CAMPBELL
BIOLOGY TENTH EDITION
Reece • Urry • Cain • Wasserman • Minorsky • Jackson

46 Animal Reproduction

Lecture Presentation by Nicole Tunbridge and Kathleen Fitzpatrick

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Pairing Up for Sexual Reproduction

- Animal reproduction takes many forms
- For example, sea slugs are both male and female, each one producing both eggs and sperm
- A population outlives its members only by reproduction, the generation of new individuals from existing ones

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Figure 46.1

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Concept 46.1: Both asexual and sexual reproduction occur in the animal kingdom

- **Sexual reproduction** is the creation of an offspring by fusion of a male gamete (**sperm**) and female gamete (**egg**) to form a **zygote**
- **Asexual reproduction** is creation of offspring without the fusion of egg and sperm

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Mechanisms of Asexual Reproduction

- Budding is a simple form of asexual reproduction found only among invertebrates
- New individuals arise from outgrowths of existing ones
- Many invertebrates reproduce asexually by **fission**, separation of a parent into two or more individuals of about the same size

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Figure 46.2

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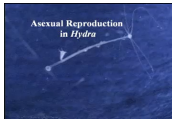
Video: Hydra Budding



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- *Fragmentation* is breaking of the body into pieces, some or all of which develop into adults
- Fragmentation must be accompanied by *regeneration*, regrowth of lost body parts
- **Parthenogenesis** is the development of a new individual from an unfertilized egg
- Parthenogenesis is mainly observed in invertebrates, but is observed rarely in some vertebrates

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Sexual Reproduction: An Evolutionary Enigma

- Sexual females have half as many daughters as asexual females; this is the "twofold cost" of sexual reproduction
- Despite this, almost all eukaryotic species reproduce sexually

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Figure 46.3-1

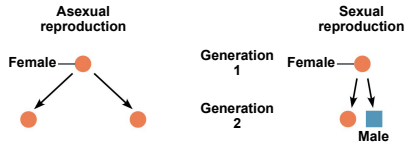

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Figure 46.3-2

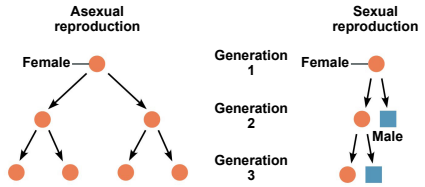

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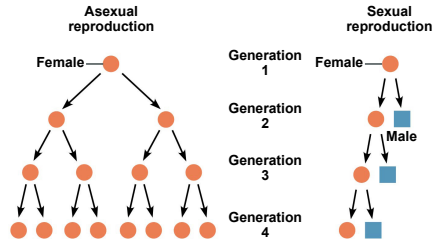
Figure 46.3-3



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- By producing offspring of varied phenotypes, sexual reproduction may enhance reproductive success of parents when environmental factors change relatively rapidly
- Asexual reproduction is expected to be most advantageous in stable, favorable environments

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Reproductive Cycles

- Most animals exhibit reproductive cycles related to changing seasons
- Reproductive cycles are controlled by hormones and environmental cues
- **Ovulation** is the release of mature eggs at the midpoint of a female cycle
- Because seasonal temperature is often an important cue in reproduction, climate change can decrease reproductive success

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- Some organisms can reproduce sexually or asexually, depending on conditions
- Several genera of fishes, amphibians, and lizards reproduce only by a complex form of parthenogenesis that involves the doubling of chromosomes after meiosis
- Asexual whiptail lizards are descended from a sexual species, and females still exhibit mating behaviors

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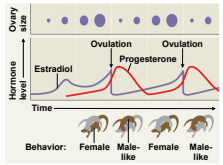
Figure 46.4

(a) *A. uniparens* females



(b) The changes in sexual behavior of *A. uniparens* individuals are correlated with the cycles of ovulation.

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Figure 46.4a

(a) *A. uniparens* females

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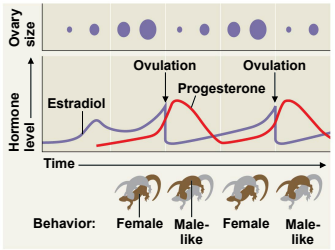
Figure 46.4b



(b) The changes in sexual behavior of *A. uniparens* individuals are correlated with the cycles of ovulation.

