

Monohybrid inheritance

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Read first: [Chromosomes, genes and proteins](#), [Mitosis and meiosis](#)

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What you need to know

This topic is about how **one gene** is passed from parents to offspring, and how to predict what the offspring will be like. It is tested on every paper: one-mark multiple-choice questions on Papers 1 and 2, a part-filled Punnett square on Paper 3, and a full genetic diagram, often with a pedigree diagram, on Paper 4. By the end of this topic you should be able to:

1. Describe **inheritance** as the passing on of genetic information from one generation to the next.
2. Describe the **genotype** as an organism's genetic make-up, written as the **alleles** it has (for example Gg).
3. Describe the **phenotype** as the features of an organism that you can observe (for example green pods).
4. Describe **homozygous** as having **two identical alleles** of a particular gene (GG or gg).
5. State that when two **identical homozygous** individuals breed together, they are **pure-breeding**: all their offspring are the same as them.
6. Describe **heterozygous** as having **two different alleles** of a particular gene (Gg).
7. State that a **heterozygous** individual is **not pure-breeding**.
8. Describe a **dominant** allele as one that is **expressed if it is present** in the genotype.
9. Describe a **recessive** allele as one that is expressed **only when there is no dominant allele** of the gene in the genotype.
10. **Interpret pedigree diagrams** that show how a characteristic is inherited in a family.
11. Use **genetic diagrams** to predict the results of monohybrid crosses and calculate **phenotypic ratios** (only **1 : 1** and **3 : 1**).
12. Use **Punnett squares**, in crosses that give more than one genotype, to work out and show the possible genotypes.
13. **Extended only**: explain how to use a **test cross** to find an unknown genotype.
14. **Extended only**: describe **codominance** as a situation where **both alleles** in a heterozygous organism **contribute to the phenotype**.
15. **Extended only**: explain the inheritance of the **ABO blood groups**: the phenotypes are groups **A, B, AB and O**, and the alleles are I^A , I^B and I^o .
16. **Extended only**: describe a **sex-linked characteristic** as one whose gene is on a **sex chromosome**, which makes it **more common in one sex** than in the other.
17. **Extended only**: describe **red-green colour blindness** as an example of sex linkage.

18. **Extended only:** use genetic diagrams to predict the results of crosses involving **codominance** or **sex linkage**, and calculate phenotypic ratios.

"Monohybrid" means the cross follows **one** gene only. Genes, alleles and chromosomes themselves are in the Chromosomes, genes and proteins note; how gametes are made is in Mitosis and meiosis.

Understand it

Genes, alleles and the two copies you carry

A **gene** is a length of DNA that codes for a protein, and it sits at a fixed place on a chromosome. Many genes come in slightly different versions: these are **alleles, alternative forms of the same gene**. Alleles are made of **DNA**, like the gene itself. For example, a pea plant's gene for pod colour has an allele for green pods and an allele for yellow pods.

Body cells are **diploid**: they have chromosomes in **pairs**, one of each pair from each parent. So a body cell has **two copies** of every gene, and those two copies can be the same allele or different alleles. Gametes are **haploid**: meiosis gives each gamete **one chromosome from each pair**, so each gamete carries **only one allele** of each gene. At fertilisation two gametes fuse, and the zygote has two alleles again, one from each parent. That is how **inheritance**, the passing of genetic information from generation to generation, happens.

Writing genotypes

We use one letter for the gene: a **capital** for the **dominant** allele and the **same letter in lower case** for the **recessive** allele. For pod colour, G = green (dominant) and g = yellow (recessive). A diploid organism has one of three **genotypes**:

Genotype	Description	Phenotype
GG	homozygous dominant (two identical alleles)	green
Gg	heterozygous (two different alleles)	green
gg	homozygous recessive (two identical alleles)	yellow

The **phenotype** is what you can see or measure: green pods, yellow pods, blood group, colour blindness. The genotype is the alleles written as letters.

Dominant and recessive

A **dominant** allele shows in the phenotype whenever it is there, so GG and Gg look the same: both are green. A **recessive** allele shows only when there is **no dominant allele**, so only gg is yellow. This gives two rules you will use all the time:

- An organism with the **recessive phenotype** must be **homozygous recessive** (gg). You know its genotype for certain.

- An organism with the **dominant phenotype** is GG or Gg . You can't tell which just by looking; you need its parents, its offspring or a test cross.

"Dominant" does not mean "more common" or "better". It only says which allele is expressed in a heterozygote.

Pure-breeding

When **two identical homozygous** organisms breed ($GG \times GG$, or $gg \times gg$), every gamete carries the same allele, so every offspring has the same genotype and phenotype as the parents, generation after generation. They are **pure-breeding** (true-breeding). A **heterozygous** organism is **not** pure-breeding: half of its gametes carry each allele, so it can have offspring unlike itself.

