

CHAPTER 3. GAMETOGENESIS

1. Definition

Gametogenesis is the biological process through which **gametes (sex cells)** are formed. It involves the **conversion of primordial germ cells (PGCs)** into mature **male gametes (spermatozoa)** and **female gametes (ova)**.

2. Origin of Gametes

- **Gametes** are derived from **primordial germ cells (PGCs)**, also called **primitive sex cells**.
- PGCs **appear in the wall of the yolk sac** around the **4th week** of embryonic development.
- During the **5th week**, PGCs **migrate** from the yolk sac to the **developing gonads**, originating from:
 - **Coelomic epithelium**
 - **Adjacent mesenchyme**
- While migrating, PGCs undergo **mitotic division**, increasing their number.

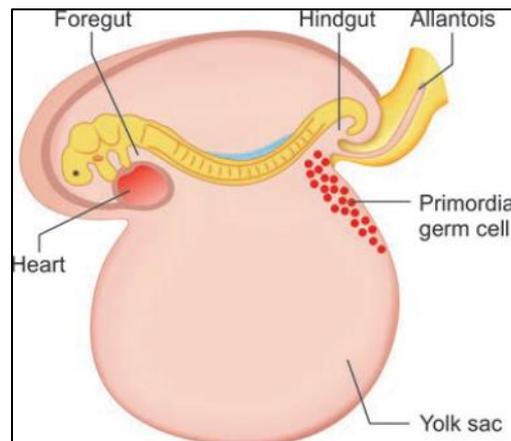


Fig. 7: Migrating primordial germ cells at the caudal end of yolk sac

3. Gonadal Differentiation

- Occurs during the **6th week** of development.
- Once in the gonads, PGCs differentiate into:
 - **Spermatogonia** in males – within the **seminiferous tubules** of the **testis**.
 - **Oogonia** in females – within the **cortex** of the **ovary**.

4. Phases of Gametogenesis

The process involves four key events:

1. **Formation and migration** of PGCs and their differentiation into male or female sex cells.
2. **Mitotic divisions** of germ cells to increase their population.
3. **Meiotic divisions** that reduce the **chromosome number (diploid → haploid)**.
4. **Differentiation and maturation** of germ cells into functional gametes.

□ *Note:* Phases 1 and 2 are **similar in both sexes**, whereas **Phases 3 and 4** differ in **timing and pattern** between males and females.

5. Table 1: Types of Gametogenesis:

Type	Description	Location
Spermatogenesis	Formation of spermatozoa from spermatogonia	Seminiferous tubules of testis
Oogenesis	Formation of ova from oogonia	Cortex of the ovary

6. Table 2: Differences between Spermatogenesis and Oogenesis

Feature	Spermatogenesis	Oogenesis
Location	Seminiferous tubules of testis	Cortex of the ovary
Onset	Begins at puberty	Begins during fetal development
Continuity	Continuous throughout life	Discontinuous, arrested at certain stages
Gametes per cycle	Millions of sperm produced daily	Usually one ovum released per cycle
Duration	~64 days (human males)	Can span decades (from fetal life to menopause)

2.1. SPERMATOGENESIS

1. Definition

Spermatogenesis is the process of **maturation of male gametes** (spermatozoa) that occurs in the **wall of seminiferous tubules** of the testes. It involves a sequence of developmental changes through which **spermatogonia** are transformed into **mature, motile spermatozoa**.

➤ General Overview

- **Time of Onset:** Begins at **puberty** (approximately 12–16 years of age)
- **Duration of Process:** Approximately **64–74 days**
- **Site:** **Seminiferous tubules** of the **testis**

2. Stages of Spermatogenesis

Spermatogenesis occurs in **three major stages**, each with specific processes and cellular changes:

2.1. Spermatocytosis

Duration: ~16 days

Definition: Conversion of **spermatogonia** into **primary spermatocytes** through **mitotic divisions**.

➤ Key Events:

- **Formation of Spermatogonial Stem Cells** from primordial germ cells (PGCs)
- **Type A Spermatogonia:** Formed by mitosis from stem cells; act as reserve cells
- **Type B Spermatogonia:** Paler cells derived from Type A, undergo final mitosis
- Type B spermatogonia enlarge to become **Primary Spermatocytes** ($44 + X + Y$)

2.2. Meiotic Divisions

Duration: ~24 days

Definition: Conversion of **primary spermatocytes** into **spermatids** via **two meiotic divisions**.

➤ First Meiotic Division (Reduction Division):

- **Primary spermatocytes** ($44 + X + Y$) → **2 Secondary spermatocytes** ($22 + X$ or $22 + Y$)

➤ Second Meiotic Division (Equational Division):

- Each **secondary spermatocyte** → **2 Spermatids** (haploid: $22 + X$ or $22 + Y$)
- Total: One primary spermatocyte produces **4 spermatids**

2.3. Spermiogenesis (a.k.a. Spermateleosis)

Duration: ~24 days

Definition: The **metamorphosis of spermatids into spermatozoa**, involving morphological and structural transformation.

Table 3: Cellular Events of Spermiogenesis

Component	Transformation During Spermiogenesis
Nucleus	Condenses and moves to one pole to form the head
Golgi Apparatus	Forms the acrosomal cap that covers the anterior 2/3 of the nucleus
Centrioles	Divide into proximal (forms part of neck) and distal centrioles (forms annulus); involved in axoneme (tail) formation
Mitochondria	Arrange helically around the axoneme in the middle piece to form the mitochondrial sheath for energy
Cytoplasm	Excess cytoplasm is shed as residual bodies of Renaud , which are phagocytosed by Sertoli cells
Cell Membrane	<ul style="list-style-type: none"> • Remains as a protective envelope; contains specializations essential for: • Sperm-egg recognition • Sperm-egg binding • Sperm-egg fusion

➤ **Summary of Major Events in Spermiogenesis**

1. **Nuclear morphogenesis and condensation**
2. **Acrosome formation** from Golgi complex
3. **Tail formation** from centrioles and flagellar development
4. **Organelle rearrangement** (especially mitochondria around the tail)
5. **Shedding of excess cytoplasm**

➤ **Microscopic View**

- A seminiferous tubule shows cells at various developmental stages:
 - **Spermatogonia**
 - **Primary and secondary spermatocytes**
 - **Spermatids**
 - **Spermatozoa**
 - **Sertoli cells** (supporting cells)

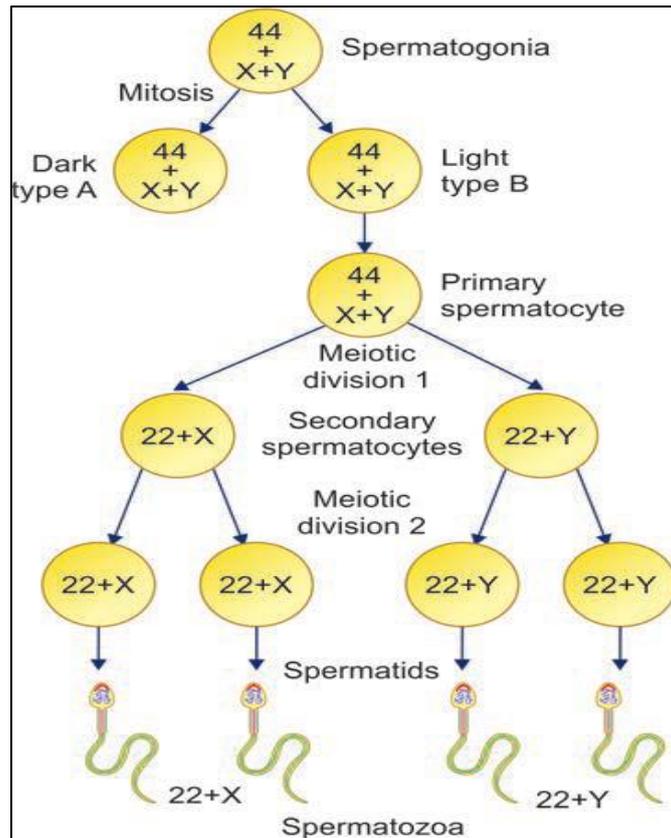


Fig. 8: Stages in spermatogenesis. Note the number of chromosomes at each stage

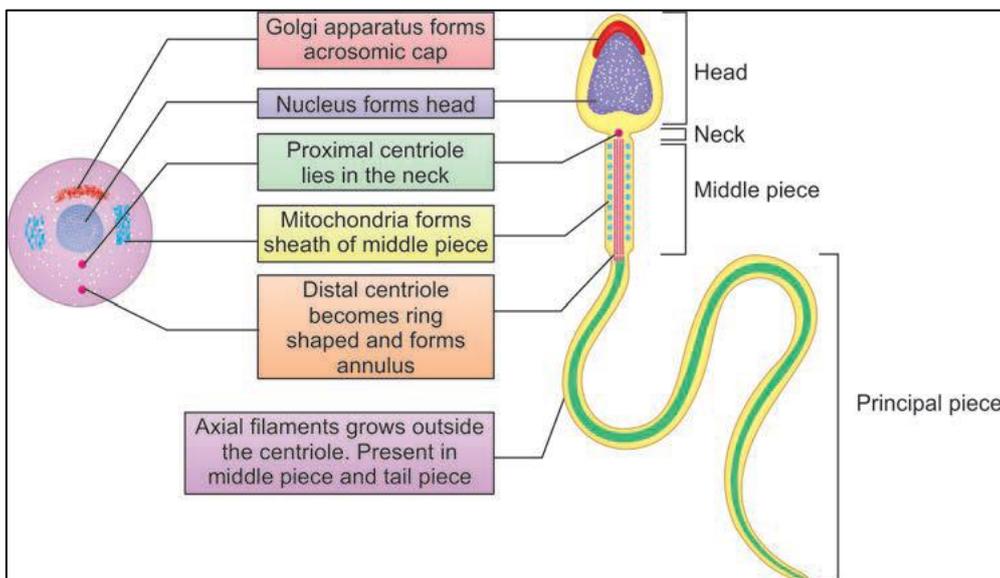


Fig. 9: Parts of a spermatozoon and their derivation

Spermatogenesis vs. Spermiogenesis

Spermatogenesis

- It is the **complete process** of formation of a spermatozoon from a **spermatogonium**.
- It includes:
 1. **Mitotic divisions** of spermatogonia
 2. **First and second meiotic divisions** (to form spermatids)
 3. **Spermiogenesis** (final transformation of spermatids into spermatozoa)

Spermiogenesis (Fig. 10)

- Refers specifically to the **final stage** of spermatogenesis.
- It is the **transformation of a rounded spermatid** into a **highly specialized, motile spermatozoon**.
- Involves:
 - Nuclear condensation
 - Acrosome formation
 - Tail development
 - Cytoplasm shedding

3. Maturation and Capacitation of Spermatozoa

3.1. Maturation (in the Epididymis)

- Newly formed spermatozoa in the **seminiferous tubules** are:
 - **Immature**
 - **Non-motile**
 - **Incapable of fertilization**
- A **fluid current** carries sperm from the **testis** to the **epididymis**.
- In the **epididymis**, spermatozoa:
 - Are **stored**
 - Undergo **biochemical maturation**
 - Experience **modifications of glycoproteins** on their plasma membranes
 - Acquire **partial motility**

3.2. Full Motility

- Achieved **after ejaculation**
- Triggered by mixing with **seminal vesicle and prostate secretions**

3.3. Capacitation (in Female Genital Tract)

- The **final maturation step**, enabling fertilization.
- Occurs in the **uterus or uterine tube**
- Involves:
 - **Removal or modification** of the glycoprotein coat and seminal proteins on sperm head
 - Allows the **acrosome reaction** to occur upon contact with **zona pellucida** of the ovum

4. Acrosome and Zona Reactions

4.1. Acrosome Reaction

- When sperm contacts the **zona pellucida**, the **membranes over the acrosome** undergo changes
- Leads to **release of lysosomal enzymes** (e.g., hyaluronidase, acrosin)
- These enzymes help the sperm to **penetrate** the zona pellucida

4.2. Zona Reaction

- A **response of the ovum** that:
 - Changes the structure of the zona pellucida
 - **Prevents polyspermy** (entry of more than one sperm)

5. Structure of a Mature Spermatozoon (Fig. 9)

A mature spermatozoon is a **motile, highly specialized male gamete**, measuring approximately **60 µm in length**. It has the following parts:

5.1. Head

- **Shape:** Piriform (pear-shaped), ~4 µm in length
- **Contents:**
 - **Nucleus** with 23 highly condensed chromosomes
 - **Acrosome cap:** Contains enzymes necessary for zona penetration during fertilization

5.2. Neck

- Connects the head to the tail
- Contains:
 - **Basal body** (funnel-shaped, also called the connecting piece)
 - **Spherical centriole**
- Composed of **nine segmented rod-like structures**

5.3. Middle Piece

- Contains part of the **axial filament**
- Surrounded by a **spiral sheath of mitochondria** (provides energy for motility)
- **Annulus:** A ring structure at the junction with the tail

5.4. Principal Piece (Tail)

- Longest part of the sperm
- Contains the continuation of the **axial filament**
- Responsible for **locomotion**

5.5 Axial Filament

- Passes through the middle piece and tail
- **Structure:**
 - Central pair of fibrils
 - Surrounded by **nine doublets** arranged circularly
 - **Nine coarse petal-shaped fibrils** outside each doublet
 - Surrounded by a **fibrous sheath**
 - Enclosed within a **plasma membrane**

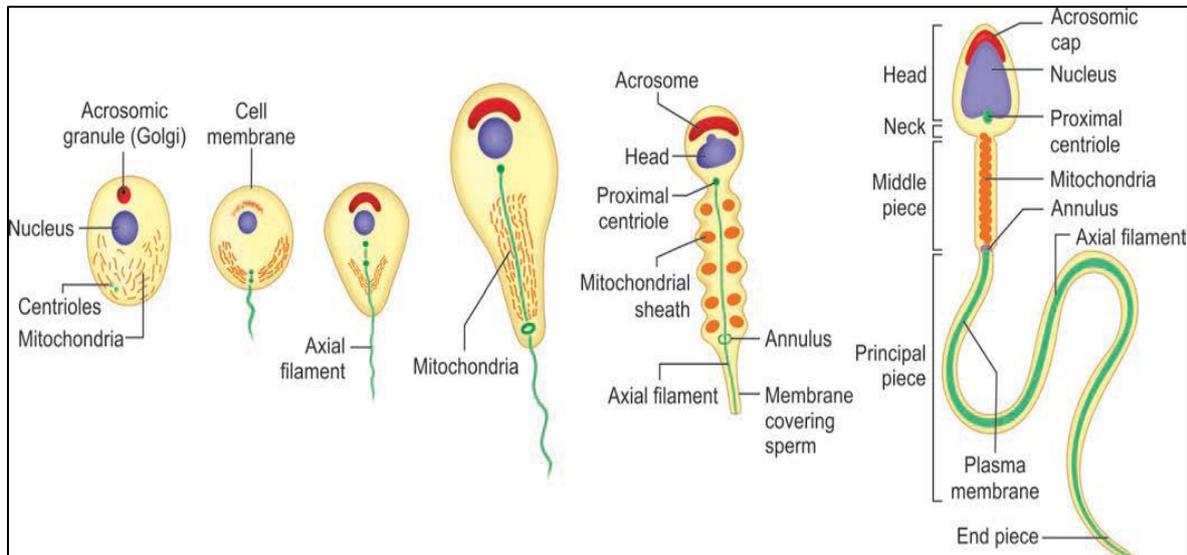


Fig 10: Stages in spermiogenesis and parts of a spermatozoon

2.2. OOGENESIS

1. Definition

Oogenesis is the process of maturation and differentiation of **primordial germ cells (PGCs)** into **oogonia**, **primary oocytes**, **secondary oocytes**, and ultimately **mature ova** in the female reproductive system.

Location: Occurs in the **ovarian cortex**.

➤ Key Peculiarities of Oogenesis

- Begins **before birth** (10th week of embryonic life)
- **Pauses** at birth and remains arrested until **puberty**
- **Resumes** at puberty (11–13 years)
- Continues **cyclically** until **menopause** (around 45–55 years)

➤ Cellular Events

- The **cortex of the ovary** contains many large, round cells called **oogonia**.
- All oogonia are produced **at a very early stage**, likely **before birth**, and **do not multiply thereafter**.
- On arrival in the gonad, **primordial germ cells (PGCs)** differentiate into oogonia.
- Oogonia then progress through various stages: **primary oocyte** → **secondary oocyte** → **ovum**.

2. Phases of Oogenesis

2.1. Before Birth

a. Before the 3rd Month

- Primordial germ cells (PGCs) undergo **mitosis** to form **oogonia**.
- This process occurs in the **absence of testicular differentiation factor (TDF)**.

b. 3rd to 7th Month

- Oogonia **continue mitotic divisions** and begin to accumulate in large numbers.
- They become surrounded by a **single layer of flat epithelial cells**, forming **primordial follicles**.
- Some oogonia **enlarge** to become **primary oocytes**.

c. 7th Month to Birth

- Formation of **primordial follicles** continues.
- Primary oocytes enter **prophase I of meiosis I** but are **arrested** in this stage due to the presence of **oocyte maturation inhibitor (OMI)**.
- The **oogonia are diploid (2n)**.
- **Degeneration** of many oogonia and primary oocytes also occurs during this period.

- By birth, **millions** of germ cells are reduced to about **2 lakh (200,000) primary oocytes** per ovary.

2.2. From Birth to Puberty

- **No new oogonia are formed.**
- Existing **primary oocytes remain arrested in prophase I (diplotene stage)** of meiosis I.
- There is both **maturation and degeneration** of primordial follicles, resulting in a **gradual decline** in the number of primary oocytes.

2.3. After Puberty: Ovarian Cycle Begins

The ovarian cycle prepares the oocyte **cyclically** for potential fertilization.

a. Maturation and Meiotic Resumption

- During each cycle, a few primary oocytes **resume meiosis I.**
- Meiosis I results in **two unequal haploid cells (23 chromosomes):**
 - A large **secondary oocyte** (which receives most of the cytoplasm)
 - A small **first polar body**

b. Ovulation and Meiosis II

- The **secondary oocyte immediately begins meiosis II, but is arrested in metaphase II.**
- **Ovulation** occurs while the oocyte is in metaphase II.

c. If Fertilization Occurs

- The secondary oocyte **completes meiosis II, producing:**
 - A large **ovum**
 - A **second polar body**
- The **first polar body may also divide**, leading to a total of **three polar bodies.**

d. If Fertilization Does Not Occur

- The secondary oocyte **does not complete meiosis II.**
- It **degenerates about 24 hours** after ovulation.

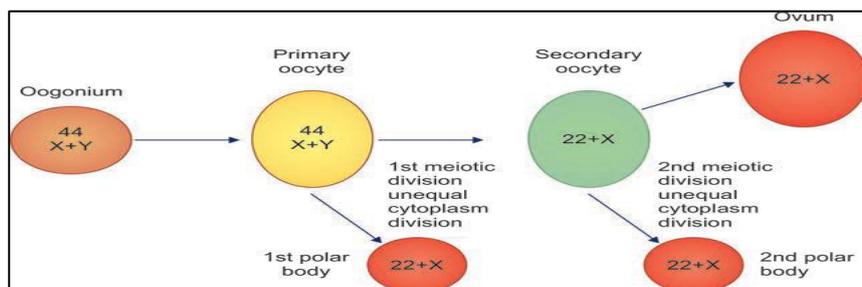


Fig. 11: Stages in oogenesis