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Variation in Patterns of Sexual Reproduction

- For many animals, finding a partner for sexual reproduction may be challenging
- One solution is **hermaphroditism**, in which each individual has male and female reproductive systems
- Two hermaphrodites can mate, and some hermaphrodites can self-fertilize

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- Individuals of some species undergo sex reversals
- Some species exhibit male to female reversal (for example, certain oysters), while others exhibit female to male reversal (for example, a coral reef fish)

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Concept 46.2: Fertilization depends on mechanisms that bring together sperm and eggs of the same species

- The mechanisms of **fertilization**, the union of egg and sperm, play an important part in sexual reproduction
- In external fertilization, eggs shed by the female are fertilized by sperm in the external environment
- A moist habitat is always required for external fertilization to allow sperm to swim to the egg and to prevent the gametes from drying out

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Figure 46.5

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- Among species with external fertilization, some exhibit spawning, in which individuals cluster in the same area to release their gametes into the water at the same time
- In some cases chemical signals trigger spawning; in other environmental cues are responsible

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- In internal fertilization, sperm are deposited in or near the female reproductive tract, and fertilization occurs within the tract
- Internal fertilization requires behavioral interactions and compatible copulatory organs
- All fertilization requires critical timing, often mediated by environmental cues, pheromones, and/or courtship behavior

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Ensuring the Survival of Offspring

- Internal fertilization is typically associated with production of fewer gametes but the survival of a higher fraction of zygotes
- Internal fertilization is also often associated with mechanisms to provide protection of embryos and parental care of young

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- The embryos of some terrestrial animals develop in eggs with calcium- and protein-containing shells and several internal membranes
- Some other animals retain the embryo, which develops inside the female
- In many animals, parental care helps ensure survival of offspring

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Figure 46.6

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Gamete Production and Delivery

- To reproduce sexually, animals must produce gametes
- In most species individuals have **gonads**, organs that produce gametes
- Some simple systems do not have gonads, but gametes form from undifferentiated tissue
- More elaborate systems include sets of accessory tubes and glands that carry, nourish, and protect gametes and developing embryos

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- Most insects have separate sexes with complex reproductive systems
- In many insects, the female has a **spermatheca** in which sperm is stored during copulation

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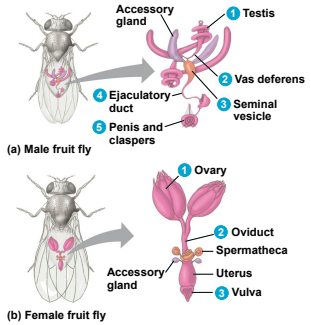
Figure 46.7



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- A **cloaca** is a common opening between the external environment and the digestive, excretory, and reproductive systems
- A cloaca is common in nonmammalian vertebrates; mammals usually have a separate opening to the digestive tract

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- Monogamy is relatively rare among animals
- Males and/or females of some species have evolved mechanisms to decrease the chance of their mate mating with another individual
- Females can sometimes influence the relative reproductive success of their mates

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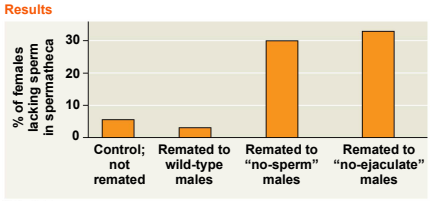
Figure 46.8



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Concept 46.3: Reproductive organs produce and transport gametes

- The following section focuses on the human reproductive system

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Human Male Reproductive Anatomy

- The male's external reproductive organs are the scrotum and penis
- Internal organs are the gonads, which produce sperm and hormones, accessory glands that secrete products needed for sperm movement, and ducts that carry sperm and glandular secretions

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Figure 46.9

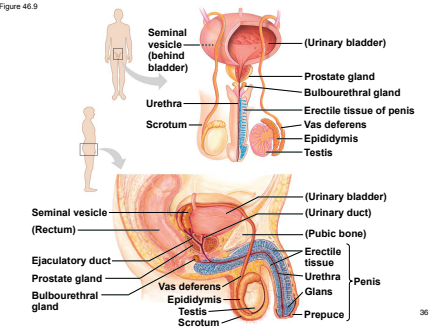

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Figure 46.9a

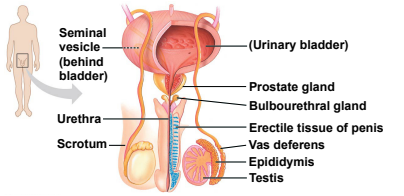

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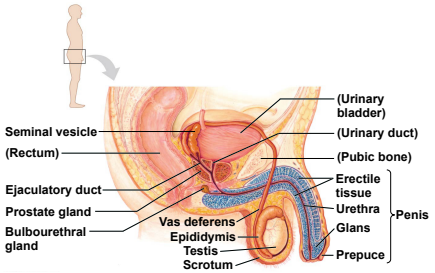
Figure 46.9b