Genetic diagrams and Punnett squares

A **genetic diagram** sets out a cross in a fixed order. Here is a cross between two heterozygous green-podded pea plants:

	Parent 1		Parent 2
parental phenotypes	green	×	green
parental genotypes	Gg	×	Gg
gametes	G and g	×	G and g

The gametes go into a **Punnett square**: one parent's gametes along the top, the other's down the side, and each box gets one allele from its row and one from its column.

	G	g
G	GG	Gg
g	Gg	gg

- **Offspring genotypes:** GG , Gg , Gg , gg (1 GG : 2 Gg : 1 gg).
- **Offspring phenotypes:** green, green, green, yellow.
- **Phenotypic ratio:** 3 green : 1 yellow.

Each box is **one chance in four** of what one offspring will be, not an actual count. So the probability that one offspring is yellow is $\frac{1}{4} = 0.25 = 25\%$. With real numbers the ratio is only roughly 3 : 1, because which gametes meet is random: 240 seeds would be expected to give $240 \times \frac{1}{4} = 60$ yellow, but 57 or 64 would be quite normal.

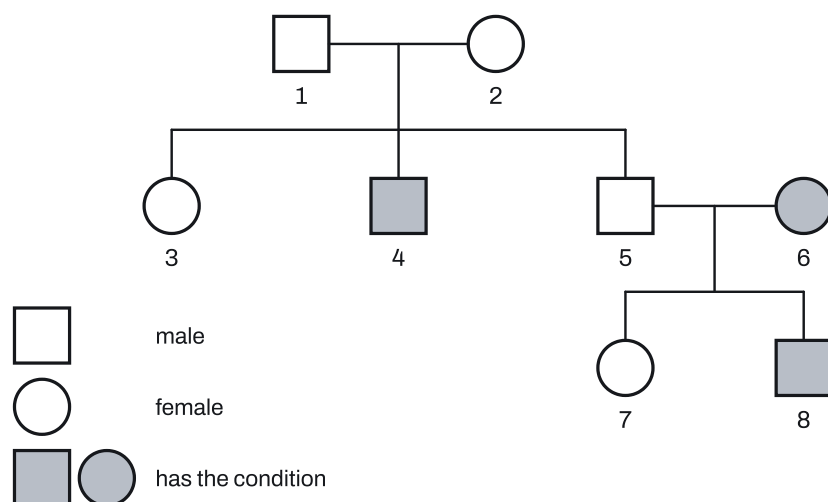
The crosses worth knowing

Only a handful of crosses exist for one gene with a dominant allele. Once you know them, most multiple-choice questions take seconds.

Parents	Offspring genotypes	Phenotypic ratio	Chance of recessive phenotype
$Gg \times Gg$	1 GG : 2 Gg : 1 gg	3 dominant : 1 recessive	25%
$Gg \times gg$	1 Gg : 1 gg	1 dominant : 1 recessive	50%
$GG \times gg$	all Gg	all dominant	0%
$GG \times Gg$	1 GG : 1 Gg	all dominant	0%
$GG \times GG$ or $gg \times gg$	all the same as the parents	pure-breeding	0% or 100%

Pedigree diagrams

A **pedigree diagram** is a family tree for one characteristic. **Squares are males, circles are females**, a horizontal line between a male and a female shows they are parents, and a vertical line leads down to their children. Shading shows who has the characteristic; always read the **key**, because the shading can mean either phenotype. Individuals are numbered so you can refer to them.



In this family, individuals 1 and 2 do **not** have the condition, but their son 4 **does**. The allele for the condition was hidden in both parents, so it must be **recessive**, and 1 and 2 must both be **heterozygous** (Ff): each passed an f to son 4, who is ff . The logic works the other way round too:

- **Two unaffected parents with an affected child** → the condition is **recessive**, and both parents are heterozygous.
- **Two affected parents with an unaffected child** → the condition is **dominant**, and both parents are heterozygous (see the last diagram in this note).
- **Anyone showing the recessive phenotype** is homozygous recessive.

- **Anyone with the dominant phenotype who has a parent or a child with the recessive phenotype** is heterozygous: they must have received, or passed on, a recessive allele. In the diagram, 5 is unaffected but his son 8 is ff , so 5 is Ff ; and 7 is unaffected but her mother 6 is ff , so 7 is Ff .
- If none of these rules settles it (individual 3 here), the answer is " FF or Ff ".

Test cross (Extended)

Extended only: an organism with the **dominant phenotype** could be homozygous or heterozygous. To find out, cross it with a **homozygous recessive** organism (which can only give recessive alleles) and look at the offspring:

- **All** offspring show the dominant phenotype → the unknown parent is **homozygous dominant** ($GG \times gg$ gives all Gg).
- **Any** offspring show the recessive phenotype (about **1 : 1** with large numbers) → the unknown parent is **heterozygous** ($Gg \times gg$ gives 1 Gg : 1 gg).

