Bio Factsheet

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Gamete Formation in Animals

The process of gamete formation is called **gametogenesis**. It occurs in all sexually reproducing organisms.
Gametes are **haploid** cells and so have only one set of chromosomes. Because of this, at some stage in their production, **meiosis** (reduction division) must occur.

Exam Hint. *Gamete production involves both meiosis and mitosis. Meiosis ensures that they only have half the normal amount of genetic material i.e. they are haploid. Large numbers of gametes (particularly male gametes) are needed and mitosis is essential to produce these large numbers.*

In gametogenesis:

- meiosis reduces the chromosome number by half, to one set.
- meiosis introduces genetic variation so that all gametes are slightly genetically different from each other.
- mitosis has the capability to produce large numbers of gametes.
- at fertilization the haploid male and haploid female gametes fuse so that the diploid state (two sets of chromosomes) is restored in the zygote.
- the production of sperm is called **spermatogenesis**; the production of eggs is called **oogenesis**.

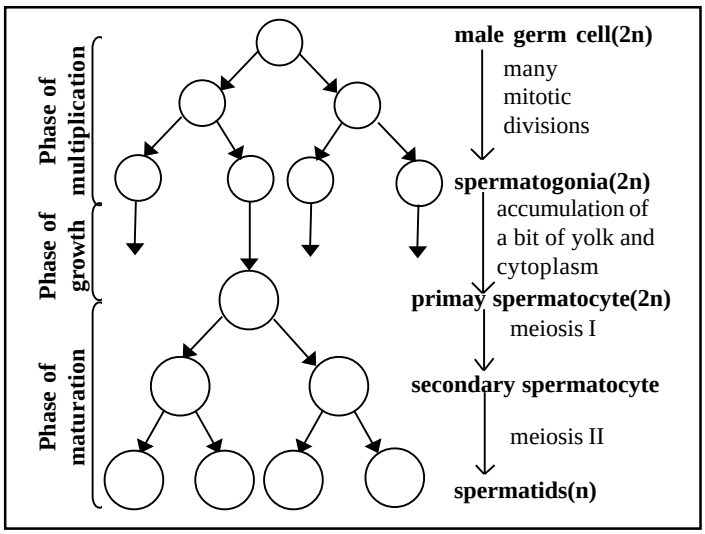
Gametogenesis in humans

In men spermatogenesis occurs in the testes, from puberty until death, although at much reduced rates after middle age.
In women oogenesis occurs partly in the ovaries and partly in the ovarian funnel and oviduct, from puberty until the menopause, (the 'change', which occurs around the age of fifty).

The flow chart summarises the processes involved in the production of human sperm.

In exams, the process is sometimes shown as in Fig 1.

Fig 1. Outline of the process of spermatogenesis



The summary flow chart and Fig1 will answer most of the exam questions about the actual process of sperm formation. The other commonly – examined aspects are:

1. What is the significance of meiosis and mitosis here?
2. Adaptations of sperm
3. Application questions that use gamete formation to test your ability to apply your knowledge to new situations.

Before considering these three, it is worth considering the above summaries in a bit more detail.

1. Gonadotropic releasing hormone (GnRH) stimulates the secretion of Follicle stimulating hormone (FSH) and Interstitial cell stimulating hormone (ICSH) from the **anterior** lobe of the pituitary gland

2. ICSH stimulates the interstitial cells / cells of Leydig to produce testosterone

3. Testosterone stimulates spermatogenesis

4. Sperm development involves:
mitosis to produce spermatogonia
which grow to form primary spermatocytes;
meiosis I produces secondary spermatocyte
meiosis II produces spermatids in the seminiferous tubules;

