

Chromosomes, meiosis and gametes

Revision notes · Gene loci and linkage, how meiosis produces genetic variation, specialised mammalian gametes, and fertilisation in mammals and flowering plants.

For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11. **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

Chromosomes, meiosis and gametes **Spec 3.9-3.13**

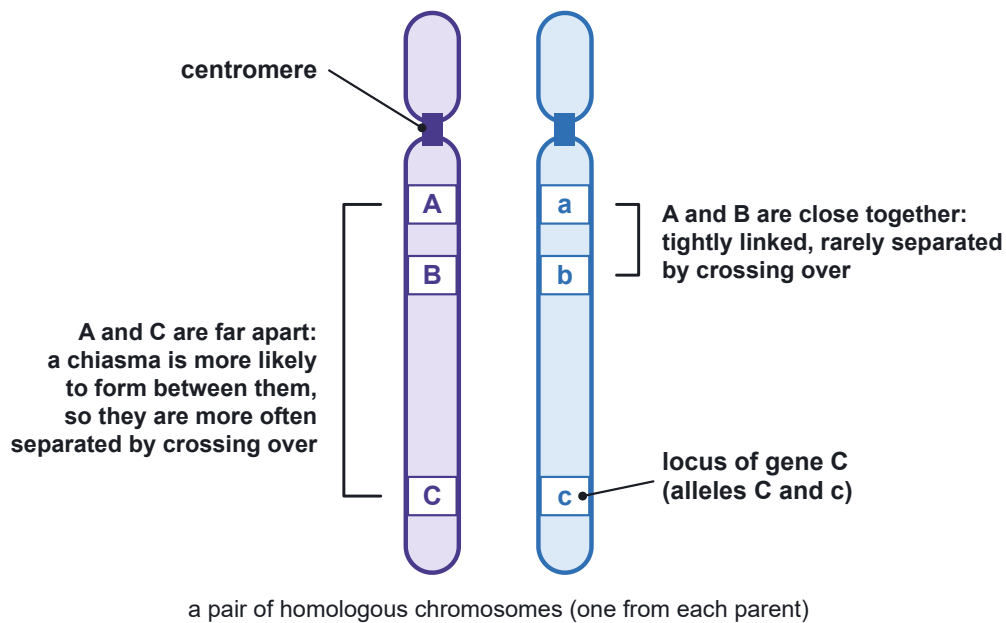
Gene loci and linkage **Spec 3.9**

Locus	The location of a gene on a chromosome. Plural: loci.
Linkage	Genes on the same chromosome are said to be linked, because they tend to be inherited together.

Body cells are diploid ($2n$): they contain pairs of **homologous chromosomes**, one from each parent. Homologous chromosomes carry the same genes at the same loci, but may carry different **alleles** (versions) of each gene.

Genes on different chromosomes are inherited independently, because the chromosomes assort independently at meiosis. Genes on the same chromosome are **linked**: the alleles on one chromosome are passed on together in the same gamete. This means a dihybrid cross involving linked genes does not give the expected 9:3:3:1 ratio.

Linked alleles can be separated by **crossing over** during meiosis, which produces new combinations of alleles called recombinants. The further apart two loci are on a chromosome, the more likely a chiasma forms between them, so the more often the linkage is broken. Loci that are very close together are rarely separated, so they are inherited together almost always.



Homologous chromosomes carry the **same genes at the same loci**; loci close together are rarely separated.

Exam tip: A locus is a position, not a gene and not an allele. Say 'the location of a gene on a chromosome'.

Meiosis and genetic variation Spec 3.10

Meiosis is the division that makes gametes. It involves two divisions, with only one round of DNA replication beforehand, so a diploid cell ($2n$) produces four **haploid** (n) cells. The cells are not identical to each other, which is a source of **genetic variation** in the offspring.

1. Meiosis I (reduction division): homologous chromosomes pair up. They are separated, so each daughter cell is haploid but each chromosome still has two chromatids.
2. Meiosis II: the chromatids of each chromosome are separated, as in mitosis. Four haploid cells result.

Crossing over in prophase I

Homologous chromosomes pair up to form a **bivalent**. Chromatids of the two homologous chromosomes (non-sister chromatids) break and rejoin at points called **chiasmata**, exchanging sections of DNA. This swaps alleles between the chromatids, so each chromatid now carries a new combination of alleles. (The names of the stages of prophase are not required.)