The recessive partner is used because it hides nothing: whatever allele the unknown parent gives shows in the offspring's phenotype.

Codominance (Extended)

Extended only: in **codominance** neither allele is dominant: in a heterozygote **both alleles contribute to the phenotype**. In some cattle, $C^R C^R$ is red, $C^W C^W$ is white, and $C^R C^W$ is **roan**, a coat with both red and white hairs. Codominant alleles are written as one capital letter with **different superscripts**, not as capital and lower case.

- Red $\times$ white ($C^R C^R \times C^W C^W$) → all roan ($C^R C^W$).
- Roan $\times$ roan ($C^R C^W \times C^R C^W$) → **1 red : 2 roan : 1 white**.
- Roan $\times$ white ($C^R C^W \times C^W C^W$) → **1 roan : 1 white**.

With codominance **every genotype has its own phenotype**, so you can read the genotype straight from the phenotype.

ABO blood groups (Extended)

Extended only: the ABO blood group gene has **three** alleles, though each person still has only **two**. I^A and I^B are **codominant** with each other, and both are **dominant** to I^o .

Genotype	Blood group (phenotype)
$I^A I^A$ or $I^A I^o$	A
$I^B I^B$ or $I^B I^o$	B
$I^A I^B$	AB (both alleles expressed: codominance)
$I^o I^o$	O

Blood group is a good example of a characteristic with a limited number of phenotypes and no in-betweens. Two people with groups A and B can have a child with **any** of the four groups, if both are heterozygous:

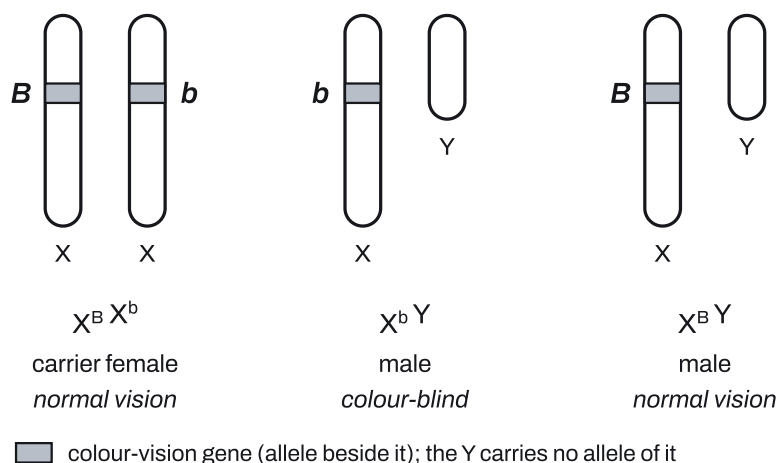
	I^B	I^o
I^A	$I^A I^B$ (AB)	$I^A I^o$ (A)
I^o	$I^B I^o$ (B)	$I^o I^o$ (O)

Each blood group has a probability of 25% here.

Sex linkage and colour blindness (Extended)

Extended only: sex is decided by the **sex chromosomes**: females are **XX** and males are **XY**. The **Y** chromosome is much smaller and carries **few genes**. A **sex-linked characteristic** is one whose gene is on a sex chromosome (in practice, the **X**). Because males have only **one X**, a male with one recessive allele shows the characteristic; a female needs **two**. So sex-linked recessive characteristics are **more common in males**.

Red-green colour blindness is the syllabus example. The gene is on the X chromosome; X^B carries the allele for normal colour vision (dominant) and X^b the allele for colour blindness (recessive). The Y chromosome carries **no allele** of this gene, so write it as a plain Y .



Genotype	Phenotype
$X^B X^B$	female, normal colour vision
$X^B X^b$	female, normal colour vision, carrier
$X^b X^b$	female, colour-blind
$X^B Y$	male, normal colour vision
$X^b Y$	male, colour-blind

Two facts explain nearly every sex-linkage question:

- A **son** gets his **X from his mother** and his **Y from his father**. So a son's colour vision depends only on his **mother**. A colour-blind mother ($X^b X^b$) has only X^b to give, so **all her sons are colour-blind**.
- A **daughter** gets **one X from each parent**, including her father's only X. So a colour-blind father passes X^b to **every** daughter (who are at least carriers), and passes nothing of this gene to his sons.

Key facts and formulas

There is no formula list in the IGCSE Biology exam, so everything below must be learnt. Rows marked "(Extended)" are for Papers 2 and 4 only.