5. FSH and testosterone stimulates the Sertoli cells

6. which stimulate sperm maturation

7. release spermatozoa into the lumen

8. increase in testosterone inhibits GnRH

9. testosterone inhibits ICSH

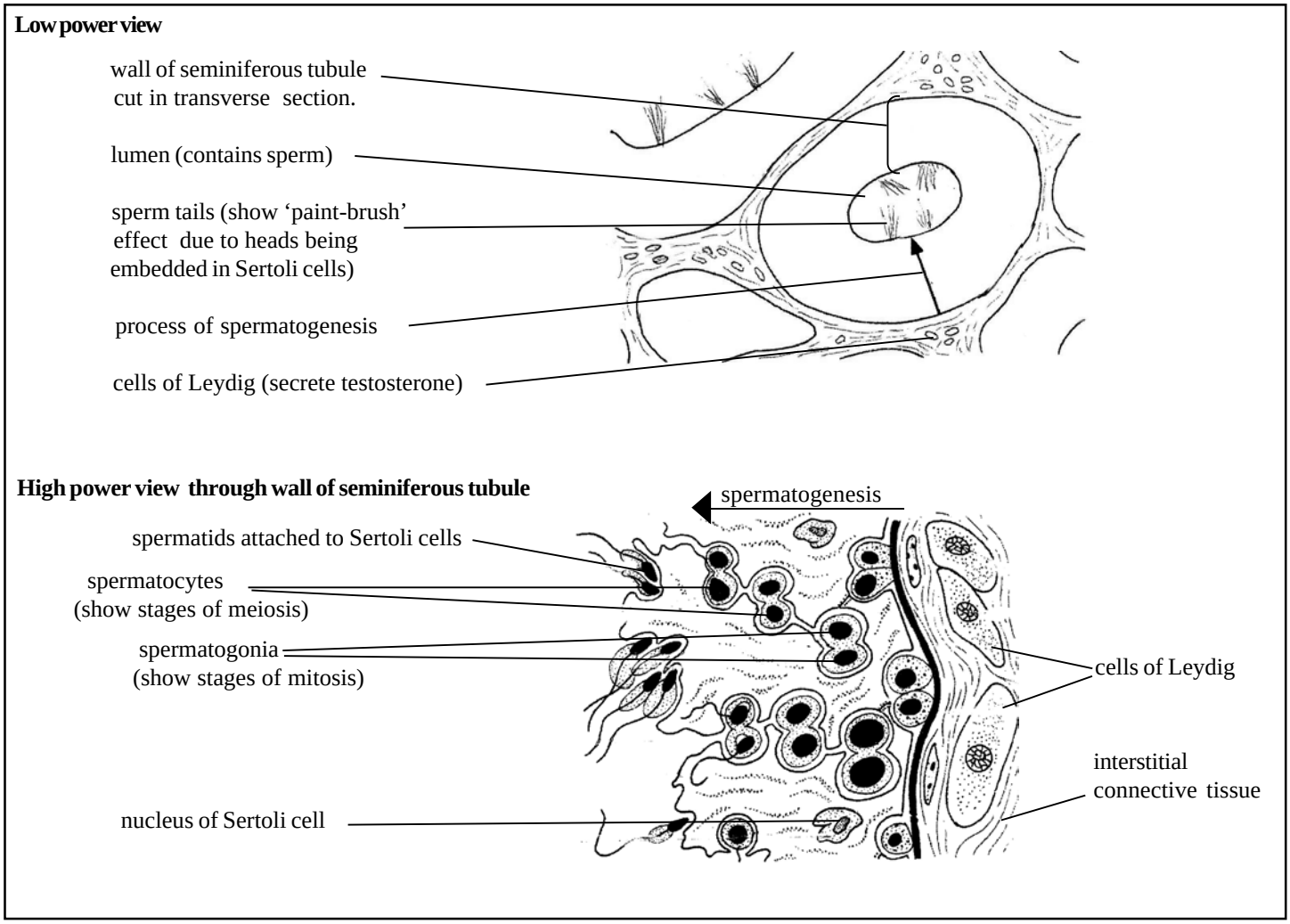
10. inhibin suppresses FSH

11. negative feedback

- The **male germ cells** are the outermost layer of cells in the seminiferous tubule wall and show stages of mitosis as they form **spermatogonia**. Some spermatogonia remain as male germ cells, so that these do not become depleted. Most continue to divide mitotically to produce more spermatogonia which make up the outer half of the tubule wall. These quickly develop into **primary spermatocytes**.
- The spermatocytes are found in the inner half of the tubule wall and show stages of meiosis, eventually forming haploid **spermatids**.
- Also found in the seminiferous tubule walls, stretching from the basement membrane at the outside to the inner lumen, are the **Sertoli cells**. The heads of spermatids become embedded in recesses in the cell membranes of the Sertoli cells from which they apparently gain nutrients and where they mature into **spermatozoa**. This final maturation of sperm is under the control of the male sex hormone, **testosterone**, (which is secreted by the **cells of Leydig** in the testis) and by FSH. When the spermatozoa are fully matured they are released and are stored in the lumens of the seminiferous tubules and epididymis.

Remember*: *ICSH in the male is the same substance as LH in the female.

Fig 2. Histology of testis tissue, showing stages in spermatogenesis.



Note, in the above drawing that the spermatocytes are joined by cytoplasmic bridges. Cytokinesis does not complete until mature spermatozoa are released from the Sertoli cells. The reason for this is related to the fact that sperm carry either an X or a Y sex chromosome. The X-chromosome carries many essential genes which are lacking on the smaller Y-chromosome. Some of the X-chromosome genes may code for substances which regulate sperm maturation, so without the cytoplasmic bridges the Y –sperm could not develop or survive. Thus no males could be produced.

