett cells | $g_1 \times g_2$ | Count zygote classes |
| Gamete types | $2^n$ | $n$ heterozygous loci |
| Dihybrid $F_2$ phenotype | $9 : 3 : 3 : 1$ | Two genes, independent |
| Dihybrid as product | (3:1) $\times$ (3:1) | Probability shortcut |
| Specific phenotype prob. | multiply fractions | e.g. $\frac{3}{4} \times \frac{1}{4} = \frac{3}{16}$ |
| Recombination frequency | recomb./total $\times 100\%$ | Linked genes |
| Map distance | 1 cM = 1% RF | Gene mapping |
| ABO dominance | $I^A = I^B > i$ | Blood-group genetics |
| Human chromosomes | 46 (23 pairs) | Karyotype baseline |
| Down's / Klinefelter / Turner | 47 / $47, XXY$ / $45, X0$ | Chromosomal disorders |
| Colour blindness | 8% M, 0.4% F | X-linked recessive |
| Carrier fraction (dominant) | $\frac{2}{3}$ | Counselling problems |

## Related Collegedunia Resources

**Same chapter — other resources:**

- NCERT Solutions
- Revision Notes
- NCERT Book PDF
- Exemplar Book PDF
- Exemplar Solutions
- Handwritten Notes

**Continue learning:**

- Ch 3: Reproductive Health
- Ch 5: Molecular Basis of Inheritance
- Class 12 Biology — All Chapters

*End of Formula Sheet — Class 12 Biology Chapter 4 Principles of Inheritance and Variation. Continue with Chapter 5 (Molecular Basis of Inheritance) for the DNA basis of these genes, or revisit Chapter 6 (Evolution) for the population-genetics extension of $p$ and $q$.*