DP IB Biology: HL

Your notes

11.4 Sexual Reproduction

Contents

11.4.1 Oogenesis & Spermatogenesis

Your notes

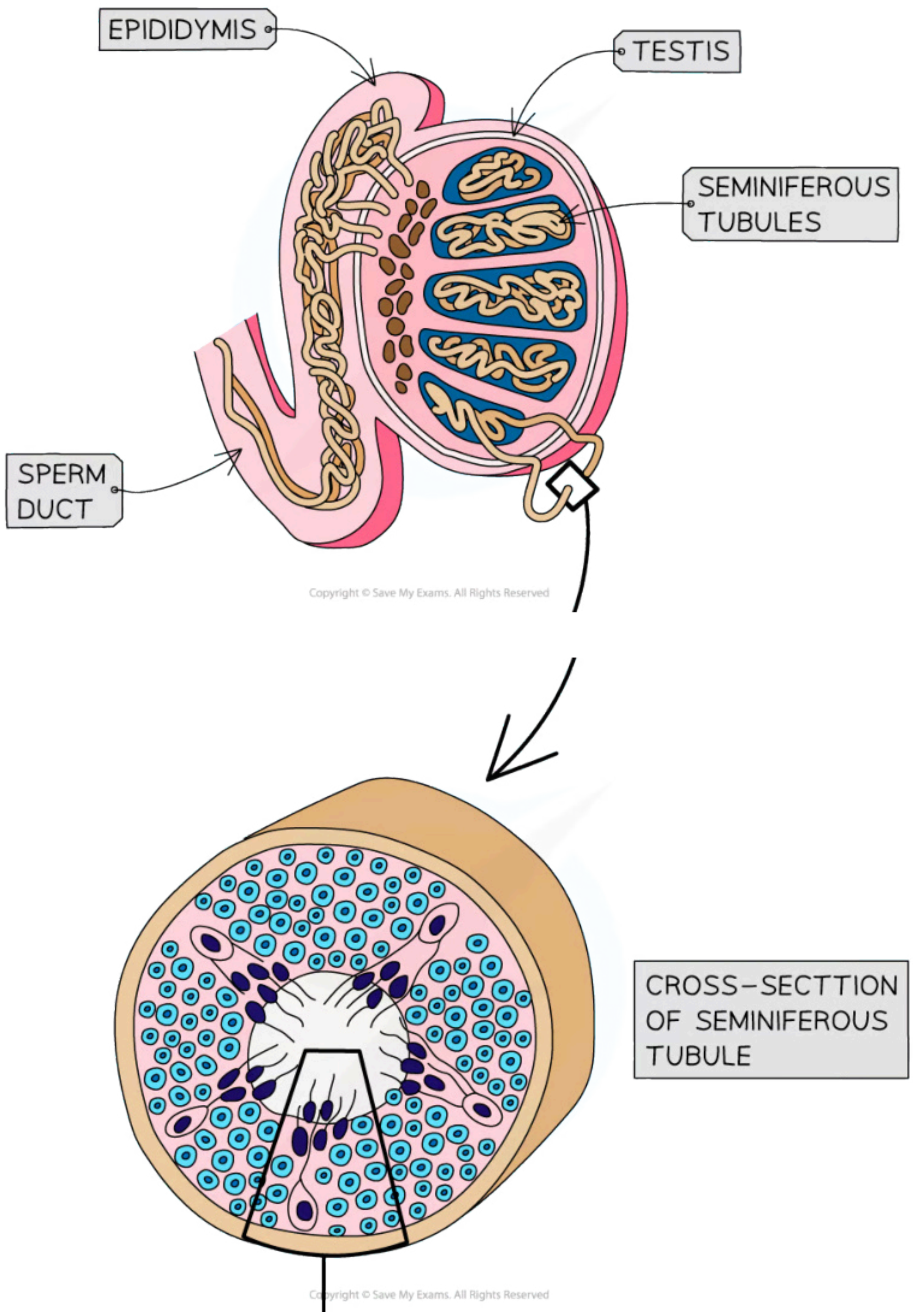
Similarities Between Oogenesis & Spermatogenesis

- **Sexual reproduction** involves **fertilisation**; the **fusion of sex cells**, or **gametes**, from two parents
  - Gametes are **specialised**, haploid cells
  - The fusion of gametes forms a zygote
- In animals, male gametes are **sperm** cells and female gametes are **ova** (singular ovum), also known as **oocytes**
- Gametes are produced in pairs of glands known as **gonads**
  - Sperm are produced in the male **testes** (singular testis)
  - Ova are produced in the female **ovaries** (singular ovary)
- The process of gamete formation is known as **gametogenesis**, and it involves both **mitosis** and **meiosis**
  - Specifically the production of sperm cells is **spermatogenesis** and production of ova is **oogenesis**
- Gametogenesis in both males and females involves the following stages:
  - Cells **dividing by mitosis** to produce many new cells, all of which have **the potential to develop into gametes**
  - Cells **growing** and differentiating
  - Cells **dividing by meiosis** to produce **haploid gametes**

Spermatogenesis

- The production of sperm takes place in the **testes** in males **from puberty onwards**
- The testes contain **many small tubes**, or **tubules**, known as **seminiferous tubules**
  - The gaps, or **interstices**, between the seminiferous tubules are filled with cells called **interstitial cells**, sometimes known as **Leydig cells**
  - The interstitial cells produce the male sex hormone **testosterone**
- Spermatogenesis begins in the **germinal epithelium**, a layer of cells that makes up the **outer layer** of the seminiferous tubules
- Cells in the germinal epithelium **divide by mitosis**, producing diploid cells called **spermatogonia** (singular spermatogonium)
  - Of the two daughter spermatogonia cells, one will go on to eventually become a sperm cell, while the other remains in the germinal epithelium where it can continue development
- Spermatogonia begin to migrate from the germinal epithelium towards the lumen of the seminiferous tubules; they do this by moving through the gaps between **Sertoli cells**
  - Sertoli cells form the **inner lining of the seminiferous tubules**
- Spermatogonia differentiate into immature sperm cells called **primary spermatocytes**
- Primary spermatocytes mature and **divide by meiosis**
  - **Meiosis I** forms **secondary spermatocytes**
  - **Meiosis II** forms **spermatids**
- Spermatids formed during meiosis remain **associated with the Sertoli cells** as they **mature into sperm cells**, also known as **spermatozoa**
- Once fully matured, the sperm cells detach from the Sertoli cells and move **along the seminiferous tubule lumen towards the sperm duct**

- On their way towards the sperm duct, the mature sperm pass through a coiled tube called the **epididymis**



