

Exercise walk-through

17.4.1

Pedigrees, test crosses, blood groups and sex linkage

IGCSE Biology

You must be able to

- describe **inheritance** 遗传 as the passing of genetic information from generation to generation
- use **genotype** 基因型, **phenotype** 表现型, **homozygous** 纯合子, **heterozygous** 杂合子, **dominant** 显性 and **recessive** 隐性 correctly, and state which of them breeds true
- interpret pedigree diagrams for the inheritance of a given characteristic
- use genetic diagrams and **Punnett squares** 庞纳特方格 to predict the results of monohybrid crosses, and calculate 1:1 and 3:1 **ratios** 比例
- explain how to use a test cross to identify an unknown genotype
- describe codominance, and explain the inheritance of the ABO blood groups with the alleles I^A , I^B and I^o

You must be able to

- describe a sex-linked characteristic, and red-green **colour blindness** 色盲 as the example
- use genetic diagrams for crosses involving codominance or sex linkage

1

The method

Method — The six words, and the two that decide everything

word	what it means	how it is written
genotype	the alleles 等位基因 an organism has	BB, Bb or bb
phenotype	the feature you can see	black fur, blue eyes
homozygous	two identical alleles; this organism is pure-breeding 纯种	BB or bb
heterozygous	two different alleles; not pure-breeding	Bb
dominant	shows even with one copy	capital letter, B
recessive	shows only with two copies	small letter, b

Method — The six words, and the two that decide everything

- A **recessive phenotype pins the genotype exactly**: a white rabbit can only be bb . Always start a question from the recessive individual and work outwards. This one habit answers most of the marks on this subtopic.
- Choose one letter for the gene and say what it stands for before you use it: “ $B = \text{black fur}$, $b = \text{white fur}$ ”. An answer using two different letters for the same gene loses the diagram mark.

Method — The layout a genetic diagram must have

Five steps, and every one of them is a marking point:

- 1 write both **parent genotypes**;
 - 2 write the **gametes** 配子 – each gamete carries **one** allele of the gene;
 - 3 fill the **grid**;
 - 4 read off the offspring **genotypes**;
 - 5 turn them into a **phenotype ratio**.
- Only two ratios are examined: $Bb \times Bb$ gives **3:1**, and $Bb \times bb$ gives **1:1**.
 - A ratio is a prediction about *large numbers*. The **probability** 概率 for one individual offspring is the same every time, so three black rabbits in a row do not make the fourth one white.

Method — The layout a genetic diagram must have

Five steps, and every one of them is a marking point

- 1 parent genotypes
- 2 gametes, one allele each
- 3 fill the grid
- 4 read the genotypes
- 5 give the ratio

parents: $Bb \times bb$

gametes: B or b and b or b

	B	b
b	Bb	bb
b	Bb	bb

2 Bb and 2 bb, so **1 black : 1 white**, a **1:1** ratio

$Bb \times Bb$ gives **3:1**. $Bb \times bb$ gives **1:1**. Those are the only two ratios this syllabus asks for, so if you get a third one, check the gametes.

Method — Reading a pedigree

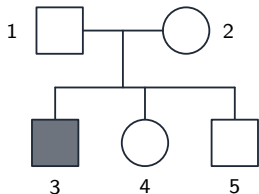
Squares are males, circles are females, and a shaded symbol means the person has the condition.

Worked example. Use the diagram above to show that the allele is recessive, and give the genotypes of individuals 1 and 2.

- 1 Find a **person who has the condition but whose parents do not**. Here that is individual 3.
 - 2 If the allele were dominant, one parent would have to show it – neither does. So the allele is **recessive**, and it was carried, hidden, by both parents.
 - 3 Individual 3 shows the recessive feature, so the genotype is **aa**, with one a from each parent.
 - 4 Both parents show the normal feature, so each also carries an A. Individuals 1 and 2 are both **Aa**.
- Then the probability follows: $Aa \times Aa$ gives a $\frac{1}{4}$ chance for each later child.

Method — Reading a pedigree

Use the diagram above to show that the allele is recessive, and give the genotypes of individuals 1 and 2



Rule 1 Two *unaffected* parents with an *affected* child means the allele is **recessive**, and both parents are **heterozygous** carriers.

Rule 2 If every affected person is *male*, suspect **sex linkage**: the gene is on the X chromosome.