Formula	Status
Genotype: the alleles an organism has; phenotype: its observable features	Learn it
Homozygous: two identical alleles; heterozygous: two different alleles	Learn it
Dominant: expressed if present; recessive: expressed only with no dominant allele	Learn it
Two identical homozygous parents are pure-breeding; a heterozygote is not	Learn it
$Aa \times Aa \rightarrow 3 \text{ dominant} : 1 \text{ recessive}$ (recessive probability $\frac{1}{4} = 25\%$)	Learn it
$Aa \times aa \rightarrow 1 \text{ dominant} : 1 \text{ recessive}$ (each 50%)	Learn it
$AA \times \text{anything} \rightarrow \text{all dominant phenotype}$	Learn it
Expected number = probability $\times$ total number of offspring	Learn it
Test cross: unknown dominant $\times$ homozygous recessive; all dominant $\rightarrow AA$; any recessive $\rightarrow Aa$ (Extended)	Learn it
Codominance: $C^R C^W \times C^R C^W \rightarrow 1 : 2 : 1$; $C^R C^W \times C^W C^W \rightarrow 1 : 1$ (Extended)	Learn it
ABO: I^A and I^B codominant, both dominant to I^o ; $AB = I^A I^B$, $O = I^o I^o$ (Extended)	Learn it
Female XX, male XY; colour blindness: X^B normal, X^b colour-blind, Y carries no allele (Extended)	Learn it

How to do it

We tagged 96 questions for this topic (2021–2025, Papers 1–4). 16 of them mix types, so the counts add up to 118.

Question type	Questions
Predicting offspring from a cross	33
Genetic terms	22
Reading pedigree diagrams	17
Codominance and ABO blood groups	17
Sex-linked inheritance	16
Working back from offspring to parents	9
Test crosses	4

1. Predicting offspring from a cross (33 questions)

1. **Write the parental genotypes** using the letters the question gives. If it says "heterozygous", write Gg ; "homozygous recessive", gg ; "pure-breeding" with the dominant phenotype, GG .
2. **Split each genotype into its gametes**, one allele per gamete: Gg gives G and g . Examiners often see Gg written in a gamete box; that loses the mark.
3. **Fill the Punnett square**, one parent's gametes on each side.
4. **Write the offspring genotypes**, then the **phenotype** under each one, in the **same order**.
5. **Give what the question asks**: a ratio (3 : 1, 1 : 1), a probability (0.25, 25% or 1 in 4 are all fine) or a number (probability $\times$ total).

For example, for $Tt \times tt$ with 180 seeds: the gametes are T, t and t, t ; the offspring are Tt, Tt, tt, tt , so 1 tall : 1 short, and the expected number of short plants is $180 \times \frac{1}{2} = 90$.

Variations you will meet:

- **Part-filled Punnett square** (Paper 3): the question fills in one parent's gametes; you add the other parent's gametes, the four offspring, and the ratio.
- **A full genetic diagram** (Paper 4): parental phenotypes, parental genotypes, gametes, offspring genotypes, offspring phenotypes, then the probability. Each line is usually a mark, and a wrong line early on is carried forward, so finish every line.
- **"Choose your own letters"**: pick one letter, capital for the dominant allele and the same letter in lower case for the recessive (for example R and r). Avoid letters whose capital and lower case look alike, such as C/c or S/s .
- **Human conditions**: cystic fibrosis and albinism are caused by recessive alleles; Huntington's disease by a dominant allele; the Rhesus factor uses D and d . The method is the same; just check which allele is dominant. These are **not** sex-linked, so don't use X and Y.

- **"Probability of a heterozygous child"** (for example when the question says heterozygotes have some advantage): count the heterozygous boxes, not a phenotype. $Aa \times Aa$ gives $\frac{2}{4} = 50\%$; $AA \times Aa$ gives 50%.
- **"The first child" or "the next child"**: each child is a new, independent chance. Earlier children don't change it.
- **Observed against expected**: if 131 purple and 127 white plants appear, that is close to 1 : 1, so the cross was $Aa \times aa$. Real numbers are never exact because fertilisation is random.

2. Genetic terms (22 questions)

1. **Learn each definition as two parts**, because a two-mark definition wants both: an allele is "an **alternative form** (version) + **of a gene**".
2. **Match genotype to term**: two capitals → homozygous dominant; two lower case → homozygous recessive; one of each → heterozygous.
3. **In multiple choice**, reject options that swap the words: an allele is not "a form of a chromosome", and a heterozygote has "two different alleles of the same gene", not "two genes".

Variations you will meet:

- **Tick table** for genotypes such as ee and Ee : tick exactly one box per genotype (ee homozygous recessive, Ee heterozygous). An extra tick loses the mark.
- **"What are alleles made of?"**: DNA.
- **Name the term from its meaning**: observable features → **phenotype**; the alleles present → **genotype**; passing genetic information from generation to generation → **inheritance**; offspring always the same as the parents → **pure-breeding**.
- **"State all the possible genotypes of a plant with the dominant phenotype"**: both, YY and Yy .
- **"Is a heterozygote pure-breeding?"**: no; it makes two kinds of gamete, so it can have offspring with the recessive phenotype.
- **"How could researchers be sure plants were homozygous?"**: breed them together (or self them) over several generations; if they are homozygous, all the offspring have the same phenotype as the parents.