Independent assortment in metaphase I

In metaphase I, the bivalents line up on the equator of the cell. Each pair lines up independently of the others, and the maternal or paternal chromosome of each pair can face either pole at random. When the homologous chromosomes separate in anaphase I, the cells receive a random mixture of maternal and paternal chromosomes. This is **independent assortment**.

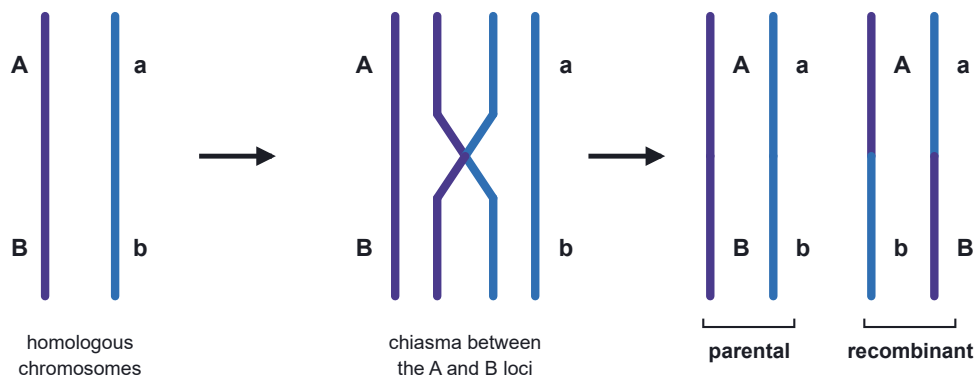
number of possible chromosome combinations in gametes = 2^n (n = haploid number)

In humans $n = 23$, so independent assortment alone can produce $2^{23} = 8\,388\,608$ different combinations of chromosomes in the gametes of one person, before crossing over is taken into account. Crossing over adds more variation. Variation is also increased because fertilisation is random, so any sperm may fertilise any egg.

Heterozygote AB/ab

Crossing over in prophase I

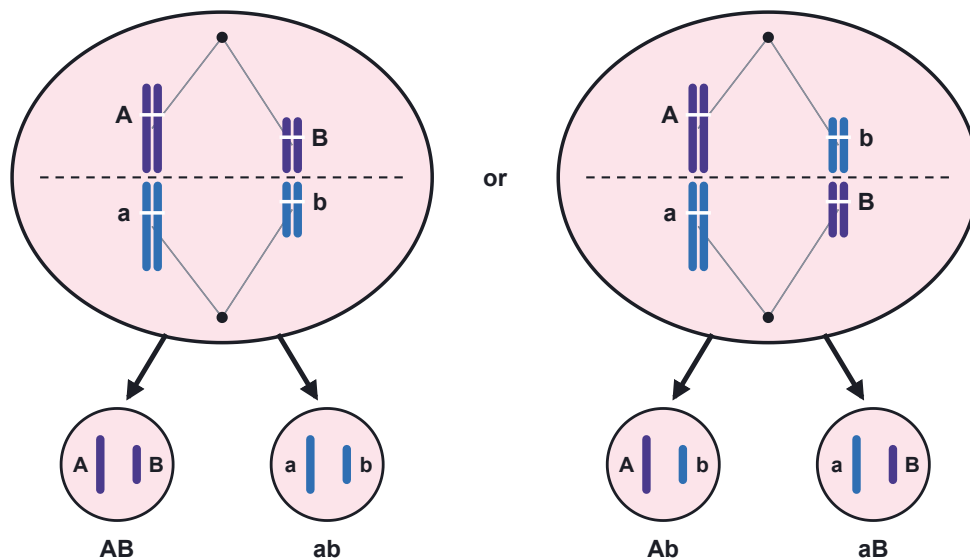
Gametes



Crossing over at a chiasma produces new combinations of alleles (recombinants).

