Animal Sexual Reproduction

Key idea: Fertilization occurs when the male and female gametes come together to form a zygote. In animals, fertilization may occur internally or externally.

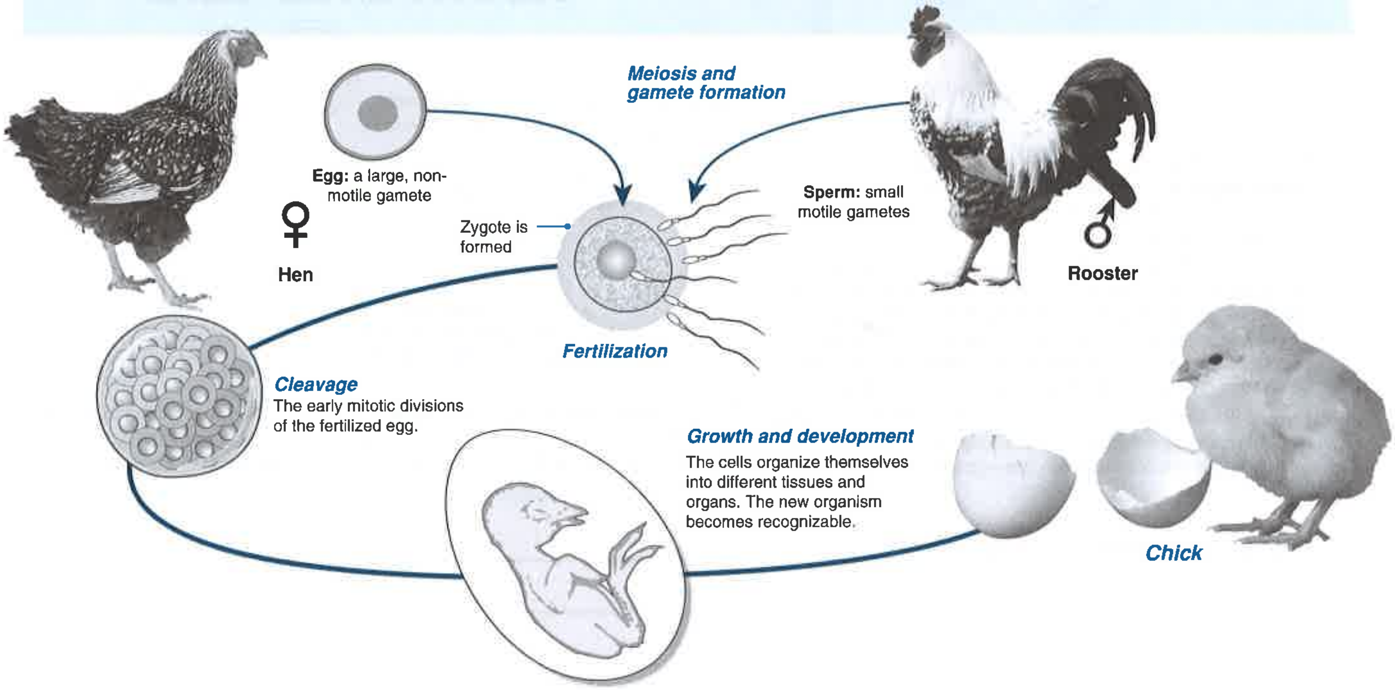
Sexual reproduction involves the production of sex cells (**gametes**) produced by sex organs (gonads). Female gametes are called **eggs**, male gametes are called **sperm**. Animal sexual reproduction follows one of three main patterns (below), determined by the location of fertilization and embryonic development. Many aquatic invertebrates and fish have **external fertilization**, in which the parents release their gametes into the water at the same time. Other invertebrates, reptiles, sharks, birds, and mammals have **internal fertilization**, in which sperm is transferred directly into the female to increase the chances of successful fertilization. In birds and most reptiles, one adaptation to life on land has been the evolution of the **amniote egg**: a structure that enables the embryo to complete its development outside the parent surrounded by a protective shell and nourished by a yolk sac. The pattern of internal development in mammals (termed gestation or pregnancy) provides the most advantages for the embryo in terms of nourishment and protection during development.

Strategies for Fertilization and Development

1. External fertilization and development
Many marine invertebrates release gametes into the sea. Large numbers of gametes are produced. *Example: giant clam (above, left).* In amphibians, a prolonged coupling, called amplexus, precedes gamete release and external fertilization and development. *Example: frogs (above, right).*

2. Internal fertilization and external development
Insects often have elaborate courtship rituals. Fertilization is internal, but the eggs are laid and develop externally. *Example: dipteran flies (above left).* In birds and reptiles, gamete fertilization is internal but the eggs are laid (usually in nests) and develop externally. *Example: quail (above, right).*

3. Internal fertilization and development
In mammals, fertilization is internal and there is a long period of internal development. *Example: lions*



1. Distinguish between **internal fertilization** and **external fertilization**, identifying advantages of each strategy:

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2. (a) Name an animal group with internal fertilization but external development: ____________________

(b) Name an animal group with internal fertilization and internal development: ____________________

(c) Describe one benefit and one cost involved in providing for internal development of an embryo:

Benefit: ____________________

Cost: ____________________

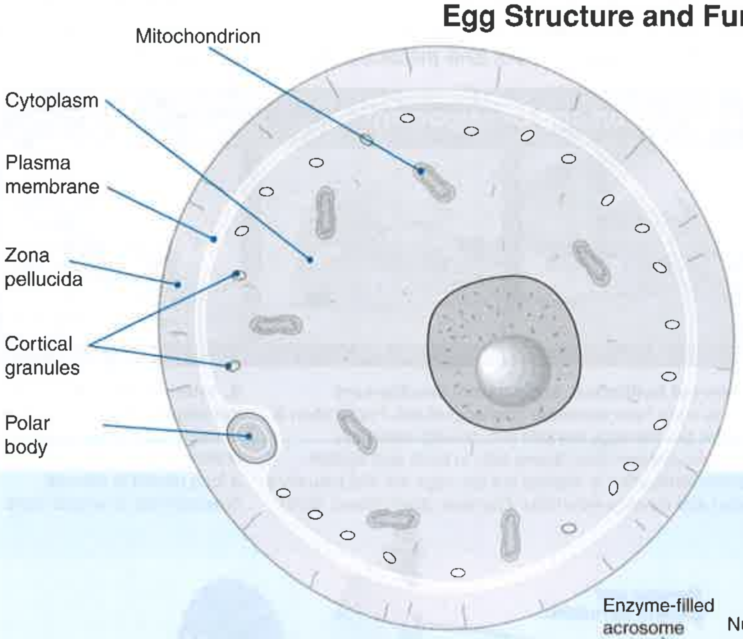
ISBN: 978-1-927173-93-0

309 Gametes

Key idea: Gametes are the sex cells of organisms. Male and female gametes differ in their size, shape, and number.

Gametes (sex cells) are produced for the purposes of sexual reproduction. The gametes of male and female mammals differ greatly in size, shape, and number. These differences reflect their different roles in fertilization and reproduction. Male gametes (**sperm**) are highly motile and produced in large numbers. Female gametes (**eggs** or ova) are large, few in number, and immobile. They move as a result of the wave-like motion produced by the ciliated cells lining the Fallopian tube. Egg cells contain some food sources to nourish the developing embryo. In mammals, this food source is small because, once implanted into the uterine lining, the embryo derives its nutrients from the mother's blood supply.

Egg Structure and Function



The ovum has no propulsion mechanism and is a simpler structure than the sperm cell. It is required to survive for a much longer time than a sperm, so it contains many more nutrients and metabolites and, as a result, it is much larger than a sperm cell (up to 100 µm).

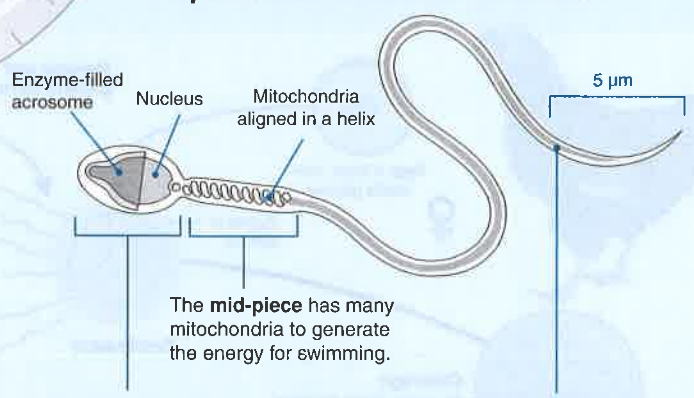
The contents of the ovum are similar to that of a typical mammalian cell, although it is externally surrounded by a jelly-like glycoprotein called the zona pellucida. A small polar body (the remnants of a sister cell) lies between the plasma membrane and zona pellucida. Cortical granules around the inner edge of the plasma membrane contain enzymes that are released once a sperm has penetrated the egg, forming a block to prevent further sperm entry (the cortical reaction).

Sperm Structure and Function

Mature spermatozoa (sperm) are produced by **spermatogenesis** in the testes. Meiotic division of spermatocytes produces spermatids, which then differentiate into mature sperm.

The sperm's structure reflects its purpose, which is to swim along the fluid environment of the female reproductive tract to the ovum, penetrate the ovum's protective barrier, and donate its genetic material. A sperm cell comprises three regions: a headpiece, containing the nucleus and penetrative enzymes, an energy-producing mid-piece, and a tail for propulsion.

Human sperm live only about 48 hours, but they swim quickly and there are so many of them (millions per ejaculation) that usually some are able to reach the egg to fertilize it.



The **headpiece** contains the nucleus and the acrosome, which contains the enzymes that help penetrate the egg.

The **tail** is a long flagellum that propels the sperm in its swim to the egg.

1. Why do sperm need to be motile? ______________________________

2. (a) How does an egg move along the Fallopian tube? ______________________________

   (b) Why does a mature egg need to be so many times larger than a sperm? ______________________________

3. Why does a sperm cell have a large number of mitochondria? ______________________________

ISBN: 978-1-927173-93-0

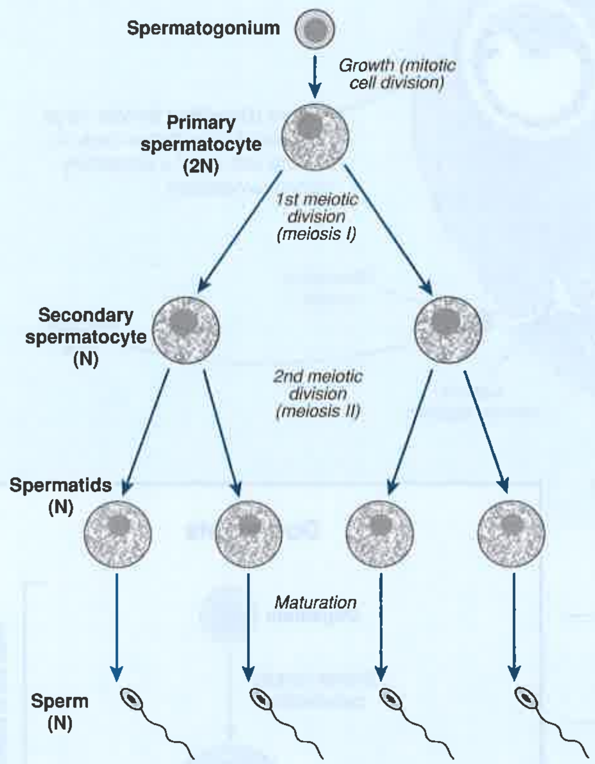
310 Spermatogenesis

Key idea: Sperm are the male gametes. They are produced by spermatogenesis in the testis.