Besides being involved in the maturation of sperm, the Sertoli cells have other major functions.

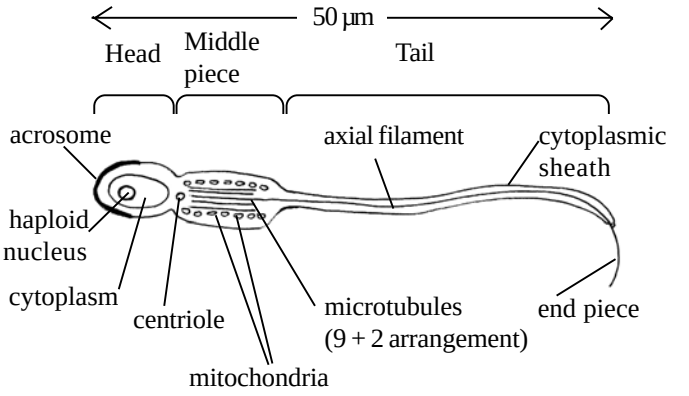
- They phagocytose degenerating/ageing spermatogenic cells and spermatozoa so that the testis does not become packed full of old spermatozoa, spermatids or spermatocytes (that do not complete spermatogenesis).
- All the Sertoli cells are joined together at their bases (near to the basement membrane) so that they form a **blood-testis barrier**. Because the spermatozoa are all genetically variable and genetically different from the person producing them, they produce surface antigens which are foreign to the body and which could provoke an immune response. The Sertoli cell barrier isolates the spermatozoa from the blood (T-lymphocytes) so that an immune response cannot be triggered.

Typical Exam Questions - Learn all of these!

1. **Explain why meiosis is important in the life cycle of a sexually reproducing organism (2).**
   It halves the number of chromosomes;
   The diploid number is restored at fertilisation;
   It introduces genetic variation in the gametes;
   Such variation can help the organism survive via natural selection;
2. **Explain how meiosis introduces genetic variation in the gametes (2).**
   Crossing-over (at Prophase 1);
   Independent/random assortment/orientation/segregation of (homologous) chromosomes in meiosis I;
   Independent/random assortment/orientation/segregation of chromatids in meiosis II;
3. **Explain the advantage of variation introduced by meiosis to the species (3)**
   Advantageous alleles may be added to the gene pool;
   Some individuals will be better adapted;
   They may be able to withstand environmental change;
   They will survive where others, lacking the adaptation, will not;
   They will reproduce;
   Pass on gene/allele;

Structure of spermatozoan

Fig. 3 Structure of a mature spermatozoan.



