Sexual Reproduction

Why do organisms only reproduce their own kind? Why do offspring more closely resemble their parents than unrelated individuals of the same species?

- The fact that organisms reproduce their own kind is a consequence of **heredity** (continuation of biological traits from one generation to the next).
- Heredity results from the transmission of heredity units, or **genes**, from parents to offspring.
- Because they share similar genes, offspring more closely resemble their parents or close relatives than unrelated individuals of the same species.
- Nevertheless, **variation** between individuals is important to ensure survival of the species.
- **Meiosis** and **sexual reproduction** significantly contribute to **genetic variation** among offspring by ensuring **recombination of genes**.

The actual transmission of genes from parents to offspring depends on the behavior of **chromosomes**. Chromosomes

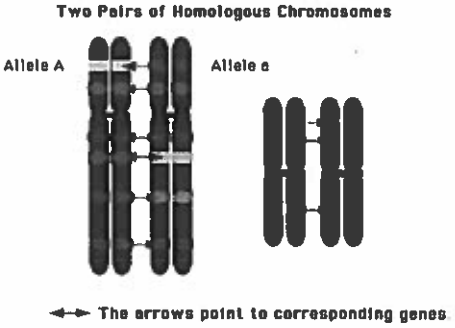
- consist of a single long **DNA** molecule that is highly folded and coiled along with proteins,
- contain hundreds or thousands of **genes**, each of which is a special region of the DNA molecule.
- each species has a characteristic **chromosome number** – humans have 46.

BACKGROUND TERMINOLOGY

Somatic cell: Any cell other than a sperm or egg cell ("body cells").

- ➔ Human somatic cells contain **46** chromosomes distinguishable by differences in **size**, **position** of the **centromere**, and staining or banding pattern **(gene arrangement)**.
- ➔ Using these criteria, chromosomes can be matched into **homologous pairs** and arranged in a standard sequence to produce a **karyotype**.

Homologous Chromosomes (homologues): A pair of chromosomes that are similar in size, centromere position and staining pattern (gene arrangement).



Autosome: A chromosome that is not a sex chromosome.

Sex chromosome: Dissimilar chromosomes that determine an individual's sex.

- ➔ Females have a homologous pair of **X** chromosomes (XX).
- ➔ Males have one **X** and one **Y** chromosome (XY).
- ➔ Thus, humans have 22 pairs of autosomes and 1 pair of sex chromosomes.

Gamete: A **haploid** reproductive cell produced by Meiosis.

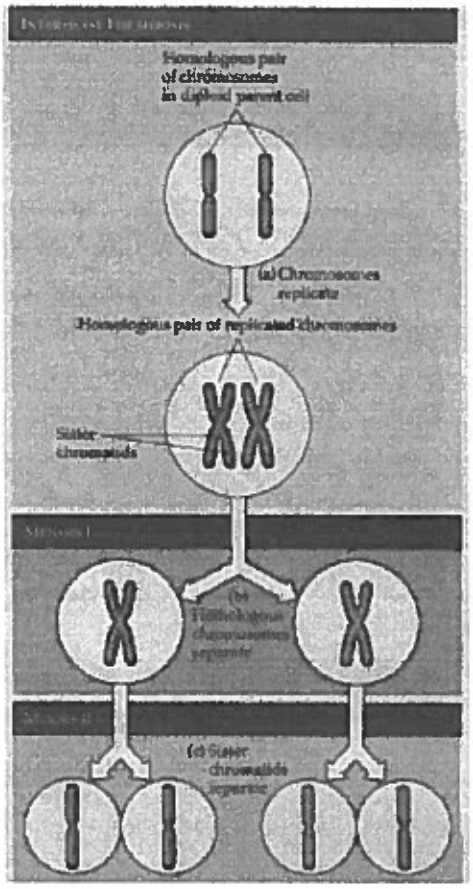
- ➔ **Sperm cells** and **ova** are gametes, and they differ from somatic cells in their chromosome number. Gametes only have one set of chromosomes (n).
- ➔ Human gametes contain a single set of 22 autosomes and one sex chromosome (either an X or a Y).
- ➔ Thus, the haploid number of humans is **23**. (the diploid number is restored when the two haploid gametes unite in the process of fertilization).

Meiosis

Meiosis includes steps that closely resemble corresponding steps in mitosis.

- Like mitosis, meiosis is preceded by **replication of the chromosomes**.
- Meiosis differs from mitosis in that this single replication is followed by two consecutive cell divisions: **Meiosis I** and **Meiosis II**.
- These cell divisions produce **four (4) daughter cells** instead of two as in mitosis.
- The resulting daughter cells have half the number of chromosomes as the original cell (**haploid**); whereas, daughter cells of mitosis have the same number of chromosomes as the parent cell (diploid).

Phases of Meiosis I and Meiosis II



Interphase

- ⇨ **Precedes** meiosis I.
- ⇨ **Chromosomes replicate** as in mitosis.
- ⇨ Each **duplicated chromosome** consists of two identical **sister chromatids** attached at their centromeres.

Meiosis I *(Reduction Division)*

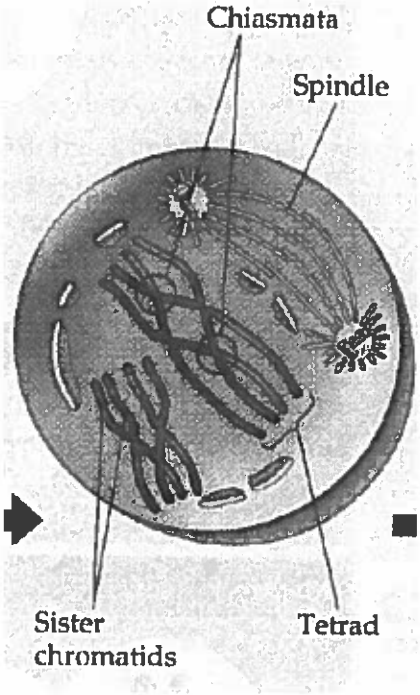
This cell division **reduces** the chromosome number by one-half. Separates **homologous chromosomes**. It includes the following four phases:
Prophase I ➔ Metaphase I ➔ Anaphase I ➔ Telophase I and Cytokinesis

Meiosis II

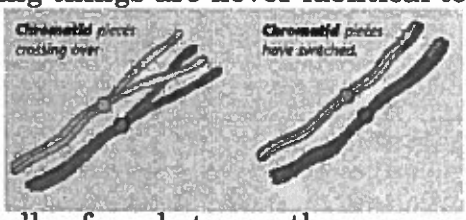
Separates **sister chromatids**. It includes the following four phases:
Prophase II
Metaphase II
Anaphase II
Telophase II and Cytokinesis

Meiosis I *(Reduction Division)*

Prophase I: This is a longer and more complex process than prophase in mitosis.

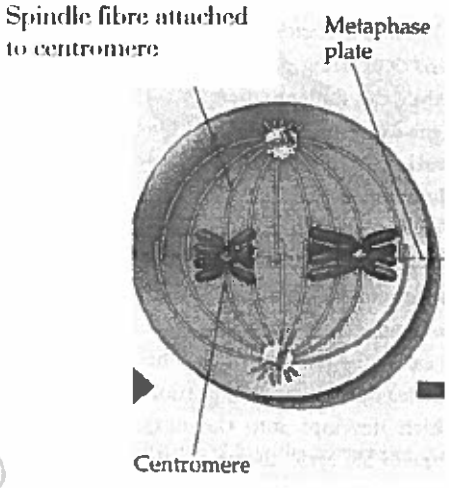


- ⇨ Threads of chromatin in the nucleus condense and coil up to form chromosomes.
- ⇨ **Synapsis** occurs.
  - o In this process, homologous chromosomes, each made up of two sister chromatids, come together as pairs.
  - o Since each chromosome has two chromatids, each homologous pair in synapsis appears as a complex of four chromatids or a **tetrad**.
- ⇨ **Crossing over** occurs in **early prophase**.
  - o Chromatids of each tetrad cross over each other at places called **chiasmata**.
  - o Two chromatid pieces (one from each pair) break off and trade over.
  - o Causes mixing of genes (helping to ensure new living things are never identical to parents).



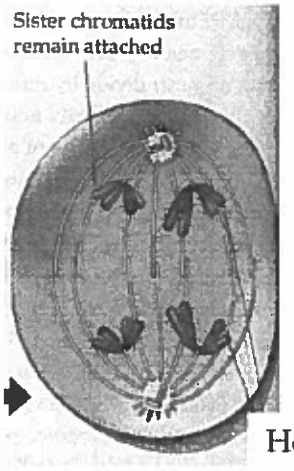
- ⇨ **Centriole** pairs move apart and spindles form between them.
- ⇨ **Nuclear membrane** disappears.
- ⇨ Chromosomes begin moving to the metaphase plate.
- ⇨ Prophase I typically occupies more than 90% of the time required for meiosis.

Metaphase I: **Tetrads** (homologous pairs) are aligned on the metaphase plate.



- ⇨ Each homologous pair lines up independently: **independent assortment**.
- ⇨ Spindles from one pole of the cell are attached to one chromosome of each pair, while spindles from the opposite pole are attached to the other chromosome (homologue).

Anaphase I: Chromosomes are moved towards the opposite poles by the spindle apparatus (process called **segregation**).



- ⇨ Sister chromatids remain attached at their centromeres and move as a unit towards the same pole, while the homologue moves toward the opposite pole.
- ⇨ This differs from mitosis – how?

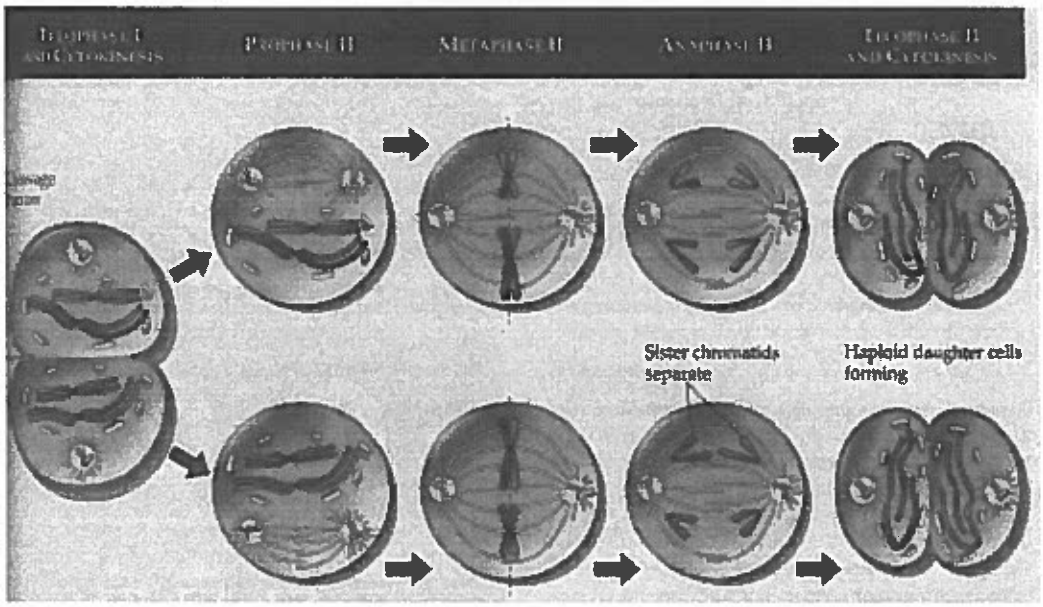
Homologous chromosomes separate

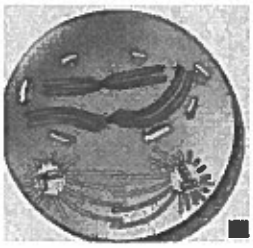
Telophase I and Cytokinesis: The spindle apparatus continues to separate homologous chromosome pairs until the chromosomes reach the poles.

- ⇨ Each pole now has a **haploid** set of chromosomes that are still composed of two sister chromatids attached at the centromere.
- ⇨ Cytokinesis occurs simultaneously with Telophase I, forming two haploid daughter cells.
  - o **Cleavage furrows** form in animal cells, and cell plates form in plant cells.

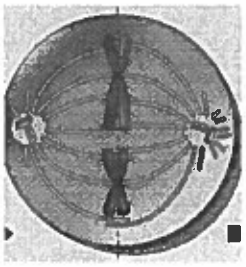
There is no further replication of the genetic material (DNA) prior to Meiosis II (i.e. no Interphase).

Meiosis II

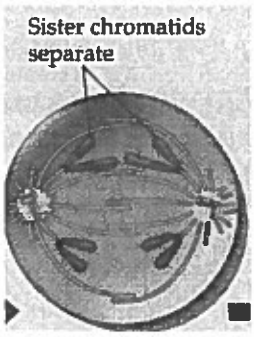




Prophase II: A spindle apparatus forms and the chromosomes progress toward the metaphase II plate.



Metaphase II: The chromosomes are positioned on the metaphase plate in mitosis-like fashion.



Anaphase II: The centromeres of sister chromatids separate, and the sister chromatid of each pair, now individual chromosomes, move toward opposite poles of the cell.

Telophase II and Cytokinesis: Nuclei form at opposite poles of the cell, and cytokinesis occurs. At the completion of cytokinesis, there are **four daughter cells**, each with the **haploid number** of unreplicated chromosomes.

Sexual Sources of Genetic Variation

Meiosis and **fertilization** are the primary sources of **genetic variation** in sexually reproducing organisms.

Sexual reproduction provides genetic variation by: independent assortment of chromosomes and crossing over during prophase I of meiosis I.

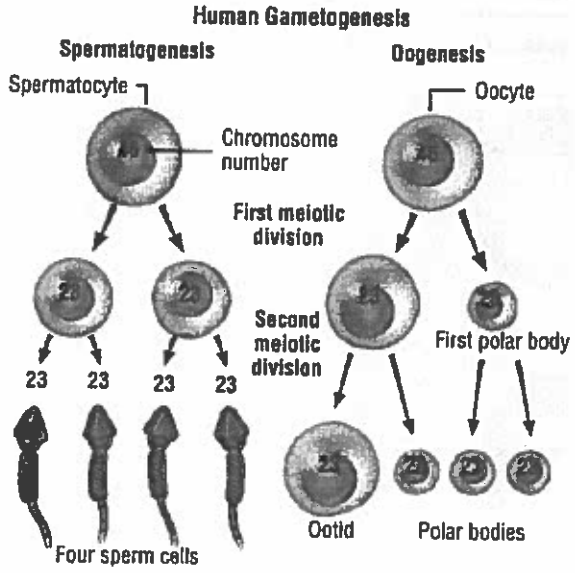
I. Independent Assortment of Chromosomes

- At **metaphase I**, each homologous pair of chromosomes aligns on the metaphase plate. Each pair consists of **one maternal** and **one paternal** chromosome.
- The orientation of the homologous pair to the poles is **random**, so there is a 50-50 chance that a particular daughter cell produced by meiosis I will receive the maternal chromosome of a homologous pair, and a 50-50 chance that it will receive the paternal chromosome.
- Each homologous pair of chromosomes orients **independently** of other pairs at metaphase I: thus, the first meiotic division results in **independent assortment**.
- **Independent Assortment:** the random distribution of maternal and paternal homologues to the gametes (more specifically, the **random distribution of genes located on different chromosomes**)
- Each human gamete contains one of **eight million** possible assortments of chromosomes inherited from the person's mother and father.

II. Crossing Over

- Another mechanism that increases genetic variation is the process of crossing over, during which **homologous chromosomes exchange genes**.
- Occurs when homologous portions of two **non-sister chromatids** trade places. During prophase I, X-shaped **chiasmata** become visible at the places where this homologous strand exchange occurs.
- Produces chromosomes that contain genes from both parents.
- In humans, there is an average of **2 to 3 crossovers per chromosome pair**.
- **Synapsis** during prophase I is precise, so that homologous chromosomes align gene by gene. The exact mechanism of synapsis is still unknown.

Gametogenesis

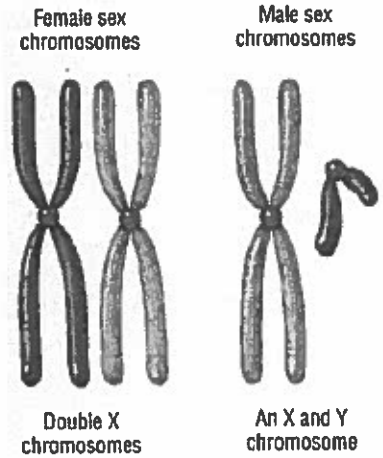


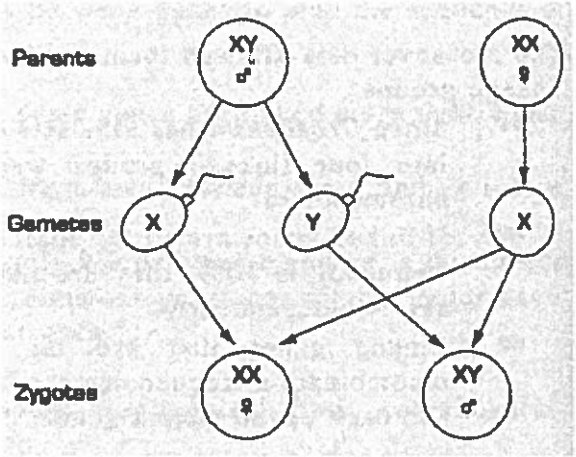
- The formation of **gametes**
- Meiosis in spermatocytes produces 4 **sperm.**
- Meiosis in oocyte produces **1 ootid** and **3 polar bodies** (uneven distribution of cytoplasm) ➔polar bodies die.

The Chromosomal Basis of Sex in Humans

Mammals, including humans, have an **X-Y mechanism** that determines sex at fertilization.

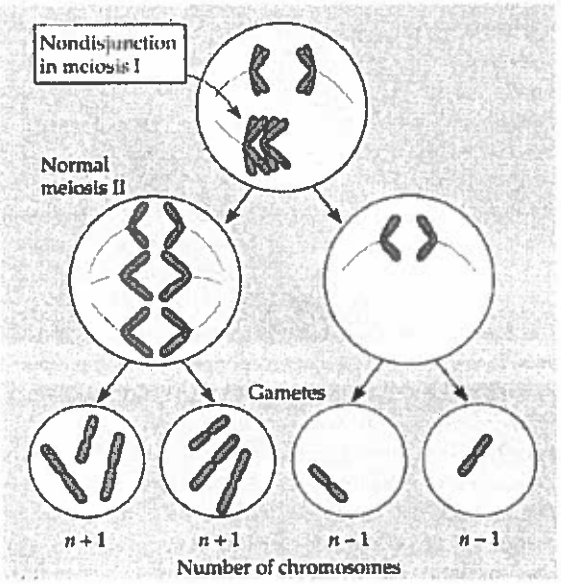
- There are two sex chromosomes, **X** and **Y**.
- Each gamete has **one sex chromosome**, so when sperm cell and ovum unite at fertilization, the zygote receives one of two possible combinations: **XX** or **XY**.
- Males are the **heterogametic** sex (**XY**). Half the sperm cells contain an **X** chromosome, while the other half contains a **Y** chromosome.
- Females are the **homogametic** sex (**XX**): all ova carry an **X** chromosome.

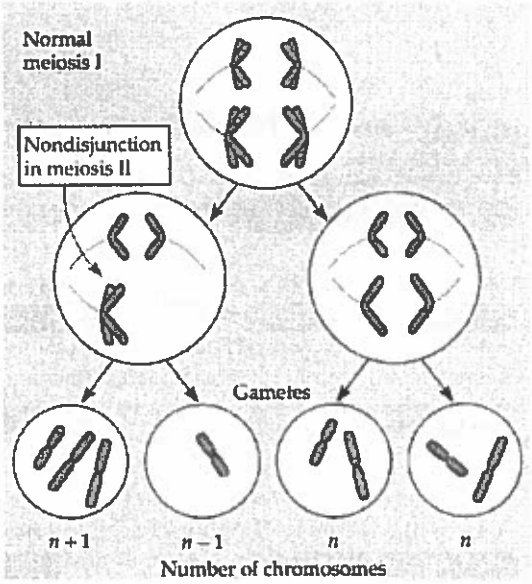




Alterations of Chromosome Number

- Ideally, the meiotic spindle distributes chromosomes to daughter cells without error.
- But there is an occasional mishap, called a nondisjunction, in which the members of a pair of **homologous chromosomes** do not move apart properly during meiosis I, or in which **sister chromatids** fail to separate during meiosis II.
- Results in one gamete receiving two of the same type of chromosome (**trisomy**) and another receiving no copy (**monosomy**).





- When a zygote with an abnormal number of chromosomes divides by mitosis, it transmits the chromosomal irregularity to all subsequent embryonic cells.
- Meiotic nondisjunction during gamete formation usually **prevents** normal embryonic development and often results in **spontaneous abortion**.
- Some types of nondisjunction cause less severe problems, and individuals may be born with a set of characteristic symptoms or **syndrome**.
- Nondisjunction conditions can be diagnosed before birth by **amniocentesis**.
- Karyotypes (ordered displays of an individuals chromosomes) are used to identify certain abnormalities in the chromosomes.

Human Disorders Due to Nondisjunction

Down syndrome

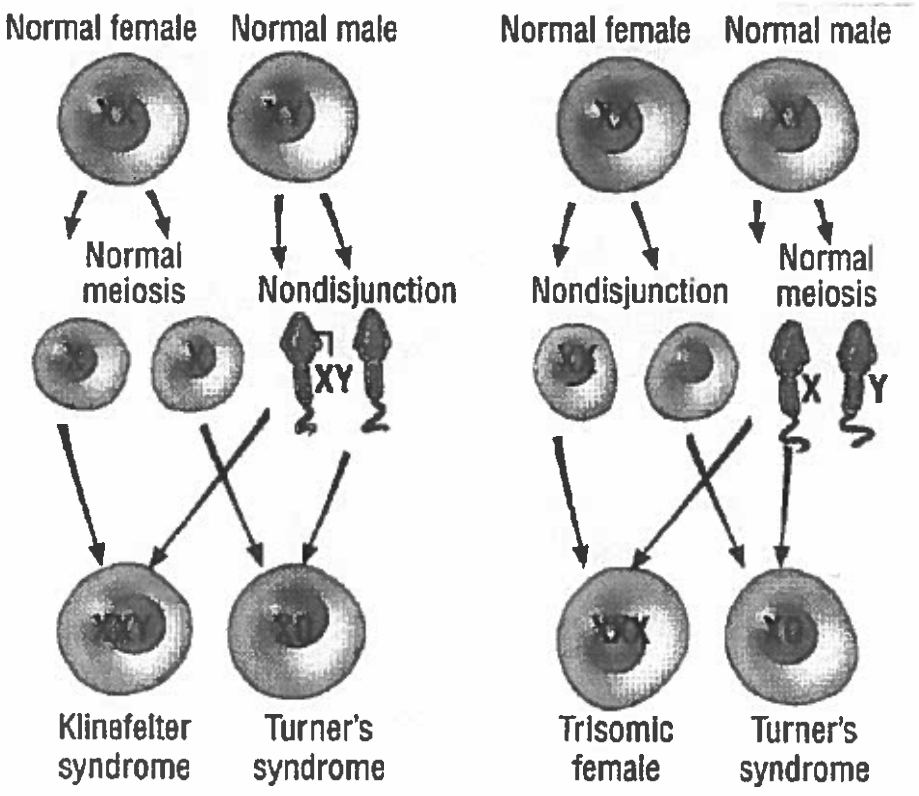
- Have an extra chromosome 21 (trisomy 21)
- This syndrome includes characteristic facial features, short stature, heart defects and mental retardation.
- There is a 50% chance of transmitting it to each child, since about half of the ova will have an extra chromosome 21.
- Incidence of Down syndrome offspring correlates with maternal age. A mother in her 40s is 25 times more likely than a woman in her 20s to have a Down syndrome baby.

Klinefelter syndrome

- Nondisjunction of sex chromosomes
- In males, have an extra X chromosome, producing **XXY**
- Occurs once in every 1000 to 2000 live births.
- **Characteristics:** have male sex organs, but the testes are abnormally small and the man is sterile; breast enlargement and other feminine body characteristics; usually of normal intelligence.
- Appear male at birth but at sexual maturity begin producing high levels of female sex hormones.

Turner's syndrome

- Nondisjunction of sex chromosomes.
- **Monosomy X (X0)** (female)
- Occurs once in every 5000 – 10000 live births (most fetuses are miscarried before the 20th week of pregnancy).
- **Characteristics:** Short stature; at puberty, secondary sexual characteristics fail to develop; internal sex organs do not mature; sterile.

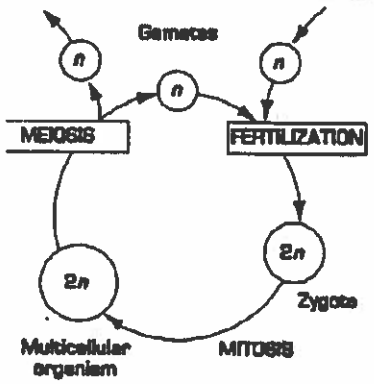


Variety of Sexual Life Cycles

Alternation of **meiosis** (haploid stage) and **fertilization** (diploid stage) is common to all sexually reproducing organisms; however, the timing of these two events in the life cycle varies among species.

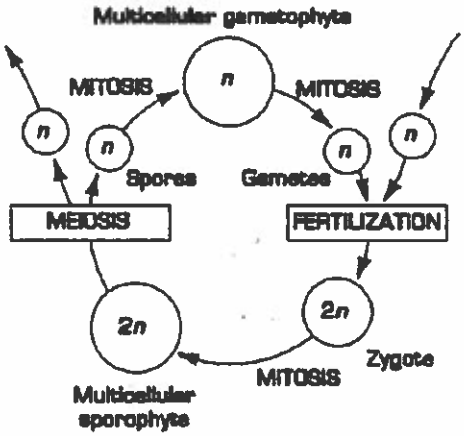
Animals: In animals, including humans, **gametes** are the only **haploid** cells.

- **Meiosis** occurs during **gamete** production. The resulting gametes undergo no further cell division before fertilization.
- **Fertilization** produces a **diploid zygote** that divides by **mitosis** to produce a **diploid multicellular animal.**



Plants and some algae: Plants and some species of algae alternate between **multicellular haploid** and **diploid generations.**

- This type of life cycle is called an alternation of generations.
- The **multicellular diploid stage** is called a **sporophyte**, or spore-producing plant. Meiosis in this stage produces **haploid cells** called **spores.**
  - Spores are very hardy cells that can remain dormant for several months and are produced when environmental conditions are difficult.
  - They will germinate or spring into life when the conditions become right for the adult plant to live.



- Haploid spores divide **mitotically** to generate a **multicellular haploid stage** called a **gametophyte**, or gamete-producing plant.
- Haploid gametophytes produce **gametes** by mitosis.
- **Fertilization** produces a **diploid zygote** which develops into the next sporophyte generation.
- In this type of life cycle, the sporophyte and gametophyte generations take turns reproducing each other.