□ male ○ female ■ has the condition

Method — A test cross finds a hidden heterozygote

An organism showing the **dominant** feature may be BB or Bb, and you cannot tell by looking. Cross it with a **homozygous recessive** (bb) and read the offspring:

what the offspring show	what the unknown parent was
any offspring with the recessive feature	heterozygous , Bb – because that offspring needed a b from each parent
all offspring show the dominant feature	very probably homozygous , BB

- The recessive parent is chosen because it can only give a b, so every offspring reveals what the other parent gave.

Method — Codominance: the ABO blood groups

In **codominance**, **both** alleles of a heterozygote show in the phenotype – neither one masks the other.

- I^A and I^B are **codominant with each other**; I^o is **recessive** to both.
- So $I^A I^B$ gives group **AB**, in which both features appear. That is the only place codominance is visible.
- Write blood-group alleles with the superscript every time. A bare “A” or “B” is not a genotype.

Method — Codominance: the ABO blood groups

In codominance , both alleles of a heterozygote show in the phenotype – neither one masks the other

genotype	blood group
$I^A I^A$ or $I^A I^o$	A
$I^B I^B$ or $I^B I^o$	B
$I^A I^B$	AB
$I^o I^o$	O

← **codominance:** both alleles show, so the phenotype is AB and not A or B

I^A and I^B are **codominant** with each other; I^o is **recessive** to both. Those two sentences generate every row above.

Method — Sex linkage

A **sex-linked** characteristic is controlled by a gene on a **sex chromosome** 性染色体, in practice always the X.

- Write the chromosome with the allele on it: X^B , X^b , and a plain Y, which carries no allele of this gene.
- A male is $X^?Y$. He has only **one** X, so a single recessive allele on it **always shows**.
- A female is $X^?X^?$. She needs **two** copies to show the feature, and with only one she is a **carrier** 攜帶者 with normal vision.
- That is the whole reason red-green colour blindness is far more common in males.

Method — Sex linkage

A sex-linked characteristic is controlled by a gene on a sex chromosome 性染色体, in practice always the X

mother $X^B X^b$ (a carrier) × father $X^B Y$

	X^B	X^b
X^B	$X^B X^B$ girl, normal	$X^B X^b$ girl, carrier
Y	$X^B Y$ boy, normal	$X^b Y$ boy, colour-blind

A boy has **one** X, so a single recessive allele on it always shows. A girl needs **two**, which is far rarer – hence “more common in one sex”.

Here half the sons are colour-blind and none of the daughters are, although half the daughters are carriers. Always write the chromosomes, never bare letters.

2

Practice

Practice 2.1 ■ 2 marks

A pea plant is homozygous for tall stems (T). State its genotype, and explain why it is pure-breeding.

Solution 2.1

Method: The six words, and the two that decide everything — p.5

Worked steps

- genotype **TT** **B1**
- both alleles are the same, so every gamete carries T and all the offspring of a cross with another TT plant are TT – the feature never changes between generations **B1**

Practice 2.2 ■ 4 marks

In cats, short hair (S) is dominant to long hair (s). A heterozygous short-haired cat is crossed with a long-haired cat. Draw a genetic diagram for this cross and give the ratio of the offspring phenotypes.

Solution 2.2

Method: The layout a genetic diagram must have — p.7

Worked steps

- state the parents: heterozygous short-haired is **Ss**, long-haired is **ss** (B1)
- gametes: S or s from the first parent, s or s from the second (B1)
- the grid gives **Ss, ss, Ss, ss** (B1)
- so **1 short-haired : 1 long-haired**, a **1:1** ratio (B1)

Practice 2.3 ■ 3 marks

A short-haired cat may be SS or Ss . Describe a test cross that would show which it is, and state how you would read the result.

Solution 2.3

Method: A test cross finds a hidden heterozygote — p.11

Worked steps

- cross the unknown cat with a **long-haired (ss)** cat (B1)
- if **any** kitten has long hair, that kitten is ss, so it received an s from the unknown parent, which must therefore be **Ss** (B1)
- if every kitten has short hair, the unknown parent is very probably **SS** (B1)

Practice 2.4 ■ 3 marks

A man has blood group AB. State his genotype, and explain what codominance means in this case.

Solution 2.4

Method: Codominance: the ABO blood groups — p.12

Worked steps

- genotype $I^A I^B$ **B1**
- codominance means **both** alleles are expressed in the phenotype **B1**
- neither allele masks the other, so this man's blood has **both** the A and the B features, rather than only one of them **B1**

Practice 2.5 ■ 2 marks

State the genotype of a person with blood group O, and the two possible genotypes of a person with blood group A.

Solution 2.5

Method: Codominance: the ABO blood groups — p.12

Worked steps

- group O: $I^O I^O$ (B1)
- group A: $I^A I^A$ or $I^A I^O$ (B1)

Practice 2.6 ■ 3 marks

Explain why red-green colour blindness is more common in boys than in girls.

Solution 2.6

Method: Sex linkage — p.14

Worked steps

- the gene is on the **X chromosome**, and the allele for colour blindness is **recessive**
B1
- a boy is $X^?Y$, with only **one** X, so a single copy of the recessive allele always shows
B1
- a girl is $X^?X^?$ and needs **two** copies; with one copy she is a carrier with normal vision, and two copies are far less likely
B1

3

Exam-style

Exam-style 3.1 ■ 1 mark

A woman of blood group A and a man of blood group B have a child of blood group O. Which row gives the genotypes of the parents?

A $I^A I^A$ and $I^B I^B$

B $I^A I^O$ and $I^B I^O$

C $I^A I^B$ and $I^O I^O$

D $I^A I^O$ and $I^B I^B$

Solution 3.1

A $I^A I^A$ and $I^B I^B$

B $I^A I^O$ and $I^B I^O$ 

C $I^A I^B$ and $I^O I^O$

D $I^A I^O$ and $I^B I^B$

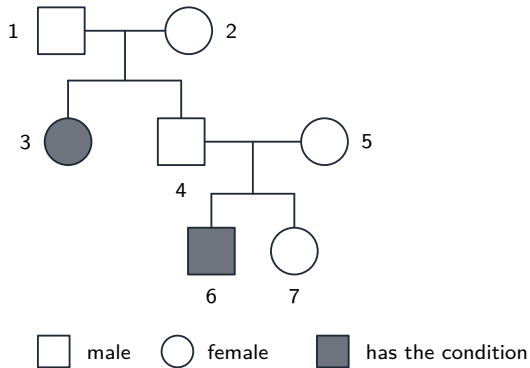
Worked steps

B

- the child is group O, so its genotype is $I^O I^O$ and it received an I^O from **each** parent **B1**
- so each parent carries an I^O as well as the allele for their own group: $I^A I^O$ and $I^B I^O$

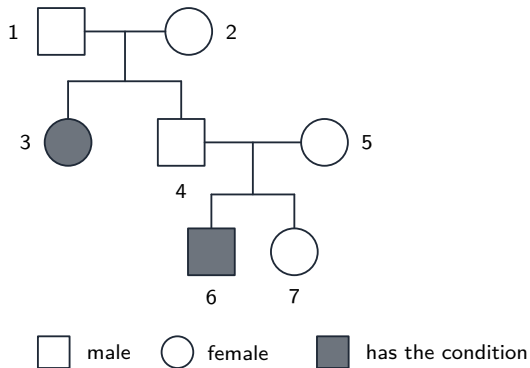
Exam-style 3.2 ■ 7 marks

The pedigree diagram shows how an inherited condition passes through one family.



Exam-style 3.2 (a) ■ 2 marks

State whether the allele for the condition is dominant or recessive, and give the evidence from the diagram.



Solution 3.2 (a)

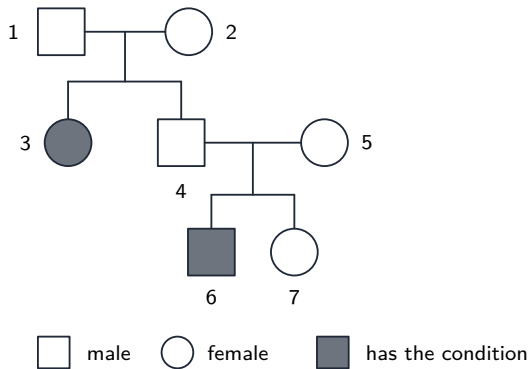
Method: Reading a pedigree — p.9

Worked steps

- the allele is **recessive** (B1)
- individuals 1 and 2 do not have the condition, but their daughter 3 does, so the allele must have been carried without showing (B1)

Exam-style 3.2 (b) ■ 2 marks

Explain how the diagram shows that the gene is **not** on the X chromosome.



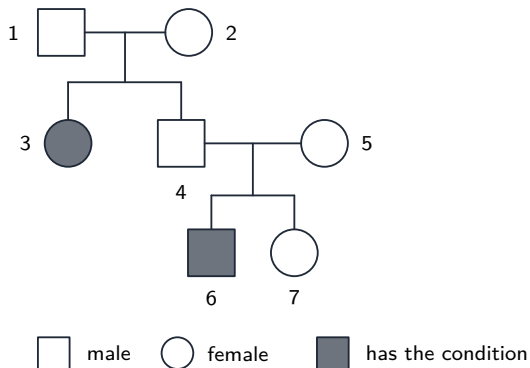
Solution 3.2 (b)

Worked steps

- individual 3 is an **affected female**, so she has the recessive allele on **both** of her X chromosomes, one of them from her father, individual 1 **B1**
- individual 1 has only one X, so he would then have the condition himself – and he does not, so the gene cannot be on the X chromosome **B1**

Exam-style 3.2 (c) ■ 2 marks

Using the symbols A and a, give the genotypes of individuals 4 and 5, and explain how you worked them out.



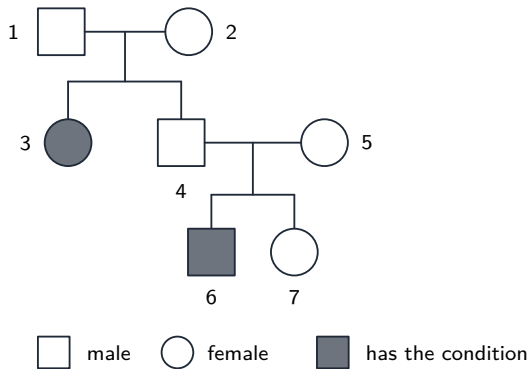
Solution 3.2 (c)

Worked steps

- individual 6 has the condition, so he is **aa**, with one a from each parent **B1**
- individuals 4 and 5 do not have the condition, so each also carries an A: both are **Aa** **B1**

Exam-style 3.2 (d) ■ 1 mark

Calculate the probability that the next child of individuals 4 and 5 has the condition.



Solution 3.2 (d)

Worked steps

- $Aa \times Aa$ gives AA , Aa , Aa , aa , so the probability is $\frac{1}{4}$, or **25%** B1

Exam-style 3.3 ■ 12 marks

A woman with normal colour vision has a father who is red-green colour-blind. She marries a man who is red-green colour-blind.

Exam-style 3.3 (a) ■ 2 marks

Explain why the woman must be a carrier of the colour-blindness allele.

Solution 3.3 (a)

Method: The layout a genetic diagram must have — p.7

Worked steps

- her father is colour-blind, so his genotype is X^bY , and his only X carries X^b
B1
- every daughter receives that X, so she has X^b ; she has normal vision, so her other X must carry X^B , making her $X^B X^b$ – a carrier B1

Exam-style 3.3 (b) ■ 4 marks

Draw a genetic diagram for this couple. Show the parents' genotypes, their gametes, and all the possible children with their phenotypes.

Solution 3.3 (b)

Worked steps

- parents: mother $X^B X^b$, father $X^b Y$ (B1)
- gametes: X^B or X^b from the mother, X^b or Y from the father (B1)
- the grid gives $X^B X^b$, $X^b X^b$, $X^B Y$ and $X^b Y$ (B1)
- phenotypes: a **carrier daughter** with normal vision, a **colour-blind daughter**, a **son with normal vision** and a **colour-blind son** (B1)

Exam-style 3.3 (c) ■ 2 marks

State the probability that a daughter of this couple is colour-blind, and the probability that a son is colour-blind.

Solution 3.3 (c)

Worked steps

- a daughter: $\frac{1}{2}$, or **50%** **B1**
- a son: $\frac{1}{2}$, or **50%** **B1**

Exam-style 3.3 (d) ■ 2 marks

The couple have three children, none of them colour-blind. State the probability that a fourth child is colour-blind, and explain your answer.

Solution 3.3 (d)

Worked steps

- **50%**, the same as for every other child **B1**
- each fertilisation is independent of the ones before it, so the three earlier children do not change the chance **B1**

Exam-style 3.3 (e) ■ 2 marks

The couple have a daughter with normal colour vision. State her genotype and explain how you know it exactly.

Solution 3.3 (e)

Worked steps

- $X^B X^b$, a carrier (B1)
- her father is $X^b Y$, so his only X gave her X^b ; she has normal vision, so her mother's X must have carried X^B – no other genotype is possible (B1)