- the **haploid nucleus** carries genetic information from the father to the offspring.
- the **acrosome** contains a high concentration of **hyaluronidase enzyme** which enables the sperm to penetrate the egg cell membrane which contains **hyaluronic acid polymer**.
- the **mitochondria** generate ATP to provide energy for the sperm to swim.
- the **microtubules** and **axial filament** regulate the tail movements during swimming.

Typical Exam Questions

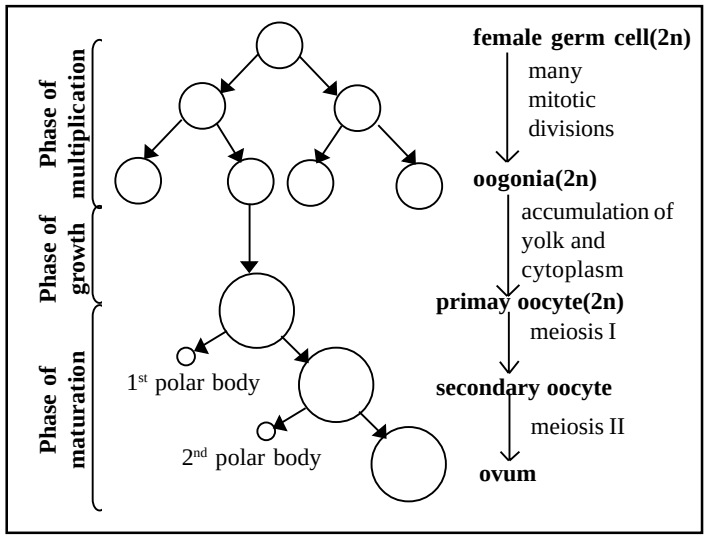
1. What is the significance of:

(i) the large numbers of mitochondria in sperm?
release energy/ATP for movement;

(ii) the small amounts of cytoplasm in sperm compared with an egg?
It allows them to move quicker/ allows more per ejaculate;

Oogenesis

Fig. 4 Outline of the process of oogenesis.



- The **female germ cells** arise from the endoderm lining the yolk sac of the fetus and migrate into the fetal ovaries.

Exam Hint: *It was originally thought that germ cells formed from the epithelium surrounding the ovary, which is why it is misnamed as the 'germinal epithelium. This is a common error made by students.*

- Around the third month of prenatal development, the germ cells undergo many mitoses and form several thousand **diploid oogonia**. These immediately divide into larger diploid cells called **primary oocytes**. These cells enter **prophase of meiosis** I but do not complete meiosis 1 until after puberty. The primary oocytes are situated in the **primary follicles** of the ovaries.
- Primary follicles will not develop further until after puberty when they are stimulated by FSH, in the pre-ovulatory phase of the menstrual cycle. Several primary follicles will commence development each month, with the primary oocytes growing larger due to the accumulation of much yolk (food store) and cytoplasm. At this time **meiosis I** is completed, producing two cells. One cell receives nearly all the cytoplasm and is called the **secondary oocyte**. The other cell, called the **first polar body**, receives a small amount of cytoplasm and the discarded nucleus. The secondary oocyte then starts meiosis II but this stops at metaphase II.
- At **ovulation** the secondary oocyte, 1st polar body and some surrounding follicle cells are discharged from the ovary into the ovarian funnel/oviducts. At this time **meiosis II** is completed with most of the cytoplasm and the haploid female nucleus going into the **ovum**. A small amount of cytoplasm and the discarded haploid nucleus go into the **second polar body**. Later, the polar bodies disintegrate. Developing follicles that have not reached ovulation degenerate.

Note: meiosis II only completes if a sperm penetrates the secondary oocyte. Thus when the ovum forms it already contains a haploid male nucleus as well as a haploid female nucleus. Fertilisation is when the male nucleus migrates to the female nucleus and fuses with it to form the diploid nucleus of the zygote.

