

Reproduction

Revision notes · IB Biology D3.1: sexual and asexual reproduction, human reproductive systems, the menstrual cycle, IVF, flowering plant reproduction and HL pregnancy.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Reproduction Spec D3.1

Sexual and asexual reproduction Spec D3.1.1, D3.1.2

In **asexual reproduction** one parent produces offspring by mitosis (or a similar division). The offspring are **genetically identical** to the parent and to each other, apart from rare mutations.

In **sexual reproduction** two parents each produce haploid gametes. The gametes fuse, so each offspring has a **new combination of genes** that is different from both parents and from its siblings.

Relative advantages of the two methods		
Feature	Asexual reproduction	Sexual reproduction
Number of parents	One	Usually two (or one hermaphrodite producing both gametes)
Genetic outcome	Offspring genetically identical to the parent	Offspring with new gene combinations, so genetic variation
When it is an advantage	Parent is already adapted to an existing, stable environment, so its successful combination of alleles is kept	Environment changes: variation gives some offspring traits suited to the new conditions, so the population can adapt
Other points	Fast; no need to find a mate; every individual can produce offspring	Slower; needs gametes from two parents to meet

Meiosis and fusion of gametes in the sexual life cycle

A sexual life cycle alternates between a diploid and a haploid stage. **Meiosis** halves the chromosome number to produce haploid gametes, and **fusion of gametes** (also called fertilization) restores the diploid number in the zygote.

- **Meiosis breaks up parental combinations of alleles:** crossing over and random orientation of bivalents mean each gamete carries a unique mix of the parent's maternal and paternal alleles.
- **Fusion of gametes produces new combinations:** a gamete from one parent joins a gamete from another, so the zygote combines two different sets of alleles.
- Without meiosis the chromosome number would double every generation.

Exam tip: When asked for an advantage, tie it to the environment: asexual reproduction for an existing environment the parent is adapted to, sexual reproduction for a changed environment.

Male and female sexes and human reproductive systems Spec D3.1.3, D3.1.4

The **prime difference** between the sexes is that the **male gamete travels to the female gamete**. A moving cell must be small, so sperm have very little cytoplasm and almost no food reserves. The egg

does not move, so it can be large and store food reserves for the early embryo.

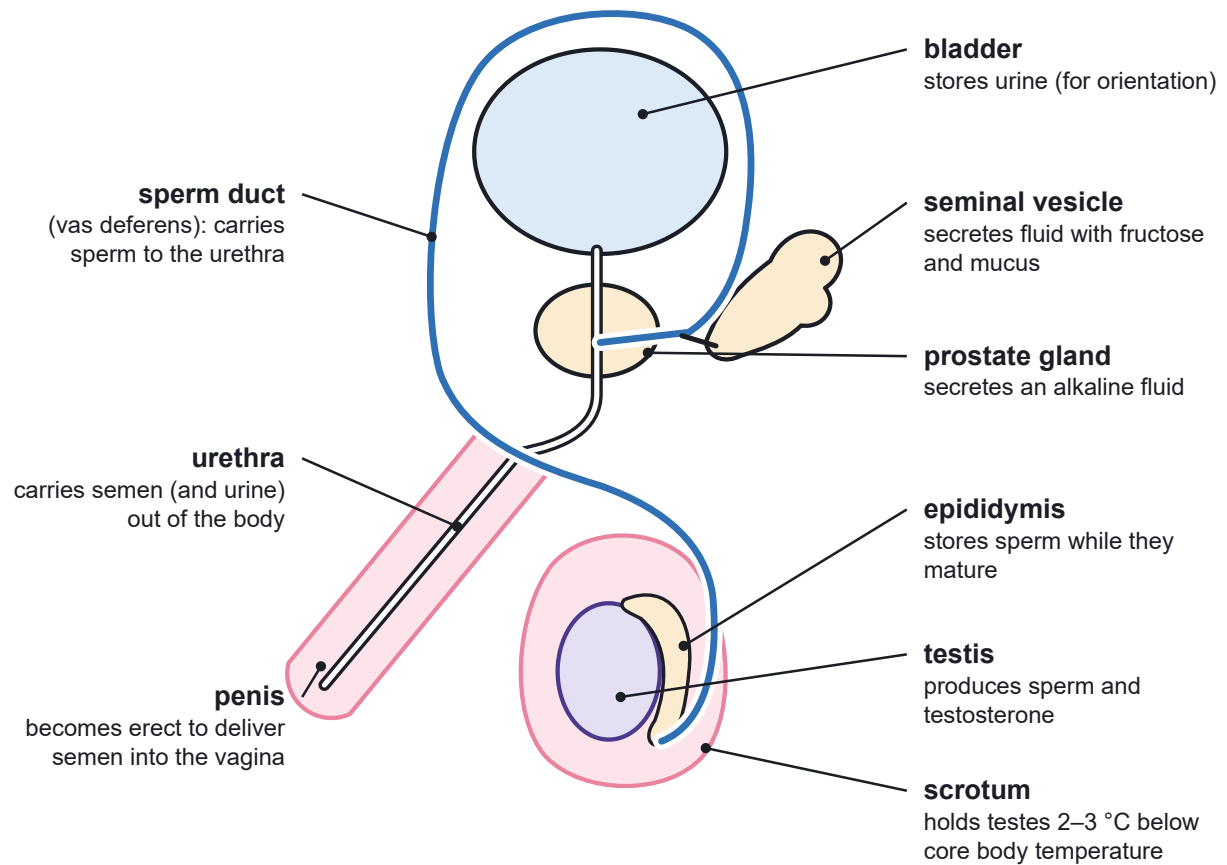
- **Numbers of gametes:** small gametes are cheap to make, so males produce huge numbers (millions of sperm per ejaculation); females produce few, large eggs (usually one per menstrual cycle in humans).
- **Reproductive strategies:** because eggs are scarce and costly, females usually invest more in each offspring (here, pregnancy and lactation); males can potentially father many offspring and often compete for mates.

Male reproductive system

Structures and functions: male-typical system	
Structure	Function
Testis	Produces sperm in seminiferous tubules and secretes testosterone
Scrotum	Holds the testes outside the body, about 2-3 °C below core temperature, which sperm production needs
Epididymis	Stores sperm while they mature and gain the ability to swim
Sperm duct (vas deferens)	Carries sperm from the epididymis towards the urethra during ejaculation
Seminal vesicle	Secretes fluid containing fructose (energy for sperm) and mucus into semen
Prostate gland	Secretes an alkaline fluid that helps neutralise acidity in the vagina
Urethra	Carries semen (and urine) out through the penis
Penis	Becomes erect to deliver semen into the vagina

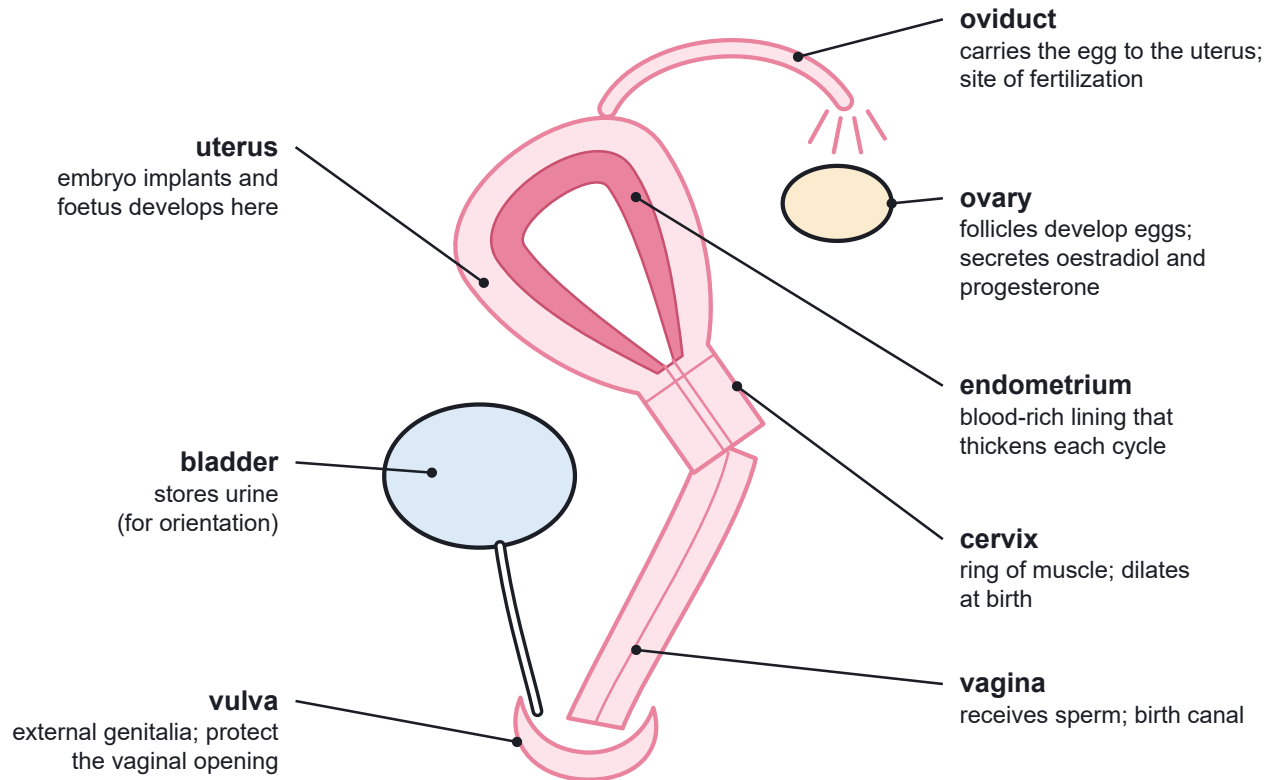
Female reproductive system

Structures and functions: female-typical system	
Structure	Function
Ovary	Contains follicles that develop eggs; releases an egg at ovulation; secretes oestradiol and progesterone
Oviduct (fallopian tube)	Carries the egg towards the uterus; site of fertilization
Uterus	Muscular organ in which the embryo implants and the foetus develops
Endometrium	Blood-rich lining of the uterus that thickens each cycle, ready for implantation
Cervix	Ring of muscle at the base of the uterus; keeps the foetus in place and dilates at birth
Vagina	Receives the penis and sperm; the birth canal
Vulva	External genitalia that protect the vaginal opening



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The male-typical reproductive system (side view, front of the body on the left). Sperm made in the **testis** mature in the epididymis and leave through the sperm duct and urethra.



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The female-typical reproductive system (side view, front of the body on the left). The egg is fertilized in the **oviduct** and the embryo implants in the endometrium.

Exam tip: Drawing questions want labels with functions. Draw clear single lines, use a ruler for label lines and write the function next to each structure.

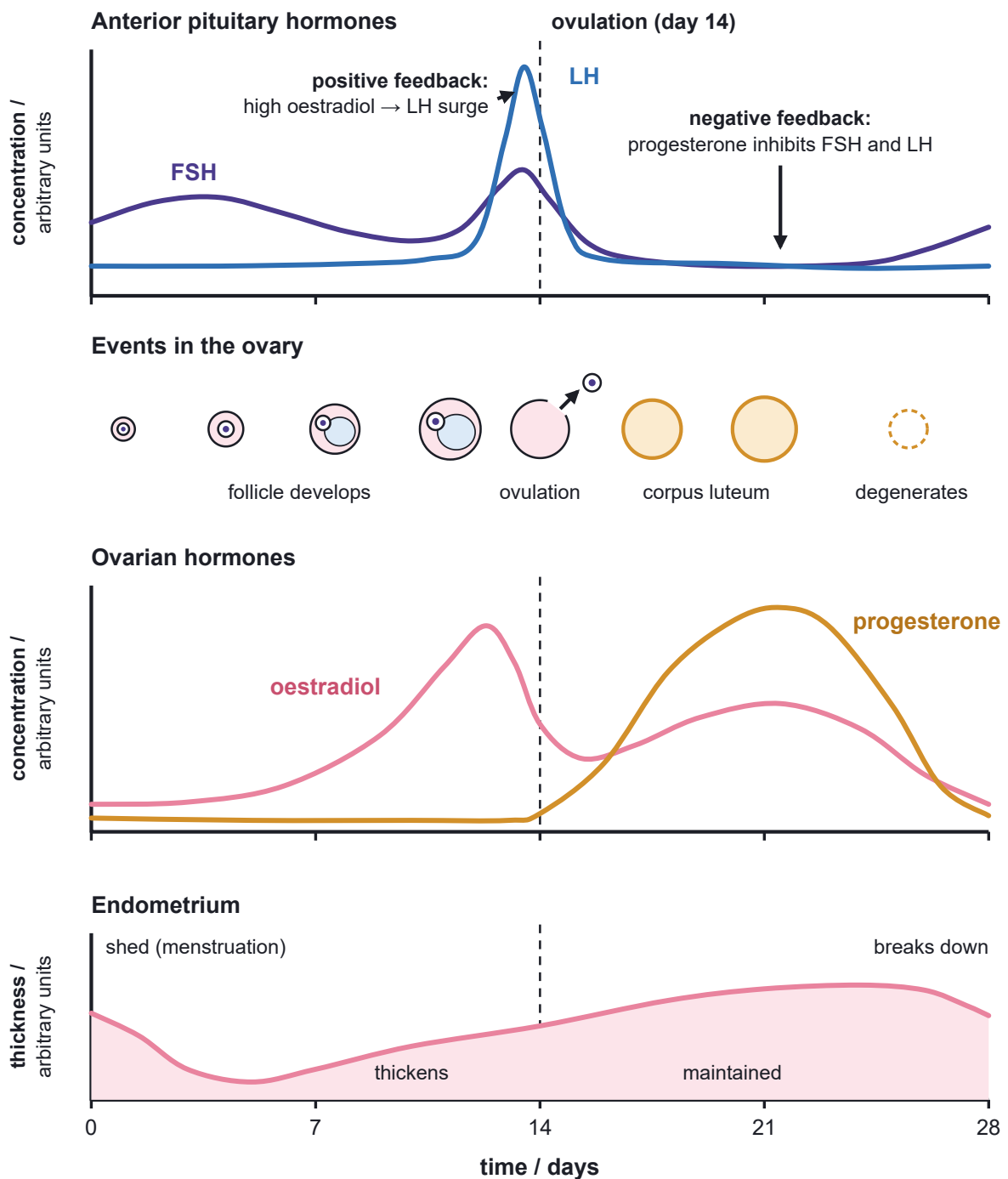
Ovarian and uterine cycles and their hormones Spec D3.1.5

The **ovarian cycle** (follicle growth, ovulation, corpus luteum) and the **uterine cycle** (endometrium builds up, is maintained, then breaks down) together make the **menstrual cycle**, roughly 28 days long.