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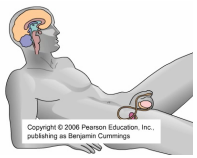
Animation: Male Reproductive Anatomy



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Testes

- The male gonads, or **testes**, consist of highly coiled tubes surrounded by connective tissue
- Sperm form in these **seminiferous tubules**
- **Leydig cells** produce hormones and are scattered between the tubules

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- Production of normal sperm cannot occur at the body temperatures of most mammals
- The testes of many mammals are held outside the abdominal cavity in the **scrotum**, where the temperature is lower than in the abdominal cavity

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Ducts

- From the seminiferous tubules of a testis, sperm pass into the coiled duct of the **epididymis**
- During **ejaculation**, sperm are propelled through the muscular **vas deferens** and the **ejaculatory duct**, and then exit the penis through the **urethra**

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Accessory Glands

- **Semen** is composed of sperm plus secretions from three sets of accessory glands
- The two **seminal vesicles** contribute about 60% of the total volume of semen
- The **prostate gland** secretes its products directly into the urethra through several small ducts
- The bulbourethral glands secrete a clear mucus before ejaculation that neutralizes acidic urine remaining in the urethra

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Penis

- The human **penis** is composed of three cylinders of spongy erectile tissue
- During sexual arousal, the erectile tissue fills with blood from the arteries, causing an erection
- The head of the penis, or **glans**, has a thinner skin covering than the shaft and is more sensitive to stimulation
- The glans is surrounded by a fold of skin called the **prepuce**, or foreskin

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Human Female Reproductive Anatomy

- The female external reproductive structures include the clitoris and two sets of labia
- The internal organs are a pair of gonads and a system of ducts and chambers that carry gametes and house the embryo and fetus

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Figure 46.10

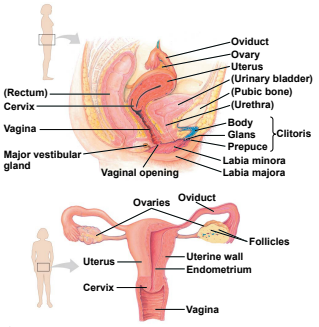

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Figure 46.10a

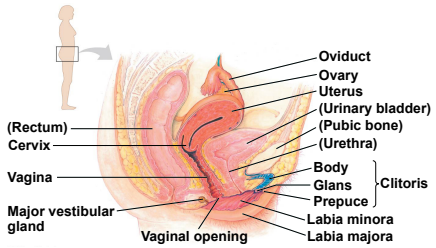

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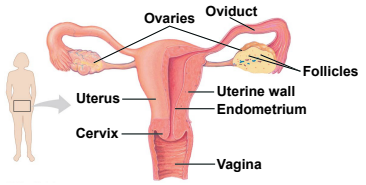
Figure 46.10b



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Animation: Female Reproductive Anatomy

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Ovaries

- The female gonads, the **ovaries**, lie in the abdominal cavity
- Each ovary contains many **follicles**, which consist of a partially developed egg, called an **oocyte**, surrounded by support cells

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Oviducts and Uterus

- The egg cell travels from the ovary to the uterus via an **oviduct**, or fallopian tube
- Cilia in the oviduct convey the egg to the **uterus**, also called the womb
- The uterus lining, the **endometrium**, has many blood vessels
- The uterus narrows at the **cervix**, then opens into the vagina

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Vagina and Vulva

- The **vagina** is a muscular but elastic chamber that is the repository for sperm during copulation and serves as the birth canal
- The vagina opens to the outside at the **vulva**, which consists of the **labia majora**, **labia minora**, hymen, and **clitoris**

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- The clitoris has a head called a glans covered by the prepuce, a small hood of skin
- The vagina, labia minora, and clitoris are rich with blood vessels; the clitoris also has many nerve endings

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Mammary Glands

- The **mammary glands** are not part of the reproductive system but are important to mammalian reproduction
- Within the glands, small sacs of epithelial tissue secrete milk

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Gametogenesis

- **Gametogenesis** is the production of gametes

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- **Spermatogenesis**, the formation of sperm, is continuous and prolific
- Hundreds of millions of sperm are produced per day; each sperm takes about 7 weeks to develop