3. Reading pedigree diagrams (17 questions)

1. **Read the key first**: which symbols are male and female, and what the shading means.
2. **Find the telling family**: two parents with the **same** phenotype and a child with a **different** one. The child's phenotype is **recessive**, and both parents are **heterozygous**.
3. **Fill in the certain genotypes**: every recessive-phenotype individual is homozygous recessive.
4. **Then the heterozygotes**: any dominant-phenotype individual with a recessive-phenotype parent or child.
5. **Explain with the individuals' numbers**, for example "individual 2 is green but has yellow offspring, 4 and 6, so it must carry g : Gg ".

Variations you will meet:

- **Counting:** "how many males", "how many have the condition", "how many have only one I^o allele". Count carefully from the key; examiners saw many answers that miscounted the symbols.
- **"Which individuals must be heterozygous?":** use step 4. For a sex-linked recessive condition, only **females** can be heterozygous (carriers); males have one X.
- **"Is the condition dominant or recessive?":** find the telling family and name the individuals. If two affected parents have an unaffected child, the allele for the condition is dominant; if it were recessive, two affected (aa) parents could only have affected children.
- **"Could the condition be sex-linked?"** (Extended): a sex-linked recessive condition is passed from carrier mothers to sons, and an affected female must have an affected father. An affected daughter of an unaffected father rules sex linkage out.

4. Codominance and ABO blood groups (17 questions)

Extended only.

1. **Spot codominance:** the heterozygote shows **both** phenotypes (roan, speckled, red and white hairs, blood group AB), or a cross of two pure-breeding types gives a **new** phenotype in every offspring.
2. **Write genotypes with superscripts:** $C^R C^W$, $I^A I^o$. Never use the X and Y chromosomes here.
3. **Cross as usual** with a Punnett square, then name each box's phenotype from the table.
4. **Give the ratio or probability**, for example 1 red : 2 roan : 1 white, or 25% blood group O.

Variations you will meet:

- **"Explain why the AB blood group shows codominance":** in the heterozygote $I^A I^B$, **both alleles are expressed** in the phenotype. Say **alleles** (not genes) and **phenotype**; examiners saw many answers lose the mark by talking about genes or genotypes.
- **Parents' genotypes from the children's blood groups:** a child with group O is $I^o I^o$, so **each parent carries I^o** . Parents with groups A and B who have a group O child must be $I^A I^o$ and $I^B I^o$.
- **"Which parents could have a child with group O?":** both must carry I^o . An AB parent ($I^A I^B$) can **never** have a group O child.
- **"Chance the child has the same blood group as a parent":** fill the square, then add the boxes that match either parent. For $I^A I^B \times I^o I^o$ the children are A or B (50% each), never AB or O, so the answer is 0%.
- **Codominant crosses in animals and plants:** speckled chickens, roan horses and cattle. Speckled $\times$ white gives 1 speckled : 1 white.
- **"State an example of codominance in humans":** the ABO blood groups (group AB).

5. Sex-linked inheritance (16 questions)

Extended only.

1. **Write every genotype with X and Y:** females $X^B X^B$, $X^B X^b$ or $X^b X^b$; males $X^B Y$ or $X^b Y$. The allele goes on the X only.

- Gametes:** a female gives X^B and/or X^b ; a male gives one X (with its allele) and Y.
- Punnett square**, then name each offspring's **sex and phenotype**.
- Read the question's wording carefully:** "the chance a child is colour-blind" (out of all four boxes) is different from "the chance a **son** is colour-blind" (out of the two male boxes), and from "the chance the child is a colour-blind son".

For a carrier mother and a father with normal vision ($X^B X^b \times X^B Y$):

	X^B	Y
X^B	$X^B X^B$ (normal female)	$X^B Y$ (normal male)
X^b	$X^B X^b$ (carrier female)	$X^b Y$ (colour-blind male)

Chance a child is colour-blind: 1 in 4, 25%. Chance a son is colour-blind: 1 in 2, 50%. Chance a daughter is colour-blind: 0%, but 50% of daughters are carriers.

Variations you will meet:

- "Explain why all the sons of a colour-blind mother are colour-blind":** she is $X^b X^b$, so every egg carries X^b ; sons get their X from their mother (their Y comes from the father), and the Y carries no allele to mask it, so every son is $X^b Y$.
- "Why is colour blindness more common in males?":** males have only one X chromosome, so one recessive allele is enough; females need two, one from each parent.
- "Which statement describes colour blindness?":** the recessive allele is on the X chromosome. Not on the Y, not codominant, and it can occur in females (if their father is colour-blind and their mother carries the allele).
- Genotype of a colour-blind male:** $X^b Y$. Not $X^B Y$, and never $X^b X^b$.
- Haemophilia and fruit-fly eye colour:** the same method with different letters.
- A colour-blind father and a carrier mother ($X^b Y \times X^B X^b$):** daughters $X^B X^b$ or $X^b X^b$, so 50% of daughters are colour-blind; sons $X^B Y$ or $X^b Y$, 50%.

