FERTILIZATION AND DEVELOPMENT

Fertilization is the union of a monoploid (n) sperm nucleus with a monoploid (n) egg nucleus to form a diploid ($2n$) cell, the **zygote**, which is the first cell of the new organism. Fertilization restores the diploid species number of chromosomes.

External Fertilization.

The union of a sperm and egg outside the body of the female is called **external fertilization.** External fertilization generally occurs in a watery environment, and is characteristic of reproduction in fish, frogs, and many other aquatic vertebrates.

In external fertilization, large numbers of eggs and sperm are released into the water at the same time to increase the chances that fertilization will take place and to help ensure that at least some of the fertilized eggs will develop and survive to adulthood.

Internal Fertilization.

The union of a sperm and egg in the moist reproductive tract of a female is called **internal fertilization.** Reproduction in most terrestrial, or land-dwelling, vertebrates, including birds and mammals, is characterized by internal fertilization.

With internal fertilization, relatively few eggs are produced at one time. The chances that fertilization will occur are much greater with internal fertilization than with external fertilization.

Stages of Development.

The early stages of embryonic development are similar in all animals. Development begins when the zygote undergoes a rapid series of mitotic cell divisions called **cleavage.**

* **Cleavage.** During cleavage, there is no increase in the size of the embryo—just an increase in the number of cells (Figure 4-10). Cell growth and specialization begin after cleavage.

* **Blastula Formation.** The mitotic divisions of cleavage result in the formation of the **blastula**, a hollow ball made up of a single layer of cells.

* **Gastrulation.** As mitotic divisions continue, one side of the blastula pushes inward, or indents, a process called **gastrulation.** The resulting embryonic stage, called a **gastrula**, consists of an inner layer, or **endoderm**, and an outer layer, or **ectoderm.** A third layer, called the **mesoderm**, forms between the endoderm and ectoderm. The endoderm, mesoderm, and ectoderm are called the **germ layers.**

* **Differentiation and Growth.** The germ layers differentiate to form the various tissues, organs, and organ systems of the developing animal (Table 4-1).

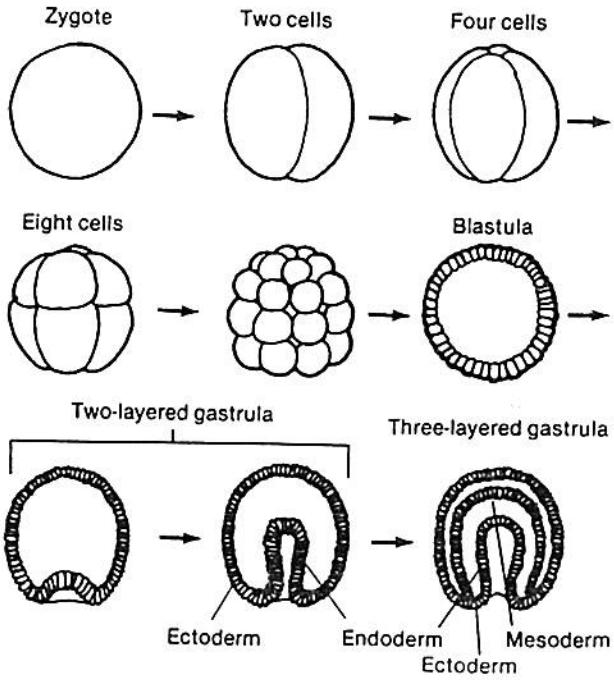


***Figure 4-10.** Early stages of embryonic development.

***Table 4-1. Tissues and Organs Formed From Embryonic Germ Layers**

Embryonic Layer	Organs and Organ Systems
Ectoderm	Nervous system; skin
Mesoderm	Muscles; circulatory, skeletal, excretory, and reproductive systems
Endoderm	Lining of digestive and respiratory tracts; liver; pancreas

* Embryonic development involves growth, as well as differentiation. Growth includes both an increase in the size of the embryonic cells and an increase in the number of cells.

* External Development.

Embryonic development may occur outside or inside the body of the female. **External development** of the embryo occurs outside the female's body. **Internal development** involves the growth of the embryo within the body of the female.

The eggs of many fish and amphibians are fertilized externally and develop externally in an aquatic environment. In eggs that develop externally, the embryo obtains food in the form of yolk, which is part of the egg. In general, the parents provide little or no care for eggs that develop externally in water.

* The eggs of birds, many reptiles, and a few mammals, such as the platypus, develop externally on land. The eggs of these animals are en-

closed in tough shells that protect the developing embryo and prevent it from drying out. Tiny pores in the shell allow the exchange of respiratory gases.

* In addition to the shell, the eggs of these animals are enclosed by several membranes, each of which serves a specific function (Figure 4-11).

* The **yolk sac** surrounds the yolk, which is the embryo's source of food. Blood vessels that penetrate the yolk sac transport food to the embryo.

* The **amnion** is a sac that surrounds the embryo. The sac is filled with **amniotic fluid**, which provides a watery environment, protects the embryo from shock, and prevents adhesion of embryonic tissue to the shell.

* The **allantois** is a membrane that provides a storage site for uric acid, a nitrogenous waste. Blood vessels that penetrate the allantois transport nitrogenous wastes from the embryo to the allantois, where they are stored. The allantois also functions in the exchange of respiratory gases.

* The **chorion** is a membrane that lines the inside of the shell, and together with the allantois, functions in the exchange of respiratory gases.

Internal Development. In most mammals, both fertilization and development are internal. The eggs of mammals have little yolk and are very small compared with the eggs of reptiles and birds. In all mammals, the young are nourished after birth by milk from the mother's mammary glands.

Placental Mammals. Most mammals are placental mammals in which the embryo develops in the uterus of the female, and receives food and oxygen and gets rid of wastes through the placenta.

The **placenta** is a temporary organ that forms within the uterus from embryonic and maternal tissues and is rich in both embryonic and maternal blood vessels. The embryo is connected to the placenta by the **umbilical cord**, which contains blood vessels that carry dissolved materials between the mother and the embryo. In the placenta, the exchange of materials between mother and embryo occurs by diffusion and active transport. Food and oxygen pass from the mother's blood into the blood of the embryo, while wastes pass from the embryo's blood into the blood of the mother. The blood of the mother and the embryo never mix.

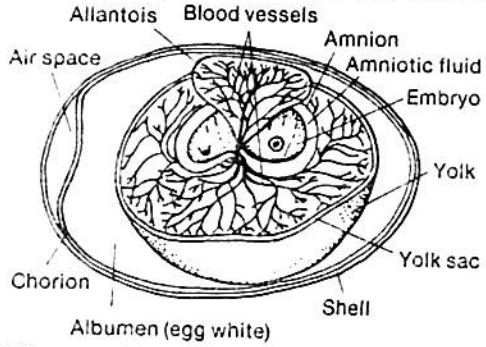


*Figure 4-11. Structure of a bird's egg.

Marsupials. Pouched mammals, or **marsupials**, are nonplacental mammals. In this group, which includes kangaroos and opossums, fertilization is internal, but no placenta or umbilical cord forms. Marsupial embryos obtain nourishment from yolk in the egg for a relatively short time; they are then born at a very immature stage of development. After birth, they crawl into an external pouch on the mother's abdomen, where they feed on milk from mammary glands. The young marsupial remains in the pouch until development is complete.

QUESTIONS

1. The embryos of marsupials, such as the kangaroo and opossum, complete their development externally. What is the source of nutrition for the last stages of a marsupial embryo's development? (1) milk from maternal mammary glands (2) diffusion of nutrients through the uterine wall (3) concentrated food in the yolk stored in the egg (4) food gathered from the environment and fed to the embryo

2. In mammals, the placenta is essential to the embryo for (1) nutrition, reproduction, and growth (2) nutrition, respiration, and excretion (3) locomotion, respiration, and excretion (4) nutrition, reproduction, and excretion

3. Which characteristic of sexual reproduction has specifically favored the survival of terrestrial animals? (1) fertilization within the body of the female (2) male gametes that may be carried by the wind (3) gametic fusion in the outside environment (4) female gametes that develop within gonads

4. Which structure allows animal embryos to receive nourishment directly from the mother? (1) amnion (2) shell (3) placenta (4) ovary

* 5. In a developing embryo, the process most closely associated with the differentiation of cells is (1) gastrulation (2) menstruation (3) ovulation (4) fertilization

* 6. In most species of fish, a female produces large numbers of eggs during a reproductive cycle. This would indicate that reproduction in fish is most probably characterized by (1) internal fertilization and internal embryonic development (2) internal fertilization and external embryonic development (3) external fertilization and internal embryonic development (4) external fertilization and external embryonic development

* 7. In the early development of a zygote, the number of cells increases without an increase in mass by a process known as (1) ovulation (2) cleavage (3) germination (4) metamorphosis

* 8. Distinguish between internal and external fertilization and development. What adaptations in each insure the survival of the species?

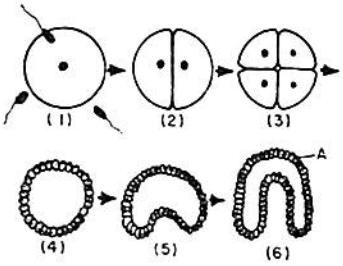
* **9.** Which type of fertilization and development is exhibited by birds and many reptiles?
(1) external fertilization and external development
(2) internal fertilization and internal development
(3) external fertilization and internal development
(4) internal fertilization and external development

* **10.** Which structure is a source of food for embryos that develop externally? (1) yolk (2) placenta (3) chorion (4) amnion

* **11.** If an allantois failed to develop in a bird egg, the most likely result would be that (1) the embryo would not be protected from its environment (2) a placenta could not develop (3) the processes of gas exchange and excretion would be affected (4) food could not be transported to the developing embryo

* **12.** The structure in a bird egg that absorbs shock and provides a watery environment for an embryo is known as the (1) placenta (2) yolk sac (3) chorion (4) amniotic sac

Base your answers to questions 13 through 16 on the diagram below, which represents some stages in the embryonic development of a specific vertebrate.



* **13.** Structures 2 and 3 are formed as a direct result of (1) meiosis (2) gastrulation (3) cleavage (4) differentiation

* **14.** The structure in stage 4 represents a (1) zygote (2) blastula (3) gastrula (4) follicle

* **15.** The cells of layer A give rise to the (1) digestive system and liver (2) excretory system and muscles (3) circulatory system and gonads (4) nervous system and skin

* **16.** Which cells are *not* represented in the diagrams? (1) endoderm cells (2) mesoderm cells (3) diploid cells (4) monoploid cells

HUMAN REPRODUCTION AND DEVELOPMENT

* Male Reproductive System.

The male reproductive system functions in the production of sperm and the placement of sperm in the female reproductive system. The reproductive system is also responsible for production of male sex hormones.

* **Sperm Production.** The sperm-producing organs, the testes, are located in an outpocketing of the body wall called the **scrotum** (Figure 4-12). The temperature in the scrotum, which is 1° to 2°C cooler than normal body temperature, is best suited for the production and storage of sperm.

* From the testes, the sperm pass through a series of ducts into which liquid is secreted by various glands. The liquid serves as a transport medium for the sperm cells, and is an adaptation for life on land. The liquid and sperm together are called **semen.**

* Semen passes to the outside of the body through the urethra, a tube through the penis. The **penis** is used to deposit the semen in the female reproductive tract.

* **Hormone Production.** The testes produce the male sex hormone testosterone, which regulates the maturation of sperm cells. Testosterone also regulates the development of male secondary sex characteristics, including body form, beard development, and deepening of the voice.

* Female Reproductive System.

The female reproductive system functions in the production of egg cells and the female sex hormones.

* **Egg Production.** The female reproductive organs, the ovaries, are located within the lower portion of the body cavity (Figure 4-13). In the ovaries, each egg cell is present in a tiny sac called a **follicle.** About once a month, a follicle matures and bursts, and the egg within it is released from the surface of the ovary, a process called **ovulation.** The egg cell then passes into the **oviduct,** or **Fallopian tube,** which leads to the **uterus.** If sperm are present, fertilization may occur in the oviduct. If the egg is fertilized, it passes into the uterus, where embryonic development may occur. If the egg is not fertilized, it degenerates.