Sperm are produced by a process called **spermatogenesis** in the testis. Mammalian sperm are highly motile and produced in large numbers. In human males, sperm production begins at puberty and continues throughout life, but does decline with age. Thousands of sperm are produced every second, and take approximately two months to fully mature.

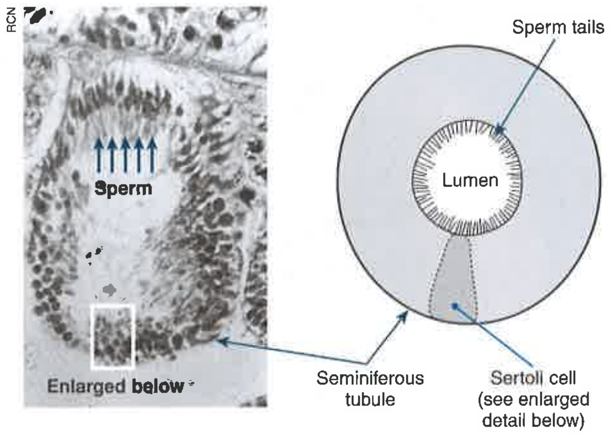
Spermatogenesis

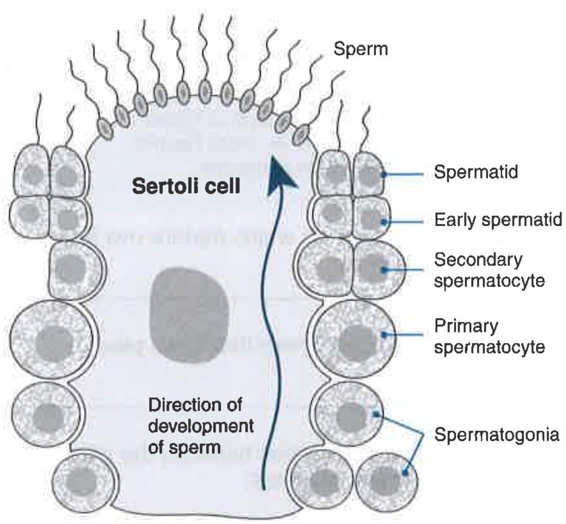
Spermatogenesis is the process by which mature spermatozoa (sperm) are produced in the testis. In humans, they are produced at the rate of about 120 million per day. Spermatogenesis is regulated by the hormones **follicle stimulating hormone** (FSH) (from the anterior pituitary) and testosterone (secreted from the testes in response to **luteinizing hormone** (LH) (from the anterior pituitary). Spermatogonia, in the outer layer of the seminiferous tubules, multiply throughout reproductive life. Some of them divide by meiosis into spermatocytes, which produce spermatids. These are transformed into mature sperm by the process of spermiogenesis in the seminiferous tubules of the testis. Full sperm motility is achieved in the epididymis.



Cross Section Through Seminiferous Tubule

The photograph below shows maturing sperm (arrowed) with tails projecting into the lumen of the seminiferous tubule. Their heads are embedded in the Sertoli cells in the tubule wall and they are ready to break free and move to the epididymis where they complete their maturation. The same cross-section is illustrated diagrammatically (bottom).





1. (a) Name the process by which mature sperm are formed: ______

   (b) Identify where this process takes place: ______

   (c) State how many mature sperm form from one primary spermatocyte: ______

   (d) State the type of cell division which produces mature sperm cells: ______

2. Describe the role of FSH and LH in sperm cell production: ______

3. Each ejaculation of a healthy, fertile male contains 100-400 million sperm. Suggest why so many sperm are needed:

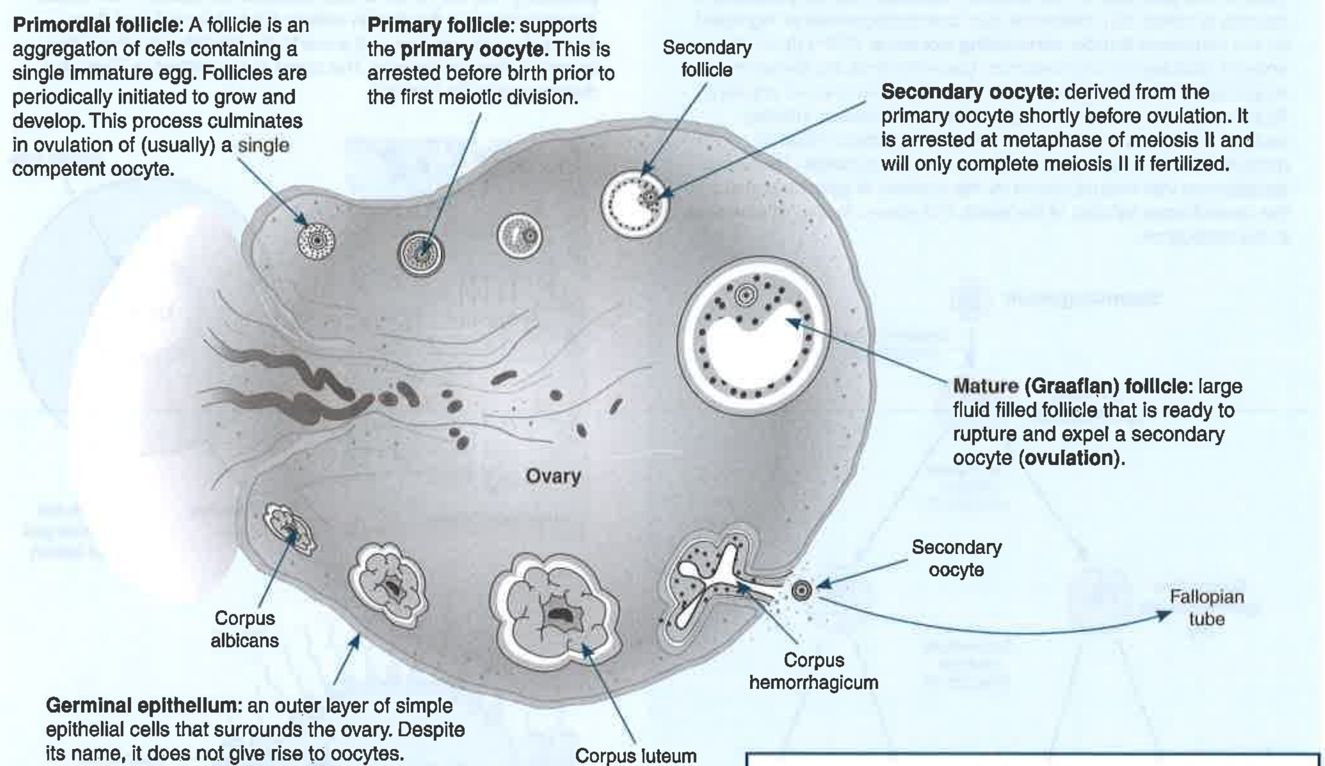
ISBN: 978-1-927173-93-0

311 Oogenesis

Key idea: Eggs are the female gametes. They are produced by oogenesis, which takes place in the ovaries.

Egg cell (ovum, plural ova) production in females occurs by **oogenesis**. Unlike spermatogenesis, no new eggs are produced after birth. Instead, a human female is born with her entire complement of immature eggs. These remain in prophase of meiosis I throughout childhood. After puberty, most commonly a single egg cell is released from the ovaries at regular monthly intervals as part of the menstrual cycle. These egg cells are arrested in metaphase of meiosis II. This second meiotic division is only completed upon fertilization. The release of egg cells from the ovaries takes place from the onset of puberty until menopause, when menstruation ceases and the woman is no longer fertile.

Development of the Ovarian Follicle and Egg Cell within the Ovary



1. (a) Name the process by which mature ova form:

   ____

   (b) Name the place(s) where this takes place:

   ____

2. Discuss the main differences between the production of male gametes and female gametes:

   ____

   ____

   ____

   ____

3. Explain why males can be potentially fertile all their life, while female fertility decreases and eventually ceases with age:

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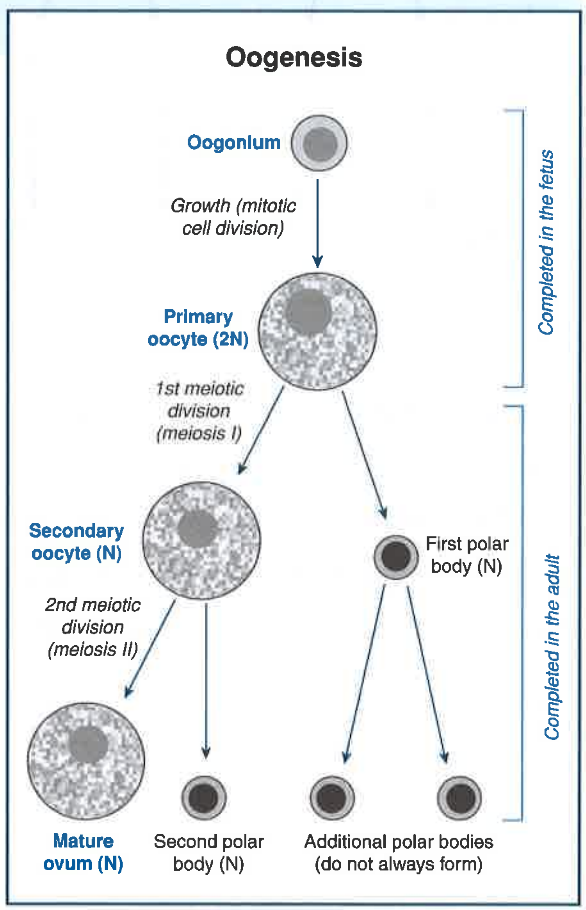


ISBN: 978-1-927173-93-0

312 Fertilization and Early Growth

Key idea: Fertilization occurs when a male and female gamete fuse to form a zygote.

Fertilization occurs when a sperm penetrates an egg cell at the secondary oocyte stage and the sperm and egg nuclei unite to form the zygote. In mammals, when fertilization occurs, specific mechanism take place to prevent polyspermy (fertilization of the egg by more than one sperm). These include a change in membrane potential, and the cortical reaction (see below). A zygote resulting from polyspermy contains too many chromosomes, and is not viable (does not develop). Fertilization is seen as time 0 in a period of gestation (pregnancy) and has five stages (below). After fertilization, the zygote begins its development, i.e. its growth and differentiation into a multicellular organism.

Fertilization (Time 0)

The stages in fertilization are represented below in a numbered sequence (1-5)

1. Capacitation

The surface of the sperm cell undergoes changes that are essential to enabling the acrosome reaction and sperm entry.