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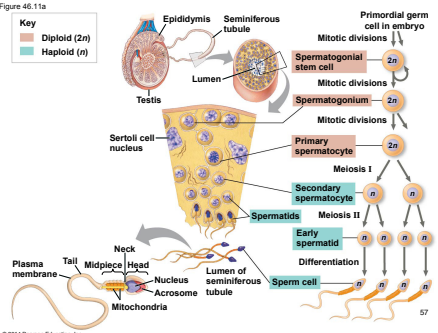
Figure 46.11a



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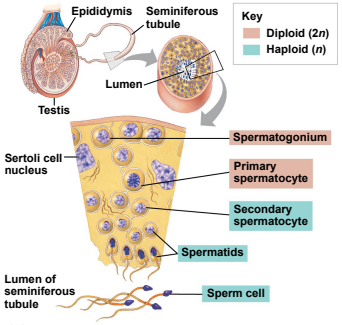

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Figure 46.11ab

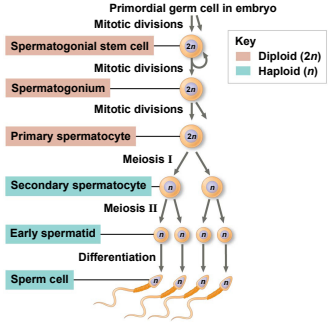

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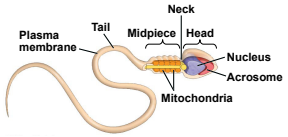
Figure 46.11ac



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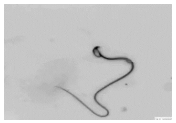
Video: Motion of Isolated Flagellum



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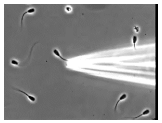
Video: Flagellum Movement in Swimming Sperm



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- **Oogenesis**, the development of a mature egg, is a prolonged process
- Immature eggs form in the female embryo but do not complete their development until years or decades later

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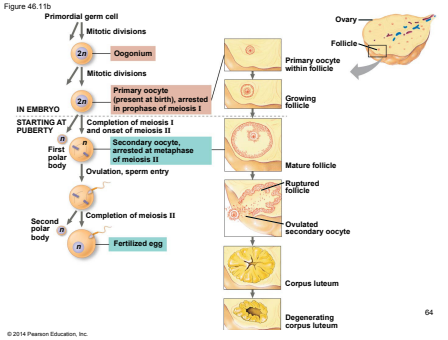
Figure 46.11b



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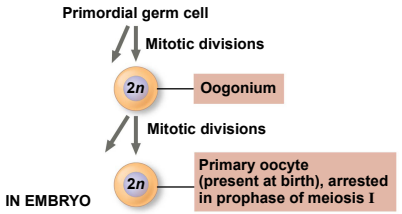

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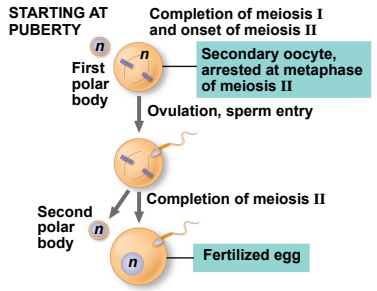

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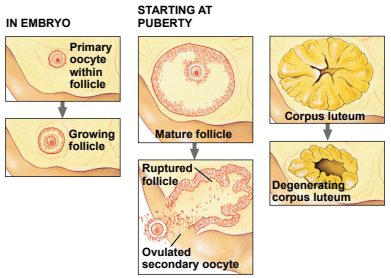
Figure 46.11bc



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- Spermatogenesis differs from oogenesis in three ways
  - All four products of meiosis develop into sperm while only one of the four becomes an egg
  - Spermatogenesis occurs throughout adolescence and adulthood
  - Sperm are produced continuously without the prolonged interruptions in oogenesis

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Concept 46.4: The interplay of tropic and sex hormones regulates mammalian reproduction

- Human reproduction is coordinated by hormones from the hypothalamus, anterior pituitary, and gonads
- Gonadotropin-releasing hormone (GnRH) is secreted by the hypothalamus and directs the release of **FSH (follicle-stimulating hormone)** and **LH (luteinizing hormone)** from the anterior pituitary

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- FSH and LH regulate processes in the gonads and the production of sex hormones
- The main sex hormones are steroid hormones
- **Testosterone** is the main androgen
- Estrogens consist of mainly **estradiol** and **progesterone**
- Sex hormones serve many functions in addition to gamete production, including sexual behavior and the development of primary and secondary sex characteristics