Fig. 5 Ovarian follicles.

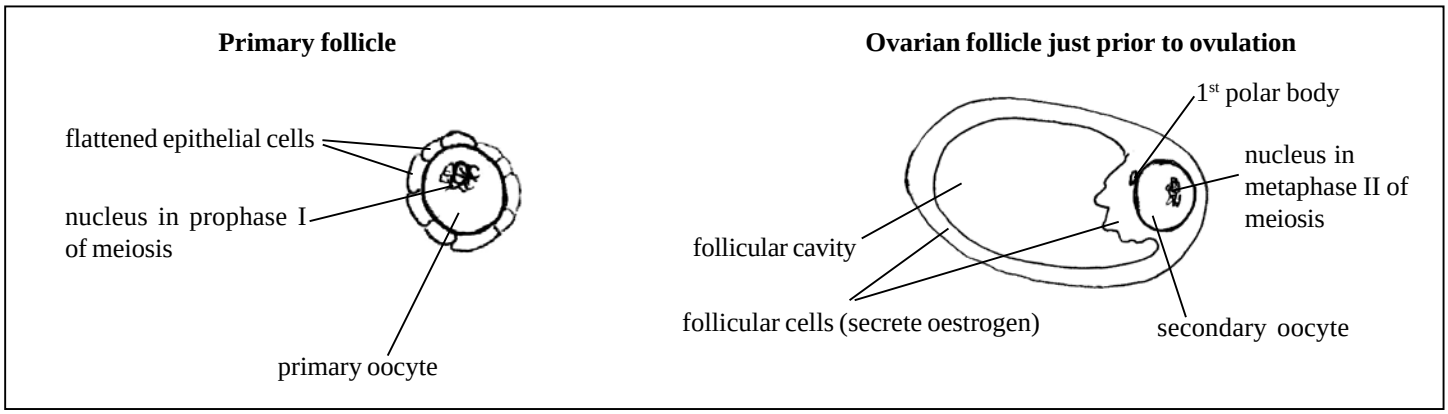
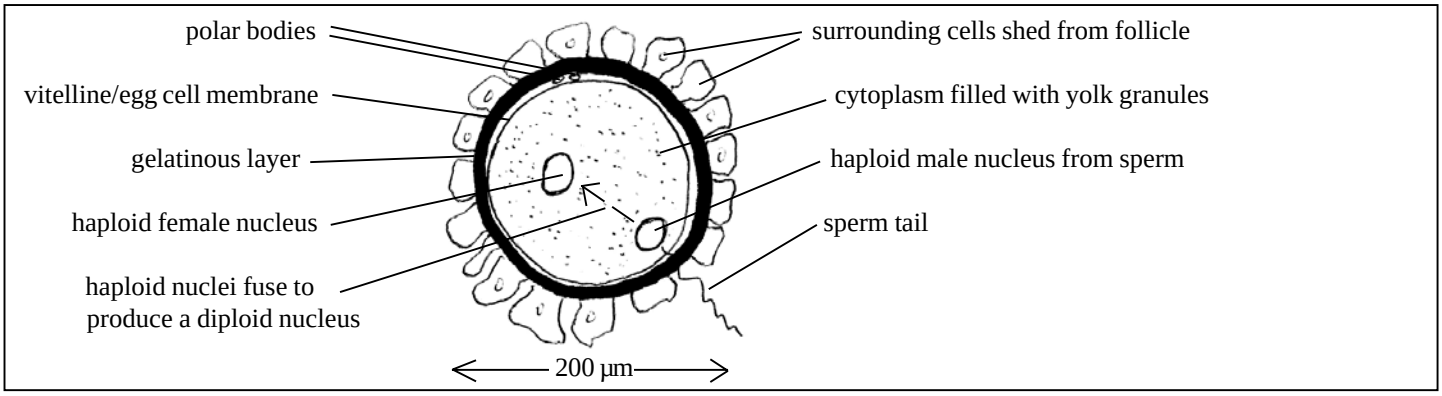


Fig. 6. An ovum just prior to the completion of fertilisation



***Exam hint**. It is worth making a list of the similarities and the differences between spermatogenesis and oogenesis because examiners sometimes ask for these.*

Types of egg in the animal kingdom

Eggs in the animal kingdom vary in the following respects:

- in the amount of yolk (food) they contain, and
- in the amount of protection they have.