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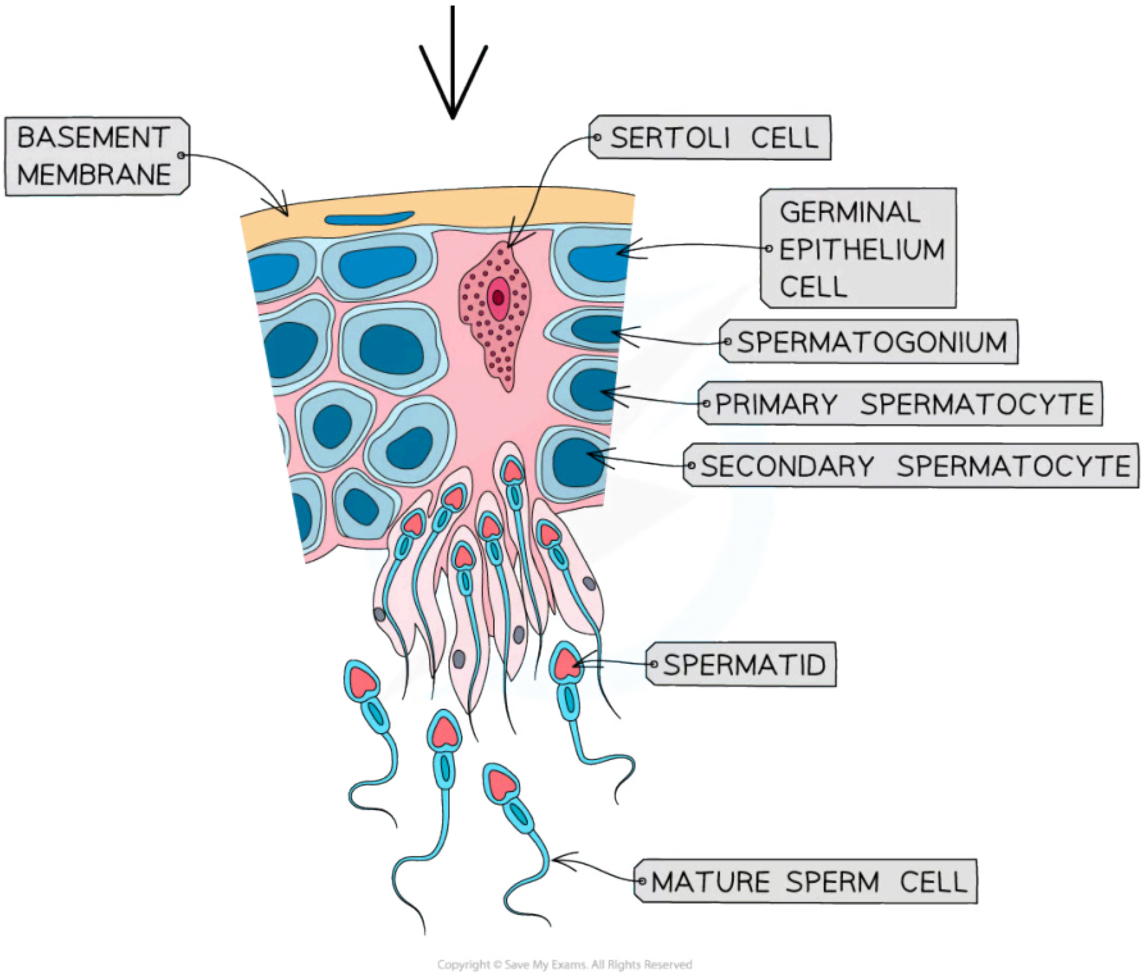
BASEMENT MEMBRANE
SERTOLI CELL
GERMINAL EPITHELIUM CELL
SPERMATOGONIUM
PRIMARY SPERMATOCYTE
SECONDARY SPERMATOCYTE
SPERMATID
MATURE SPERM CELL
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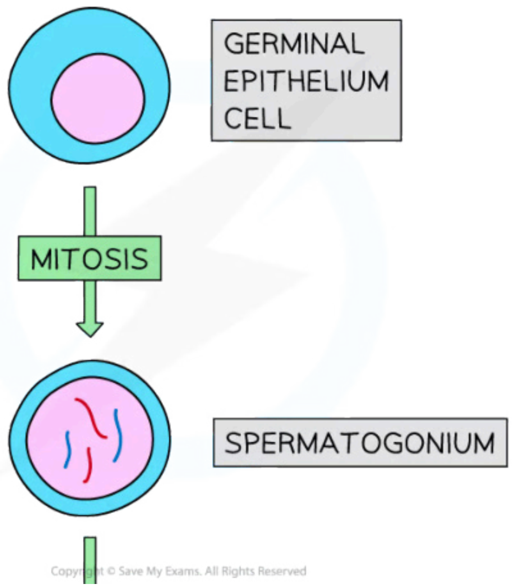
GERMINAL EPITHELIUM CELL
MITOSIS
SPERMATOGONIUM
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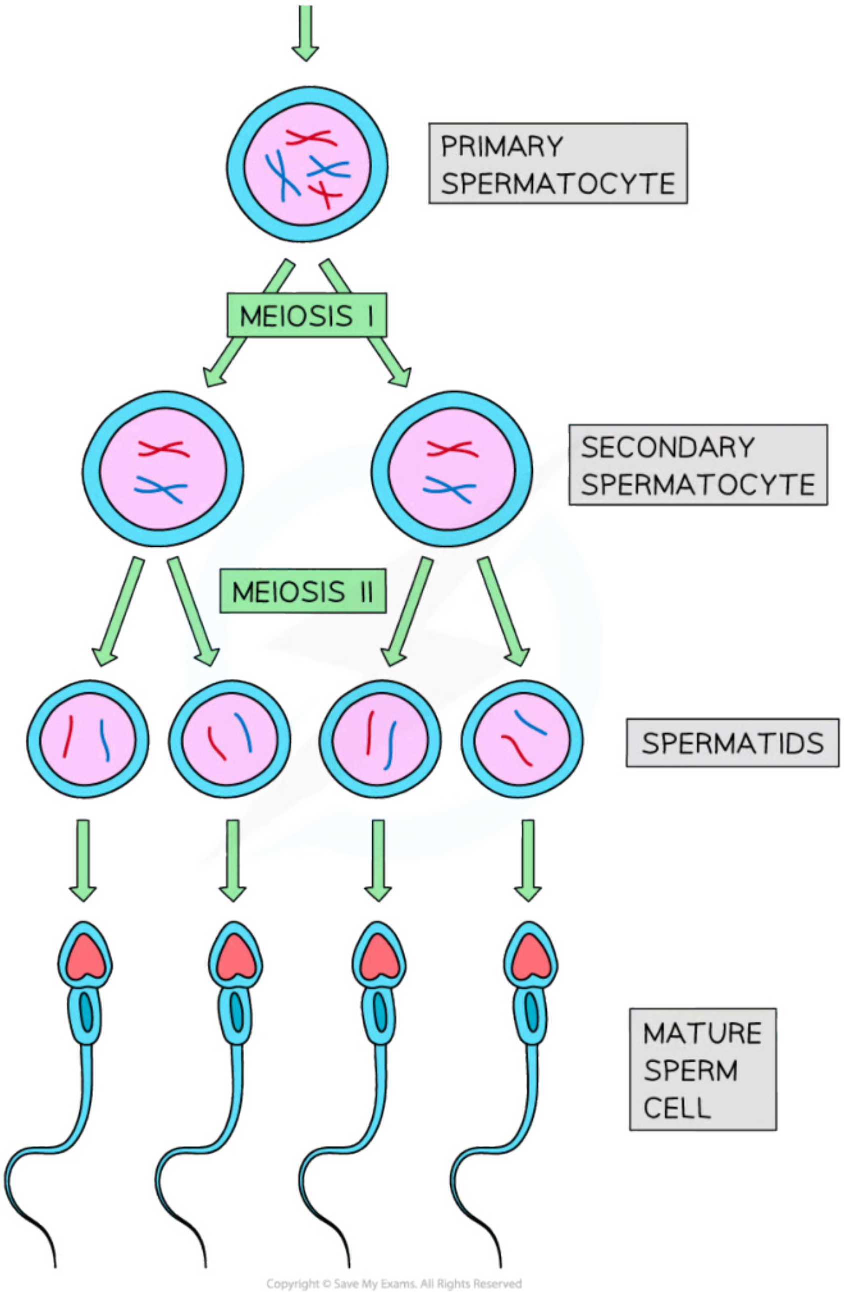


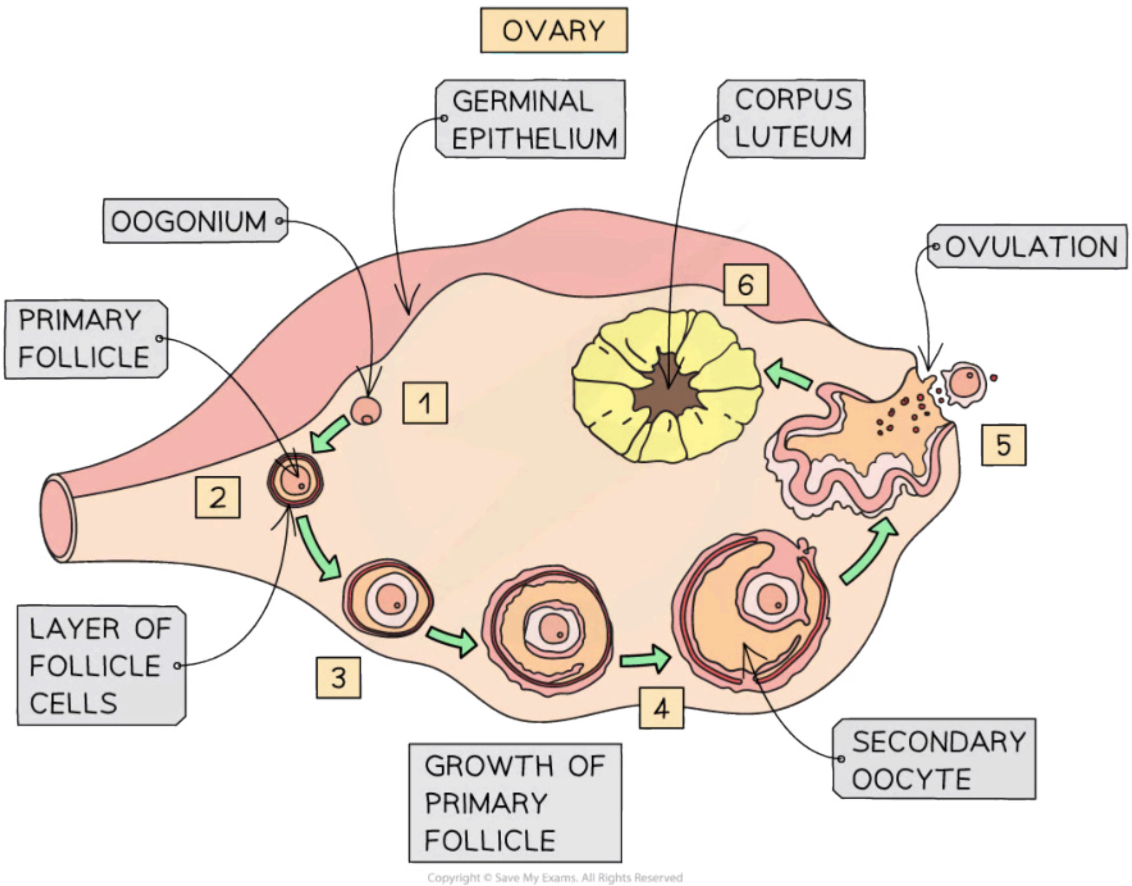
Spermatogenesis begins in the germinal epithelium of the seminiferous tubules and the new cells migrate towards the tubule lumen as they differentiate. Both mitosis and meiosis are involved.