2. The Acrosome Reaction

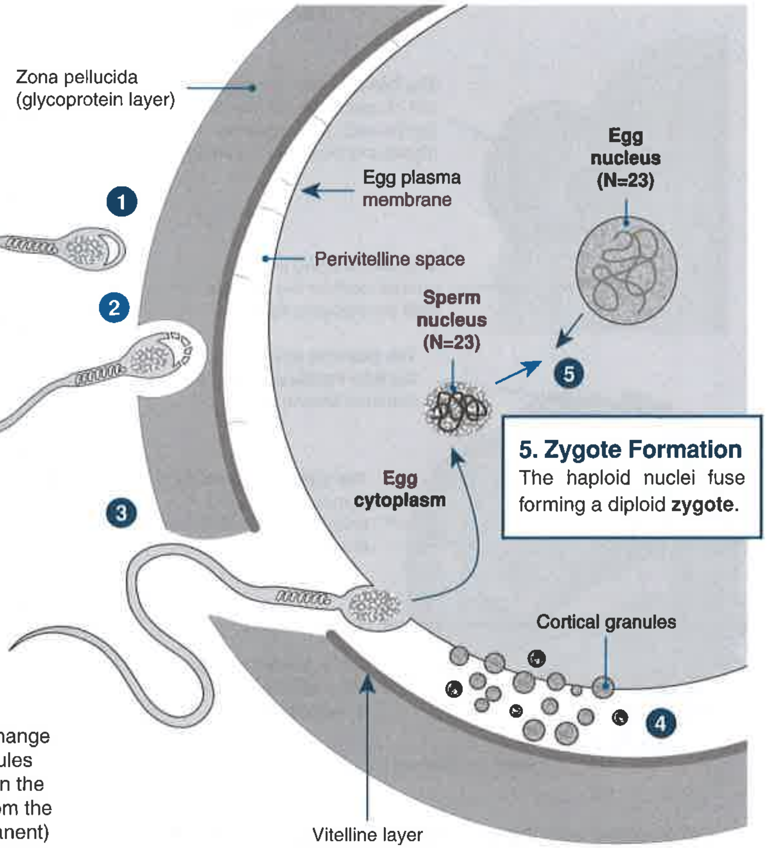
Enzymes from the acrosome (an enzyme-filled bag at the tip of the sperm) are released and digest a pathway through the follicle cells (not shown) and the jelly-like zona pellucida surrounding the egg cell (secondary oocyte).

3. Fusion of Sperm Head

The plasma membranes of the sperm and egg fuse, and the nucleus of the sperm enters the egg cytoplasm. Fusion causes a sudden membrane depolarization that acts as a "fast block" to further sperm entry. The fusion of the two plasma membranes also triggers the completion of meiosis II in the egg cell and induces the cortical reaction (below).

4. The Cortical Reaction

The fusion of the two plasma membranes induces a permanent change in the egg surface that prevents further sperm entry. Cortical granules in the egg cytoplasm release their contents into the space between the plasma membrane and the vitelline layer. Substances released from the granules raise and harden the vitelline layer to form a slow (permanent) block to further sperm entry.



1. Briefly describe the significant events (and their importance) occurring at each of the following stages of fertilization:

   (a) Capacitation: ______________________________

   ____

   (b) The acrosome reaction: ______________________________

   ____

   (c) Fusion of egg and sperm plasma membranes: ______________________________

   ____

   (d) The cortical reaction: ______________________________

   ____

   (e) Fusion of egg and sperm nuclei: ______________________________

   ____

2. Why is it important that fertilization of the egg by more than one sperm (polyspermy) does not occur? ______________________________

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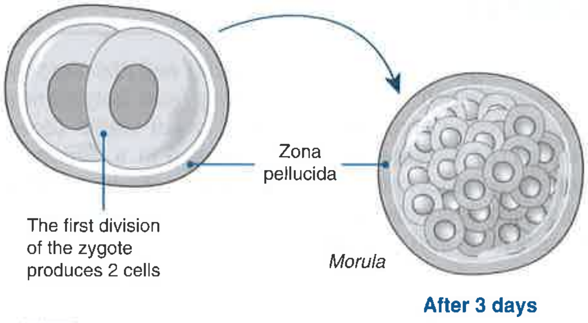
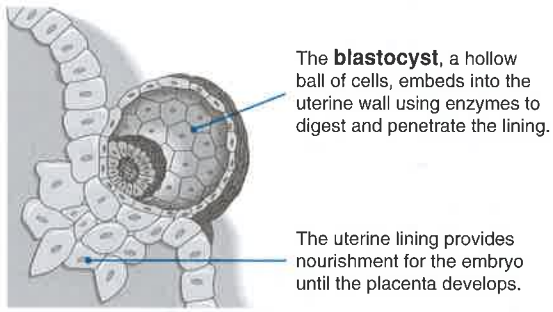
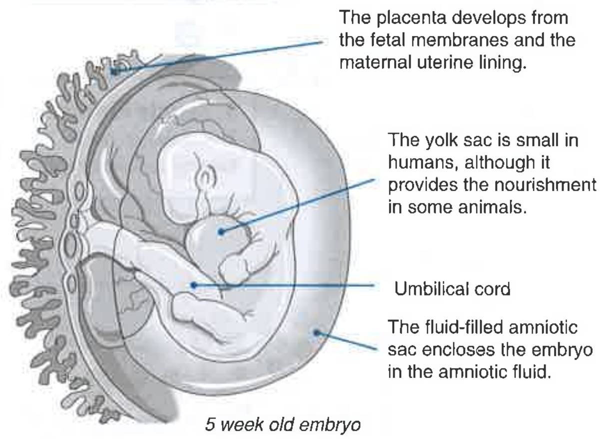






5 week old embryo

Early Growth and Development

Cleavage and Development of the Morula

Immediately after fertilization, rapid cell division takes place. These early cell divisions are called **cleavage** and they increase the number of cells, but not the size of the zygote. The first cleavage is completed after 36 hours, and each succeeding division takes less time. After three days, successive cleavages have produced a solid mass of cells called the **morula**, (left) which is still about the same size as the original zygote.

Implantation of the Blastocyst (after 6-8 days)

After several days in the uterus, the morula develops into the blastocyst. It makes contact with the uterine lining and pushes deeply into it, ensuring a close maternal-fetal contact. Blood vessels provide early nourishment as they are opened up by enzymes secreted by the blastocyst. The embryo produces **HCG** (human chorionic gonadotropin), which prevents degeneration of the corpus luteum and signals that the woman is pregnant.

Embryo at 5-8 Weeks

Five weeks after fertilization, the embryo is only 4-5 mm long, but already the central nervous system has developed and the heart is beating. The embryonic membranes have formed; the amnion encloses the embryo in a fluid-filled space, and the allanto-chorion forms the fetal portion of the placenta. From two months the embryo is called a fetus. It is still small (30-40 mm long), but the limbs are well formed and the bones are beginning to harden. The face has a flat, rather featureless appearance with the eyes far apart. Fetal movements have begun and brain development proceeds rapidly. The placenta is well developed, although not fully functional until 12 weeks. The umbilical cord, containing the fetal umbilical arteries and vein, connects fetus and mother.

3. (a) Explain why the egg cell, when released from the ovary, is termed a secondary oocyte: ____________________

____

(b) At which stage is its meiotic division completed? ____________________

4. What contribution do the sperm and egg cell make to each of the following:

(a) The nucleus of the zygote? Sperm contribution: ____________ Egg contribution: ____________

(b) The cytoplasm of the zygote? Sperm contribution: ____________ Egg contribution: ____________

5. What is meant by cleavage? Explain its significance to the early development of the embryo: ____________

____

____

6. (a) What is the importance of implantation to the early nourishment of the embryo? ____________

____

(b) What is the purpose of HCG production by the embryo? ____________________

____

____

7. Why is the fetus particularly prone to damage from drugs towards the end of the first trimester (2-3 months):

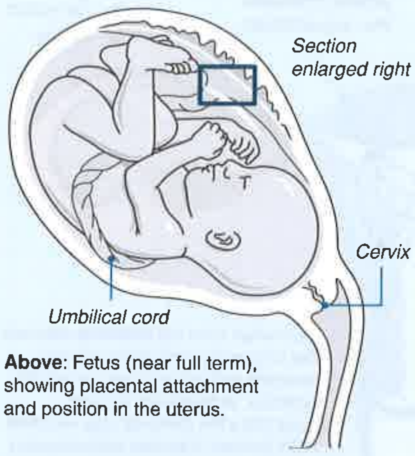
____

ISBN: 978-1-927173-93-0

313 The Placenta

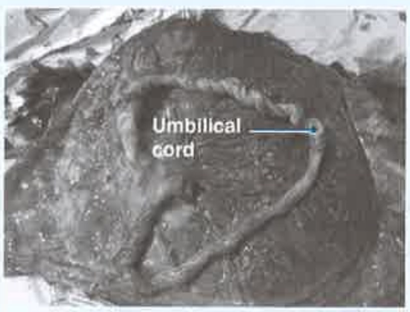
Key idea: The placenta allows materials to be exchanged between the fetus and its mother. It also acts as a temporary endocrine organ, secreting hormones to maintain pregnancy.

The human fetus depends entirely on its mother for nutrients, oxygen, and the elimination of wastes. The **placenta** is the specialized organ that performs this role, enabling exchange between fetal and maternal tissues and allowing a prolonged period of fetal growth and development within the uterus. The placenta also has an endocrine role, producing progesterone and estrogen to maintain the pregnancy.



Above: Fetus (near full term), showing placental attachment and position in the uterus.

Below: Photograph of a human placenta, just after delivery.



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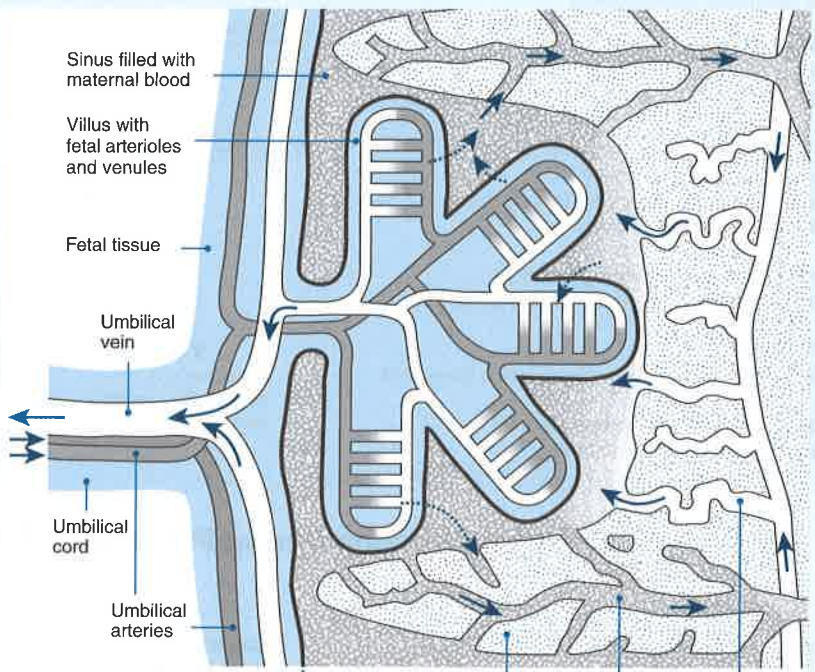
Schematic diagram showing part of the placenta in section



The placenta is a disc-like organ, about the size of a dinner plate and weighing about 1 kg. It develops when fingerlike projections (villi) from the fetal membranes grow into the uterine lining. The villi contain the numerous capillaries connecting the fetal arteries and vein. They continue invading the maternal tissue until they are bathed in the maternal blood sinuses. The maternal and fetal blood vessels are in such close proximity that oxygen and nutrients can diffuse from the maternal blood into the capillaries of the villi. From the villi, the nutrients circulate in the umbilical vein, returning to the fetal heart. Carbon dioxide and other wastes leave the fetus through the umbilical arteries, pass into the capillaries of the villi, and diffuse into the maternal blood. Note that fetal blood and maternal blood do not mix: the exchanges occur via diffusion through thin walled capillaries.

1. Describe the structure and function of the human placenta: ______________________

____

____

____

____

2. The umbilical cord contains the fetal arteries and vein. Describe the status of the blood in each type of fetal vessel:

   (a) Fetal arteries: Oxygenated and containing nutrients / Deoxygenated and containing nitrogenous wastes (delete one)

   (b) Fetal vein: Oxygenated and containing nutrients / Deoxygenated and containing nitrogenous wastes (delete one)

3. Describe how substances are exchanged between the mother and the fetus: ______________________

____

____

ISBN: 978-1-927173-93-0

314 The Hormones of Pregnancy

Key idea: Hormones secreted during pregnancy maintain the pregnancy and prepare the body for birth.

In a non-pregnant adult human female, the levels of estrogen and progesterone regulate the secretion of the pituitary hormones that control the ovarian cycle. Pregnancy interrupts this cycle and maintains the corpus luteum and the placenta as endocrine organs with the specific role of maintaining the developing fetus during its development. During the last month of pregnancy the hormone oxytocin induces the uterine contraction that will expel the baby from the uterus.

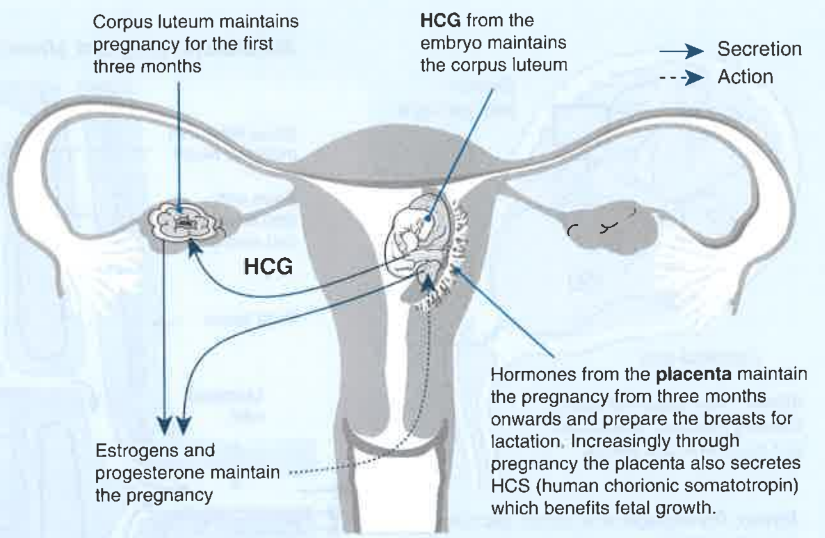
HCG (Human chorionic gonadotropin)
- Secreted by the developing embryo
- Maintains corpus luteum

Progesterone
- Maintains endometrium
- Inhibits uterine contraction

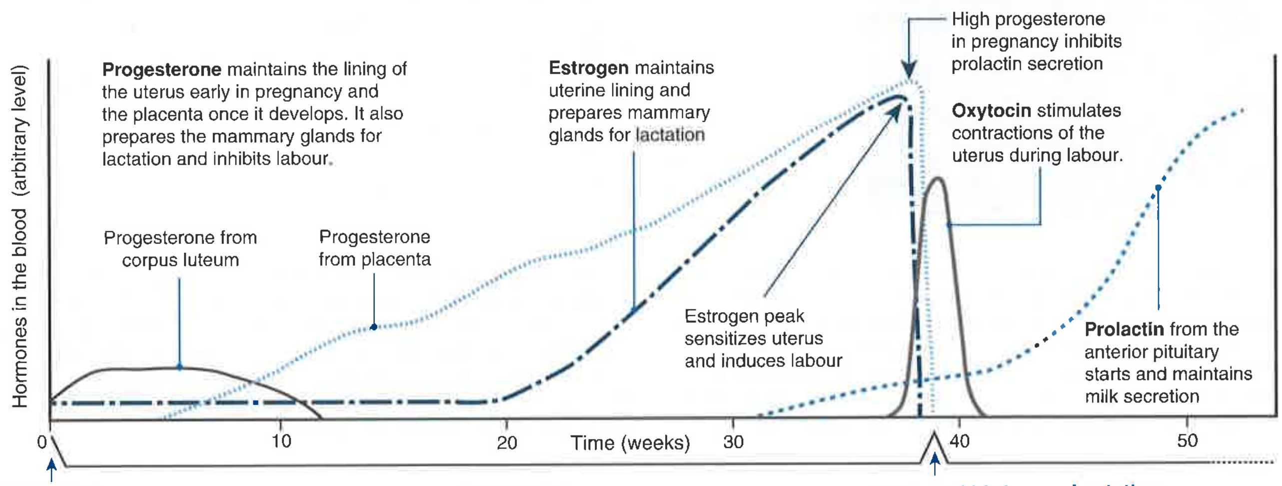
Estrogens
- Maintain endometrium
- Prepare mammary glands for lactation
- High levels induce labour

Human placental lactogen (HPL)
- Stimulates breast growth and development

Relaxin
- Produced by the placenta towards the end of the pregnancy
- Relaxes pubic symphysis at birth
- Helps dilate cervix at birth



Hormonal Changes During Pregnancy, Birth, and Lactation



During the first 12-16 weeks pregnancy, the **corpus luteum** secretes enough progesterone to maintain the uterine lining and sustain the developing embryo. After this, the placenta takes over as the primary endocrine organ of pregnancy. **Progesterone** and **estrogen** from the placenta maintain the uterine lining, inhibit the development of further ova (eggs), and prepare the breast tissue for **lactation** (milk production). At the end of pregnancy, the placenta loses competency, progesterone levels fall, and high estrogen levels trigger the onset of labour. The estrogen peak coincides with an increase in oxytocin, which stimulates uterine contractions in a positive feedback loop: the contractions and the increasing pressure of the cervix from the infant stimulate release of more oxytocin, and more contractions and so on, until the infant exits the birth canal. After birth, the secretion of prolactin increases. Prolactin maintains lactation during the period of infant nursing.

1. (a) Why is the corpus luteum the main source of progesterone in early pregnancy? ______________________

   ____

   (b) What hormones are responsible for maintaining pregnancy? ______________________

2. (a) Name two hormones involved in labour (onset of the birth process): ______________________

   (b) Describe two physiological factors in initiating labour: ______________________

   ____

ISBN: 978-1-927173-93-0

315 Gestational Development

Key idea: There is some relationship between animal size and gestational period but other factors influence the degree of development and independence of newborn mammals.

The gestational period (length of pregnancy) of mammals varies greatly. Although gestational period is often longer for larger animals, factors other than size alone determine the length of the pregnancy and the level of development in the young at birth. These may include life-span, developmental rates, number of offspring produced, and threats (e.g. being eaten by other animals). Animals are classed as either precocial or altricial at birth (below), but in reality there are varying degrees of classification between the two extremes.

Mammals which move independently soon after birth, and that see and hear well are called **precocial**. Mobility is important as their defence against predation is to run. Large hoofed grazers tend to be precocial.

Altricial mammals are born relatively helpless. Often they are unable to see and are fairly immobile. The young of many species are born hairless with their eyes shut. Rodents, cats, dogs, and marsupials are altricial species.

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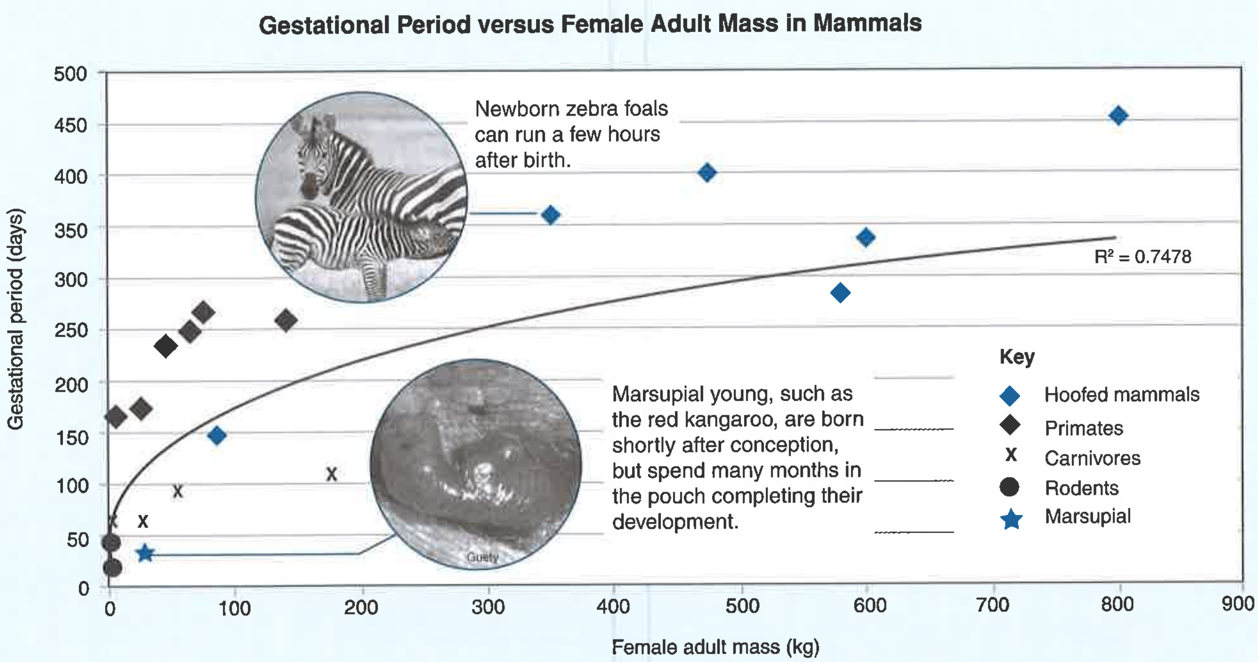
Newborn primates show varying degrees of precocial or altricial features at birth. Many primates move about shortly after birth and their eyes are open. In contrast, newborn humans have long periods of dependency.



1. Analyse the graph above and describe the relationship between animal size (weight) and gestational period:

2. Suggest why hoofed mammals (sheep, zebra, horse cow, antelope) have long gestational periods?

3. (a) What can you say about the position of the primates on the plot above?

(b) Can you suggest a reason for this pattern?

ISBN: 978-1-927173-93-0