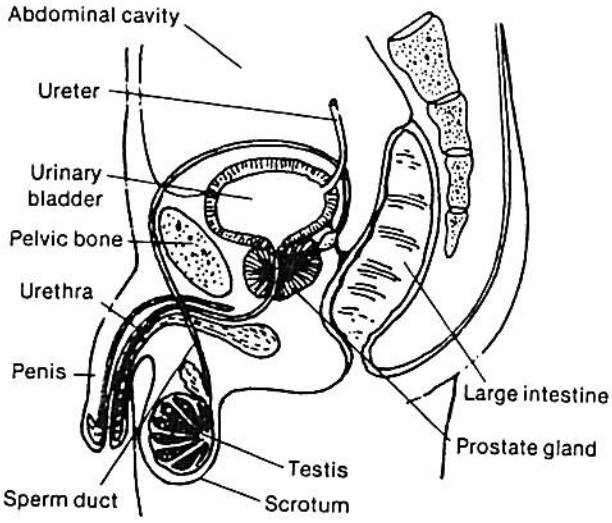
* The lower end of the uterus, the **cervix,** opens to a muscular tube called the **vagina,** or **birth canal.** When embryonic development is complete, the baby leaves the body of the mother through the vagina.

* **Hormone Production.** The ovaries produce the female sex hormones estrogen and progesterone. These hormones regulate the maturation of egg cells, as well as the development of secondary sex characteristics, including the development of the mammary glands and the broadening of the pelvis. Estrogen and progesterone are also involved in the menstrual cycle and pregnancy.

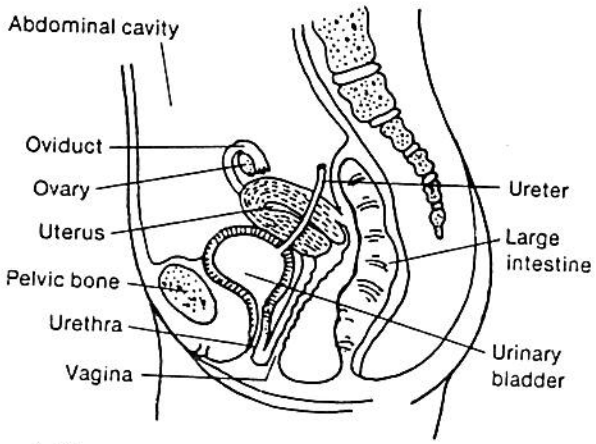
* The Menstrual Cycle.

The series of events that prepares the uterus for pregnancy is called the **menstrual cycle.** The cycle begins with the thickening of the lining of the uterine wall. The lining also becomes vascularized (filled with blood vessels). If fertilization does not occur, the thickened uterine lining breaks down and the material is expelled from the body during menstruation. The cycle then begins again.

* The menstrual cycle begins at **puberty,** the stage at which the individual becomes capable of reproducing. It is temporarily interrupted by



✻**Figure 4-12.** The male reproductive system.



✻**Figure 4-13.** The female reproductive system.

pregnancy and sometimes by illness, and ceases permanently at **menopause**. The cycle is regulated by the interaction of hormones, and lasts approximately 28 days.

✻ The menstrual cycle consists of four stages (Figure 4-14).

1. During the follicle stage, an egg matures and the follicle secretes estrogen, which stimulates the thickening of the uterine lining. This stage lasts about 14 days.
2. About midway in the cycle, **ovulation** occurs. The egg is released from the ovary and enters the oviduct.
3. Following ovulation, the **corpus luteum** forms from the ruptured follicle. The corpus luteum secretes progesterone, which continues the vascularization of the uterine lining started by estrogen. This state lasts about 12 days.
4. If fertilization does not occur, the thickened uterine lining breaks down, and the extra tissue, together with some blood and mucus, pass out of the body through the vagina. The shedding of the uterine lining is called **menstruation**. This stage lasts from 2 to 4 days.

✻ Hormones of the Menstrual Cycle.

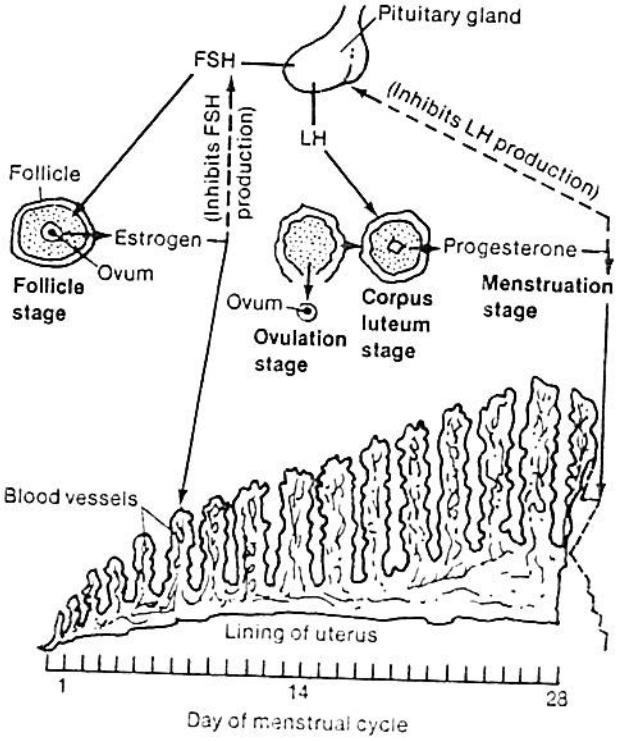
The menstrual cycle is controlled by hormones from the hypothalamus, pituitary gland, and the ovaries.

✻ During the follicle stage, the pituitary gland, under the influence of hormones from the hypothalamus, secretes FSH (follicle-stimulating hormone), which in turn stimulates the follicle to secrete estrogen. Estrogen stimulates ovulation and initiates vascularization of the uterine lining.

✻ Increased blood estrogen levels inhibit the production of FSH by the pituitary, and the secretion of LH (luteinizing hormone) by the pituitary increases. Ovulation occurs at about this time in the cycle. After ovulation, LH stimulates the formation of the corpus luteum from the ruptured follicle. The corpus luteum secretes progesterone, which enhances the vascularization of the uterine lining.

✻ If fertilization does not occur, the high levels of progesterone in the blood inhibit the production of LH by the pituitary. The drop in LH level causes a drop in the progesterone level. The lining of the uterus thins out, and at about the twenty-eighth day of the cycle, the shedding of the uterine lining, or menstruation, begins. The blood flow of menstruation is caused by the breakage of many small blood vessels.

✻ The relationship between the ovarian hormones estrogen and progesterone and the pituitary hormones FSH and LH is an example of negative feedback.



✻**Figure 4-14.** Stages of the menstrual cycle.

✻ **Fertilization and Development.** If fertilization does occur in the oviduct, the zygote undergoes cleavage to form a blastula. Six to ten days later, the blastula becomes implanted in the uterine lining. Gastrulation usually occurs after implantation. The germ layers of the gastrula begin to differentiate and grow, resulting in the formation of specialized tissues and organs. The placenta and umbilical cord form, enabling the embryo to obtain nutrients and oxygen and dispose of metabolic wastes. An amnion filled with fluid provides a watery environment for the embryo and protects it from shocks.

✻ ***In Vitro* Fertilization.** Fertilization that occurs outside the body of the female is known as ***in vitro* fertilization.** After fertilization, the early embryo is implanted into the uterus, where development is completed.

✻ **Multiple Births.** Sometimes two or more embryos may develop in the uterus simultaneously. **Fraternal twins** develop when two eggs are released from the ovary at the same time and both are fertilized. The two eggs are fertilized by two different sperm cells. Fraternal twins may be of the same sex or of opposite sexes. **Identical twins** develop when a zygote separates into two equal halves early in cleavage. Each half develops into an offspring. Since identical twins develop from the same zygote, they have identical genetic makeups, and are always of the same sex.

✻ **Birth.** The time between fertilization and birth is referred to as the **gestation period.** In humans, the gestation period is about 9 months. At the end of the gestation period, the secretion of progesterone decreases and another hormone from the pituitary causes strong muscular contractions of the uterus. The amnion bursts, and the baby is expelled from the mother's body through the vagina.

✻ During *postnatal development* (development after birth), humans pass through different stages, including childhood, puberty, adulthood, and old age. Puberty begins at early adolescence. In males, puberty usually occurs between the ages of 12 and 18; in females, it occurs from 9 to 14.

✻ **Aging** is a series of complex structural and functional changes in the body that occur naturally with the passage of time. The causes of aging are not fully understood. However, it now appears that aging may result from an interaction of both hereditary and environmental factors. The aging process ends in death, which may be described as an irreversible cessation of brain function.

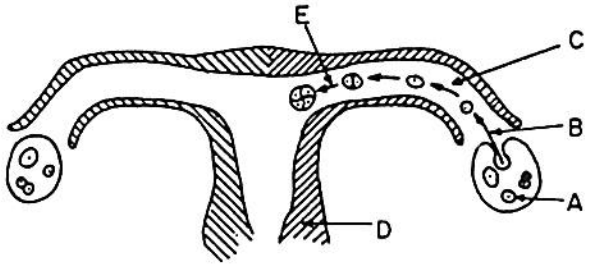
QUESTIONS

✻ 1. Which of the following organs *least* affects the human female menstrual cycle? (1) pituitary (2) ovary (3) pancreas (4) corpus luteum

✻ 2. A woman gave birth to triplets, two identical girls and one boy. The number of egg cells involved would be (1) 1 (2) 2 (3) 3 (4) 4

✻ 3. Which membrane is both a protective sac and a container for the fluid in which an embryo is suspended? (1) chorion (2) placenta (3) allantois (4) amnion

Base your answers to questions 4 through 6 on the diagram below, which represents a cross section of a part of the human female reproductive system, and on your knowledge of biology.



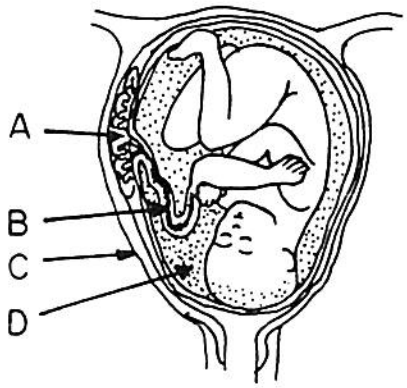
✻ 4. Which structure is prepared for implantation of a fertilized egg as a result of the action of reproductive hormones? (1) *A* (2) *B* (3) *C* (4) *D*

✻ 5. Within which structure does fertilization normally occur? (1) *A* (2) *B* (3) *C* (4) *D*

✻ 6. Which represents the process of ovulation? (1) *A* (2) *B* (3) *C* (4) *D*

✻ 7. The technique of uniting a sperm cell with an egg cell in a test tube is an example of (1) *in vitro* fertilization (2) internal fertilization (3) gametogenesis (4) artificial ovulation

Base your answers to questions 8 through 10 on the diagram below, which represents a stage in human development.



✻ 8. The exchange of oxygen, food, and wastes between mother and fetus occurs at (1) *A* (2) *B* (3) *C* (4) *D*

✻ 9. What is the function of the fluid labeled *D*? (1) nourishment (2) protection (3) excretion (4) respiration

✻ **10.** The structure labeled *C*, within which development occurs, is known as the (1) oviduct (2) birth canal (3) uterus (4) placenta

For each of the processes in questions 11 through 13 choose the stage of the human menstrual cycle, chosen from the list below, during which that process occurs.

Human Menstrual Cycle Stages
A. Ovulation
B. Follicle stage
C. Menstruation
D. Corpus luteum stage

✻ **11.** The lining of the uterus is shed. (1) *A* (2) *B* (3) *C* (4) *D*
✻ **12.** An egg is released from an ovary. (1) *A* (2) *B* (3) *C* (4) *D*
✻ **13.** An egg matures in an ovary. (1) *A* (2) *B* (3) *C* (4) *D*
✻ **14.** Which of the following hormones is *not* involved in the regulation of the human menstrual cycle? (1) progesterone (2) estrogen (3) FSH (4) testosterone
✻ **15.** Fraternal twins develop from (1) one egg and two sperm (2) two eggs and one sperm (3) two eggs and two sperm (4) one egg and one sperm
✻ **16.** Identical twins develop from (1) one egg and two sperm (2) two eggs and one sperm (3) two eggs and two sperm (4) one egg and one sperm
✻ **17.** List the four major hormones which play a role in the menstrual cycle and discuss how they interact during the cycle.

SEXUAL REPRODUCTION IN FLOWERING PLANTS

Flowers are the reproductive organs of **angiosperms**, or flowering plants.

Structure of Flowers.

Flowers may contain the following structures: sepals, petals, stamens, and pistils (Figure 4-15).

Sepals are leaflike structures at the base of a flower that enclose and protect the flower bud. In some species, the sepals are green, while in others, the sepals are white or brightly colored.

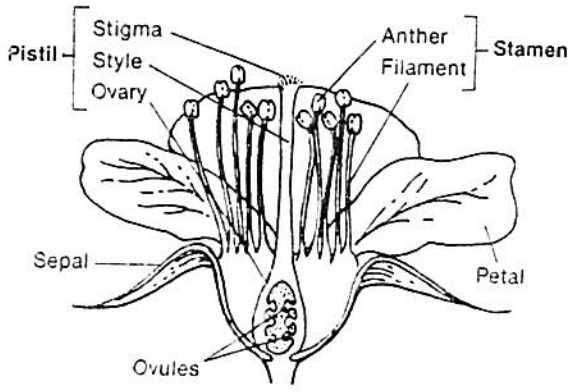


Figure 4-15. Structure of a flower.

Petals are leaflike structures inside the sepals that surround the reproductive organs of the flower. Petals may be brightly colored or white, and often have a sweet fragrance.

Stamens are the male reproductive organs of a flower. Each stamen consists of an oval-shaped **anther** supported by a stalk, or **filament. Pollen grains** containing monoploid sperm nuclei are produced by meiosis by the diploid cells of the anther. The thick wall that encloses the pollen grain prevents the contents from drying out. This is an adaptation for life on land.

Pistils are the female reproductive organs of a flower. A pistil consists of a stigma, style, and ovary. The **stigma**, which is a knoblike, sticky structure, is adapted for receiving pollen grains. The stigma is supported by the **style**, a slender stalk that connects the stigma to the **ovary**, which is at the base of the pistil. In the ovary, monoploid egg cells are produced by meiosis in structures called **ovules.**

The flowers of some species contain both stamens and pistils. In other species, some flowers contain only stamens, while others contain only pistils. The flowers of some species have both sepals and petals, while the flowers of other species lack one or the other.

Pollination and Fertilization.

The transfer of pollen grains from an anther to a stigma is called **pollination.** The transfer of pollen from an anther to a stigma of the same flower or to a stigma of another flower on the same plant is called **self-pollination.** The transfer of pollen from an anther of one flower to a stigma of a flower on another plant is **cross-pollination.** Cross-pollination increases the chances of genetic variation in the offspring.

Pollination may be carried out by wind, insects, or birds. Brightly colored petals and the odor of nectar attract insects and birds. Pollen grains adhere to their bodies and are carried to another flower, where they rub off on the sticky surface of a stigma.

When a pollen grain reaches a stigma, it germinates, or sprouts (Figure 4-16). A **pollen tube** grows from the pollen grain down through the stigma and style to an ovule within the ovary. The growth of the pollen tube is controlled by the **tube nucleus.** Two sperm nuclei and the tube nucleus pass down through the pollen tube. The sperm nuclei enter an ovule, where one sperm nucleus fertilizes the egg nucleus to form a diploid ($2n$) zygote. The other sperm nucleus fuses with two *polar nuclei* in the ovule to form a triploid ($3n$) *endosperm nucleus*, which divides to form a food storage tissue. The zygote undergoes repeated mitotic division to form a multicellular plant embryo. After fertilization, the ovule ripens to form a **seed**, while the ovary develops into a **fruit.** The seeds of flowering plants are found inside the fruits.