6. Working back from offspring to parents (9 questions)

- Turn the counts into a ratio** by dividing the larger number by the smaller: $152 : 49$ gives $152 \div 49 = 3.1$, about **3 : 1**; $118 : 112$ gives $118 \div 112 = 1.05$, about **1 : 1**.
- Match the ratio** to the table of crosses: about 3 : 1 → **both parents heterozygous**; about 1 : 1 → **heterozygous × homozygous recessive**; all one phenotype → at least one parent homozygous dominant.
- Decide dominance if you aren't told:** the phenotype that is the **3** in a 3 : 1 is dominant; a phenotype that disappears in one generation and reappears in the next is recessive; if two pure-breeding types give offspring that all look like one of them, that one is dominant.

Variations you will meet:

- **Two parents with the dominant phenotype have some offspring with the recessive phenotype:** both parents must be heterozygous.
- **A parent with the dominant phenotype and one with the recessive phenotype have some recessive offspring:** the dominant parent is heterozygous (examiners noted many missed this).
- **"State the ratio from a bar chart or table"** (Paper 3): read both numbers, then simplify, for example 60 : 20 = 3 : 1.
- **Orange-eyed flies always breed true, red-eyed ones sometimes give orange:** orange is the recessive phenotype.

7. Test crosses (4 questions)

Extended only.

1. **Cross the unknown** (dominant phenotype) with a **homozygous recessive**.
2. **All offspring dominant** → the unknown is homozygous dominant; **some recessive** offspring (about half) → heterozygous.
3. **Say why a large number of offspring** helps: with only a few offspring, a heterozygote might produce only dominant ones by chance.

Variations you will meet:

- **"Which Punnett square shows a test cross that identifies a heterozygous parent?":** the one for $Tt \times tt$, with offspring Tt, Tt, tt, tt . Not $Tt \times Tt$ (that is not a test cross) and not $TT \times tt$.
- **"Which rows are possible?":** "all dominant" goes with homozygous dominant; "dominant and recessive" goes with heterozygous. "All dominant" with heterozygous, or "all recessive" with homozygous dominant, cannot happen with many offspring.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **B1** mark for a correct result on its own, with no method needed.

Example 1

In tomato plants the allele for a tall stem, T , is dominant to the allele for a dwarf stem, t . Two heterozygous tall plants are crossed.

- (a) State what is meant by the term *heterozygous*. [1]

(b) Complete a genetic diagram to show the possible genotypes of the offspring and the expected phenotypic ratio. **[4]**

(c) The cross produced 240 seeds. Calculate the number of dwarf plants expected. **[1]**

(d) State whether the tall offspring will be pure-breeding. Explain your answer. **[2]**

(a) Having two different alleles of a particular gene **B1**.

(b) Parental genotypes $Tt \times Tt$. Gametes T and t from each parent **B1**.

	T	t
T	TT	Tt
t	Tt	tt

Offspring genotypes TT, Tt, Tt, tt **B1**; phenotypes tall, tall, tall, dwarf **B1**. Ratio **3 tall : 1 dwarf B1**.

(c) $240 \times \frac{1}{4} = 60$ dwarf plants **B1**.

(d) Not all of them **B1**: two in every three tall offspring are Tt , heterozygous, so they can give dwarf offspring; only the TT plants are pure-breeding **B1**.

Example 2

The first diagram in "Understand it" shows the inheritance of a condition in a family. The alleles are F and f .

(a) Explain how the diagram shows that the condition is caused by a recessive allele. **[2]**

(b) State the genotypes of individuals 1, 4 and 5, and explain how you know the genotype of individual 5. **[4]**

(c) Individuals 5 and 6 have another child. Complete a genetic diagram to find the probability that this child will have the condition. **[4]**

(a) Individuals 1 and 2 do not have the condition, but their son 4 does **B1**. The allele was present in the parents but not expressed, so it is recessive (1 and 2 are both heterozygous) **B1**.

(b) 1 is Ff **B1**; 4 is ff **B1**; 5 is Ff **B1**. 5 does not have the condition, so he has at least one F ; his son 8 has the condition (ff) and must have received an f from him **B1**.

(c)

	Individual 5		Individual 6
parental phenotypes	no condition	×	has the condition
parental genotypes	Ff	×	ff
gametes	F and f	×	f and f

B1 for the gametes.