Orientation 1

Orientation 2



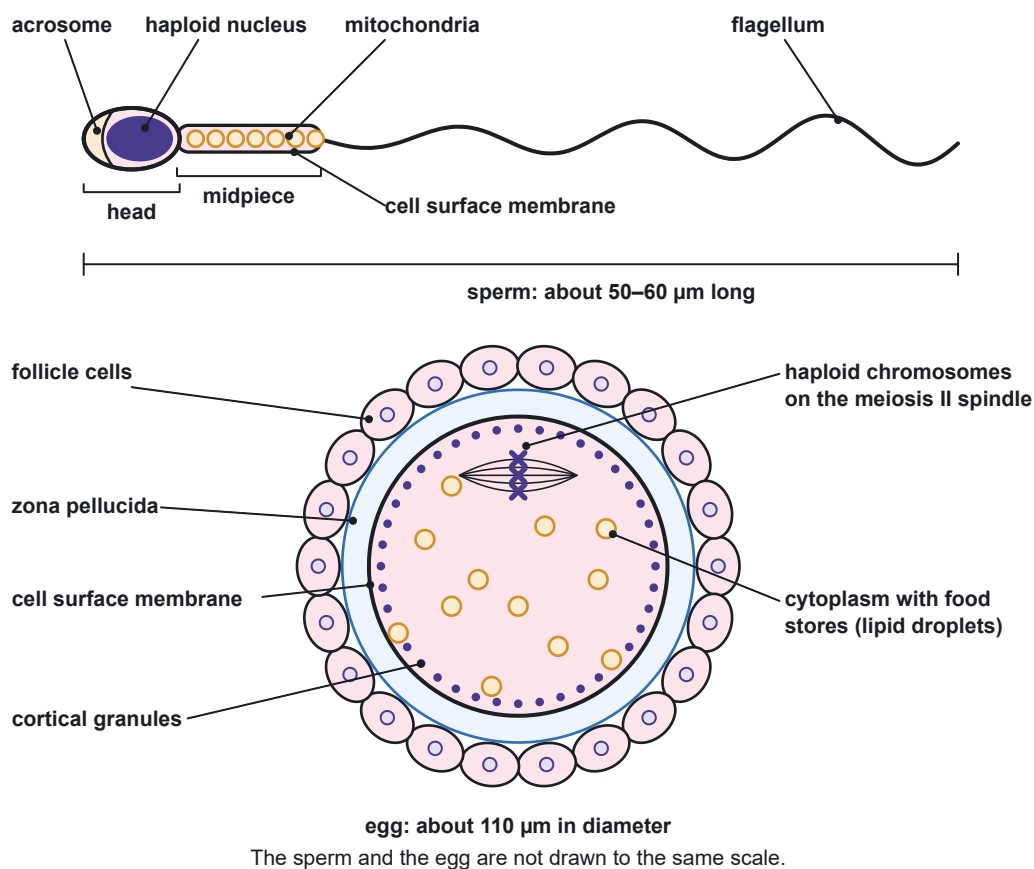
Independent assortment: each pair lines up independently, so two pairs give four kinds of gamete.

Common mistake: Crossing over is between non-sister chromatids of homologous chromosomes. Independent assortment is the random orientation of whole homologous pairs in metaphase I, not the separation of chromatids.

Specialised mammalian gametes Spec 3.11

Specialised features of mammalian gametes		
Gamete	Feature	Function
Sperm	Haploid nucleus in the head	Carries the paternal genes
Sperm	Acrosome at the front of the head: a modified lysosome containing hydrolytic (digestive) enzymes	Releases enzymes to digest a path through the zona pellucida
Sperm	Midpiece with many mitochondria, wound round the base of the flagellum	Produces ATP by aerobic respiration for swimming
Sperm	Long flagellum (tail) containing microtubules	Moves the sperm towards the egg
Egg cell	Large cell with a haploid nucleus and a lot of cytoplasm, containing food stores	Supplies nutrients to the early embryo until it implants
Egg cell	Zona pellucida: a jelly-like layer of glycoproteins outside the cell surface membrane	Contains receptors that bind sperm of the same species; protects the egg; hardens after fertilisation
Egg cell	Cortical granules: vesicles just under the cell surface membrane, containing enzymes	Released after fertilisation to prevent other sperm entering (cortical reaction)

The egg is surrounded by a layer of follicle cells, which the sperm must pass. Both gametes are **haploid**, so when the nuclei fuse, the diploid number is restored.