Oogenesis

- The production of **ova** begins **in the ovaries of the female foetus** before birth
- The ovaries are surrounded by an **outer layer of cells** called the **germinal epithelium**; the cells in this layer **divide by mitosis** throughout the first 7 months of foetal development to form **diploid cells called**

Your notes

oogonia (singular oogonium)
  - The oogonia **migrate throughout the tissues of the ovaries**
  - This process of oogonia formation **stops after 7 months**, by which time several million oogonia have been produced
  - These are all the oogonia that the ovaries will produce in the female's lifetime
- During the **few months leading up to birth**, the oogonia in the foetus' ovaries **grow in size** and enter **meiosis I**, and a **layer of cells** called **follicle cells** develop around them
  - The partially divided oogonia together with their layer of follicle cells are known as **primary follicles**
- Once the oogonia have developed into primary follicles the **oogenesis process pauses** until the start of puberty
  - Although the ovaries contain several million primary follicles at birth, many of them degrade throughout a woman's life and never reach maturity
- When puberty begins, the hormone FSH stimulates the **continued development of several primary follicles** in the ovary
  - **Only one** of the stimulated follicles will reach **maturity**
- **Meiosis I continues** and the primary follicle divides to form **two new cells**
  - The division of cytoplasm is **not equal** and the result of meiosis I is a **secondary oocyte** along with a **very small cell** called a **polar body**
  - The polar body cell has **very little cytoplasm** and **does not mature further**
- The secondary oocyte formed at the end of meiosis I enters **meiosis II**; at this point, it leaves the ovary, together with its layer of follicle cells, in the process of **ovulation**
  - The remains of the follicle that are left behind in the ovary develop later into the **corpus luteum**
- The secondary oocyte **doesn't finish meiosis II until after a sperm cell enters it**, at which point meiosis II finishes **just before the nuclei fuse**
  - The secondary oocyte **becomes an ovum very briefly** between the end of meiosis II and the fusion of the two nuclei
  - A **second polar body** is produced at the completion of meiosis II


OVARY
GERMINAL EPITHELIUM
CORPUS LUTEUM
OOGONIUM
OVULATION
PRIMARY FOLLICLE
6
1
5
2
LAYER OF FOLLICLE CELLS
3
4
SECONDARY OOCYTE
GROWTH OF PRIMARY FOLLICLE
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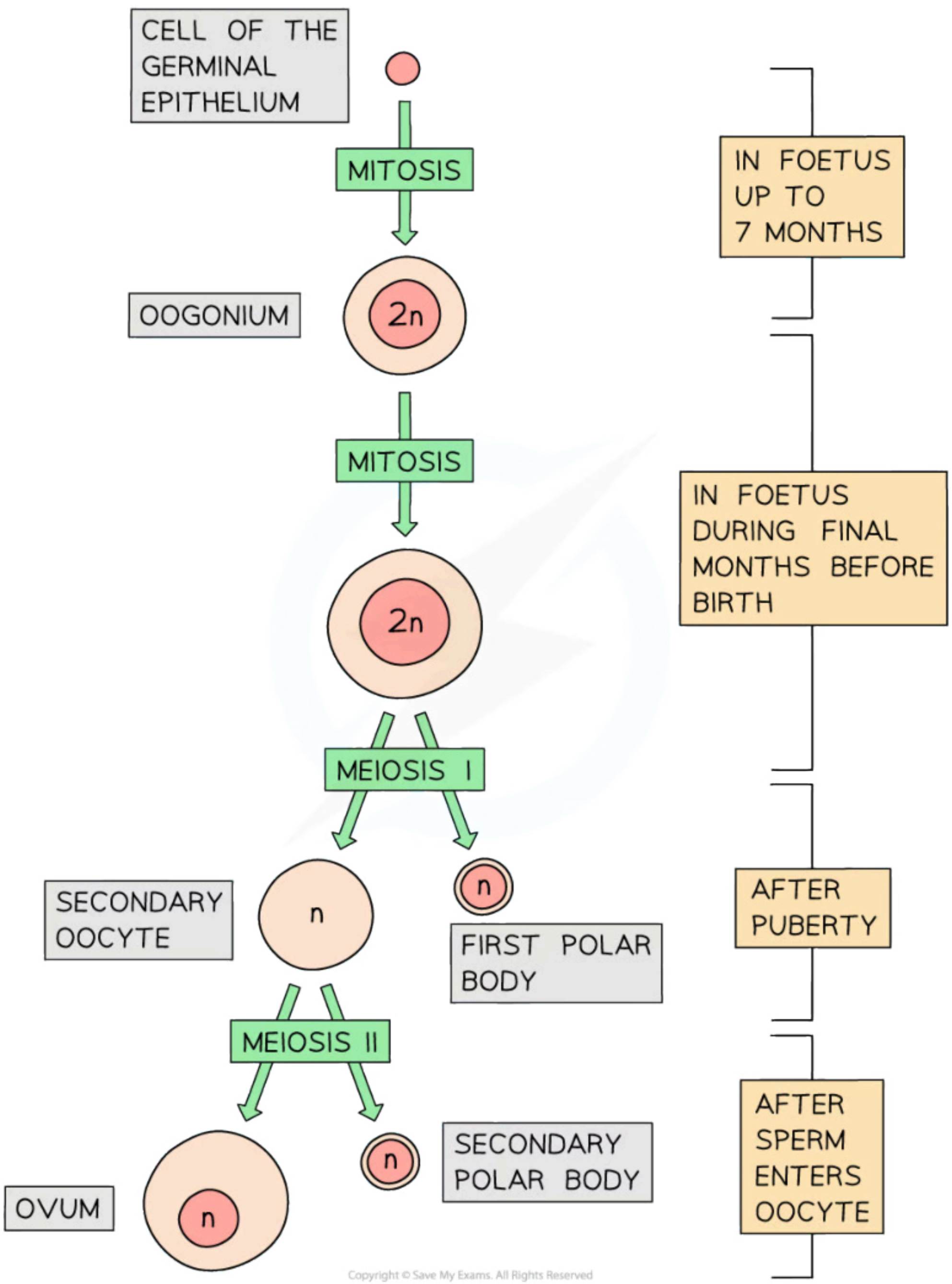


Oogenesis also begins in the germinal epithelium before new cells migrate through the tissues of the ovary. Both mitosis and meiosis are involved.

Your notes

Differences Between Oogenesis & Spermatogenesis

- Oogenesis and spermatogenesis have **some processes in common**, including:
  - Mitosis
  - Meiosis
  - Cell growth
  - Cell differentiation
- The two types of gametes that form have **very different roles** in the fertilisation process, so although there are **similarities** in **how they form**, there are **differences** between the **results** of oogenesis and spermatogenesis

Differences Between Oogenesis & Spermatogenesis Table

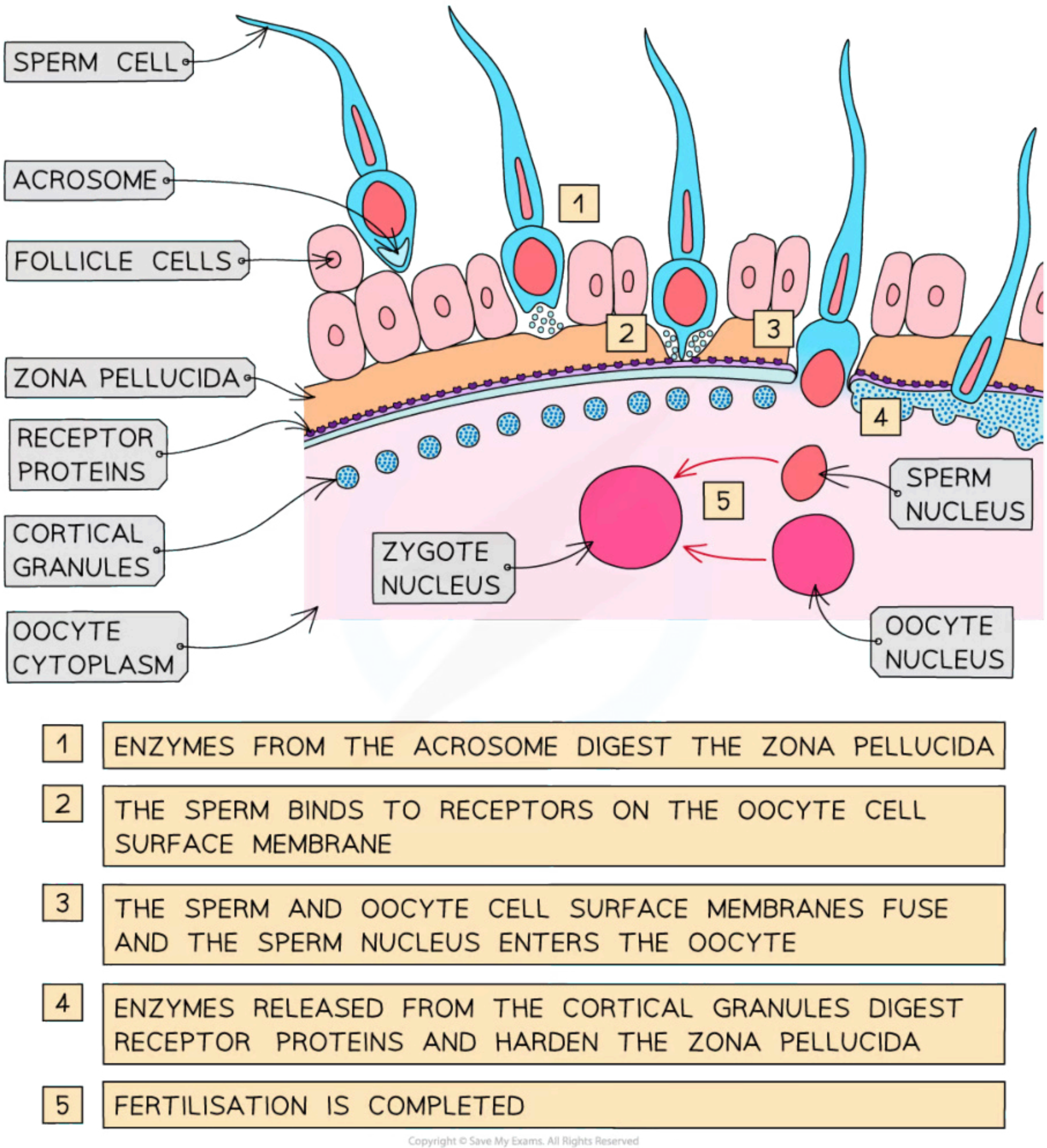
	Oogenesis	Spermatogenesis
Structure of gametes	Ova are large, immobile cells with a large cytoplasm and a surrounding layer of follicle cells	Sperm are small, mobile cells with little cytoplasm and an acrosome that contains enzymes
Daughter cells per meiotic division	One ovum is produced at the end of meiosis II; the polar bodies produced in meiosis I and II do not give rise to ova	Four sperm cells are produced at the end of meiosis II
Frequency at which process occurs	Once per menstrual cycle	Continuous from puberty onwards
Number of gametes produced	A few hundred mature ova during a woman's lifetime; less than 1% of the primary follicles that survive to puberty reach eventual maturity	Millions of sperm cells, at different stages of development, are present in the testes throughout an adult male's life

11.4.2 Fertilisation

Your notes

Preventing Polyspermy

- Fertilisation is the **fusion** of **one sperm cell** and **one ovum**; this fusion of two haploid nuclei gives rise to a diploid zygote
- During sexual reproduction, **many sperm are released**, and the sperm cells are attracted towards the secondary oocyte by chemical signals
  - Remember that at this point in the oogenesis process, meiosis II has not yet been completed, so **the female gamete is still a secondary oocyte** and not yet an ovum
- When the sperm cells reach the secondary oocyte, the process that takes place at its cell surface **prevents more than one sperm from passing through its cell surface membrane**
  - The entry of more than one sperm into a single oocyte is known as **polyspermy**
- The oocyte is surrounded by a **layer of follicle cells**, as well as a layer of glycoproteins known as the **zona pellucida**
- The sperm cells need to **digest the glycoproteins of the zona pellucida** in order to reach the oocyte cell surface membrane; they do this by **releasing digestive enzymes from a structure called the acrosome**
  - This is known as the acrosome reaction
- When the first sperm cell digests its way through the zona pellucida, it reaches the oocyte cell surface membrane; **complementary receptors on the head of the sperm bind with proteins on the oocyte cell surface membrane**, enabling the cell surface membranes of the two gametes to **fuse together** and the sperm nucleus to enter the oocyte
  - At this point the process of meiosis II continues, leading to the release of the second polar body and the **formation of the mature ovum**
- The fusion of the two cell surface membranes triggers the **movement of a series of vesicles called cortical granules**; the vesicles move from the outer layer of the ovum cytoplasm to the cell surface membrane, **releasing enzymes that digest the binding proteins on the cell surface of the ovum** and that **cause the zona pellucida to harden**
  - This is the cortical reaction
  - The enzymes are released by the process of exocytosis
  - Once the binding proteins have been broken down and the zona pellucida has hardened, **no more sperm cells can enter** the ovum; **polyspermy is prevented**
- Inside the ovum the **male and female nuclei fuse** together and **fertilisation is completed**



Mechanisms during the process of fertilisation prevent polyspermy

Your notes

Internal & External Fertilisation

- Fertilisation is the fusion of **one sperm cell** and **one ovum**
- Sperm cells tend to be **mobile**, or **motile**, enabling them to **move towards the ovum**
- For sperm to be able to move towards the ovum they need to be **released into a fluid medium**
- Aquatic animals are constantly **surrounded by a fluid medium**, so sperm can be **released directly into the environment** and **fertilisation can take place outside the body**; this is **external fertilisation**
  - Animals that carry out external fertilisation include **fish** and **amphibians**
  - In external fertilisation the **risks of gametes being eaten by predators or washed away from each other** are **high**, so species that carry out external fertilisation often **release both ova and sperm** into the water **in very large quantities** to increase the chances of reproducing successfully
- Male land animals **release sperm**, along with **fluid** produced in their bodies, into the **internal reproductive tract of the female** animal; this is **internal fertilisation**
  - Animals that carry out internal fertilisation include **birds** and **mammals**
  - Internal fertilisation ensures that the **gametes are in close proximity** to each other and that they are **protected from predation**, so gamete numbers tend to be smaller
    - **ova** are often released **one at a time** in this type of fertilisation
  - In humans the fluid is known as **semen**; sperm and semen are released into the female vagina during sexual intercourse

Your notes

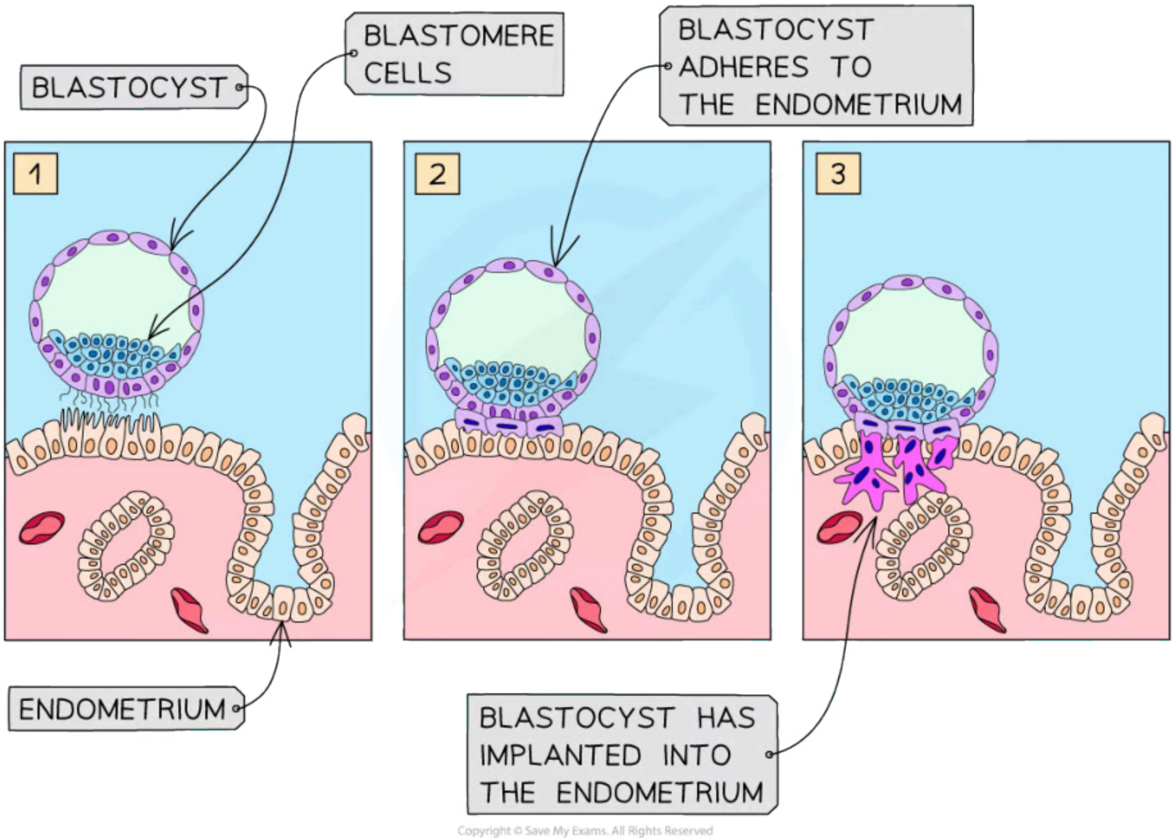
11.4.3 Pregnancy

Your notes

Implantation of the Blastocyst

- Following human fertilisation, the newly **fertilised ovum divides by mitosis** to form **two diploid nuclei** (i.e. each nucleus contains two sets of chromosomes) and the cytoplasm divides equally to form a two-cell embryo
- Mitosis continues to form a four-cell embryo and this process continues until eventually, the embryo takes the shape of a hollow ball called a **blastocyst** (with an internal group of cells called **blastomeres**)
  - Blastomeres will eventually develop into the **foetus**
- The embryo is now referred to as a blastocyst and up until this point is found **in the oviduct**
- After about seven days it consists of around 125 cells and will have reached the **uterus**
- During the embryo stage and up until this point the blastocyst is surrounded by a **protective extracellular coat** called the **zona pellucida**; at around seven days of age this coat breaks down and is lost
- The blastocyst has used up the nutrient supplies of the egg cell and now needs an external supply of **nutrients**, which it obtains by **implanting** into the **endometrium** (uterus lining)
- The outer layer of the blastocyst develops finger-like projections that allow it to **penetrate** the endometrium
- At this stage, there is already an **exchange of nutrients and oxygen with the mother's blood**
- The embryo continues to grow and develop rapidly after this point

Your notes



The blastocyst implants into the endometrium of the uterus

Comparing Gestation Between Mammals

Your notes

- The average human **gestation period** (the time between conception and birth) is around **38 weeks**
- Humans are born relatively helpless, immobile, and unable to obtain their own food
  - Species like this are classified as **altricial species**
  - Generally altricial species have **shorter gestation periods**
- Other species are born in an advanced state; they are able to move around, have good vision and are able to feed themselves almost immediately
  - Examples include ducks and horses
  - Species like this are classified as **precocial**
  - Mammals with a **large body mass** are generally precocial and have **longer gestation periods**

The correlation between animal size and the development of their young at birth

- We can compare **gestation periods** for mammals with different **adult body masses**, according to the **development of the young at birth** (i.e. whether the species is altricial or precocial)
- For **both altricial and precocial mammal species**, the length of the gestation period is **positively correlated** with adult body mass
  - However, this does not always hold true (some mammal species may have similar gestation periods despite having different body masses)

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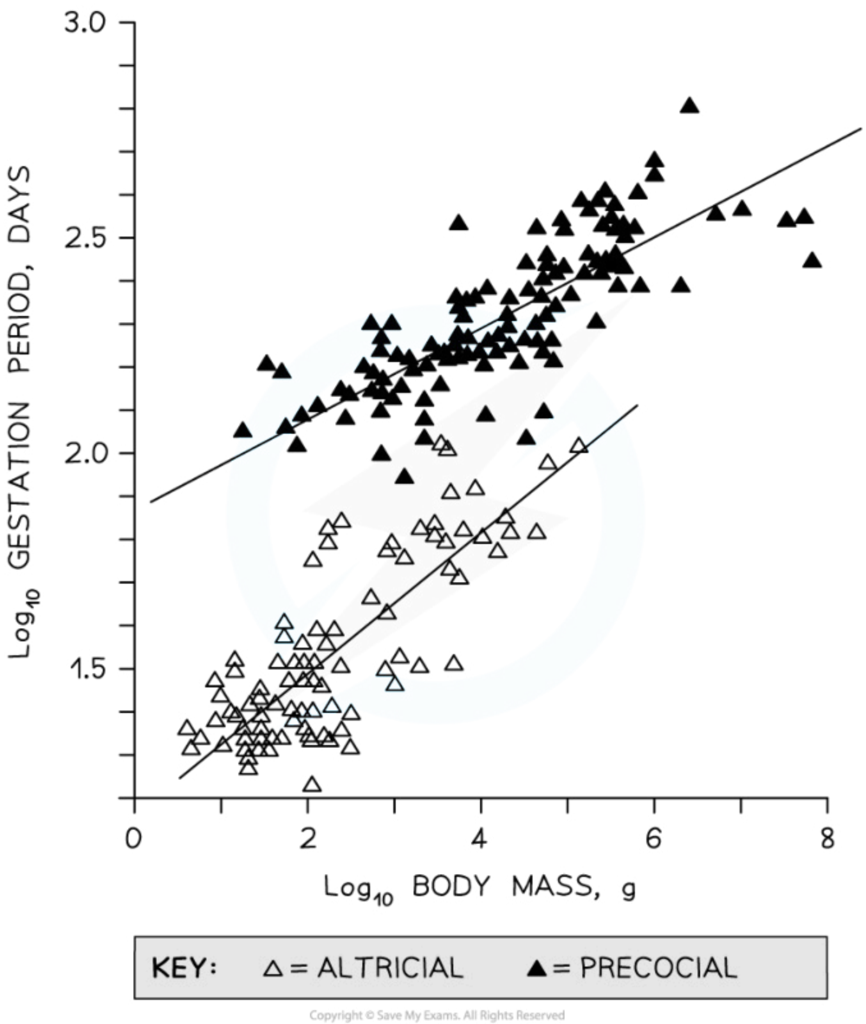


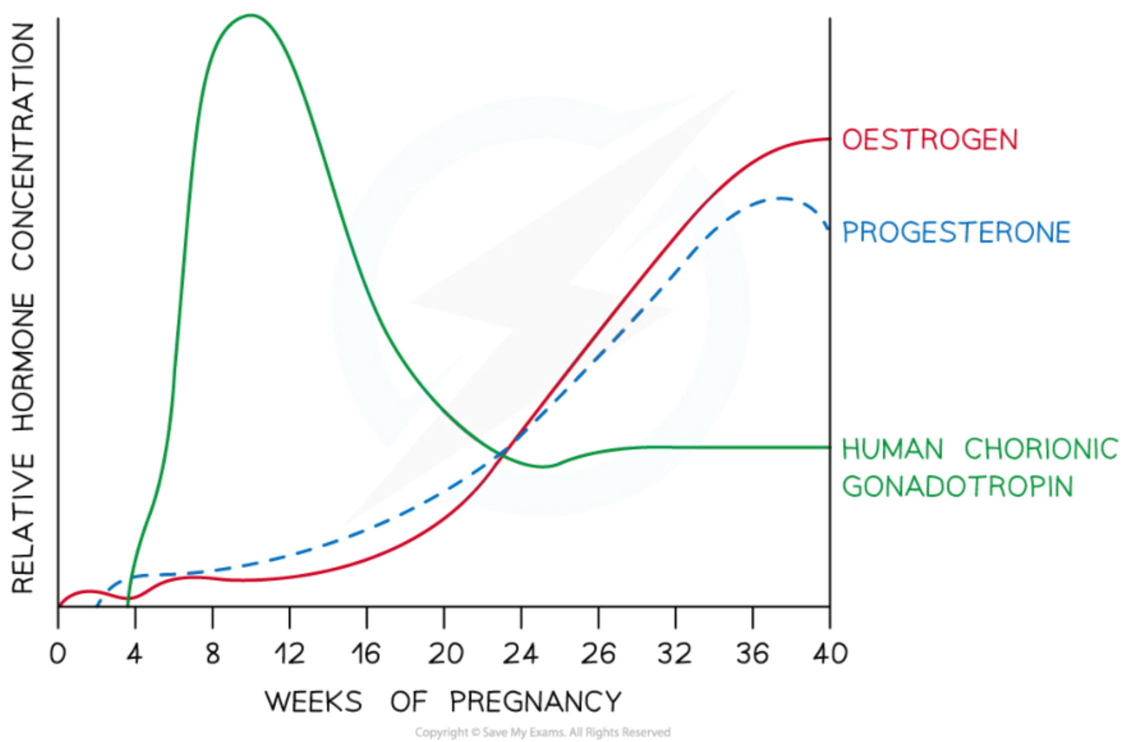
The relationship between gestation period and adult body mass for mammal species subdivided into whether the species are described as altricial or precocial

Your notes

11.4.4 Hormones in Pregnancy

Role of hCG in Early Pregnancy

- Shortly after the developing embryo implants into the endometrium it begins secretion of the hormone **human chorionic gonadotropin** (hCG)
- hCG is secreted during the first **8–10 weeks** of pregnancy
- The role of this hormone is to:
  - **Stimulate the corpus luteum** in the ovary to **maintain secretion of oestrogen and progesterone** (in order to continue the development of the endometrium)
  - **Stimulate** the **growth of the placenta** and **uterine enlargement**
  - **Inhibit menstruation**
- During the second trimester (after **12 weeks**) hCG **declines** and the placenta takes over the role of stimulating the secretion of oestrogen and progesterone
- Pregnancy tests detect the presence of hCG in the mother's urine and can be used to confirm a positive pregnancy



hCG increases during the first 12 weeks of pregnancy to stimulate the release of oestrogen and progesterone; after 12 weeks hCG declines as the placenta takes over

Hormones & Birth

Your notes

The role of progesterone

- The hormone progesterone is secreted by the placenta throughout pregnancy
- Progesterone **inhibits the production** of another hormone, **oxytocin**, by the **pituitary gland**
- Progesterone **inhibits contractions** of the **muscles** of the uterus wall (the **myometrium**), which could induce birth if not inhibited
- At the **end of pregnancy**, the **foetus** produces the hormone **oestrogen**, which signals to the placenta to **stop producing progesterone**, thereby **initiating the production of oxytocin** by the pituitary gland and the start of labour (and the start of the muscular contractions that eventually lead to the birth of the baby)

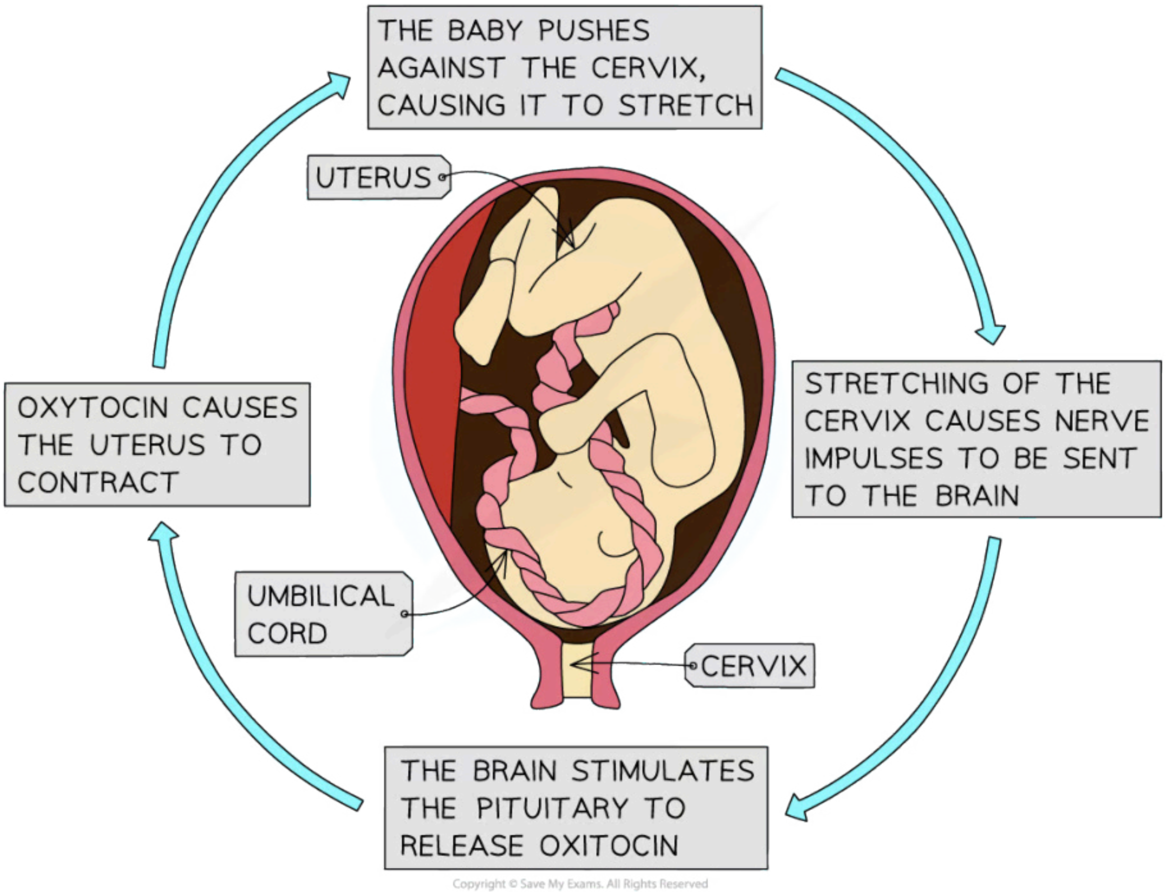
The role of oestrogen

- At the end of pregnancy, the hormone **oestrogen** is produced by the **foetus** and the **placenta**
- Oestrogen makes the **uterine wall more sensitive to oxytocin**
- **Progesterone** is also **inhibited** by oestrogen

Labour

- Oxytocin now stimulates **contractions** of the muscles in the **myometrium**
  - Oxytocin is released by the pituitary gland in the brain
- **Stretch receptors** in the **cervix** detect the contractions and signal the pituitary gland to **increase oxytocin secretion**
- More oxytocin creates **further contractions**, which in turn signal for **further release of oxytocin** in this **positive feedback loop**
- This process increases the contractions slowly and rhythmically

Your notes



The positive feedback loop stimulates the release of oxytocin and causes the contraction of the uterus wall

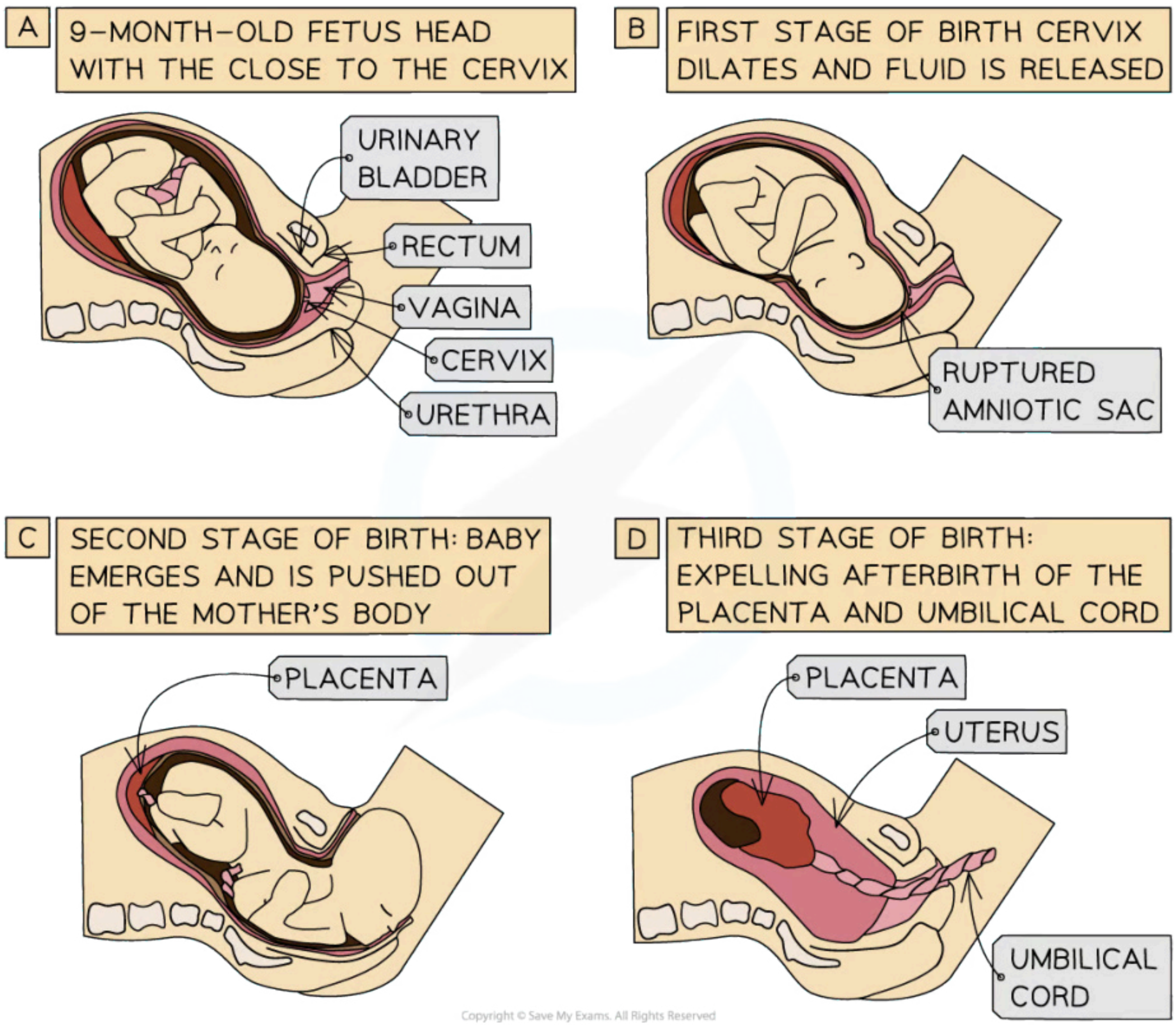
Birth

- **Relaxation** of the **cervix muscles** causes the cervix to **dilate** and **widen**
- Uterine contractions continue and cause the **amniotic sac to burst**, releasing the amniotic fluid through the open cervix
- The baby is **pushed out** through the **cervix** and **vagina** as contractions continue
- As the umbilical cord is cut, the baby is **physiologically separated** from the mother

Afterbirth

- After the baby has been delivered, **uterine contractions continue** and the placenta will separate from the uterine wall
- The mother will then **birth the placenta** and remains of the umbilical cord

Your notes



The stages of birth, which are initiated by the hormone oxytocin

11.4.5 The Placenta

Your notes

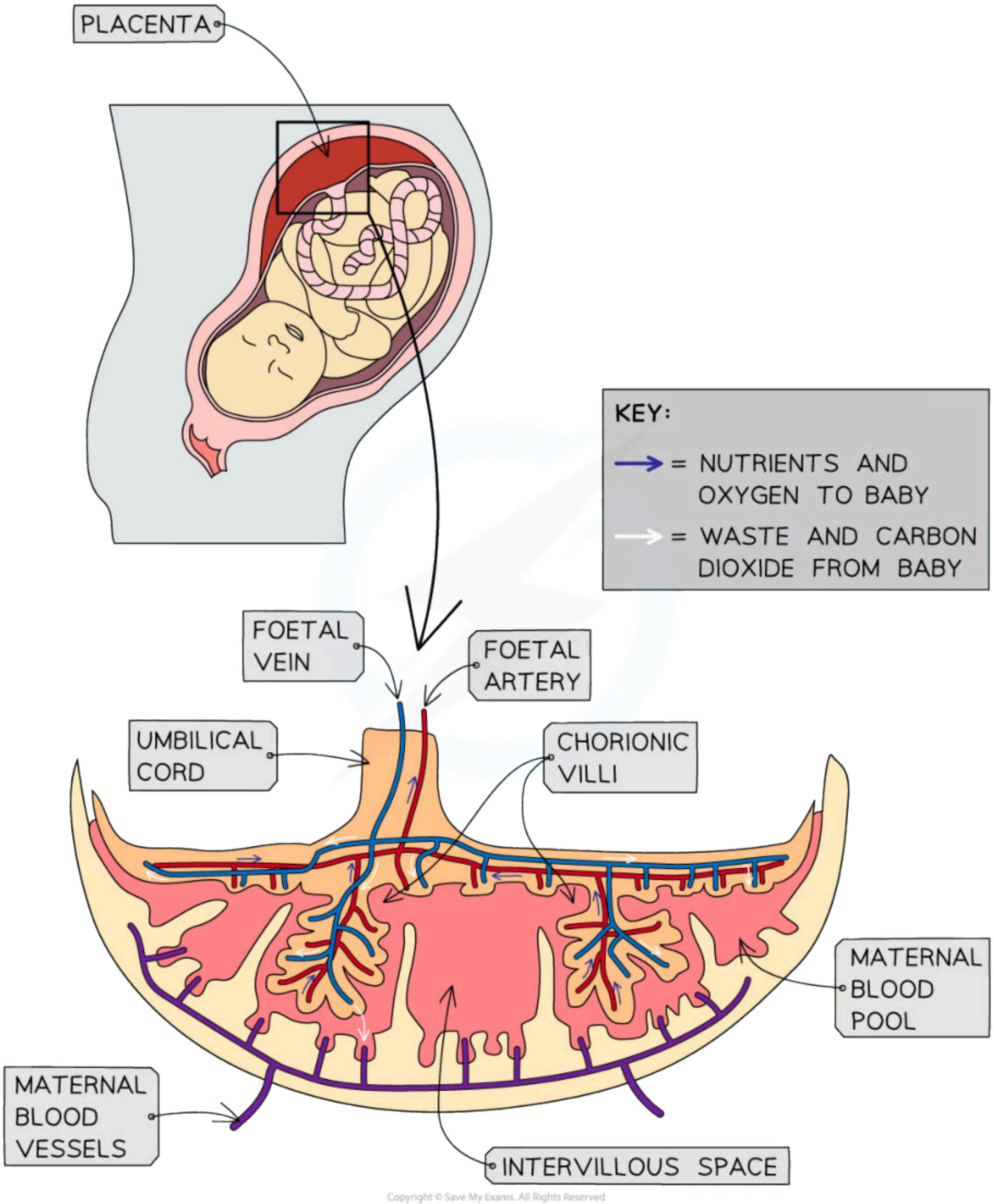
The Placenta & the Exchange of Materials

- Mammals can be split into different categories on the basis of their **mechanism for foetal nourishment**
  - **Placental** mammals, such as humans
  - **Monotremes**, or egg laying mammals, such as a platypus
  - **Marsupials,** such as kangaroos, whose offspring develop in a pouch
- **Placental mammals** rely on the complex system of **blood vessels** specially designed to maximise exchange of substances between mother and foetus without any direct connection between them
- The placenta is also responsible for **production of key pregnancy hormones** oestrogen and progesterone
- The foetus is connected to the placenta via the **umbilical cord** and is contained within the **amniotic sac** filled with **amniotic fluid** which protects the foetus

Structure of the placenta

- The placenta is an organ primarily made up of a complex arrangement of **blood vessels arranged into placental,** or **chorionic, villi** with maternal blood flow distributed around the villi
  - Throughout the course of the pregnancy, the number of villi increases to meet the demands of the growing foetus
- **Maternal blood and foetal blood never mix directly**, but flow either side of a layer of cells that make up the placental barrier; there is a very short distance between the maternal and foetal blood to allow **exchange of nutrients and gases**
  - The mother's blood flows **out of the mother's blood vessels** and forms pools in the spaces surrounding the placental villi; these spaces are known as the **inter-villous spaces**
- The **placental membrane,** or **barrier,** provides a selectively permeable barrier which restricts the exchange of substances between mother and baby
- Substances that move across the barrier **from mother to foetus** include
  - **Oxygen**
  - **Antibodies**
    - Antibodies cross the placenta using a mechanism called endocytosis
  - **Water**
  - **Glucose**
  - **Unwanted** or **harmful substances** may also cross the placental barrier, including alcohol, drugs or small pathogens such as viruses
    - Bacterial pathogens are too large to cross the barrier
- Substances that move across the barrier **from foetus to mother** include
  - **Carbon dioxide**
  - **Water**
  - **Urea**
- The placenta is connected to the growing foetus by the **umbilical cord**

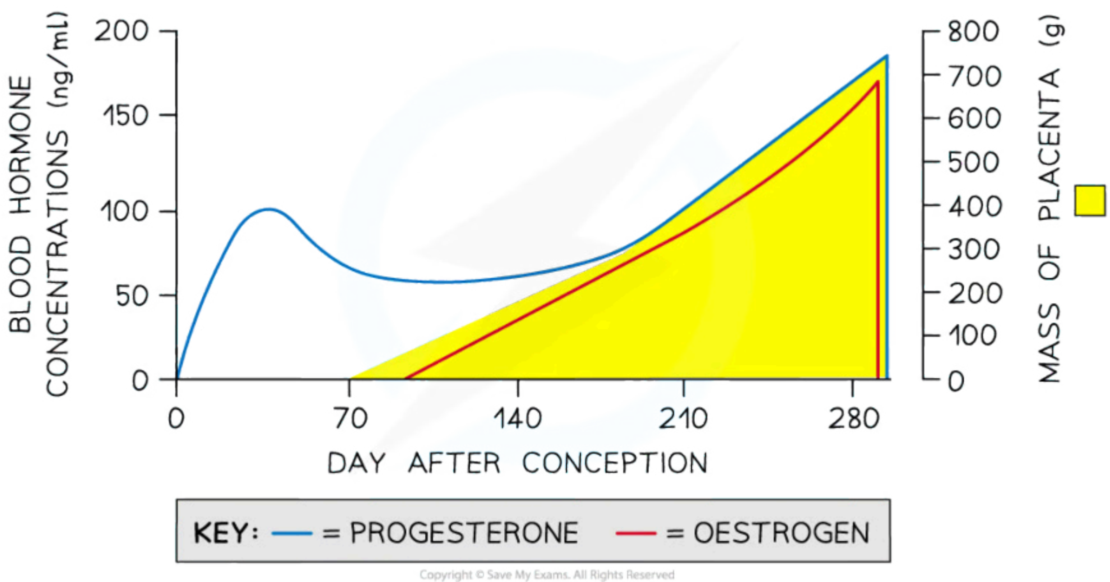
Your notes



The placenta brings the maternal and foetal blood systems close but without directly mixing

The Placenta & Hormones

- Hormones play a fundamental role in **promoting foetal development** and **maintaining the pregnancy**
- The levels of hormones change throughout the stages of pregnancy and development of pregnancy organs, such as the placenta
- Initially, the degenerating **corpus luteum** (a group of cells that form in the ovary following ovulation) releases hormones that support the initial stages of the pregnancy, up to about week 9
- The **placenta** then takes over in releasing steroid hormones, **oestrogen** and **progesterone**
  - The role of **oestrogen** is to **stimulate growth** of the **uterus** and **mammary glands** (commonly called breasts in humans)
  - The role of **progesterone** is to **support the lining of the uterus** to maintain the pregnancy
- If the placenta fails to initiate hormone production, a **miscarriage** may occur



Pregnancy hormones change throughout gestation and with placental growth

Your notes

11.4.6 Oestrogen Pollution

Your notes

Assessing the Risks of Oestrogen Pollution

NOS: Assessing risks and benefits of scientific research: the risks to human male fertility were not adequately assessed before steroids related to progesterone and oestrogen were released into the environment as a result of the use of the female contraceptive pill

- Advances in science and technology can come with **potential risks** which **may outweigh the benefits** of the research
- It is important that scientists try to establish the **extent of these potential risks** and their implications before making decisions on whether to continue with their research
  - In the absence of a thorough risk analysis the negative impacts cannot be predicted, which may result in a series of unforeseen consequences
- The resulting consequences could have far-reaching effects which extend beyond the precise nature of the processes being studied
  - For example, the use of certain fertilisers in agriculture can have a severe impact on surrounding communities with a negative effect on biodiversity

Oestrogen Pollution

- The contraceptive pill, which was introduced in 1943, can contain a **synthetic version of oestrogen**, called **ethinylestradiol**
- Over 40 years later, high levels of ethinylestradiol, attributed to contraceptive hormones, were measured in **water bodies**
- These levels had been building due to the **accumulation of hormones from human sewage** in the waterways
  - Use of oestrogen based hormones in **livestock** also contributes to the raised levels of contraceptive hormones measured
- Studies carried out into the risks of oestrogen pollution have indicated that increased exposure could be a potential contributory factor in **feminisation of fish** sampled from over 50 sites around the UK
- There has also been a suggestion that oestrogen exposure may be responsible for **reduced fertility in human men** across the UK over the past 50 years
- Possible procedures to reduce the levels of hormones in the waterways are **expensive** and **require more research** to ensure they are effective
  - While there is evidence that oestrogen pollution levels in water bodies have risen, the water and drug industries that would need to undertake these procedures claim that there is not enough evidence to be sure of a **causal link** between the pollution and the observed negative effects on fish and male fertility

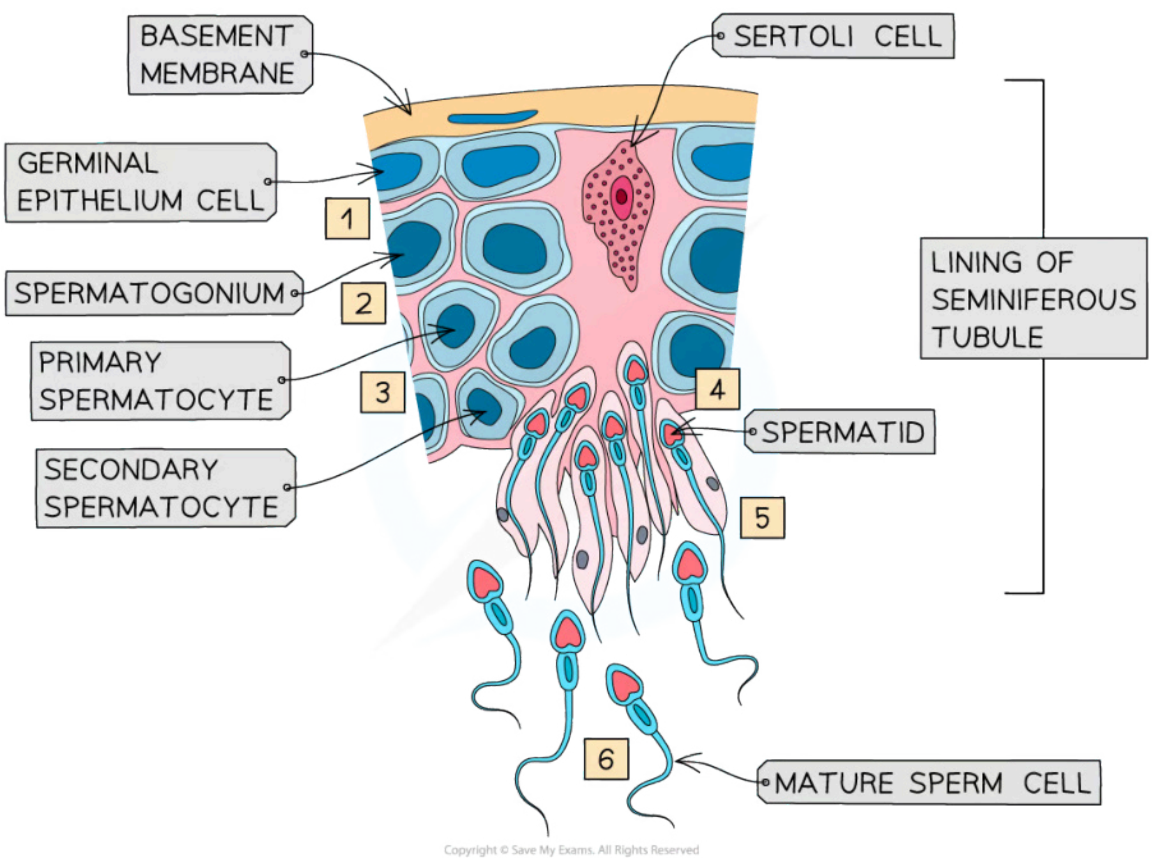
Your notes

11.4.7 Skills: Annotating Sexual Reproduction Diagrams

Annotating the Seminiferous Tubule and Ovary

Annotating the Seminiferous Tubule

- The testes contain many small tubes, or **tubules**, known as **seminiferous tubules**
- The production of sperm, or **spermatogenesis**, takes place in the lining of the seminiferous tubules
- An annotated diagram of **spermatogenesis in the lining of the seminiferous tubule** should show the following events
    1. Cells of the **germinal epithelium divide** by **mitosis** to produce **diploid spermatogonia cells**
    2. Spermatogonia **grow and differentiate** into **primary spermatocytes**
    3. Primary spermatocytes enter **meiosis I,** dividing to produce **secondary spermatocytes**
    4. Secondary spermatocytes complete **meiosis II**, producing **immature sperm cells known as spermatids**
    5. Spermatids associate with nearby **Sertoli** cells as they grow and differentiate
        - Sertoli cells are sometimes known as **nurse cells**
    6. **Mature sperm cells,** or **spermatozoa detach from the Sertoli cells** and leave the seminiferous tubule

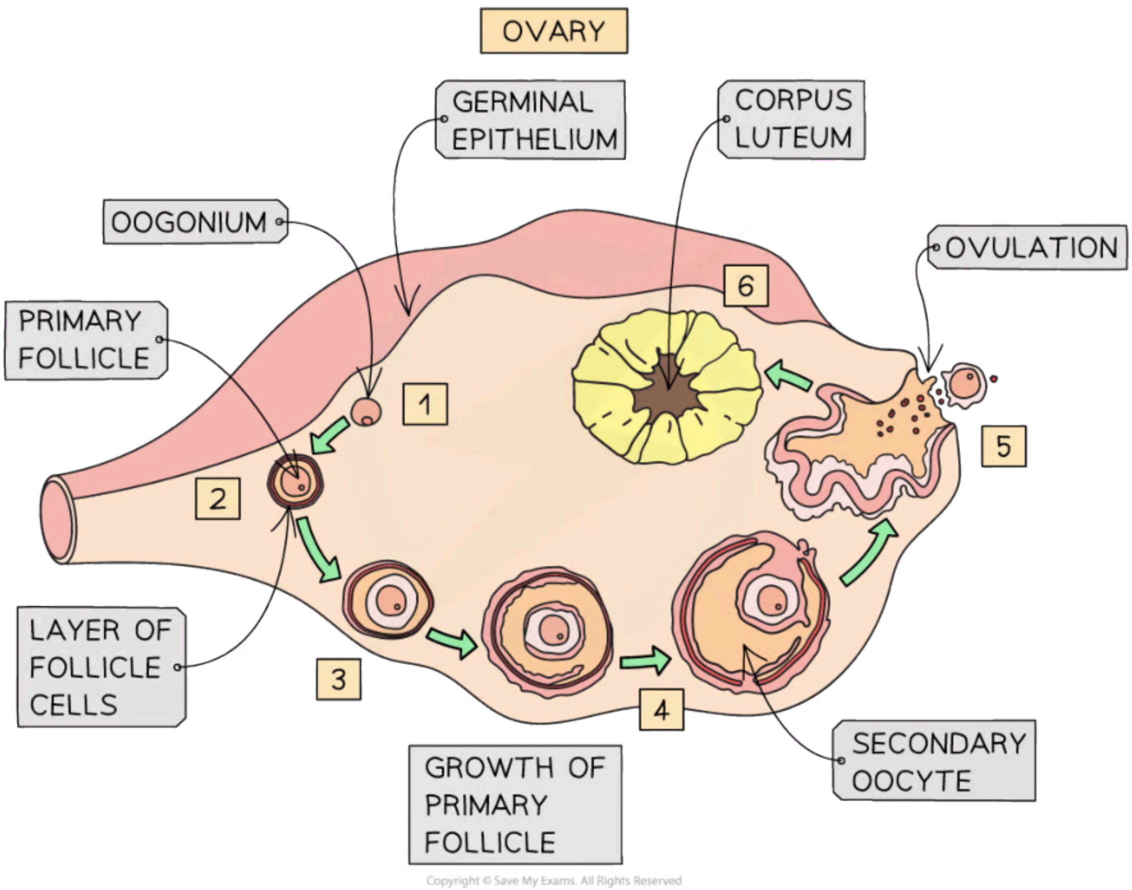


Annotating the Ovary

- The production of **ova**, or **oogenesis**, begins in the **ovaries of the female foetus** before birth
- An annotated diagram of oogenesis taking place inside the ovary should show the following events
  1. During the **first 7 months of foetal development**, cells of the germinal epithelium divide by **mitosis** to produce **diploid cells** called **oogonia**
  2. During the **second half of pregnancy** a layer of follicle cells develops around the oogonia to form a **primary follicle**, which then enters **meiosis I**
     - Note that at this point the process pauses with meiosis I still incomplete
  3. **Hormones** released from puberty up until the menopause **stimulate the growth of several primary follicles each month**
     - The hormone that stimulates a primary follicle to mature is **FSH**
  4. One of these developing primary follicles completes **meiosis I**, dividing to form a single **haploid secondary oocyte**
     - Note that the second daughter cell produced during meiosis I receives very little cytoplasm and is known as a **polar body**
  5. The secondary oocyte enters **meiosis II** and leaves the ovary in the process of **ovulation**
     - Note that meiosis II will be completed and an ovum formed after a sperm cell enters the secondary oocyte
  6. The remains of the follicle develops into a **corpus luteum**, which degenerates if fertilisation does not take place

Your notes

Your notes

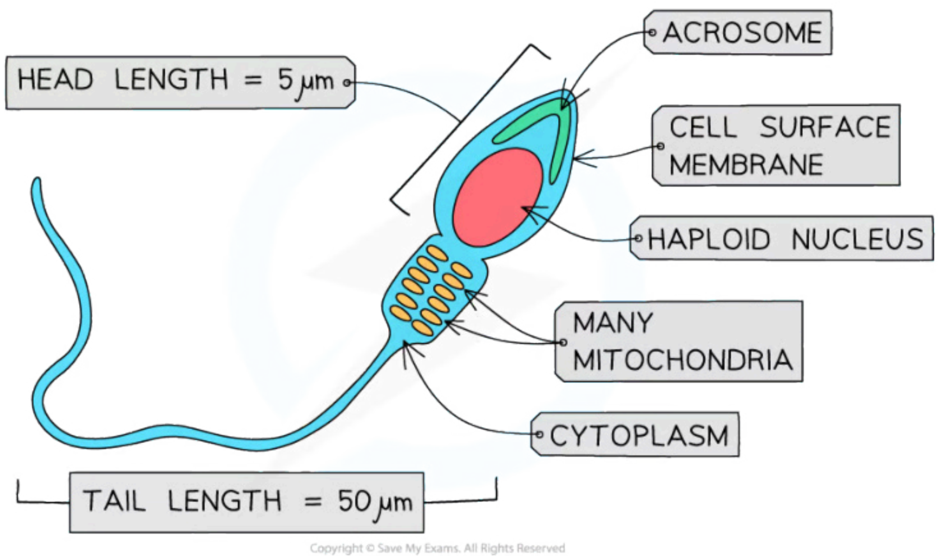


Most of the oogenesis process takes place in the ovaries

Annotating the Mature Sperm & Egg

Annotating the sperm

- Sperm and ova are examples of **specialised cells**, meaning that their **structure aids their function**
- Special features of sperm cells that relate to function include
  - A **haploid nucleus** that can **fuse with an ovum** nucleus to form a diploid zygote
  - An **acrosome** containing **digestive,** or **hydrolytic, enzymes** to aid entry into the ovum
  - Many **mitochondria** for the r**elease of energy** to aid movement
  - A **tail** made of **protein microtubules to aid movement**



Sperm cells are specialised to enable movement towards and entry into the ovum

Annotating the Egg

- Special features of ova that relate to function include
  - A **haploid nucleus** that can f**use with a sperm cell** nucleus to form a diploid zygote
  - A surrounding jelly layer, or **zona pellucida**, that can harden to **prevent polyspermy** (when the ovum is penetrated by more than one sperm, this can effect embryo development)
  - A series of **vesicles**, or **cortical granules**, containing **digestive enzymes** that are released into the zona pellucida to prevent polyspermy
  - A **cytoplasm** rich in **nutrients** for the **developing embryo** after fertilisation

Your notes

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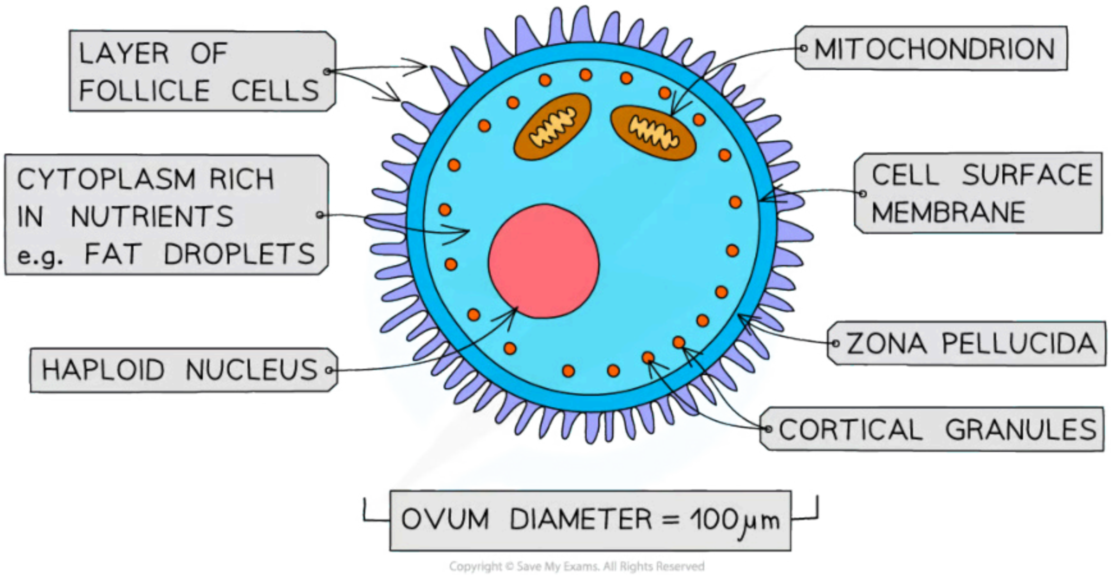

Ova are specialised to prevent polyspermy and aid development of the embryo