LOGIC BLOOM · NEET BIOLOGY

Principles of Inheritance & Variation

Class 12 · **Chapter 5** · How Traits Pass On

Mendel to modern genetics, built to be seen: monohybrid and dihybrid crosses, the three laws, every deviation, linkage, sex determination, mutation, genetic disorders and pedigree analysis. Full of Punnett grids and flowcharts so the ratios click, not just stick.

NCERT Chapter 5 | Punnett Grids | All 3 Laws | Disorders & Pedigrees | 1-Page Fact Sheet

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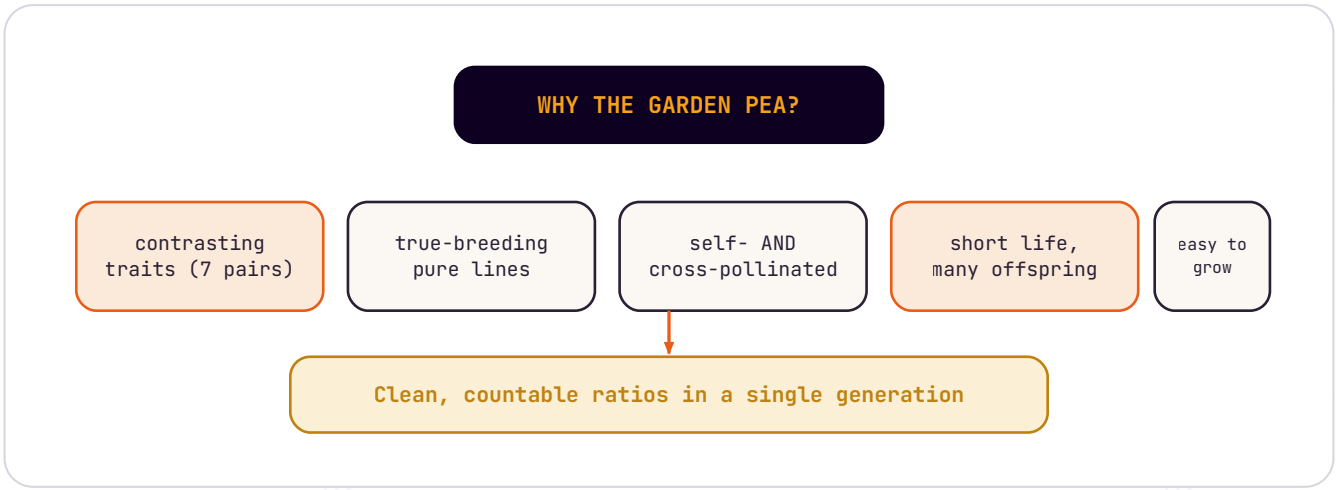
1 Mendel and the Garden Pea

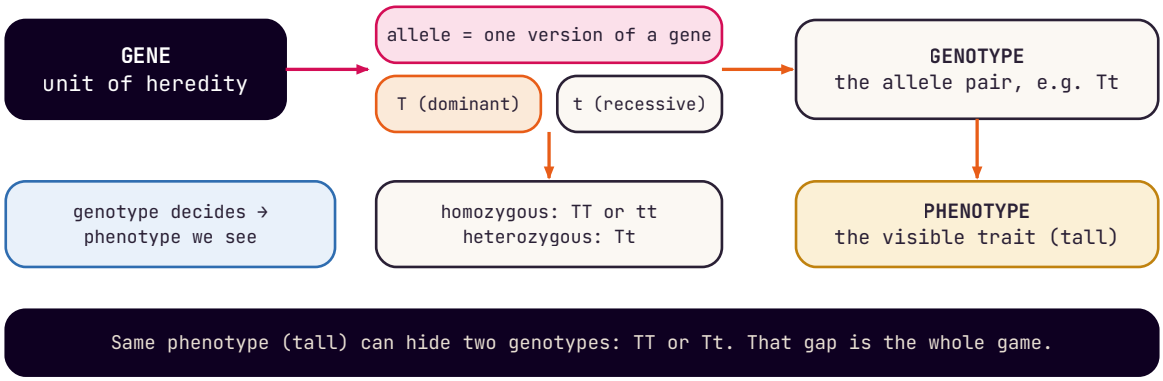
Genetics begins with one monk and one plant. Between 1856 and 1863 Gregor Mendel grew tens of thousands of pea plants and, by simply counting offspring, worked out the rules of heredity decades before anyone had seen a gene. His genius was the choice of material and the discipline to count.