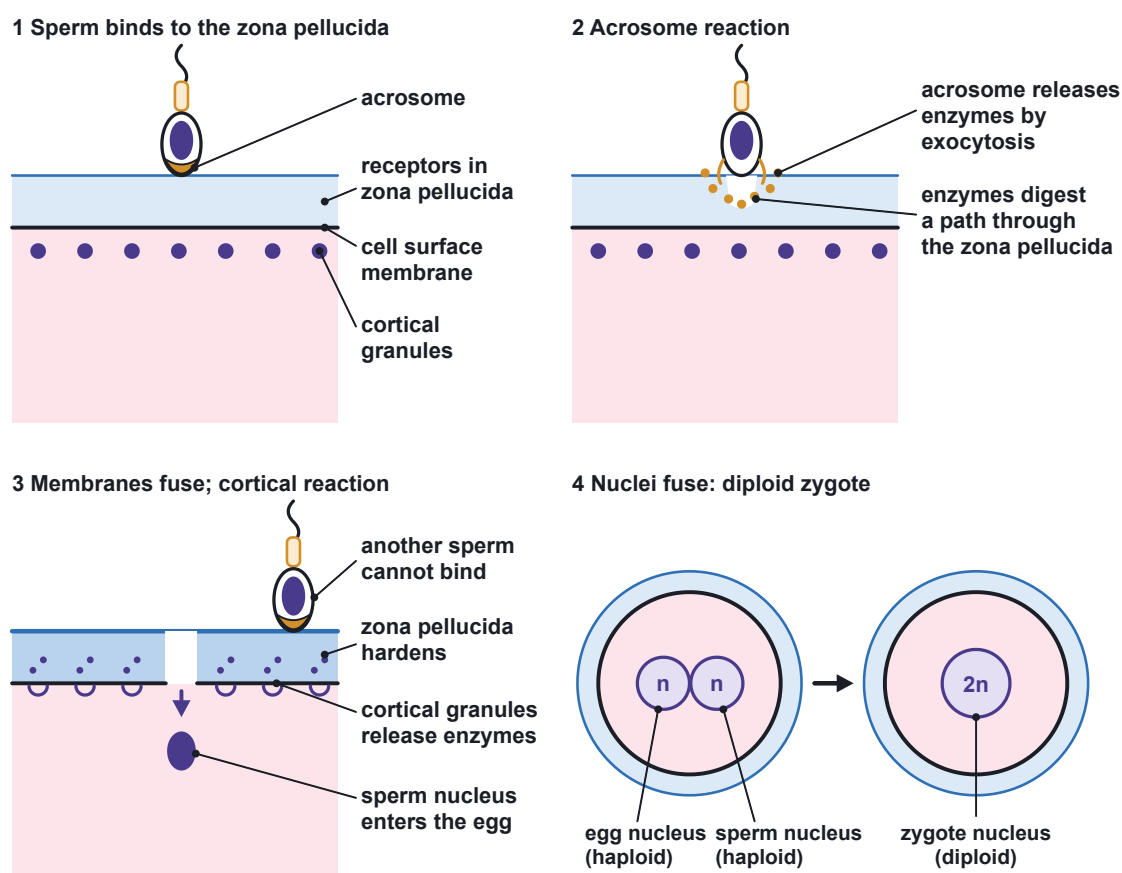
Mammalian gametes (not to the same scale): the egg is many times larger than the sperm.

Fertilisation in mammals Spec 3.12

1. Sperm swim towards the egg and pass through the layer of follicle cells.

2. The head of a sperm binds to receptors in the **zona pellucida**.
3. The **acrosome reaction** takes place: the acrosome membrane fuses with the sperm cell surface membrane and releases its enzymes by exocytosis. The enzymes digest a path through the zona pellucida.
4. The sperm cell surface membrane fuses with the egg cell surface membrane, and the sperm nucleus enters the egg cytoplasm.
5. The **cortical reaction** takes place: the cortical granules fuse with the egg cell surface membrane and release their enzymes. These change the zona pellucida so that it hardens and sperm can no longer bind to it.
6. The haploid sperm nucleus and haploid egg nucleus fuse, which forms a diploid zygote. This **fusion of nuclei** restores the diploid number.

The cortical reaction prevents **polyspermy** (more than one sperm fertilising the egg). If a second sperm entered, the zygote would have three sets of chromosomes and could not develop normally.



The **acrosome reaction** lets the sperm reach the egg; the **cortical reaction** stops other sperm entering.