These relate to life cycles and special needs of particular groups of animals.

Eggs are classified according to the quantity of yolk they contain.

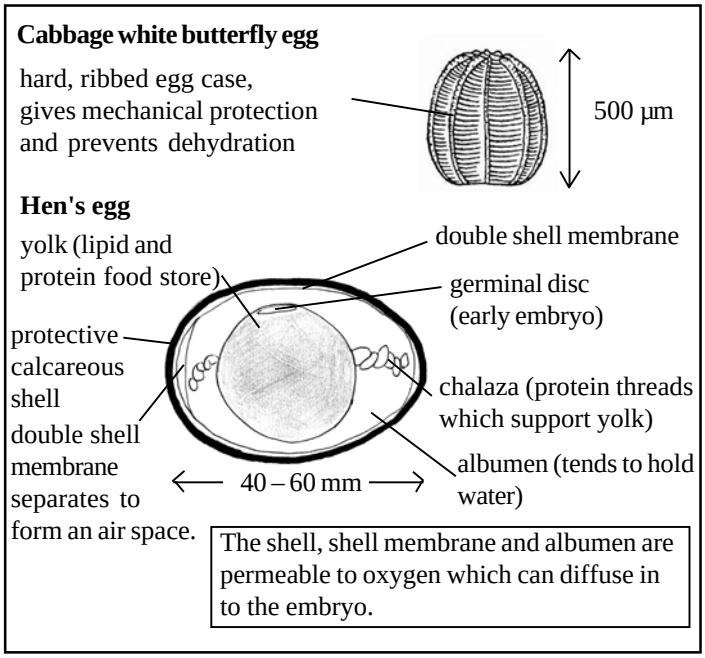
The eggs of reptiles and birds contain large amounts of yolk. Much yolk is needed because the developing embryo has to rely on it throughout development, until it is hatched as an almost fully developed young reptile or bird. The shell of reptile and bird eggs prevents the embryo from obtaining food from an external source. Reptiles have large soft-shelled eggs the shell and membranes of which reduce the risk of drying out during embryo development. In birds the shell is hard (calcified), this gives mechanical protection when the parent birds sit on the eggs to incubate them. The membranes in the bird egg also help to reduce the risk of desiccation.

1.Amphibian eggs contain a moderate amount of yolk. They have enough yolk for the egg to develop into a free-living, aquatic tadpole larva which is capable of feeding itself until it metamorphoses into an adult frog, toad, newt or salamander.

2. Insects and placental mammals eggs only contain minute amounts of yolk. There only needs to be enough yolk to support embryonic development in the initial stages, after which nutrition can be obtained from other sources. In insects the egg hatches into an independent larval form or nymph which is capable of eating and feeding itself. In placental mammals the developing embryo initially absorbs nutritive secretions from the uterine glands and later is fed via the placenta throughout pregnancy. Insect eggs are surrounded by a shell. In most insects this is thick enough and tough enough to give some mechanical protection and to prevent drying out, particularly if the egg must over-winter.

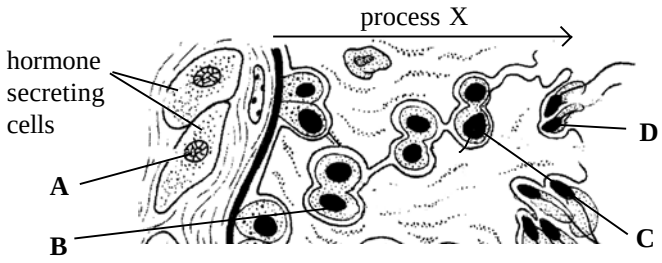
Because the mammalian egg is retained inside the oviducts and uterus of the mother it is protected and so does not need protective coverings.