The pea was the perfect subject: sharply contrasting traits, pure lines, control over pollination, and fast generations that give clean, countable ratios.

Mendel picked **seven characters**, each with two clearly different, non-overlapping forms. He first made **true-breeding** (pure) lines that always give the same trait on self-pollination, then crossed them and counted.

Character	Dominant	Recessive
Seed shape	Round	Wrinkled
Seed colour	Yellow	Green
Flower colour	Violet	White
Pod shape	Inflated	Constricted
Pod colour	Green	Yellow
Flower position	Axial	Terminal
Stem height	Tall	Dwarf



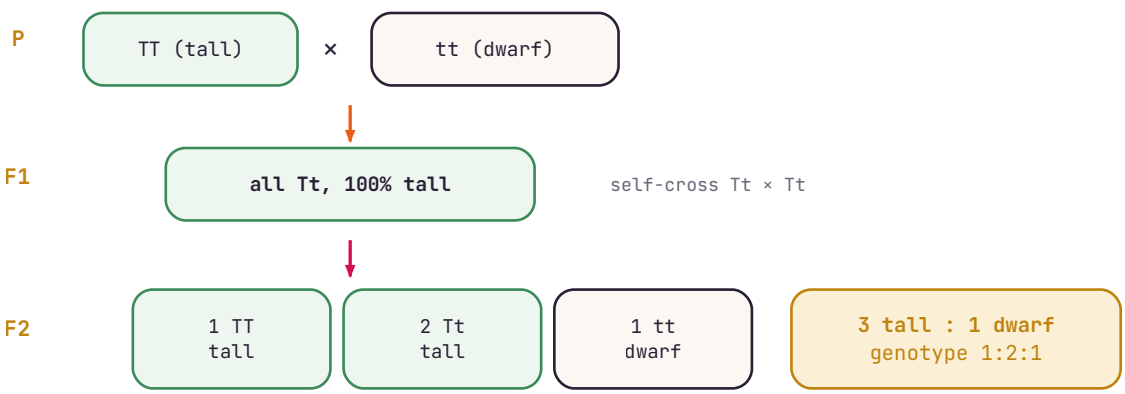
The core vocabulary. A gene has alleles; the allele pair is the genotype; the visible result is the phenotype. One phenotype can hide two genotypes.

THE WORDS YOU MUST FIX

Gene: a unit of heredity controlling a trait. **Allele:** one variant form of that gene (T or t). **Genotype:** the pair of alleles (TT, Tt, tt). **Phenotype:** the trait you see. **Homozygous:** two identical alleles (TT, tt). **Heterozygous:** two different (Tt). **Dominant** allele shows even when single; **recessive** shows only when doubled.

2 The Monohybrid Cross

Track a single character. Cross a pure tall pea (TT) with a pure dwarf (tt). Every plant in the first generation is tall. The dwarf trait has not vanished; it reappears in a quarter of the next generation. That reappearance is the clue to everything.

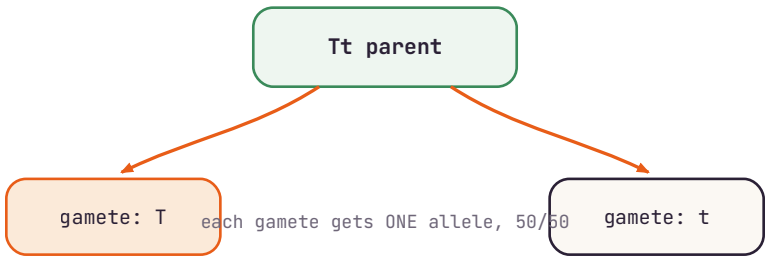


The monohybrid story: a uniform tall F1, then a 3 tall : 1 dwarf split in F2, hiding a neat 1:2:1 of genotypes.

★ LAW OF DOMINANCE

In a heterozygote (Tt) one allele expresses fully and the other is masked. The tall F1 looks exactly like the pure tall parent even though it carries a hidden dwarf allele. This explains why F1 is uniform and why recessive traits can skip a generation.

Where do the alleles go? During gamete formation the two alleles of a pair **separate**, so each gamete carries only one. This is the heart of Mendel's first law.



Law of Segregation: the paired alleles of a heterozygote part company, one to each gamete, in equal numbers.

★ LAW OF SEGREGATION (LAW OF PURITY OF GAMETES)

The two alleles of a gene separate during gamete formation and pass into different gametes, each gamete carrying just one. Alleles stay pure; they never blend inside a gamete.

Combine the gametes in a **Punnett square** and the F2 ratio falls out mechanically.

	T	t
T	TT	Tt
t	Tt	tt

Tt × Tt gives 1 TT : 2 Tt : 1 tt genotypes, which is 3 tall : 1 dwarf by phenotype.

The test cross: is that tall plant TT or Tt?

A tall plant could be TT or Tt; you cannot tell by looking. Cross it with a pure recessive (tt). If any dwarf offspring appear, the parent was Tt. All tall means TT.

	T	t
t	Tt	tt
t	Tt	tt

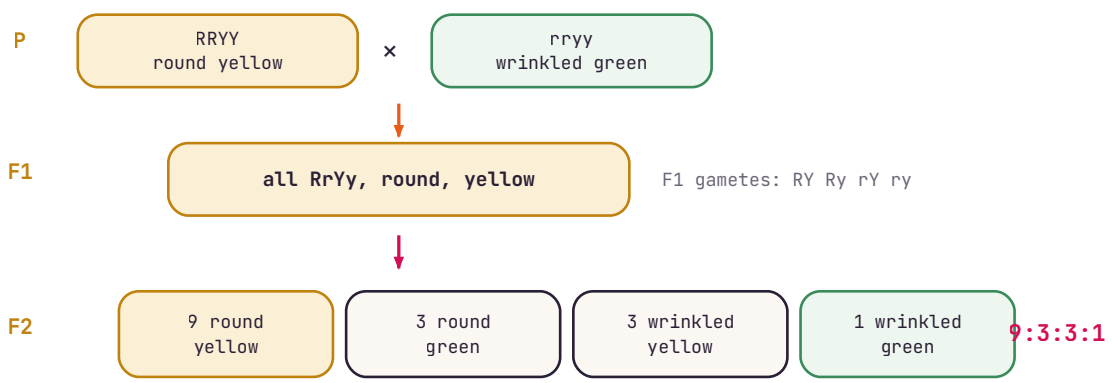
Test cross Tt × tt gives a 1 tall : 1 dwarf ratio, exposing the hidden recessive allele.

⚠ COMMON SLIPS

A test cross uses the **recessive** parent (tt), not another heterozygote. And the 3:1 is the **phenotype** ratio; the genotype ratio underneath is always 1:2:1. Examiners swap these.

3 The Dihybrid Cross

Follow two characters at once: seed shape (round R / wrinkled r) and seed colour (yellow Y / green y). Cross pure round-yellow (RRYY) with pure wrinkled-green (rryy). The F1 is all round-yellow. The F2 is where a famous ratio appears.



Two characters tracked together. F1 is uniform round-yellow; F2 splits 9:3:3:1, with brand-new combinations appearing.

The F1 (RrYy) makes four kinds of gamete in equal numbers, because the R/r pair sorts independently of the Y/y pair: **RY, Ry, rY, ry**. A 4 by 4 Punnett square gives sixteen boxes.

	RY	Ry	rY	ry
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

The dihybrid grid: 9 round-yellow, 3 round-green, 3 wrinkled-yellow, 1 wrinkled-green. The 9:3:3:1 ratio.

★ LAW OF INDEPENDENT ASSORTMENT

During gamete formation, the alleles of one gene pair assort independently of another gene pair. The colour a seed inherits does not depend on its shape. This is why parental traits recombine freely and new combinations (round-green, wrinkled-yellow) show up in F2.

READ THE 9:3:3:1

Each character alone still obeys the 3:1 rule: 12 round : 4 wrinkled and 12 yellow : 4 green. The dihybrid ratio is just two independent 3:1 splits multiplied together, (3:1) × (3:1).

⚠ THE CATCH EXAMINERS LOVE

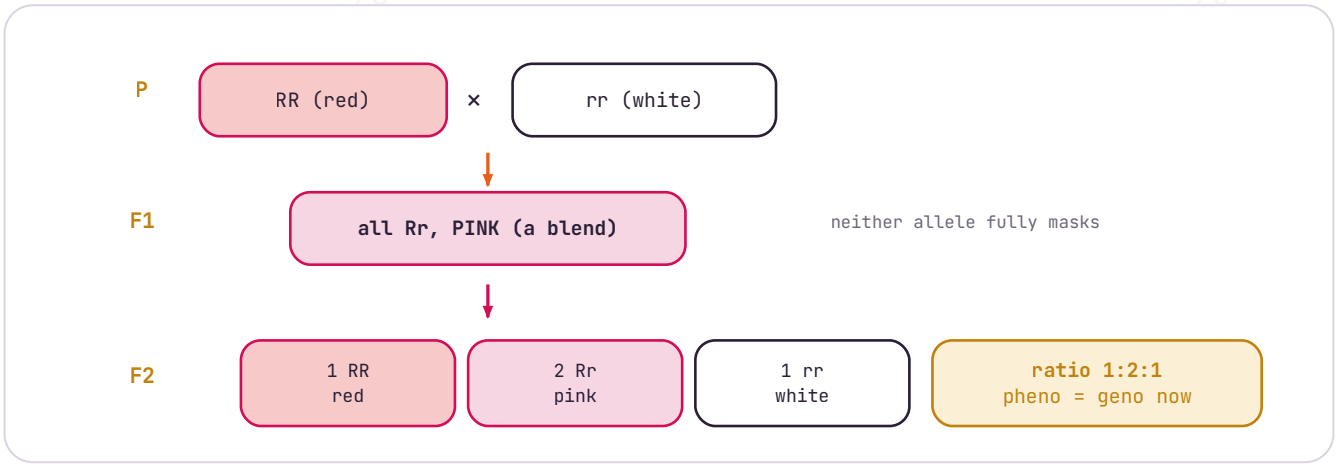
Independent assortment only holds for genes on **different** chromosomes. Genes sitting close together on the **same** chromosome are linked and do NOT give a clean 9:3:3:1. That exception is the next big idea.

4 When Mendel Bends: Deviations

Mendel's ratios assume clean dominance and single genes. Nature often refuses. These deviations are heavily tested, so learn what changes and what stays the same.

Incomplete dominance

In snapdragon (dog flower), red (RR) crossed with white (rr) gives a **pink** heterozygote. Neither allele fully masks the other, so the phenotype is a blend.



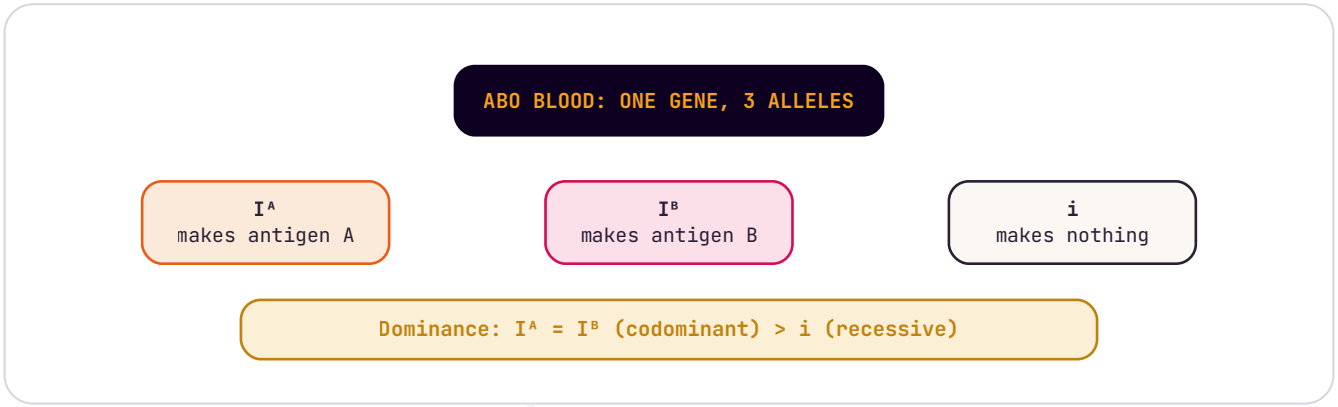
Incomplete dominance: the F1 is an intermediate pink. In F2 the phenotype ratio becomes 1:2:1, because heterozygotes now look different.

WHAT CHANGED

The genotype ratio is still 1:2:1. But because Rr now looks pink (not red), the **phenotype** ratio also becomes **1:2:1**, not 3:1. Genotype and phenotype ratios coincide.

Codominance and multiple alleles: ABO blood groups

In codominance **both** alleles show fully and separately (not blended). The human ABO blood group is the classic case, and it also shows **multiple alleles**: three alleles for one gene in the population.



One gene (I) has three alleles. IA and IB are codominant with each other and both dominate i.

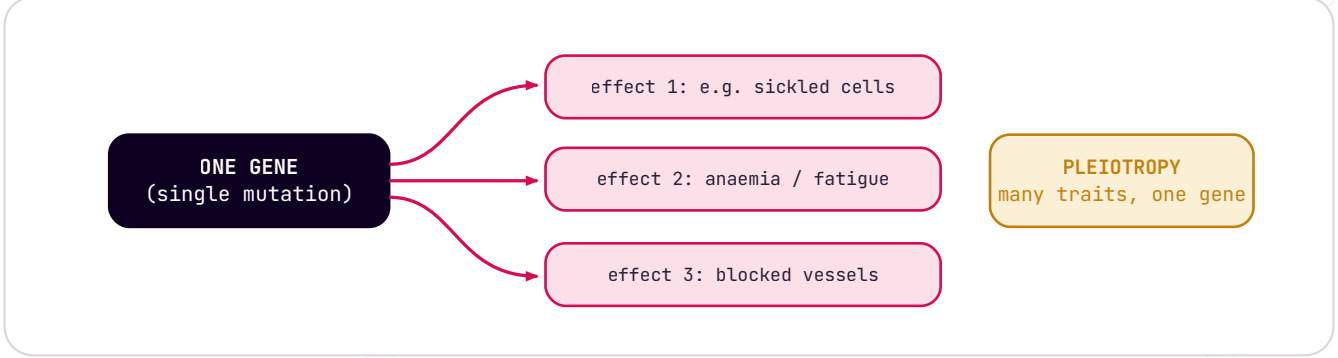
Blood group	Genotype(s)	Antigen
A	I^AI^A or I^Ai	A
B	I^BI^B or I^Bi	B
AB	I^AI^B	A and B (codominant)
O	ii	none

CODOMINANCE VS INCOMPLETE DOMINANCE

Incomplete dominance **blends** (red + white → pink). Codominance shows **both** distinctly (A and B antigens both present in AB, no blending). Do not confuse them.

Pleiotropy

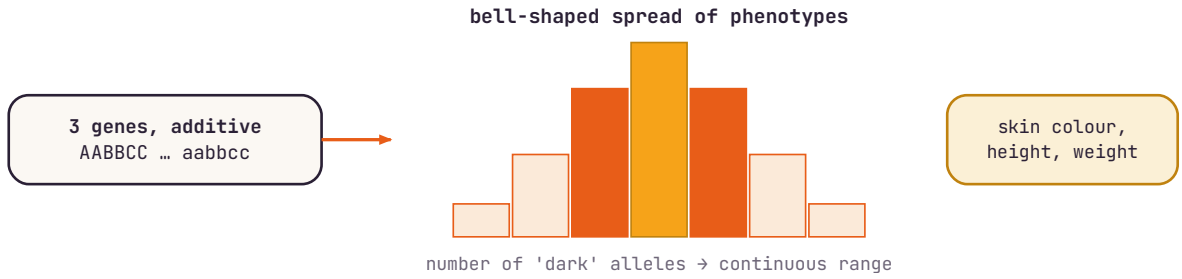
Sometimes one gene affects **many** traits at once. This is pleiotropy, the mirror image of polygenic inheritance.



Pleiotropy: a single gene has multiple, seemingly unrelated effects, as in sickle-cell anaemia or phenylketonuria.

5 Polygenic Inheritance

Traits like human skin colour, height and weight do not come in two neat boxes. They vary continuously because **many genes** each add a small, equal effect. This is polygenic inheritance.



Several additive genes produce a continuous, bell-shaped range of phenotypes. The more 'dark' alleles, the darker the skin.

★ THE RULE

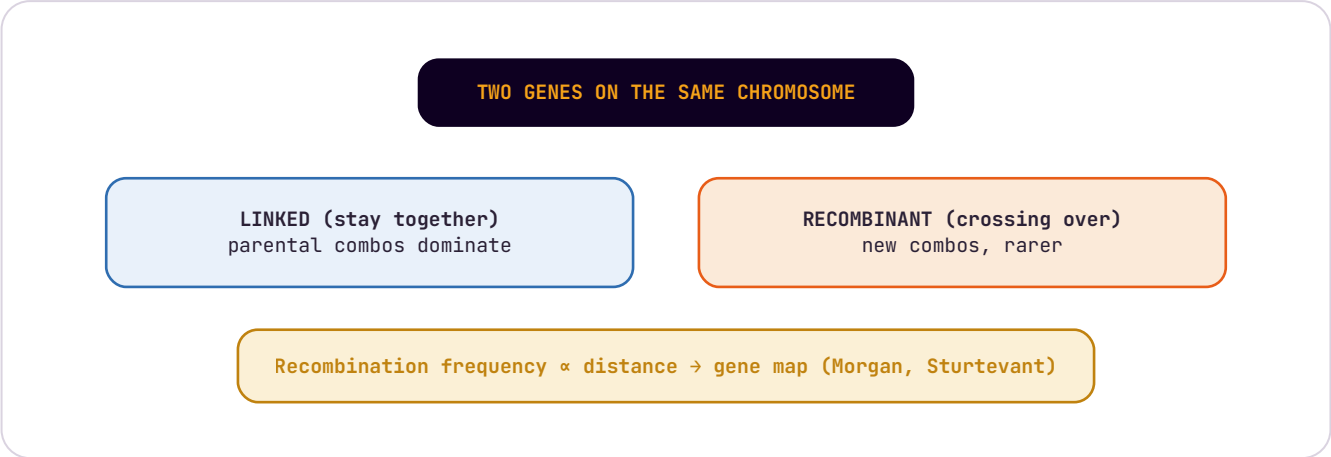
The phenotype depends on the **total number** of contributing (dominant) alleles across all the genes, plus the environment. Extreme phenotypes are rare (need all or none), intermediate ones common, giving the bell-shaped spread.

POLYGENIC VS PLEIOTROPY

Polygenic: many genes → one trait (skin colour). **Pleiotropy:** one gene → many traits (sickle cell). Same words, opposite direction.

6 Linkage and Recombination

Mendel was lucky: his seven genes lay on different chromosomes, so they assorted independently. Thomas Hunt Morgan, working on the fruit fly, found genes that refused to separate. They sat on the **same** chromosome and travelled together.



Genes on one chromosome are linked: parental combinations dominate. Crossing over occasionally shuffles them into rarer recombinant types.

★ LINKAGE

Genes physically close on the same chromosome tend to be inherited together, so their dihybrid ratio deviates from 9:3:3:1: parental types are far more common than recombinants.

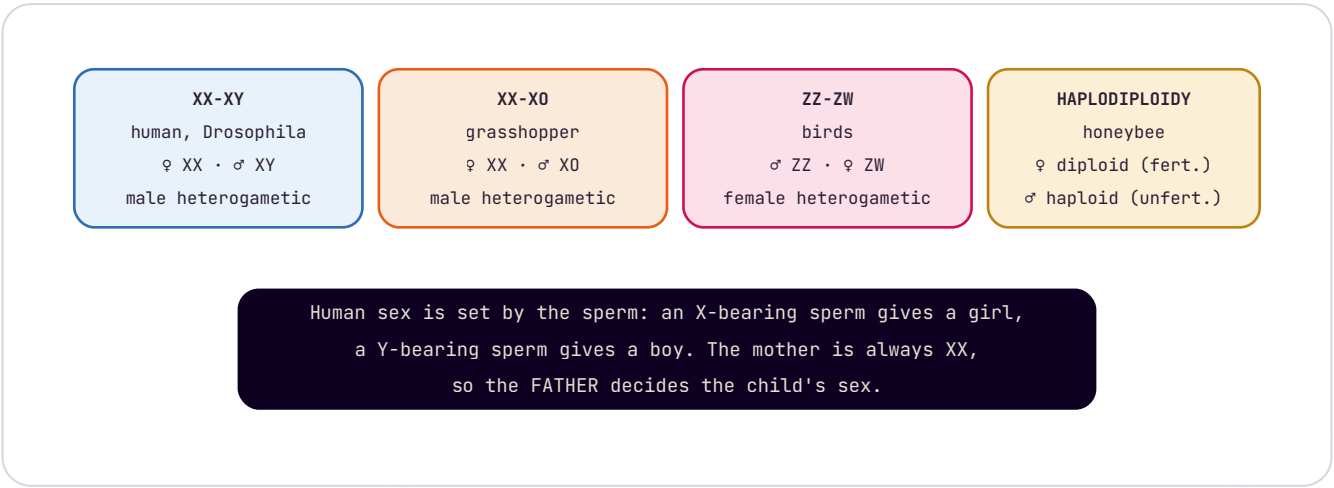
During meiosis, **crossing over** can swap segments between homologous chromosomes, breaking linkage and making recombinant gametes. The closer two genes, the less often they are separated.

RECOMBINATION MAPS THE CHROMOSOME

Recombination frequency is proportional to the distance between genes. Morgan's student Sturtevant used this to draw the first **genetic maps**: tightly linked genes recombine rarely, distant ones often.

7 Sex Determination

Whether an organism becomes male or female often comes down to a chromosome. Several systems exist, and NEET expects all four.



Four sex-determination systems. Note who is heterogametic (makes two kinds of gamete) in each, and that the honeybee uses ploidy, not sex chromosomes.

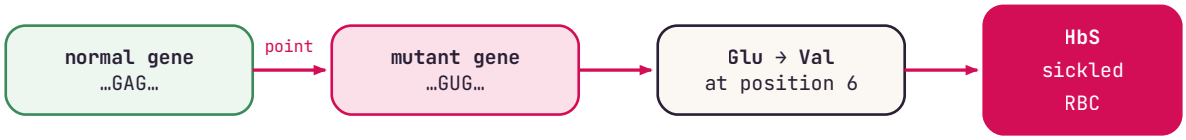
System	Female	Male	Example
XX-XY	XX	XY	Humans, Drosophila
XX-XO	XX	XO	Grasshoppers
ZZ-ZW	ZW	ZZ	Birds
Haplodiploidy	diploid	haploid	Honeybees

★ THE FATHER DECIDES (IN HUMANS)

The mother is always XX and gives an X. The father is XY and gives either an X (→ girl) or a Y (→ boy). So the sex of the child is determined by which sperm fertilises the egg, never by the mother.

8 Mutation

Variation ultimately comes from **mutation**: a change in the DNA. A change in a single base is a **point mutation**; inserting or deleting bases shifts the whole reading frame (a **frameshift**).



One base swap changes one amino acid and sickles the whole cell, autosomal recessive.

Sickle-cell anaemia from a single point mutation: GAG to GUG swaps glutamate for valine at position 6 of beta-globin, and the red cell sickles.

★ SICKLE-CELL ANAEMIA (A FAVOURITE ONE-MARK ANSWER)

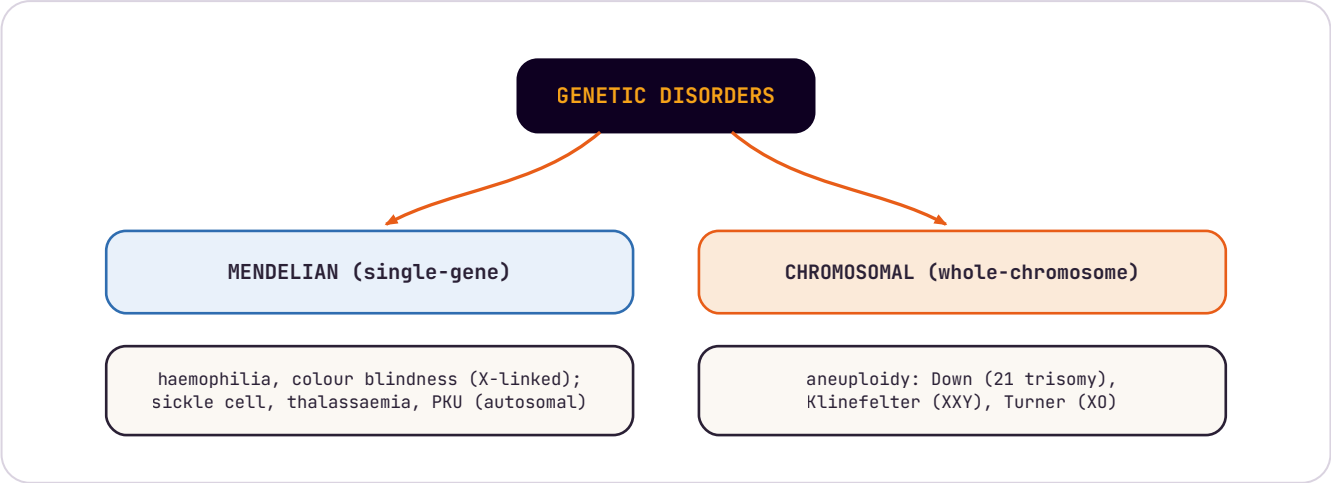
A single base substitution in the beta-globin gene (GAG → GUG) replaces glutamic acid with valine at the sixth position. It is **autosomal recessive**: only HbSHbS individuals are affected, while carriers (HbAHbS) are largely healthy and resist malaria.

⚠ POINT VS FRAMESHIFT

A point mutation changes one base and usually one amino acid. A frameshift (insertion or deletion) reshuffles every codon downstream, so its effect is far more drastic.

9 Genetic Disorders

Disorders split cleanly into two families: **Mendelian** (a fault in a single gene) and **chromosomal** (a wrong number of whole chromosomes, called aneuploidy).



The two families of genetic disorder. Single-gene Mendelian faults on the left, whole-chromosome errors on the right.

Mendelian disorders

Disorder	Inheritance	Defect
Haemophilia	X-linked recessive	Clotting factor missing; blood fails to clot
Colour blindness	X-linked recessive	Faulty red/green cone pigment
Sickle-cell anaemia	Autosomal recessive	GAG→GUG in beta-globin (chr 11)
Thalassaemia	Autosomal recessive	Reduced globin-chain synthesis
Phenylketonuria	Autosomal recessive	Enzyme missing; phenylalanine builds up

WHY MOSTLY MALES FOR X-LINKED

Haemophilia and colour blindness sit on the X. A male (XY) has only one X, so a single recessive allele shows. A female needs both X's faulty, which is far rarer, so she is usually only a carrier.

Chromosomal disorders (aneuploidy)

Three aneuploidies to memorise by their chromosome count: Down (47, trisomy 21), Klinefelter (47, XXY), Turner (45, X0).

TRISOMY VS MONOSOMY

Down's and **Klinefelter's** are trisomies: one extra chromosome (47 total). **Turner's** is a monosomy: one missing (45 total). Klinefelter is XXY (male), Turner is X0 (female).

10 Pedigree Analysis

A pedigree is a family tree drawn with standard symbols. Given who is affected across generations, you can deduce whether a trait is dominant or recessive, autosomal or X-linked. This is a guaranteed exam skill.

The symbol key, plus the quick tests for reading any pedigree: does the trait skip generations, appear in every generation, or track mainly through males?

★ THE THREE QUICK TESTS

Recessive: the trait skips generations and unaffected parents can have affected children. **Dominant:** the trait appears in every generation and every affected child has an affected parent. **X-linked recessive:** far more males affected, passed from carrier mothers to sons.

⚠ WORK TOP-DOWN, THEN TEST

Do not guess from one individual. Find an unaffected pair with an affected child (proves recessive), or check whether the trait ever skips a generation (rules dominant out). Only then decide autosomal versus X-linked from the sex pattern.

★ Inheritance · One-Page Fact Sheet

Everything for revision day. Print this page alone.

MENDEL'S LAWS

1. Dominance
2. Segregation (gametes pure)
3. Independent assortment

MONOHYBRID

TT × tt → all Tt
F2 = 3:1 (pheno)
= 1:2:1 (geno)

DIHYBRID

RrYy × RrYy
F2 = 9:3:3:1
= (3:1) × (3:1)

TEST CROSS

cross with tt
any recessive = Tt
all dominant = TT

INCOMPLETE DOM

Rr = pink (blend)
F2 pheno = 1:2:1
snapdragon

CODOMINANCE

both alleles show
I^AI^B = AB blood
3 alleles, codominant

LINKAGE

same chromosome
parental > recombinant
maps via crossing over

SEX & MUTATION

father decides sex
sickle: GAG→GUG
Glu→Val, recessive

DISORDERS

X-linked: haemophilia,
colour blindness
Down 47(21), Turner 45(X0)

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★ CONCEPT STILL NOT CLICKING?

Play it. Then practice it.

If a cross or ratio here didn't land, open the chapter in the Logic Bloom app: play it as a game, then drill practice questions till it clicks.

SCAN → PLAY THE GAME · PRACTICE NOW