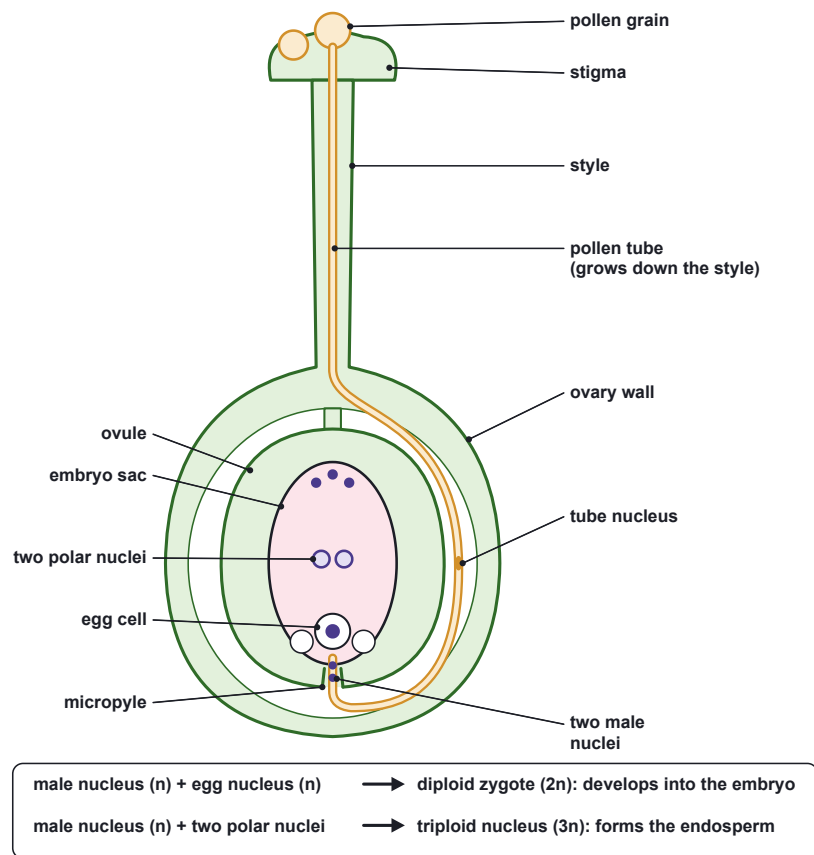
Exam tip: Link each reaction to its purpose: the acrosome reaction lets the sperm reach the egg membrane, and the cortical reaction stops further sperm entering.

Fertilisation in flowering plants Spec 3.13

After pollination (the transfer of pollen to a stigma), the events of fertilisation take place in the following order.

1. A compatible pollen grain absorbs water and nutrients from the stigma and germinates.
2. A **pollen tube** grows out of the grain, down through the style towards the ovary. It is guided by chemicals released by the ovule (chemotropism), and the tube nucleus directs its growth. The tip of the tube secretes enzymes that digest the tissues of the style.

3. The generative nucleus divides by mitosis to form **two male nuclei**, which travel down the tube.
4. The tube enters the ovule through a small pore, the **micropyle**, and enters the embryo sac.
5. The tip of the tube bursts and releases the two male nuclei.
6. One male nucleus fuses with the nucleus of the egg cell to form a diploid zygote, which develops into the embryo.
7. The other male nucleus fuses with the two polar nuclei in the centre of the embryo sac to form a triploid nucleus, which develops into the endosperm (food store). This is called **double fertilisation**.



Double fertilisation: one male nucleus forms the zygote, the other forms the triploid endosperm nucleus.

Common mistake: The pollen tube carries nuclei, not sperm cells. Describe the fusion of nuclei: male nucleus with egg nucleus, and male nucleus with the polar nuclei.

Quick check

1. Define the term locus.
2. In which stage of meiosis does crossing over occur?
3. Why is the zona pellucida hardened after fertilisation?
4. What do the two male nuclei do in a flowering plant?
5. Why does a sperm have many mitochondria?

Quick check answers

Chromosomes, meiosis and gametes

1. The location of a gene on a chromosome.
2. Prophase I.
3. To prevent other sperm from entering, which would cause polyspermy.
4. One fuses with the egg nucleus to form the zygote; the other fuses with the polar nuclei to form the endosperm.
5. To make ATP by aerobic respiration for the movement of the flagellum.