Fig. 7. Structure of eggs.



Practice Questions

1. The drawing shows a section through part of a human testis.



(a) (i) Name process X. **1**

(ii) Describe the overall functions of process X. **3**

(b) (i) Name cells A, B, C and D. **4**

(ii) What percentage of each of cells A, B and D would you expect to contain a Y- chromosome? Explain your answer for each cell. **3**

(c) Sperm may contain surface antigens which could provoke an immune response in the person producing them. Suggest why this does not happen. **3**

Total 14

2. (a) Eggs are always larger than sperm. Explain why. **3**

(b) Compare the eggs of placental mammals with the eggs of birds, in relation to their reproductive methods. **6**

Total 9

3. (a) (i) In spermatogenesis division of the cytoplasm does not complete until the spermatocytes develop into mature sperm. Suggest why this is so. **3**

(ii) How does cytoplasmic division in the phase of maturation of oogenesis differ from cytoplasmic division in the phase of maturation of spermatogenesis? **3**

(b) Why is important for gametogenesis to include both mitotic and meiotic processes? **3**

Total 9

Answers

1. (a) (i) spermatogenesis; **1**
(ii) to produce spermatozoa/sperm;
which are haploid (to compensate for doubling in fertilization);
and all genetically different (to provide variation); **3**

(b) (i) A = cells of Leydig/interstitial cells; B = spermatogonia/primary spermatocytes;
C = secondary spermatocytes; D = spermatids; **4**
(ii) A = 100% because it is a male diploid cell so has genotype XY;
B = 100% because it is a male diploid cell/produced by mitosis so has genotype XY;
D = 50% because it is produced by meiosis so is haploid, either X or Y-sperm; **3**

(c) the sperm would have to come into contact with (T-lymphocytes to be recognized as foreign;
these are in the blood and other tissues of the body which the sperm cannot come into contact with;
because the Sertoli cells/linings of other sperm ducts provide a barrier which is impenetrable to sperm; **3**

2. (a) eggs contain more food/yolk than sperm (which makes eggs larger);
sperm only need enough food/yolk to provide energy for swimming (once in the oviduct) to locate the egg and fertilise it;
eggs need enough food/yolk to support embryonic development until another method of nutrition becomes available; **3**

(b) eggs of placental mammals only need a small quantity of yolk, to support the embryo for a few days/eggs are microscopic;
embryo then obtains nutrition from uterine secretions of mother;
embryo/fetus later fed via placenta until birth;
bird eggs need a lot of yolk and so are very large;
bird embryo is isolated in the egg, so yolk has to support the complete development until hatching;
mammalian embryo is inside uterus so it is protected/no chance of drying out;
bird egg has hard shell to protect it against knocks/albumin to prevent it from drying out; **max 6**

3. (a) (i) once meiosis has occurred the cells will contain either an X or a Y-chromosome;
the Y-chromosome carries few genes but the X-chromosome carries many genes;
the cytoplasmic bridges between spermatocytes/spermatids enable chemicals synthesized by X-chromosome genes to pass to the Y-cells;
without these chemicals the Y-sperm would not complete development and there would be no males born; **max 3**
(ii) in spermatogenesis, cytoplasmic division is delayed until mature sperm form but in oogenesis, cytoplasmic division occurs immediately after nuclear division;
in spermatogenesis, cytoplasmic division is equal but in oogenesis, a small amount of cytoplasm goes into the polar bodies but most cytoplasm remains with the secondary oocyte/ovum;
this enables the ovum to receive all the yolk; **3**

(b) mitosis allows many gametes to be formed (throughout life);
meiosis allows all gametes to be genetically different from each other;
this gives survival value to the offspring/genetic variation is the 'raw material' enabling evolution/natural selection; **3**

Acknowledgements:
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Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU.