17 INHERITANCE

YOUR NOTES

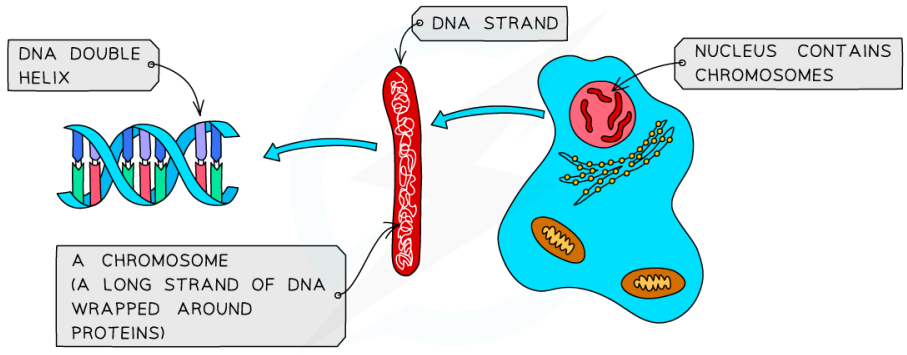
CONTENTS:

VIEW EXAM QUESTIONS

17.1 DEFINITIONS

Defining Inheritance & Related Terms

- **Inheritance** is the **transmission of genetic information from generation to generation**
- **Chromosomes** are located in the **nucleus** of cells
- They are **thread-like structures of DNA, carrying genetic information in the form of genes**
- A **gene** is a short length of **DNA** found on a chromosome that **codes for a specific protein**
- This could be a structural protein such as collagen found in skin cells, an enzyme or a hormone
- Genes control our characteristics as they code for proteins that play important roles in what our cells do



Genes are short lengths of DNA that code for a protein. They are found on chromosomes

- Alleles are **different versions of a particular gene**. The ABO gene for blood group type has three alleles, IA, IB and IO

17 INHERITANCE

17.1 DEFINITIONS cont...

YOUR NOTES

EXTENDED ONLY

Diploid & Haploid Nuclei

- All humans have **23 different chromosomes** in each cell
- In most body cells, not including the gametes (sex cells), we have 2 copies of each chromosome, leading to a total of **46 chromosomes**
- Nuclei with two sets of chromosomes are known as **diploid nuclei**
- The **gametes** (egg and sperm cells) only have one copy of each chromosome, meaning they have a **total of 23 chromosomes** in each cell
- Nuclei with one set of unpaired chromosomes are known as **haploid nuclei**

EXAM TIP

An easy way to remember the difference between haploid and diploid is to remember:

Haploid = Half the normal number of chromosomes.

It's worth noting that the human diploid chromosome number is 46. In an exam, you may be given information about a different species, with a different number of chromosomes. Make sure you read exam questions carefully.

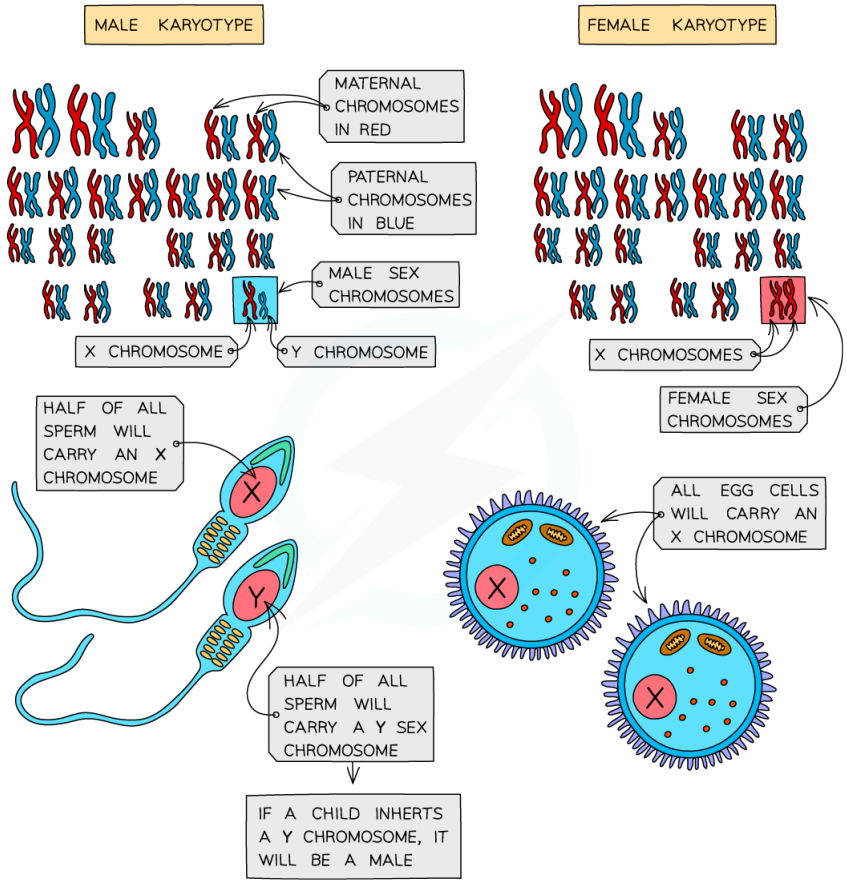
17.2 INHERITANCE OF SEX

- Sex, or gender, is determined by an **entire chromosome pair** (as opposed to most other characteristics that are just determined by one or a number of genes)
- **Females** have the sex chromosomes **XX**
- **Males** have the sex chromosomes **XY**
- As only a father can pass on a Y chromosome, he is **responsible for determining the gender of the child**

17 INHERITANCE

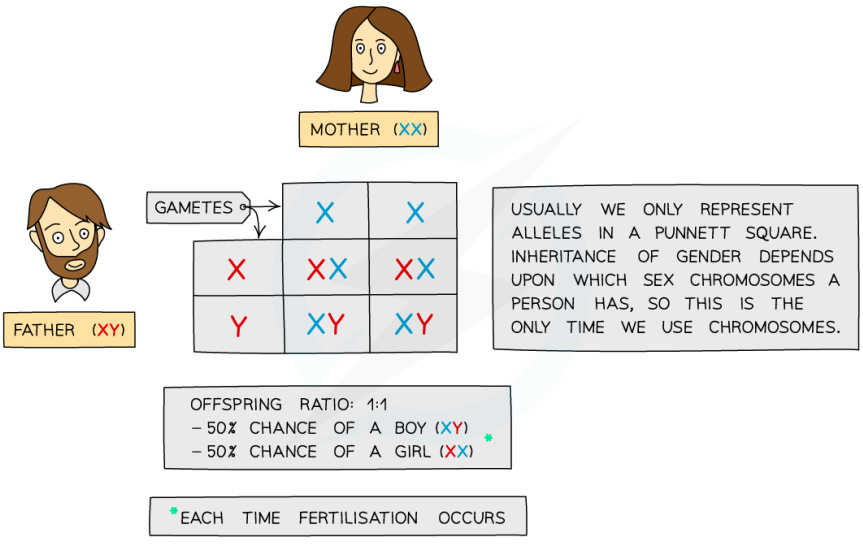
17.2 INHERITANCE OF SEX cont...

YOUR NOTES



Sperm cells determine the sex of offspring

- The inheritance of gender can be shown using a **genetic diagram** (known as a **Punnett square**), with the X and Y chromosomes taking the place of the alleles usually written in the boxes



Punnett square showing the inheritance of gender

17 INHERITANCE

17.3 PROTEIN SYNTHESIS

YOUR NOTES

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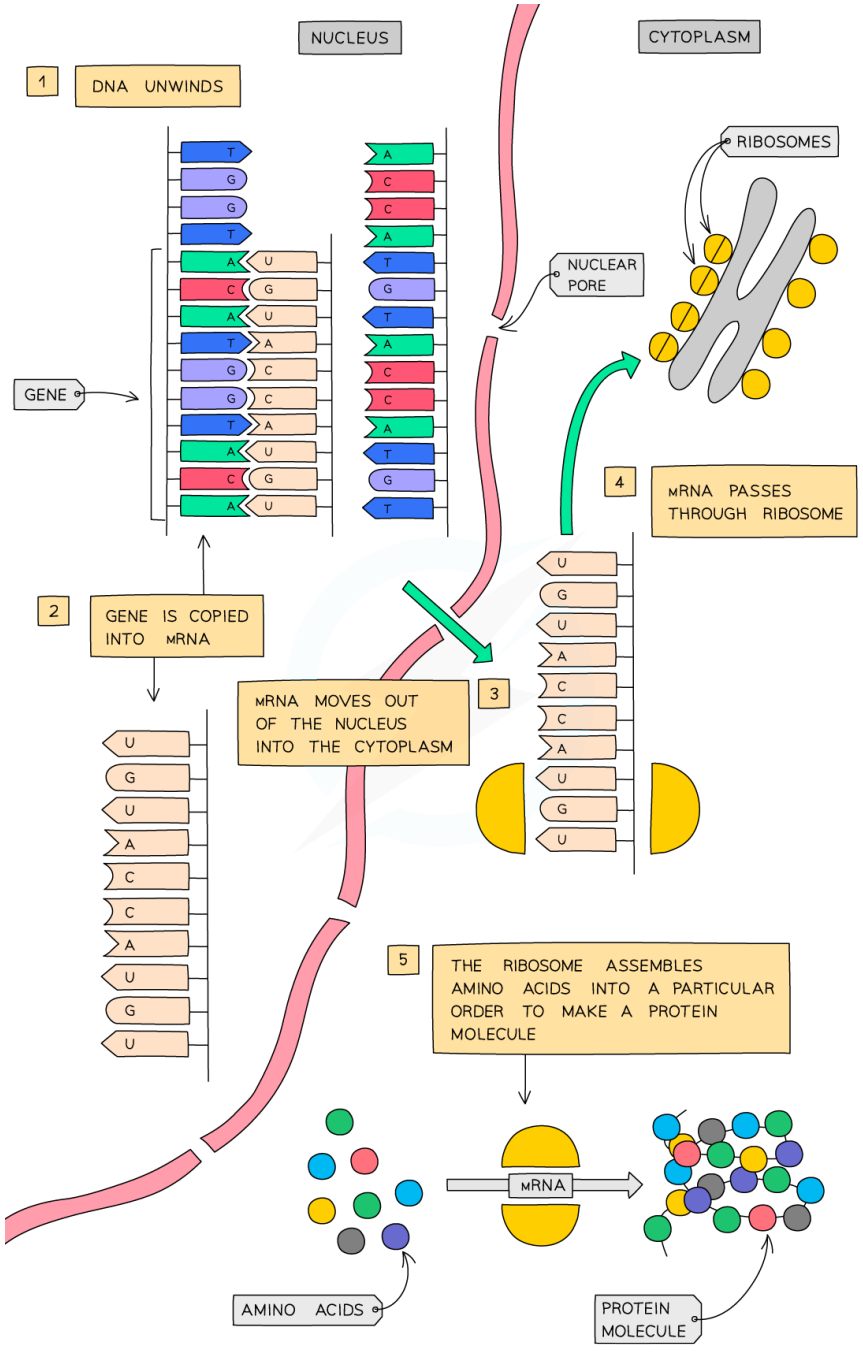
Transcription & Translation



Protein synthesis

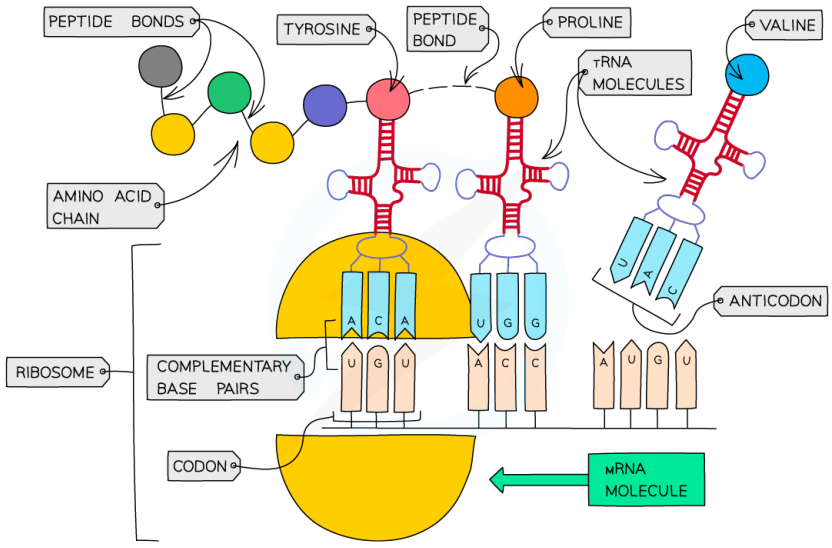
17 INHERITANCE

17.3 PROTEIN SYNTHESIS cont...

YOUR NOTES

EXTENDED ONLY cont...

- Proteins are made by **ribosomes** with the sequence of amino acids controlled by the **sequence of bases** contained within DNA
- DNA **cannot travel out of the nucleus** to the ribosomes (it is far too big to pass through a nuclear pore) so the base code of each gene is transcribed onto an RNA molecule called **messenger RNA** (mRNA).
- mRNA then **moves out of the nucleus** and attaches to a ribosome
- The ribosome 'reads' the code on the mRNA in groups of three
- Each triplet of bases **codes for a specific amino acid**
- In this way the ribosome **translates** the sequence of bases into a **sequence of amino acids** that make up a protein
- Once the amino acid chain has been assembled, it is released from the ribosome so it can fold and form the final structure of the protein



The triplet code of DNA (carried by mRNA) is read by the ribosome and amino acids are attached together in a specific sequence to form the protein

- In this way, DNA **controls cell function** by c**ontrolling the production of proteins**
- The proteins may be **enzymes, antibodies,** or **receptors** for **neurotransmitters**
- Although all body cells in an organism contain the same genes, **many genes in a particular cell are not expressed** because **the cell only makes the specific proteins it needs**

17 INHERITANCE

17.4 CELL DIVISION

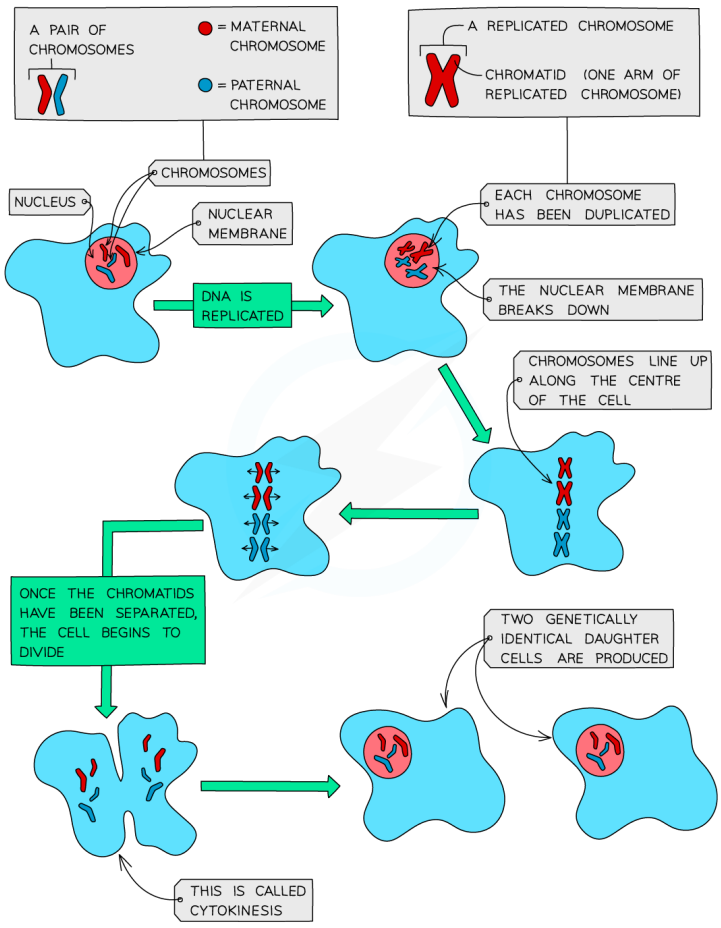
YOUR NOTES

Mitosis: Basics

- Most body cells have two copies of each chromosome
- We describe these cells as **diploid**
- When cells divide their chromosomes double beforehand
- This ensures that when the cell splits in two, each new cell still has two copies of each chromosome (is still diploid)
- This type of cell division is used for **growth, repair of damaged tissues, replacement of cells** and **asexual reproduction** and is known as **mitosis**
- Mitosis is defined as **nuclear division giving rise to genetically identical cells**

EXTENDED ONLY

Mitosis



The process of cell division by mitosis

17 INHERITANCE

17.4 CELL DIVISION cont...

YOUR NOTES

EXTENDED ONLY cont...

Process:

- Just before mitosis, each chromosome in the nucleus copies itself exactly (forms x – shaped chromosomes)
- Chromosomes line up along the centre of the cell where cell fibers pull them apart
- The cell divides into two; each new cell has a copy of each of the chromosomes

Importance:

- All cells in the body (excluding gametes) are produced by mitosis of the zygote
- Mitosis is important for replacing cells e.g, skin cells, red blood cells and for allowing growth (production of new cells e.g. when a zygote divides to form an embryo)

Occurs in:

- Growth: mitosis produces new cells
- Repair: to replace damaged or dead cells
- Asexual reproduction: mitosis produces offspring that are genetically identical to the parent

Stem Cells

- Many tissues in the human body contain a small number of **unspecialised cells**
- These are called **stem cells** and their function is to divide by mitosis and **produce new daughter cells that can become specialised** within the tissue and be used for different functions

Meiosis: Basics

- **Meiosis** is a type of nuclear division that **gives rise to cells that are genetically different**
- It is used to produce the **gametes** (sex cells)

17 INHERITANCE

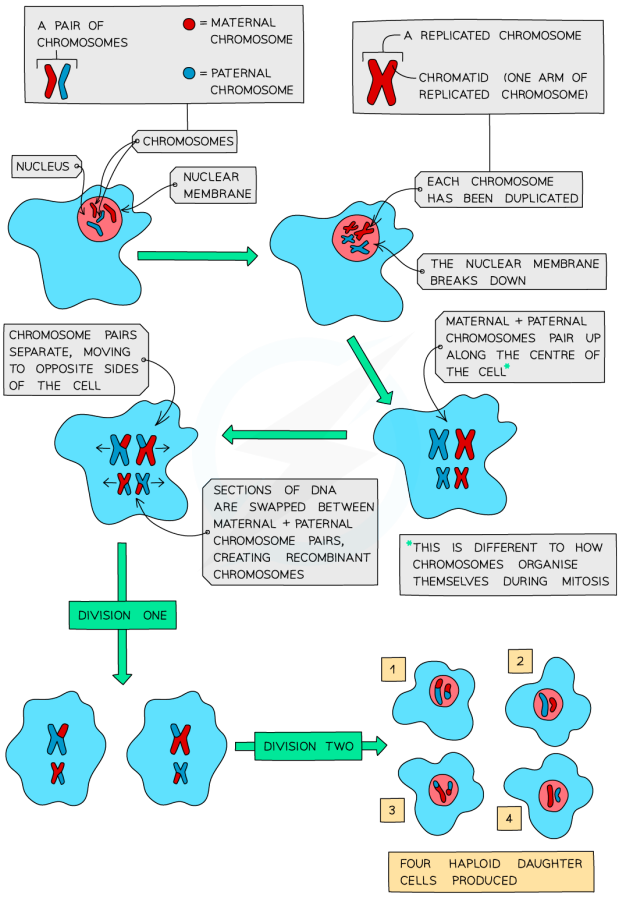
17.4 CELL DIVISION cont...

YOUR NOTES

EXTENDED ONLY

Meiosis

- The number of chromosomes must be **halved** when the **gametes** (sex cells) are formed
- Otherwise there would be double the number of chromosomes after they join at fertilisation in the zygote (fertilized egg)
- This halving occurs during **meiosis**, and so it is described as a **reduction division** in which the **chromosome number is halved from diploid to haploid**, resulting in **genetically different cells**
- It starts with chromosomes doubling themselves as in mitosis and lining up in the centre of the cell
- After this has happened the cells divide twice so that only one copy of each chromosome passes to each gamete
- We describe gametes as being **haploid** – having half the normal number of chromosomes
- Because of this double division, meiosis produces **four** haploid cells



The process of cell division by meiosis to produce haploid gamete cells

17 INHERITANCE

17.4 CELL DIVISION cont...

YOUR NOTES

EXTENDED ONLY cont...

Process:

- Each chromosome makes identical copies of itself (forming X-shaped chromosomes)
- First division: chromosomes pair up along the centre of the cell, recombination occurs and then cell fibres will pull the pairs apart, each new cell will have one of each recombinant chromosome pair
- Second division: chromosomes will line up along the centre of the cell, cell fibres will pull them apart (as with mitosis)
- A total of four haploid daughter cells will be produced

Importance:

- Production of gametes e.g. sperm cells and egg cells, pollen grains and ovum
- Increases genetic variation of offspring
- Meiosis produces variation by forming new combinations of maternal and paternal chromosomes every time a gamete is made, meaning that when gametes fuse randomly at fertilisation, each offspring will be different from any others

Differences between Mitosis & Meiosis

MITOSIS	MEIOSIS
TWO CELLS PRODUCED (KNOWN AS DAUGHTER CELLS)	FOUR CELLS PRODUCED (KNOWN AS DAUGHTER CELLS)
DAUGHTER CELLS ARE DIPLOID	DAUGHTER CELLS ARE HAPLOID
DAUGHTER CELLS ARE GENETICALLY IDENTICAL TO EACH OTHER AND TO THE PARENT CELL	DAUGHTER CELLS ARE GENETICALLY DIFFERENT FROM EACH OTHER AND THE PARENT CELL
ONE CELL DIVISION OCCURS	TWO CELL DIVISIONS OCCUR

EXAM TIP

Questions on cell division often ask for **differences between mitosis and meiosis.**
Learn 2 or 3 and remember to **BE SPECIFIC** when giving your answer.
You should also know the reasons for:

- a specific type of cell division taking place
- and the types of cells where each happen.

17 INHERITANCE

17.5 MONOHYBRID INHERITANCE

YOUR NOTES

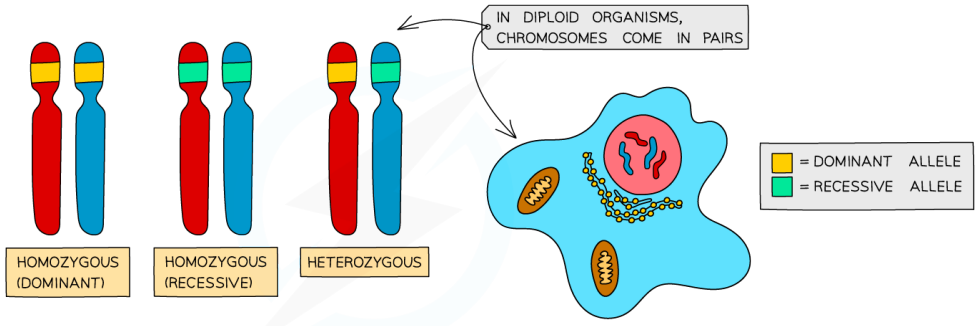
Definitions

- A **gene** is a short length of DNA found on a chromosome that codes for a particular **characteristic** (expressed by the formation of different proteins)
- **Alleles** are variations of the same gene
- For example, the gene for eye colour can have the alleles blue or brown
- As we have two copies of each chromosome, we have two copies of each gene and therefore two alleles for each gene
- One of the alleles is inherited from the mother and the other from the father
- This means that the alleles do not have to 'say' the same thing
- For example, an individual has two copies of the gene for eye colour but **one allele could code for brown eyes and one allele could code for blue eyes**
- The observable characteristics of an organism (seen just by looking – like eye colour, or found – like blood type) is called the **phenotype**
- The **combination of alleles that control each characteristic** is called the **genotype**
- Alleles can be **dominant** or **recessive**
- A dominant allele **only needs to be inherited from one parent** in order for the characteristic to show up in the phenotype
- A recessive allele needs to be **inherited from both parents in order** for the characteristic to show up in the phenotype
- If there is only one recessive allele, it will remain hidden and the dominant characteristic will show
- If the two alleles of a gene are the same, we describe the individual as being **homozygous** (homo = same)
- An individual could be **homozygous dominant** (having two copies of the dominant allele), or **homozygous recessive** (having two copies of the recessive allele)
- If the two alleles of a gene are different, we describe the individual as being **heterozygous** (hetero = different)
- When completing genetic diagrams, alleles are abbreviated to single letters
- The dominant allele is given a **capital letter** and the recessive allele is given the same letter, but **lower case**

17 INHERITANCE

17.5 MONOHYBRID INHERITANCE cont...

YOUR NOTES



Alleles of a gene can carry the same instructions or different instructions. You can only inherit two alleles for each gene, and they can be the same or different

- We **cannot always tell the genotype** of an individual for a particular characteristic just by looking at the phenotype – a phenotype associated with a dominant allele will be seen in both a dominant homozygous and a dominant heterozygous genotype
- If two individuals who are both **identically homozygous** for a particular characteristic are bred together, they will **produce offspring with exactly the same genotype and phenotype as the parents** – we describe them as being 'pure breeding' as they will always produce offspring with the same characteristics
- A **heterozygous** individual can pass on **different alleles** for the same characteristic each time it is bred with any other individual and can therefore **produce offspring with a different genotype and phenotype than the parents** – as such, **heterozygous individuals are not pure breeding**

Genetic Diagrams

- **Monohybrid inheritance** is the inheritance of characteristics controlled by a single gene (mono = one)
- This can be determined using a genetic diagram known as a **Punnett square**
- A Punnett square diagram shows the **possible combinations of alleles** that could be produced in the offspring
- From this the **ratio** of these combinations can be worked out
- Remember the **dominant allele** is shown using a capital letter and the **recessive allele** is shown using the same letter but lower case
- You should always write the **dominant allele first, followed by the recessive allele**
- **Example:**
- The height of pea plants is controlled by a single gene that has two alleles: tall and short
- The tall allele is dominant and is shown as **T**
- The small allele is recessive and is shown as **t**

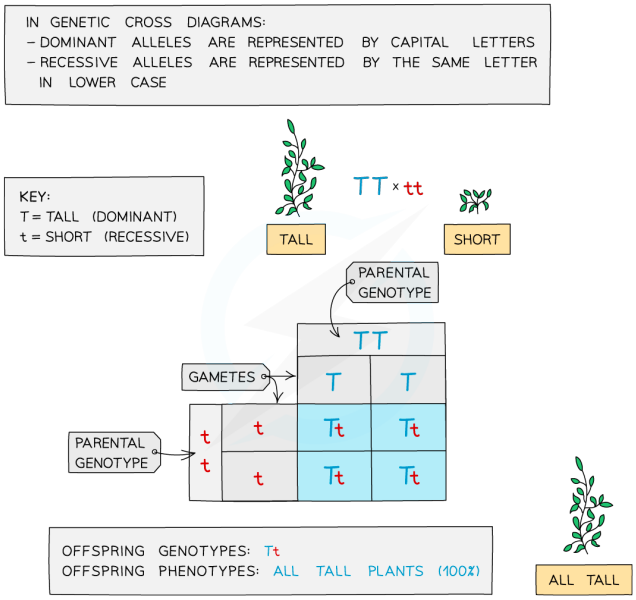
17 INHERITANCE

17.5 MONOHYBRID INHERITANCE cont...

YOUR NOTES

'Show the possible allele combinations of the offspring produced when a pure breeding short plant is bred with a pure breeding tall plant'

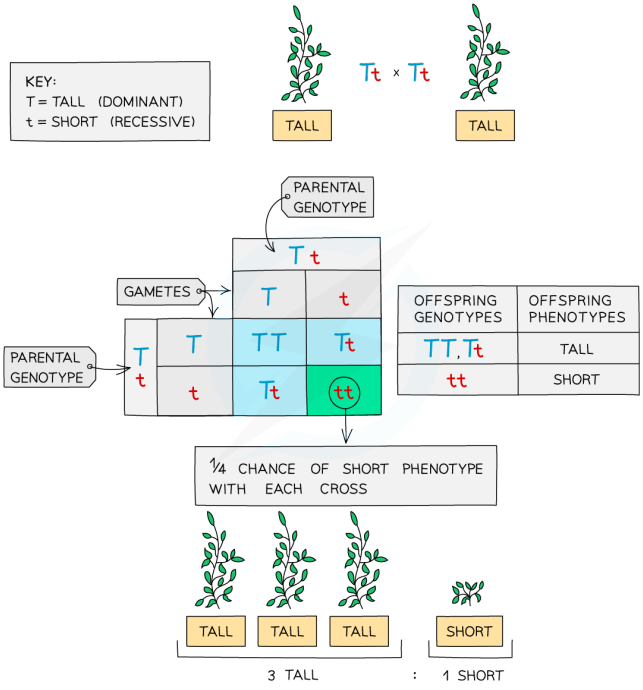
- The term '**pure breeding**' indicates that the individual is homozygous for that characteristic



A pure–breeding genetic cross in pea plants

- This shows that there is a 100% chance that all the offspring will be tall

'Show the possible allele combinations of the offspring produced when two of the offspring from the first cross are bred together'



A genetic cross diagram (F2 Generation)

17 INHERITANCE

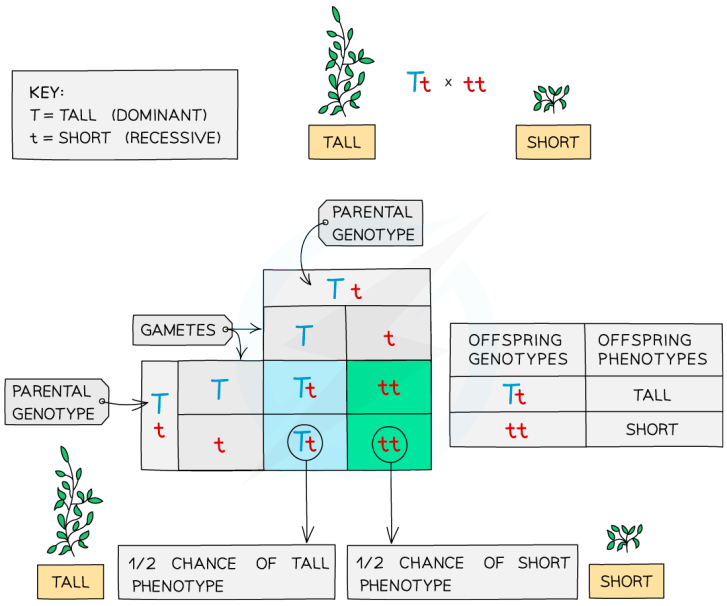
17.5 MONOHYBRID INHERITANCE cont...

YOUR NOTES

- All of the offspring of the first cross have the same genotype, **Tt** (heterozygous), so the possible combinations of offspring bred from these are:
  - There is more variation in this cross, with a **3:1** ratio of tall : short, meaning each offspring has a 75% chance of being tall and a 25% chance of being short
  - The F2 generation is produced when the offspring of the F1 generation (pure-breeding parents) are allowed to interbreed

'Show the results of crossing a heterozygous plant with a short plant'

- The heterozygous plant will be tall with the genotype **Tt**
- The short plant is showing the recessive phenotype and so must be homozygous recessive – **tt**
- The results of this cross are as follows:



A cross between a heterozygous plant with a short plant

- In this cross, there is a **1:1 ratio of tall to short**, meaning a **50%** chance of the offspring being tall and a **50%** chance of the offspring being short

17 INHERITANCE

17.5 MONOHYBRID INHERITANCE cont...

YOUR NOTES

How to construct Punnett squares

- Determine the parental genotypes
- Select a letter that has a clearly different lower case, for example: Aa, Bb, Dd
- Split the alleles for each parent and add them to the Punnett square around the outside
- Fill in the middle four squares of the Punnett square to work out the possible genetic combinations in the offspring
- You may be asked to comment on the ratio of different allele combinations in the offspring, calculate a percentage chances of offspring showing a specific characteristic or just determine the phenotypes of the offspring
- Completing a Punnett square allows you to predict the probability of different outcomes from monohybrid crosses

EXAM TIP

You should always write the dominant allele first, followed by the recessive allele.

If you are asked to use your own letters to represent the alleles in a Punnett square, try to **choose a letter that is obviously different** as a capital than the lower case so the examiner is not left in any doubt as to which is dominant and which is recessive. For example, C and c are not very different from each other, whereas A and a are!

EXTENDED ONLY

Identifying an Unknown Genotype

- Breeders can use a **test cross** to find out the genotype of an organism showing the dominant phenotype
- This involves crossing the unknown individual with an individual showing the recessive phenotype – if the individual is showing the recessive phenotype, then its genotype must be homozygous recessive
- By looking at the **ratio of phenotypes in the offspring**, we can tell whether the unknown individual is homozygous dominant or heterozygous

17 INHERITANCE

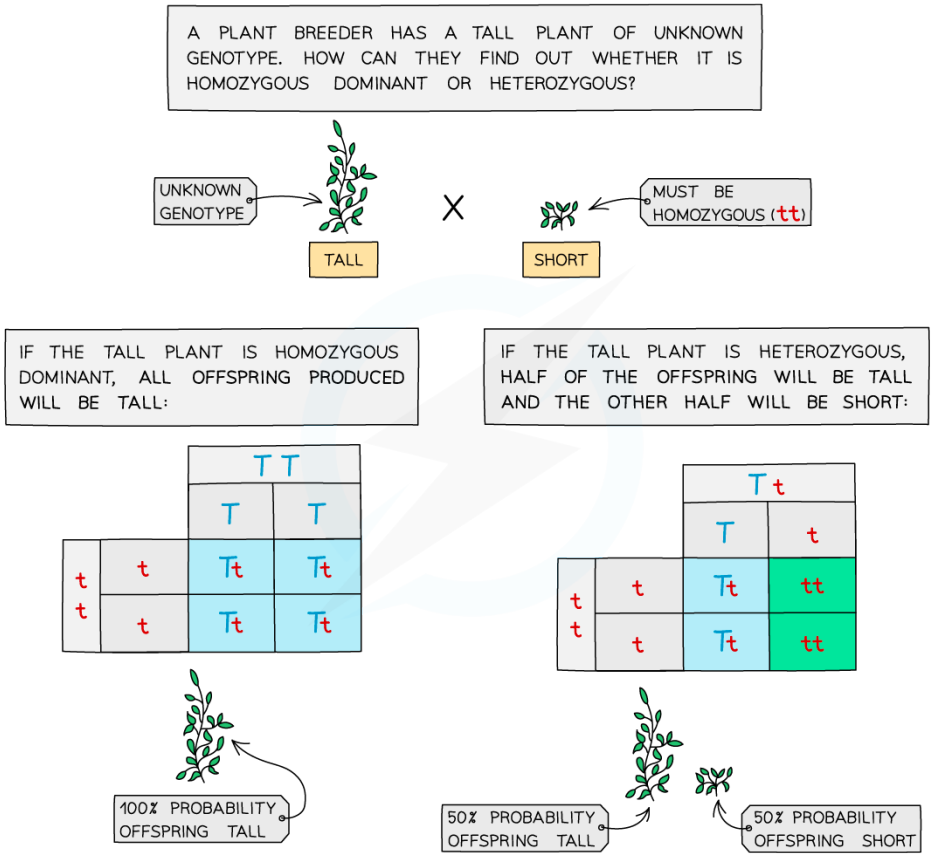
17.5 MONOHYBRID INHERITANCE cont...

YOUR NOTES

EXTENDED ONLY cont...

A plant breeder has a tall plant of unknown genotype. How can they find out whether it is homozygous dominant or heterozygous?'

- The short plant is showing the recessive phenotype and so must be homozygous recessive – **tt**



Determining genotypes from offspring

- If the tall plant is homozygous dominant, all offspring produced will be tall
- If the tall plant is heterozygous, half the offspring will be tall and the other half will be short

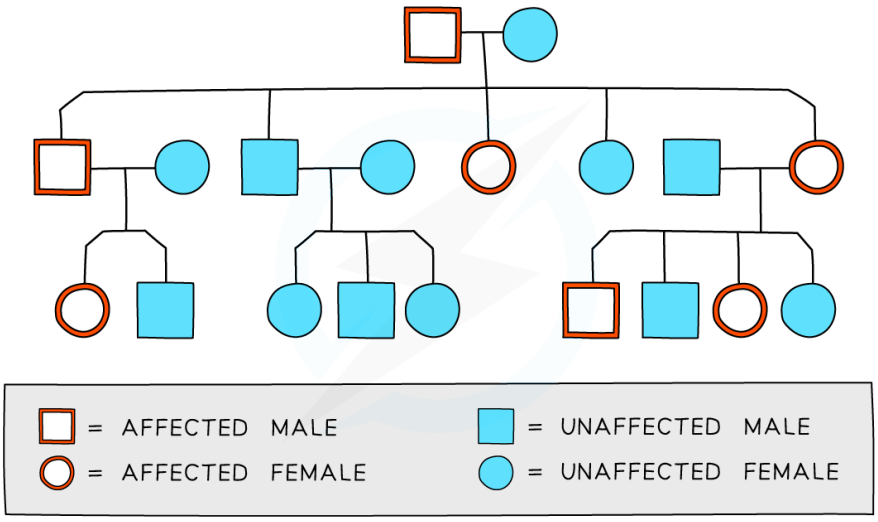
17 INHERITANCE

17.5 MONOHYBRID INHERITANCE cont...

YOUR NOTES

Family Pedigrees

- Family pedigree diagrams are usually used to trace the **pattern of inheritance** of a specific characteristic (usually a disease) **through generations of a family**
- This can be used to work out the probability that someone in the family will inherit the genetic disorder



A family pedigree chart

- Males are indicated by the **square shape** and females are represented by circles
- Affected individuals are **red** and unaffected are **blue**
- Horizontal lines between males and females show that they have produced children (which are shown underneath each couple)
- The family pedigree above shows:
  - both males and females are affected
  - every generation has affected individuals
  - that there is one family group that has no affected parents or children
  - the other two families have one affected parent and affected children as well

17 INHERITANCE

17.6 CODOMINANCE & SEX-LINKED CHARACTERISTICS

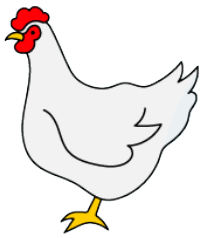
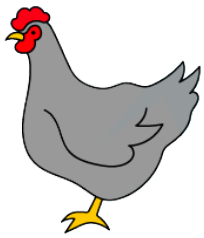
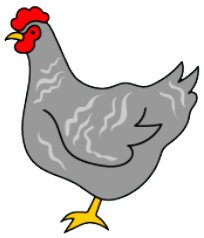
YOUR NOTES

EXTENDED ONLY

Codominance

- Some genes have alleles that are **equally dominant** and so are both expressed equally in the phenotype
- This is known as **codominance**
- Both codominant alleles are shown with upper case letters in genetic diagrams, but the **letters used are different**
- For example, feather colour in hens may be white, black or speckled (it has both white feathers and black feathers)
- The alleles can be shown as **W** for white and **B** for black
- There are three possible genotypes: **WW, BB and BW**
- There are also three possible phenotypes: WW = white, BB = black, and BW = speckled

Inheritance of a characteristic with codominant alleles

			
PHENOTYPE	WHITE	BLACK	SPECKLES
GENOTYPE	WW	BB	BW

Inheritance of Blood Group

- Inheritance of blood group is an example of codominance
- There are three alleles of the gene governing this instead of the usual two
- Alleles I^A and I^B are codominant, but both are dominant to I^O
- I represents the gene and the superscript A, B and O represent the alleles
- I^A results in the production of antigen A in the blood
- I^B results in the production of antigen B in the blood
- I^O results in no antigens being produced in the blood
- These three possible alleles can give us the following genotypes and phenotypes:

17 INHERITANCE

17.6 CODOMINANCE & SEX-LINKED CHARACTERISTICS cont...

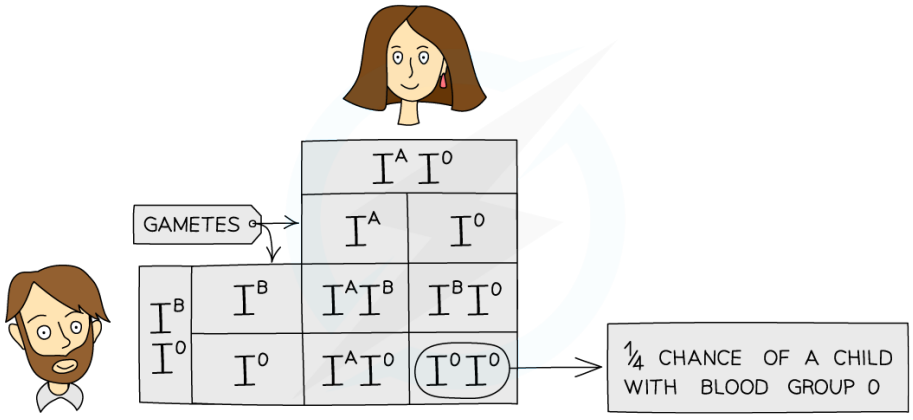
YOUR NOTES

EXTENDED ONLY cont...

GENOTYPE	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
$I^O I^O$	O

- We can use genetic diagrams to predict the outcome of crosses that involve codominant alleles:

'Show how a parent with blood group A and a parent with blood group B can produce offspring with blood group O'



Punnett square showing the inheritance of Blood Group

- The parent with blood group A has the genotype $I^A I^O$
- The parent with the blood group B has the genotype $I^B I^O$
- We know these are their genotypes (as opposed to both being homozygous) as they are able to produce a child with blood group O and so the child must have inherited an allele for group O from each parent
- Parents with these blood types have a 25% chance of producing a child with blood type O

17 INHERITANCE

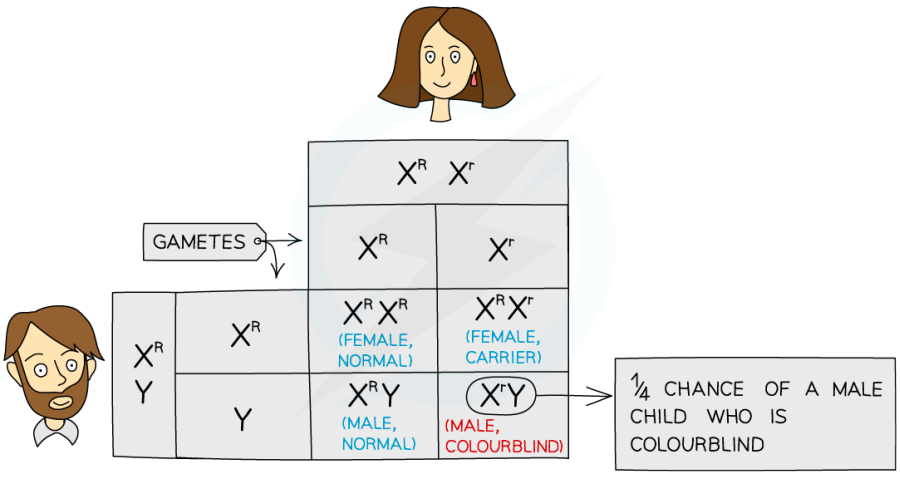
17.6 CODOMINANCE & SEX-LINKED CHARACTERISTICS cont...

YOUR NOTES

EXTENDED ONLY cont...

Sex-Linked Characteristics

- When alleles that control a particular characteristic are found on the **sex chromosomes**, we describe the inheritance that results as '**sex linked**'
- In almost all cases, there are **only alleles on the X chromosome** as the **Y chromosome is much smaller**
- Because males **only have one X chromosome**, they are **much more likely to show sex-linked recessive conditions** (such as red-green colour blindness and haemophilia)
- Females, having two copies of the X chromosome, are likely to inherit one dominant allele that masks the effect of the recessive allele
- A female with one recessive allele masked in this way is known as a **carrier**; she doesn't have the disease, but she has a 50% chance of passing it on to her offspring
- If that offspring is a male, he will have the disease
- The results of a cross between a normal male and a female who is a carrier for colourblindness is as follows:



Punnett square showing the inheritance of colourblindness, an X-linked condition

- In the cross above, there is a 25% chance of producing a male who is colourblind, a 25% chance of producing a female carrier, a 25% chance of producing a normal female and a 25% chance of producing a normal male

> NOW TRY SOME EXAM QUESTIONS

17 INHERITANCE

EXAM QUESTIONS

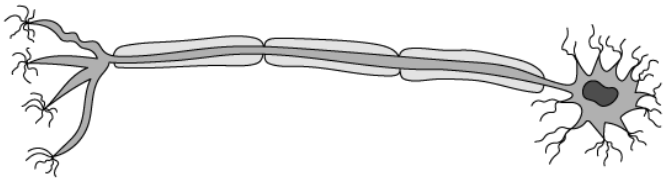
YOUR NOTES

QUESTION 1

New cells are formed by cell division of existing cells. The diagram below shows four different cells. Which one is formed by meiosis?

A 

B 

C 

D 

QUESTION 2

Albinism is a condition where pigment does not get produced in the skin, hair and eyes. This is an inherited condition that is caused by a recessive allele.

If both parents have albinism what are the chances of the offspring being an albino child?

A 0%

B 25%

C 75%

D 100%

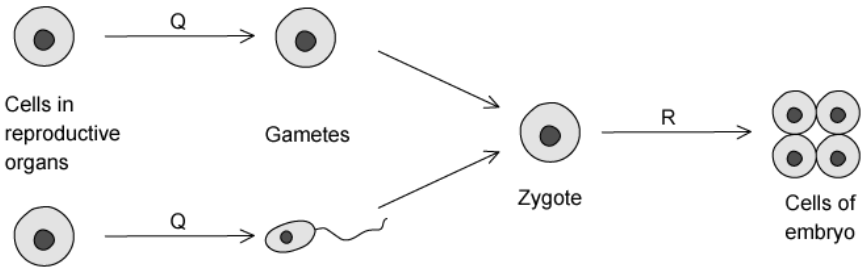
17 INHERITANCE

YOUR NOTES

EXAM QUESTIONS cont...

QUESTION 3

The diagram below shows the process in sexual reproduction.



Which of the processes are shown by stages Q and R?

	Q	R
A	meiosis	mitosis
B	mitosis	mitosis
C	meiosis	meiosis
D	mitosis	meiosis

QUESTION 4

What does the term haploid mean?

A A nucleus containing two sets of chromosomes

B A nucleus containing a single set of chromosomes

C A person with only one X chromosome

D A person with XXY chromosomes

17 INHERITANCE

EXAM QUESTIONS cont...

YOUR NOTES

QUESTION 5

A farmer is growing pea plants; the allele for tall is T and is dominant to the allele for dwarf, t. She wants to know what cross she would need to do to produce a ratio of 1 tall: 1 dwarf plants?

A tt x tt

B Tt x Tt

C TT x Tt

D Tt x tt

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