	F	f
f	Ff	ff
f	Ff	ff

Offspring genotypes Ff , Ff , ff , ff **B1**; phenotypes no condition, no condition, condition, condition **B1**.
Probability $\frac{2}{4} = 0.5$ (50%) **B1**.

Example 3

Extended only. A woman with blood group A, who is heterozygous, has children with a man with blood group AB.

- (a) State the genotypes of the woman and the man. **[2]**
- (b) Complete a genetic diagram to show the possible blood groups of their children, and give the probability that a child has blood group B. **[4]**
- (c) Explain why none of their children can have blood group O. **[2]**
- (d) Explain why blood group AB is an example of codominance. **[2]**

(a) Woman $I^A I^o$ **B1**; man $I^A I^B$ **B1**.

(b) Gametes I^A and I^o (woman); I^A and I^B (man) **B1**.

	I^A	I^B
I^A	$I^A I^A$ (A)	$I^A I^B$ (AB)
I^o	$I^A I^o$ (A)	$I^B I^o$ (B)

Offspring genotypes **B1**; blood groups A, AB, A, B, so **2 A : 1 AB : 1 B B1**. Probability of group B = $\frac{1}{4} = 25\%$ **B1**.

- (c)** Group O needs the genotype $I^o I^o$, one I^o from each parent **B1**. The man ($I^A I^B$) has no I^o allele to pass on **B1**.
- (d)** In the heterozygote $I^A I^B$ **B1**, both alleles are expressed (both contribute to the phenotype) **B1**.

Example 4

Extended only. Red-green colour blindness is caused by a recessive allele, b , on the X chromosome. A woman with normal colour vision, whose father was colour-blind, has children with a man with normal colour vision.

- (a) Explain why the woman must be a carrier. **[2]**
- (b) Complete a genetic diagram to find the probability that their first child is a colour-blind boy, and the probability that a son is colour-blind. **[5]**

(c) Explain why red-green colour blindness is more common in males than in females. **[2]**

(a) Her father was X^bY and gave her his only X, carrying X^b **B1**. She has normal vision, so her other X carries X^B : she is $X^B X^b$ **B1**.

(b) Parental genotypes $X^B X^b \times X^B Y$ **B1**. Gametes X^B , X^b and X^B , Y **B1**.

	X^B	Y
X^B	$X^B X^B$	$X^B Y$
X^b	$X^B X^b$	$X^b Y$

Offspring: normal female, normal male, carrier female (normal vision), colour-blind male **B1**. Probability of a colour-blind boy = $\frac{1}{4} = 25\%$ **B1**. Of the two sons ($X^B Y$, $X^b Y$), one is colour-blind: **50% B1**.

(c) The gene is on the X chromosome and the Y has no allele of it; males have only one X, so a single recessive allele is expressed **B1**. Females need two recessive alleles, one on each X, which is less likely **B1**.

Common mistakes

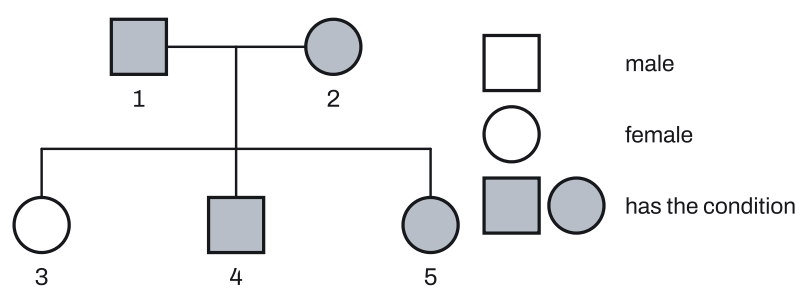
- **Putting the whole genotype in a gamete.** Each gamete carries **one** allele: write G and g , not Gg . Examiners see this, and parental genotypes copied into the gamete boxes, every year.
- **Changing or mixing the letters.** Use the letters the question gives, in the same case all through. Switching halfway (or using R and h for one gene) loses marks.
- **Writing phenotypes as genotypes**, or the other way round. A phenotype is a feature in words ("no cystic fibrosis"), not "heterozygous" or "carrier" or Ff .
- **Phenotypes in a different order from the genotypes.** Write them underneath, one for one.
- **Treating an ordinary condition as sex-linked.** Only use X and Y when the question says the gene is on a sex chromosome. Cystic fibrosis and albinism are not sex-linked.
- **Putting a colour-blindness allele on the Y chromosome**, or leaving X and Y out of a sex-linked cross. The allele goes on the X; write the Y bare.
- **Answering for the wrong group.** "The chance a son is colour-blind" is out of the sons only; "the chance a child is a colour-blind son" is out of all children. Read which one is asked.
- **Crossing two heterozygotes by habit.** Check each parent's genotype from the question; examiners report many answers that used $Aa \times Aa$ when one parent was aa .
- **Confusing allele with gene, antigen or antibody.** An allele is an alternative form of a gene. Say "alleles" when explaining codominance or dominance, not "genes" or "traits".
- **Not knowing "pure-breeding".** It means homozygous parents that always give offspring like themselves. It is not "natural" or "selective".
- **Misreading a pedigree.** Check the key; count symbols one by one; explain using the individuals' numbers rather than repeating the question.