The four hormones		
Hormone	Secreted by	Main effects
FSH (follicle-stimulating hormone)	Anterior pituitary	Stimulates development of follicles; stimulates follicle cells to secrete oestradiol
LH (luteinizing hormone)	Anterior pituitary	Surge triggers ovulation; stimulates the empty follicle to become the corpus luteum
Oestradiol	Follicle cells in the ovary	Thickens the endometrium; low levels inhibit FSH and LH; high levels stimulate the LH and FSH surge
Progesterone	Corpus luteum	Maintains and further thickens the endometrium; inhibits FSH and LH secretion

- Days 1–5: the endometrium is shed (menstruation). Progesterone and oestradiol are low, so FSH secretion rises.

- 2 . FSH stimulates several follicles to develop; usually one matures. Its cells secrete increasing amounts of oestradiol.
- 3 . Oestradiol stimulates the endometrium to thicken again. At first it inhibits FSH (negative feedback).
- 4 . By about day 12-13 oestradiol is high. High oestradiol stimulates the pituitary to release much more LH and FSH: **positive feedback** causes the LH surge.
- 5 . The LH surge triggers ovulation at about day 14: the mature follicle releases a secondary oocyte into the oviduct.
- 6 . LH stimulates the empty follicle to develop into the **corpus luteum**, which secretes progesterone (and some oestradiol).
- 7 . Progesterone maintains the thick endometrium and, with oestradiol, inhibits FSH and LH (**negative feedback**), so no new follicles develop.
- 8 . If there is no pregnancy, the corpus luteum degenerates after about 10-12 days. Progesterone falls, the endometrium breaks down (menstruation) and FSH rises again: the cycle repeats.



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The menstrual cycle. High oestradiol causes the LH surge by **positive feedback**; progesterone from the corpus luteum inhibits FSH and LH by **negative feedback**.

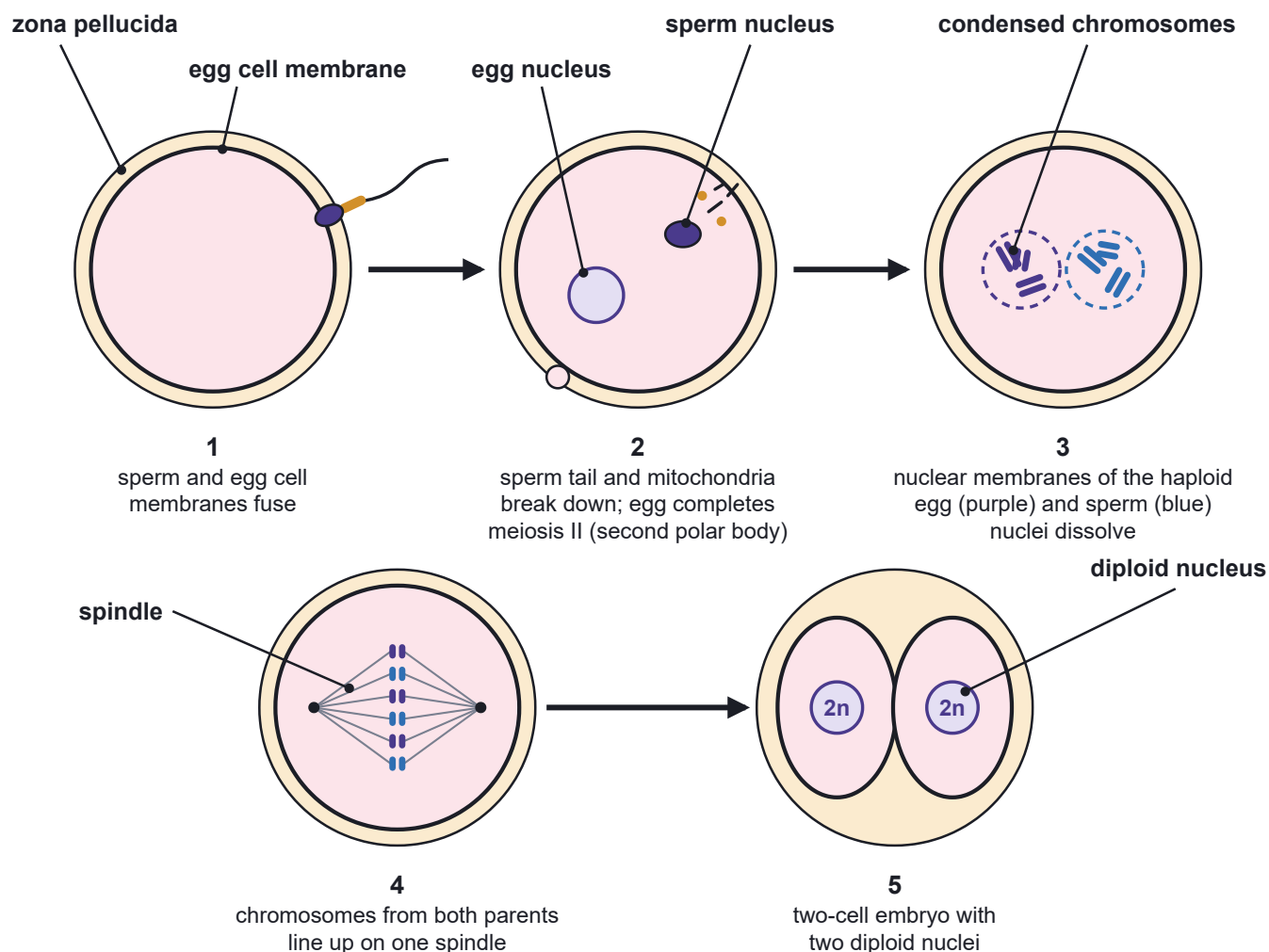
Common mistake: Oestradiol has both effects: low to moderate levels inhibit FSH and LH, but sustained high levels before ovulation stimulate the LH surge. Say which level you mean.

Fertilization in humans and hormones in IVF Spec D3.1.6, D3.1.7

Fertilization

1. Fertilization usually happens in the oviduct. A sperm reaches the egg and its **cell membrane fuses with the egg cell membrane**.
2. The sperm nucleus enters the egg cytoplasm. The sperm's **tail and mitochondria are destroyed**, so mitochondria (and mitochondrial DNA) are inherited from the mother only.

3. The egg, a secondary oocyte, completes its second meiotic division, so a haploid egg nucleus and a haploid sperm nucleus are both present in the cytoplasm.
4. The **nuclear membranes of the sperm and egg nuclei dissolve**; the two nuclei do not fuse into one nucleus first.
5. All the condensed chromosomes, from both parents, take part in a **joint mitosis** on one spindle. This produces **two diploid nuclei**, so the zygote divides into a two-cell embryo.



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Fertilization in humans. The two haploid nuclei do not fuse first: their chromosomes join in a **joint mitosis** on one spindle, giving two diploid nuclei.

Hormones in IVF

In **in vitro fertilization (IVF)** eggs are fertilized outside the body. Hormones are used so that many eggs can be collected at once.

1. **Down-regulation:** a drug is given (usually daily for a few weeks) that stops the pituitary releasing FSH and LH, so the **normal secretion of hormones is suspended** and the woman's own cycle cannot interfere with the timing.
2. **Superovulation:** injections of FSH (with LH activity) are given at a much higher dose than normal, so many follicles develop at once.
3. When follicles are mature, an injection of hCG (which acts like LH) makes the eggs complete their maturation; they are collected from the follicles about 36 hours later.

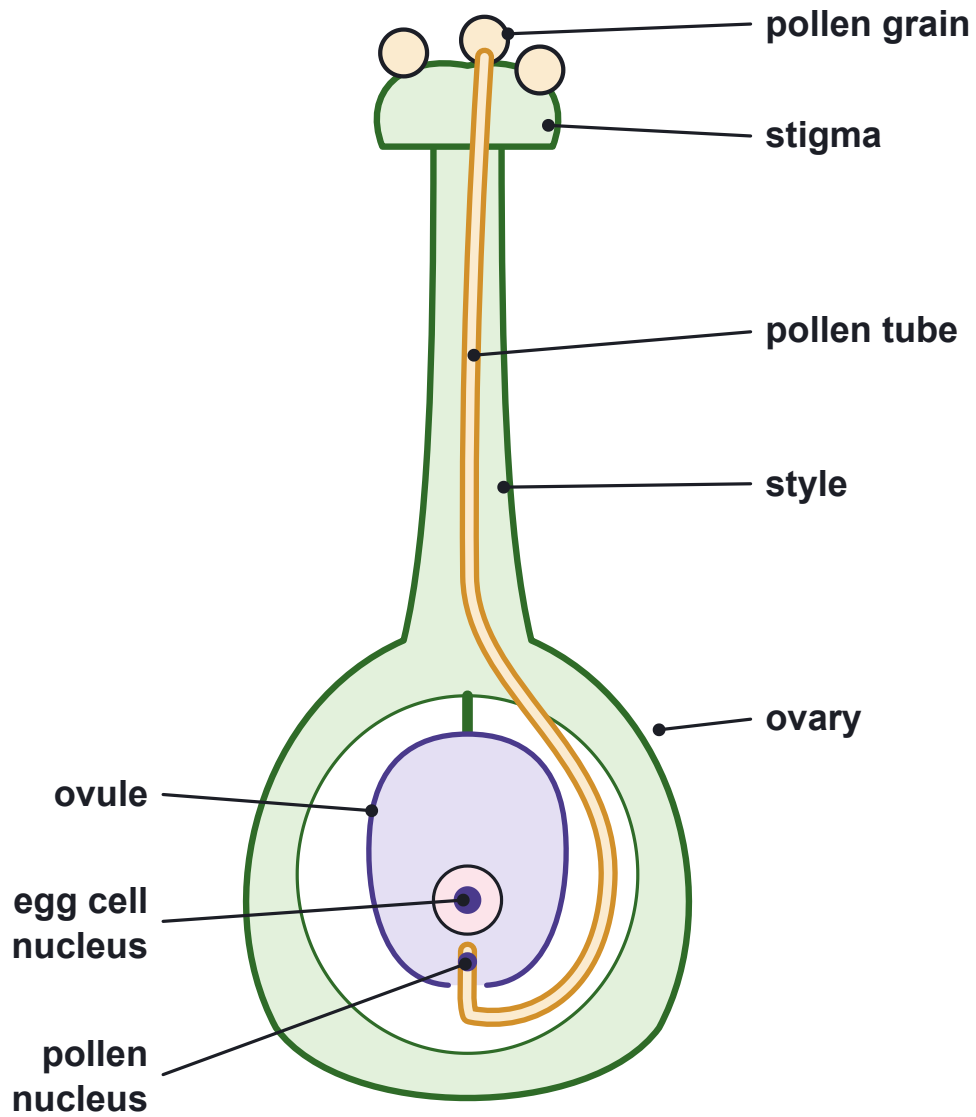
4. Eggs are mixed with sperm (or a sperm is injected into each egg) and the embryos are cultured for a few days.
5. One or two embryos are transferred to the uterus. Progesterone is given to help keep the endometrium ready for implantation.

Exam tip: For IVF, use the two key phrases: normal secretion of hormones is suspended, then artificial doses of hormones induce superovulation.

Sexual reproduction in flowering plants and insect-pollinated flowers Spec D3.1.8, D3.1.9

Flowering plants reproduce **sexually**, even when one plant (a hermaphrodite) has both male and female parts, because haploid gametes still fuse at fertilization.

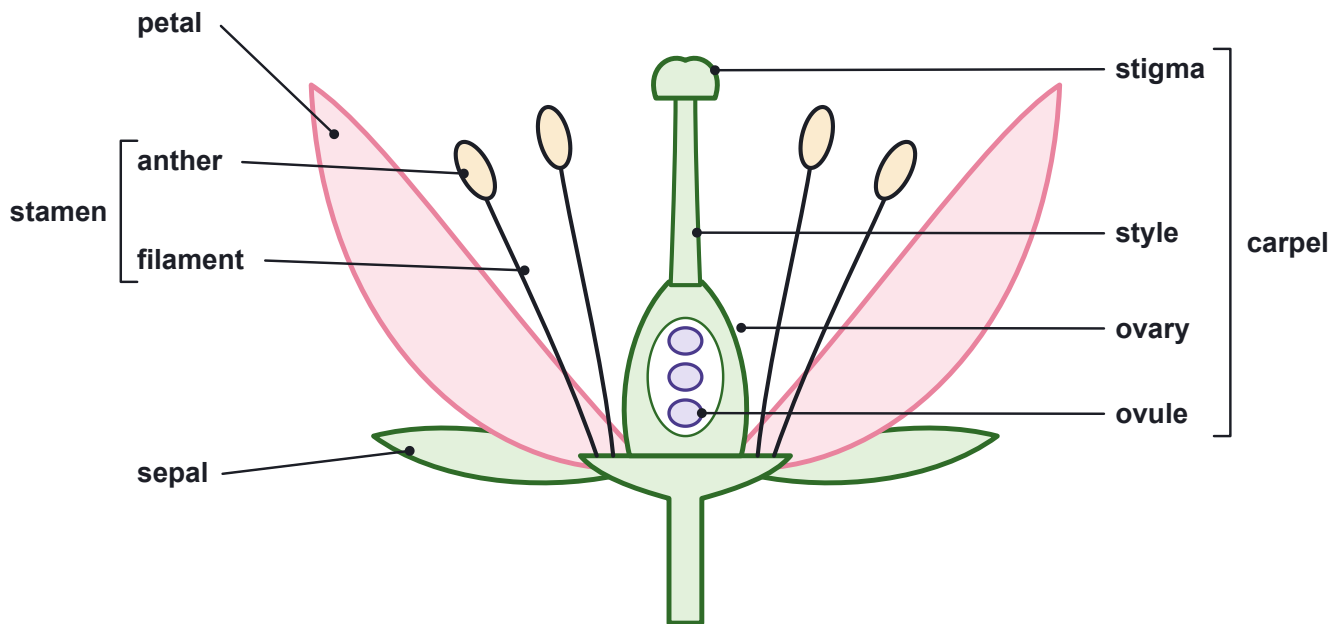
1. **Gamete production:** male gametes form inside **pollen grains** made in the anthers; the female gamete (egg cell) forms inside each **ovule** in the ovary.
2. **Pollination:** pollen is transferred from an anther to a stigma, by animals or wind.
3. **Pollen development:** the pollen grain absorbs water and sugar on the stigma and germinates. A pollen tube grows down through the style to the ovary, carrying the male gametes.
4. **Fertilization:** the tube enters an ovule through the micropyle and a male gamete nucleus fuses with the egg cell nucleus, giving a diploid zygote.
5. The zygote divides by mitosis to form an **embryo**. The ovule becomes a seed and the ovary develops into a fruit.



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After pollination the **pollen tube** grows down the style and delivers the male gametes to the ovule. The 'pollen nucleus' in the figure is the male gamete nucleus that fuses with the egg cell nucleus.

Features of an insect-pollinated flower



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An insect-pollinated flower. The **stamen** (anther and filament) is male; the **carpel** (stigma, style, ovary, ovule) is female.

Structures and functions	
Structure	Function
Petal	Large, brightly coloured and often scented to attract insects
Nectary	Secretes nectar, a sugary reward for insect visitors
Anther	Produces pollen; placed where a visiting insect brushes against it
Filament	Stalk holding the anther in position
Stigma	Sticky surface that receives pollen from an insect
Style	Holds the stigma up; the pollen tube grows through it
Ovary	Contains the ovules; becomes the fruit
Ovule	Contains the female gamete; becomes the seed
Sepal	Protects the flower while it is a bud

Exam tip: Annotated diagrams score for function, not just names: write what each structure does next to its label, as in the table.

Cross-pollination and self-incompatibility Spec D3.1.10, D3.1.11

Self-pollination (pollen reaching a stigma of the same plant) leads to **inbreeding**. Offspring become more homozygous, so genetic diversity falls and harmful recessive alleles are expressed more often, reducing vigour. **Cross-pollination** transfers pollen to a different plant of the same species.

Methods of promoting cross-pollination

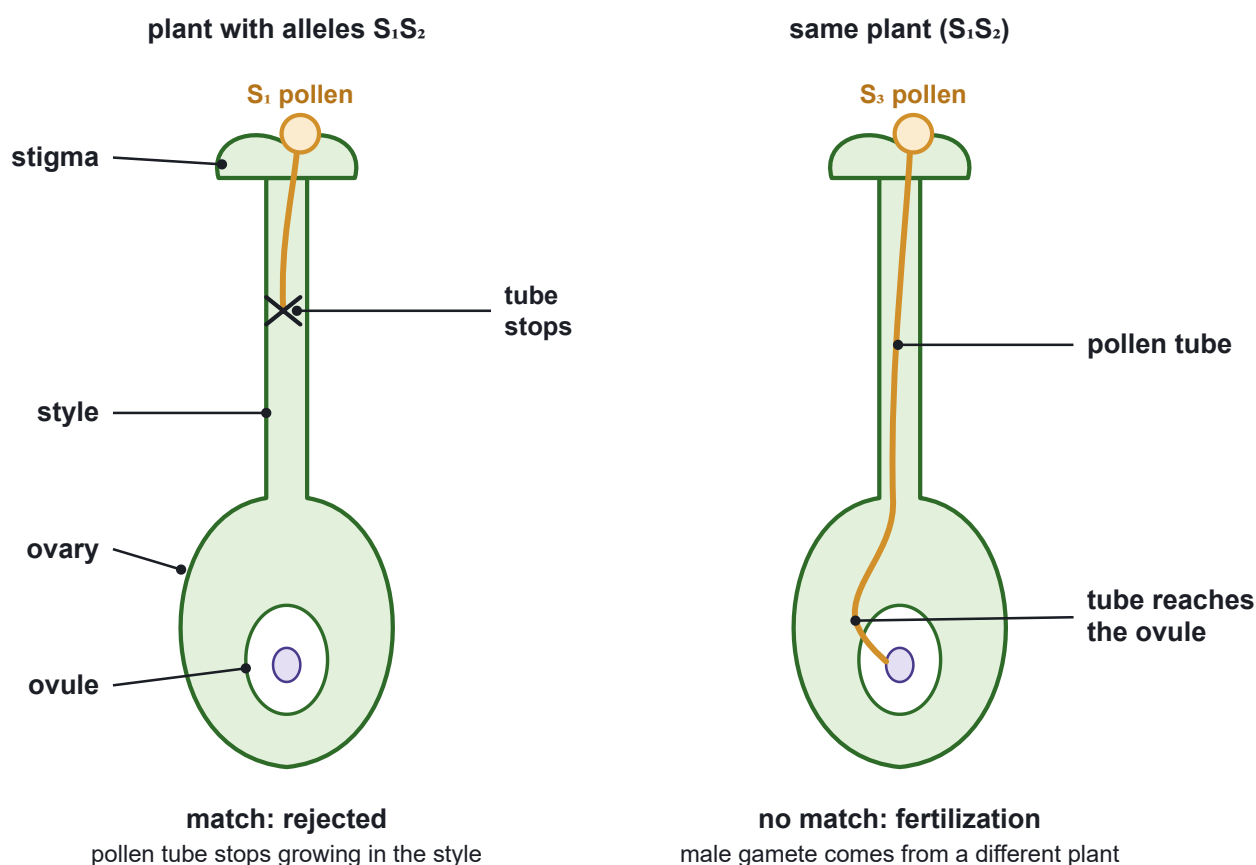
- **Different maturation times:** the anthers release pollen before the stigma of the same flower is receptive (or the other way round), so pollen has to come from another flower.
- **Separate male and female flowers** on the same plant, for example maize, with male flowers at the top and female flowers lower down.

- **Separate male and female plants**, for example holly: a female plant can only be pollinated by pollen from a male plant.
- **Animals or wind** carry pollen between plants: insects, birds and bats travel from flower to flower, and wind carries light pollen long distances.

Self-incompatibility

In many species a **self-incompatibility** gene (often called the S gene) has many alleles. In the commonest type, if the S allele carried by a pollen grain matches either S allele of the plant it lands on, the pollen is recognised as 'self' and its pollen tube stops growing in the style. In some other species, such as the cabbage family, the pollen's S type is set by the plant that made it, and matching pollen fails to germinate on the stigma.

- Pollen from the same plant always matches, so self-fertilization is blocked.
- Pollen from a plant with different S alleles grows normally, so male and female gametes that fuse come from different plants.
- This keeps genetic variation within the species high.



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Self-incompatibility. Pollen whose S allele matches either allele of the plant is rejected, so the male gamete must come from a different plant.

Exam tip: Linking question: how can interspecific relationships assist reproductive strategies? Animal pollinators gain nectar or pollen as food while carrying pollen between plants.

Seed dispersal and germination Spec D3.1.12

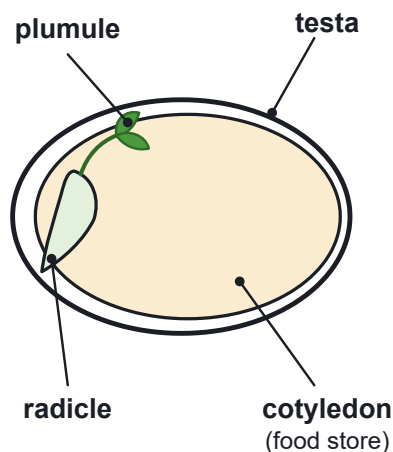
Distinguishing pollination and seed dispersal		
	Pollination	Seed dispersal
What moves	Pollen (containing male gametes)	Seeds (containing embryos), often inside fruits
From and to	Anther to stigma	Parent plant to a new site away from it
When	Before fertilization	After fertilization, once seeds are mature
Purpose	Allows fertilization	Reduces competition with the parent and siblings; spreads the species to new areas

- **Wind:** light seeds or fruits with wings or parachutes (sycamore, dandelion).
- **Animals:** fleshy fruits eaten and seeds passed out in faeces; hooked fruits that catch on fur.
- **Water:** buoyant fruits such as coconuts.
- **Explosive:** pods that dry and burst, flinging seeds (peas and other legumes).

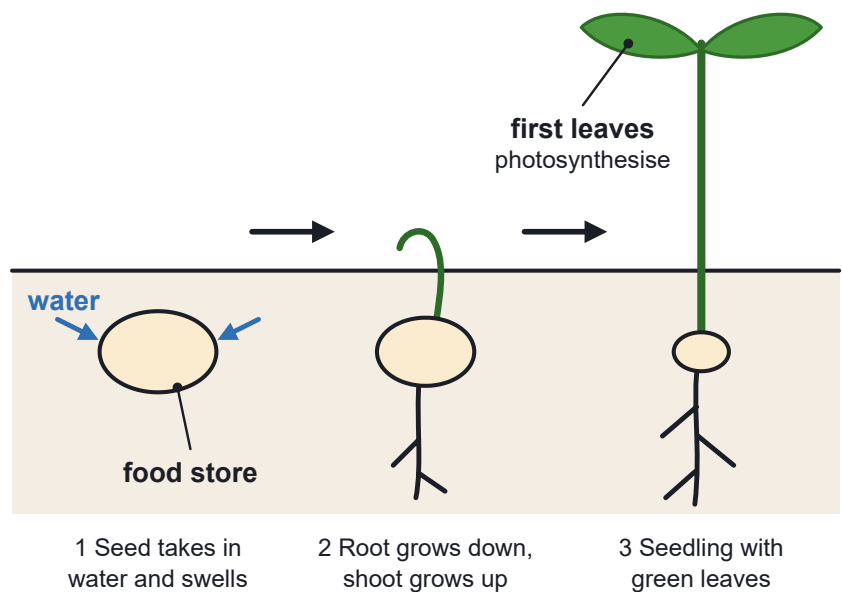
Germination

A seed contains an embryo (radicle, plumule and cotyledons) and food reserves, inside a protective testa. Germination needs **water, oxygen and a suitable temperature**.

1. The seed absorbs water, so it swells, the testa splits and enzymes are activated.
2. The embryo produces the plant growth regulator gibberellin (gibberellic acid), which stimulates production of hydrolytic enzymes such as amylase. This is best understood in cereal grains, where the enzymes are made in the aleurone layer around the food store.
3. Food reserves are **mobilized**: amylase digests starch into maltose and sugars, proteases digest proteins into amino acids, and lipases digest lipids.
4. These soluble products are transported to the growing regions of the embryo for aerobic respiration and growth.
5. The radicle grows out first and becomes the root; the plumule grows up into the shoot. Once leaves open and photosynthesise, the seedling no longer depends on its reserves.



Inside a bean seed



Food reserves are used until photosynthesis begins

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A bean seed and its germination. Food reserves in the cotyledons are used until **photosynthesis** begins.

Common mistake: Do not mix up dispersal and pollination: pollination moves pollen before fertilization; dispersal moves seeds after it.

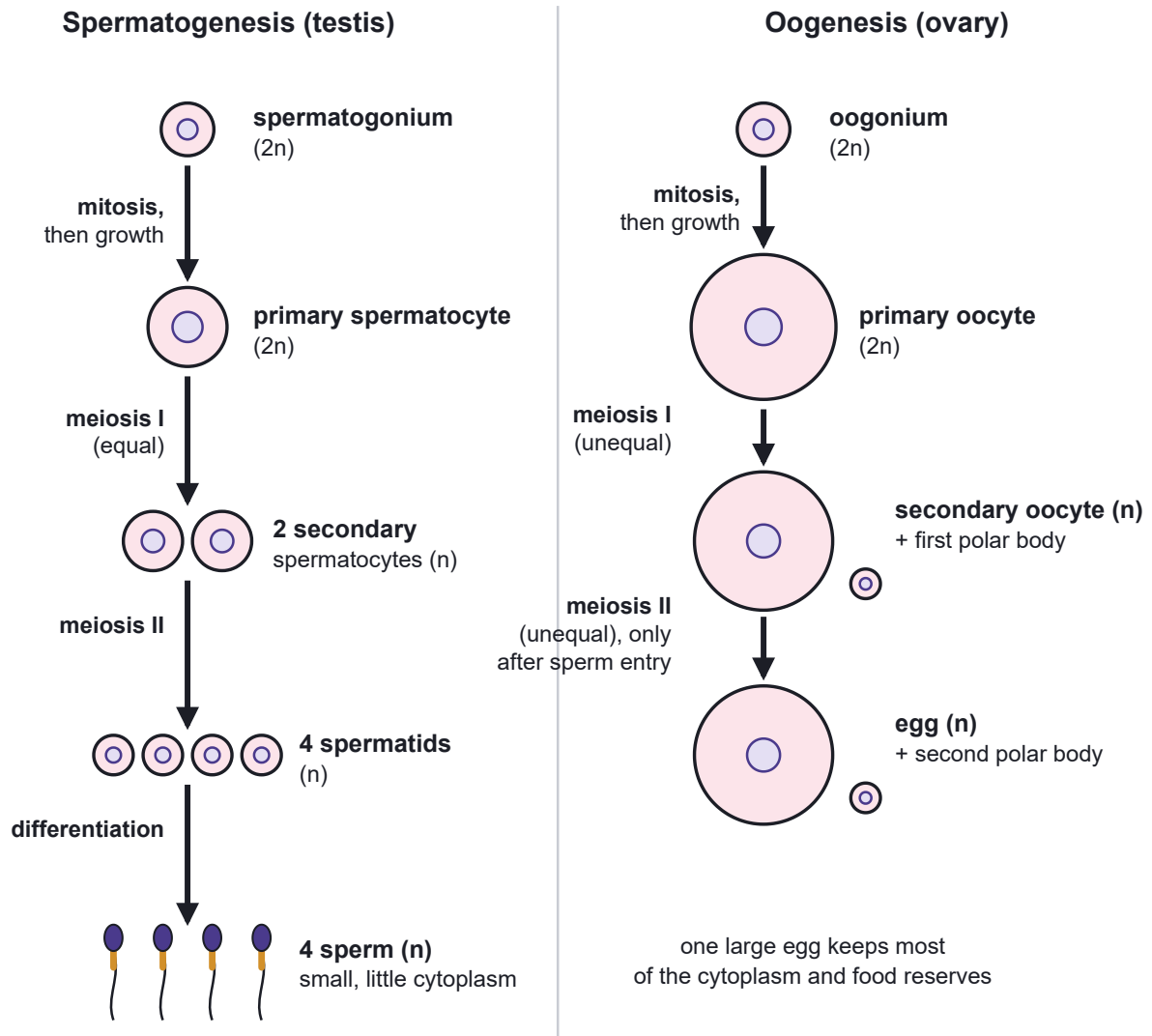
Puberty, spermatogenesis and oogenesis Spec D3.1.13, D3.1.14 HL only

Control of puberty

1. In late childhood the hypothalamus increases its release of **gonadotropin-releasing hormone (GnRH)**.
2. GnRH stimulates the anterior pituitary to increase release of **LH and FSH**.
3. LH and FSH stimulate the gonads to produce more steroid sex hormones: testosterone in the testes, and oestradiol and progesterone in the ovaries.
4. The increased sex hormones cause the changes of puberty, such as growth of the reproductive organs, the start of gamete production and secondary sexual characteristics.

Gametogenesis

Stages of spermatogenesis and oogenesis		
Stage	Spermatogenesis (testis)	Oogenesis (ovary)
Mitosis	Germ cells (spermatogonia) in the wall of the seminiferous tubules divide by mitosis throughout adult life	Germ cells (oogonia) divide by mitosis in the ovary before birth
Cell growth	Some cells grow into primary spermatocytes	Cells grow into primary oocytes, each inside a follicle; meiosis I starts but pauses
Meiosis I	Each primary spermatocyte divides equally into two secondary spermatocytes	In each menstrual cycle one primary oocyte completes meiosis I, unequally: one secondary oocyte gets nearly all the cytoplasm, the other cell is a small first polar body
Meiosis II	Gives four haploid spermatids	Completed only after a sperm enters; unequal again, giving the egg and a second polar body
Differentiation	Spermatids develop into sperm with a tail, mitochondria and an acrosome, helped by Sertoli cells	The egg keeps a large volume of cytoplasm with food reserves
Outcome	Four small sperm per primary spermatocyte; millions produced every day	One large egg per primary oocyte; usually one released per cycle



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Spermatogenesis gives **four small sperm** per primary spermatocyte; oogenesis gives **one large egg** per primary oocyte because both meiotic divisions are unequal.

Exam tip: Linking question: what biological processes involve doubling and halving? Meiosis halves the chromosome number in gametes and fertilization doubles it again.

Preventing polyspermy, the blastocyst and implantation

Spec D3.1.15, D3.1.16

HL only

Mechanisms to prevent polyspermy

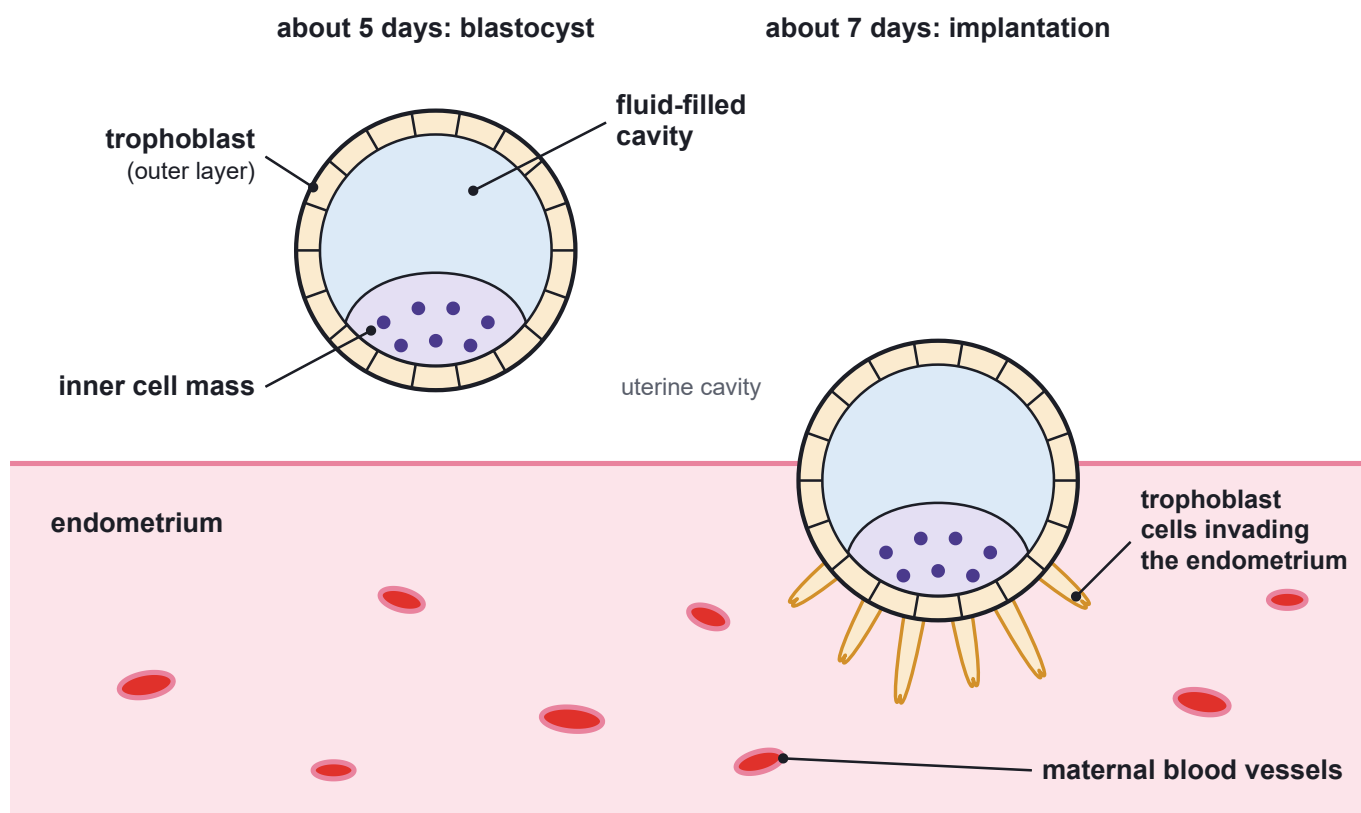
An egg with more than one sperm nucleus would have too many chromosomes and could not develop normally. Two reactions ensure only one sperm fertilizes each egg.

1. **Acrosome reaction:** when a sperm reaches the **zona pellucida** (the glycoprotein layer around the egg), its acrosome releases hydrolytic enzymes that digest a path through it, so the sperm can **penetrate the zona pellucida** and reach the egg cell membrane.
2. The sperm cell membrane fuses with the egg cell membrane.
3. **Cortical reaction:** this fusion causes **cortical granules** just under the egg membrane to release their contents by exocytosis. Enzymes from them alter the zona pellucida so that it hardens and its sperm-binding sites are destroyed, so **other sperm cannot pass through**.

Development of a blastocyst and implantation

- The zygote divides repeatedly by mitosis as it is moved along the oviduct towards the uterus.

- After about five days it has become a **blastocyst**: a hollow ball of cells with an outer layer (trophoblast), an inner cell mass that will form the embryo, and a fluid-filled cavity.
- At about day 7 the blastocyst sinks into the thickened endometrium: this is **implantation**. Trophoblast cells invade the endometrium, giving the embryo nutrients and oxygen and later forming part of the placenta.



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The blastocyst forms after about 5 days and **implants** in the endometrium at about day 7. The inner cell mass becomes the embryo.

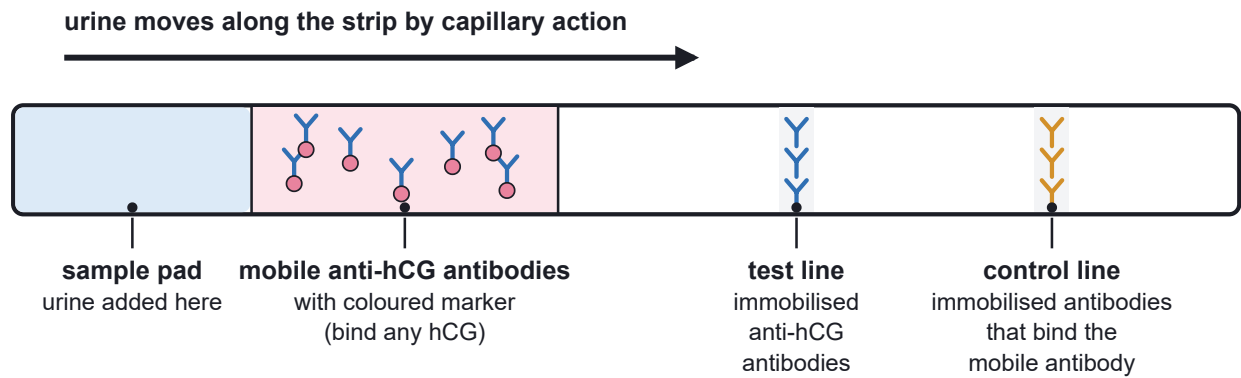
Exam tip: The names of other embryo stages are not required. Know the blastocyst, its parts and implantation.

Pregnancy testing and the placenta Spec D3.1.17, D3.1.18 HL only

Pregnancy testing

From soon after implantation the embryo, and then the developing placenta, secretes **human chorionic gonadotropin (hCG)**. Some hCG passes into the urine, where a test strip can detect it.

1. Urine is applied to one end of the strip. It moves along by capillary action.
2. In the first zone, mobile **monoclonal antibodies** that bind hCG are attached to a coloured marker. Any hCG binds to them.
3. In the test line, monoclonal antibodies against hCG are fixed to the strip. They bind the hCG-antibody-marker complex, so colour builds up: a line appears only if hCG is present.
4. In the control line, fixed antibodies bind the mobile antibodies whether or not hCG is present. This line shows the test has worked.



Pregnant: hCG present test line and control line coloured



Not pregnant: no hCG control line only



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A pregnancy test uses **monoclonal antibodies** against hCG. The control line shows the test has worked; the test line appears only if hCG is in the urine.

Role of the placenta

The **placenta** forms from foetal tissue and the endometrium. Foetal blood flows in capillaries inside **placental villi**, which project into spaces filled with maternal blood. The villi give a **large surface area** for exchange, and the two bloods do not mix.

Exchange across the placenta	
Direction	Substances
Mother to foetus	Oxygen, glucose, amino acids, fatty acids, water, mineral ions, vitamins, some antibodies
Foetus to mother	Carbon dioxide, urea and other wastes

Because the placenta supplies everything the foetus needs and removes its wastes, the foetus can be **retained in the uterus to a later stage of development** than in mammals that do not develop a placenta, such as marsupials, whose young are born very small and finish developing in a pouch.

Exam tip: Linking question: what are the roles of barriers in living systems? The placenta keeps maternal and foetal blood separate while still allowing exchange.

Hormones in pregnancy and childbirth, and HRT Spec D3.1.19, D3.1.20 HL only

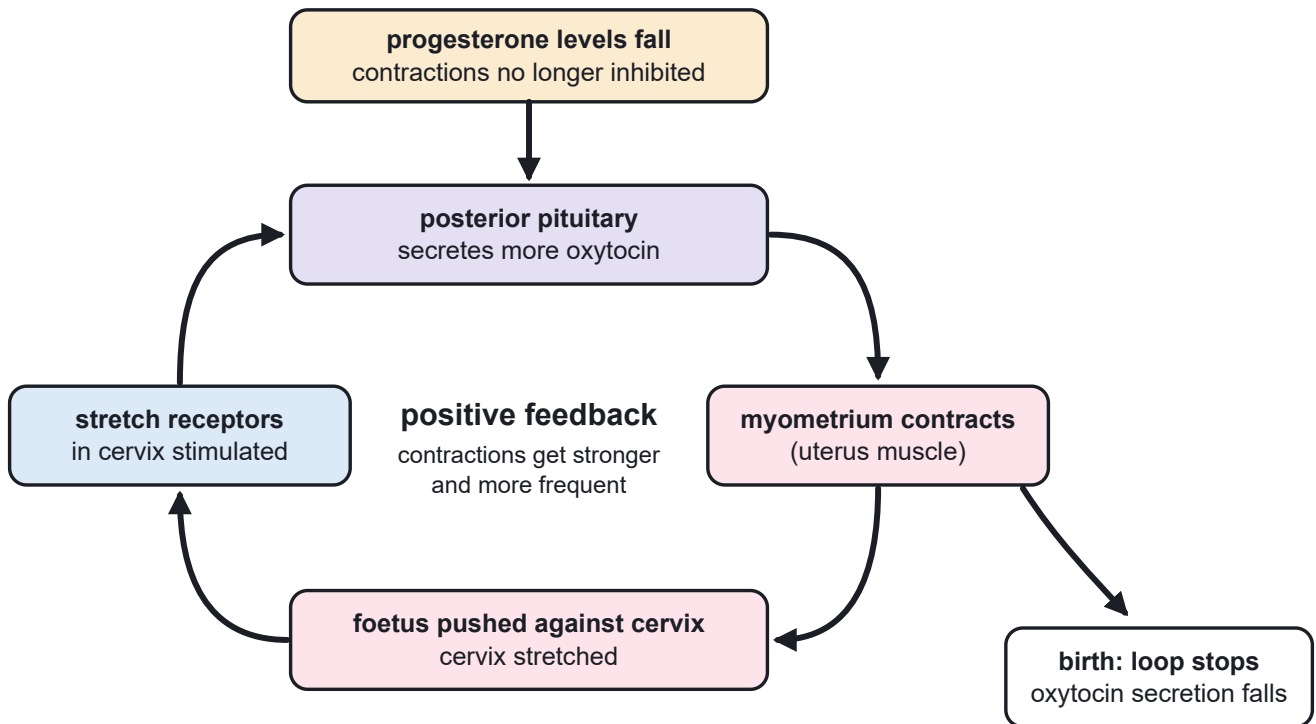
Hormonal control of pregnancy

1. The embryo secretes hCG, which keeps the corpus luteum alive instead of letting it degenerate.
2. The corpus luteum continues secreting **progesterone** (and oestradiol), which maintains the endometrium and prevents menstruation.
3. Progesterone also inhibits contractions of the uterus muscle (myometrium) and inhibits FSH and LH, so no new cycle starts.

4. From about the end of the third month the placenta secretes enough progesterone itself, and the corpus luteum degenerates. Placental progesterone maintains the pregnancy to term.

Childbirth

1. At the end of pregnancy **progesterone levels decrease**, so contractions are no longer inhibited.
2. This allows the posterior pituitary to increase secretion of **oxytocin**.
3. Oxytocin stimulates contractions of the myometrium. Contractions push the foetus against the cervix, and stretch receptors there stimulate more oxytocin secretion.
4. This is **positive feedback**: contractions become stronger and more frequent until the baby is born, then oxytocin secretion falls.



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Childbirth is controlled by **positive feedback**: each contraction stretches the cervix and causes more oxytocin secretion, until the baby is born.

Hormone replacement therapy and coronary heart disease

After the menopause the ovaries stop secreting oestradiol and progesterone. **Hormone replacement therapy (HRT)** gives these hormones to relieve symptoms.

- **Early epidemiological studies** found that women taking HRT had a lower incidence of coronary heart disease (CHD). This was taken to be cause and effect.
- **Later randomized controlled trials**, where women were randomly given HRT or a placebo, showed that HRT led to a **small increase** in the risk of CHD.
- The original correlation was explained by a **confounding factor**: HRT patients tended to have a higher socioeconomic status, and higher socioeconomic status itself causes a lower risk of CHD.

Exam tip: Nature of science: a correlation does not prove causation. Randomized controlled trials remove confounding factors by random allocation to treatment and control groups.

Quick check

1. State one advantage of asexual reproduction.
2. Which hormone surge triggers ovulation, and what causes it?
3. What happens to the sperm's tail and mitochondria at fertilization?
4. What is the function of the stigma?
5. **HL only** Which reaction prevents polyspermy?

Quick check answers

Reproduction

1. Offspring are genetically identical to a parent that is already adapted to the existing environment.
2. An LH surge, caused by positive feedback from high oestradiol levels.
3. They are destroyed; only the sperm nucleus contributes.
4. A sticky surface that receives pollen.
5. The cortical reaction, which alters the zona pellucida so other sperm cannot pass through.