How to get the marks

- **"Describe what is meant by allele"** (2 marks): "alternative form" **and** "of a gene". Saying an allele can be dominant or recessive is not a definition.
- **Genetic diagrams**: one mark per line is typical: parental phenotypes, parental genotypes, gametes (each allele on its own, often in a circle), offspring genotypes, offspring phenotypes (in the same order), ratio or probability. Errors are carried forward, so fill in every line even if unsure.
- **Probabilities**: 0.25, 25%, $\frac{1}{4}$ and "1 in 4" all score. A ratio such as 1 : 3 is sometimes accepted, but a probability is the safer answer when a probability is asked for.
- **Ratios**: give them in the order the question asks (for example "green : yellow") and in lowest terms, 3 : 1 not 6 : 2 (though 2 : 2 for 1 : 1 is often accepted).
- **Pedigree explanations**: one mark for the genotype and one for a reason that names individuals: "individual 2 is green but has yellow offspring (4 and 6), so it must be Gg ".
- **"Explain codominance"**: "both alleles are expressed in the phenotype of the heterozygote". Name the heterozygote ($I^A I^B$).
- **"Explain why all the sons..."** (sex linkage): X from the mother, Y from the father; Y carries no allele; so the son's phenotype comes from his mother's X.
- **"State"** needs only the fact (a genotype, a ratio, a term); **"explain"** needs a reason with "because".
- **Multiple choice**: draw a quick Punnett square in the margin. It takes seconds and avoids guessing.

Quick check

1. In a plant, the allele for red flowers, R , is dominant to the allele for white flowers, r . State (a) whether the genotype Rr is homozygous or heterozygous, and (b) the phenotype of a plant with this genotype.
2. A plant with genotype Rr is crossed with a plant with genotype rr . They produce 180 seeds. State the expected phenotypic ratio and calculate the expected number of white-flowered plants.
3. **Extended only.** In guinea pigs, black fur (B) is dominant to white fur (b). A black guinea pig of unknown genotype is crossed with a white guinea pig, giving 7 black and 6 white young. State the name of this type of cross and the genotype of the black parent, and explain your answer.
4. **Extended only.** In some cattle, red ($C^R C^R$) and white ($C^W C^W$) coat colours are codominant, and $C^R C^W$ cattle are roan. Two roan cattle are crossed. Give the expected phenotypic ratio and the percentage of the calves expected to be roan.
5. **Extended only.** A colour-blind woman has children with a man with normal colour vision. State the probability that (a) a son is colour-blind and (b) a daughter is colour-blind.
6. The diagram below shows a family with a condition caused by an allele H or h . Shaded symbols have the condition. Use individuals 1, 2 and 3 to decide whether the allele for the condition is dominant or recessive, and give the genotypes of 1 and 3.



Answers

1. (a) Heterozygous (two different alleles). (b) Red flowers, because R is dominant and is expressed when present.
2. Gametes R, r and r, r ; offspring Rr, Rr, rr, rr . Ratio **1 red : 1 white**. Expected white = $180 \times \frac{1}{2} = 90$.
3. A **test cross**. The black parent is Bb (heterozygous): white young are bb , so each received a b from the black parent. ($BB \times bb$ would give only black young.) 7 : 6 is close to the 1 : 1 expected from $Bb \times bb$.
4. $C^R C^W \times C^R C^W$ gives $C^R C^R, C^R C^W, C^R C^W, C^W C^W$: **1 red : 2 roan : 1 white**. Roan: $\frac{2}{4} = 50\%$.
5. The woman is $X^b X^b$ and the man $X^B Y$. (a) Every son is $X^b Y$: **100%**. (b) Every daughter is $X^B X^b$ (a carrier with normal vision): **0%**.
6. Parents 1 and 2 both have the condition, but their daughter 3 does not, so the allele for the condition is **dominant**: if it were recessive, two hh parents could only have hh children. Individual 3 is hh (she shows the recessive phenotype), so each parent gave her an h : individual 1 is Hh .

Past questions to try

- **0610/41/O/N/21 Q2**: choosing letters for a cross and comparing 71 : 26 with the expected ratio, in (a) and (b).
- **0610/42/O/N/24 Q5**: blood groups on a pedigree diagram, codominance and an ABO cross.
- **0610/41/O/N/24 Q5**: colour blindness in a family: why all the sons are colour-blind, and a sex-linked genetic diagram.
- **0610/22/F/M/22 Q33**: what a test cross can show about a tall pea plant.