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Figure 46.12

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Hormonal Control of the Male Reproductive System

- FSH promotes the activity of Sertoli cells, which nourish developing sperm
- LH regulates Leydig cells, which secrete testosterone and other androgens, which in turn promote spermatogenesis

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- Testosterone regulates the production of GnRH, FSH, and LH through negative feedback mechanisms
- Sertoli cells secrete the hormone inhibin, which reduces FSH secretion from the anterior pituitary

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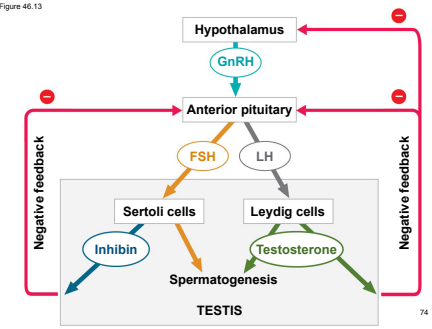
Figure 46.13



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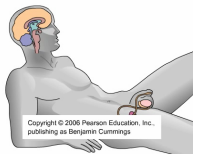
Animation: Male Hormones



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Hormonal Control of the Female Reproductive Cycles

- In females, the secretion of hormones and the reproductive events they regulate are cyclic
- Prior to ovulation, the endometrium thickens with blood vessels in preparation for embryo implantation
- If an embryo does not implant in the endometrium, the endometrium is shed in a process called **menstruation**

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- Hormones closely link the two cycles of female reproduction
  - Changes in the uterus define the menstrual cycle (also called the **uterine cycle**)
  - Changes in the ovaries define the **ovarian cycle**

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The Ovarian Cycle

- The sequential release of GnRH then FSH and LH stimulates follicle growth
- Follicle growth and an increase in the hormone estradiol characterize the follicular phase of the ovarian cycle
- The follicular phase ends at ovulation, and the secondary oocyte is released

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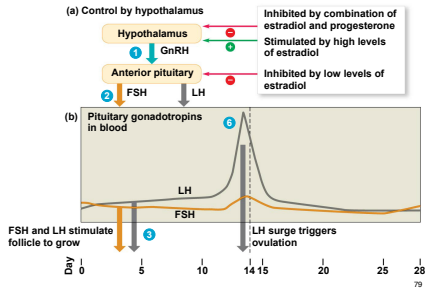
Figure 46.14a



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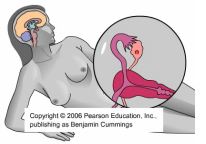
Animation: Ovulation



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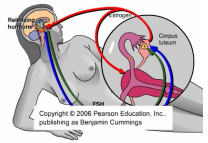
Animation: Post-ovulation



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- In the luteal phase, following ovulation, the follicular tissue left behind is stimulated to transform into a corpus luteum
- The corpus luteum secretes progesterone and estradiol, which exert negative feedback on the hypothalamus and pituitary

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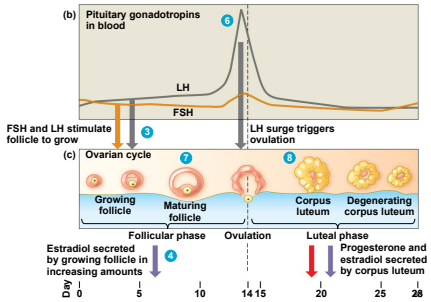
Figure 46.14b



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The Uterine (Menstrual) Cycle

- Hormones coordinate the uterine cycle with the ovarian cycle
  - Thickening of the endometrium during the proliferative phase coordinates with the follicular phase
  - Secretion of nutrients during the secretory phase coordinates with the luteal phase
  - Shedding of the endometrium during the menstrual flow phase coordinates with the growth of new ovarian follicles

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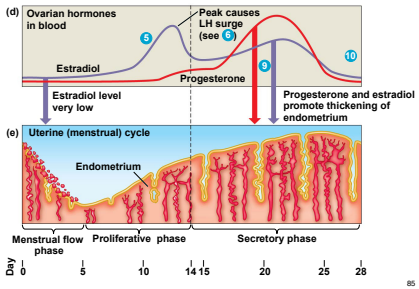
Figure 46.14d



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- A new cycle begins if no embryo implants in the endometrium
- Cells of the uterine lining can sometimes migrate to an abnormal, or **ectopic**, location
- Swelling of these cells in response to hormone stimulation results in a disorder called **endometriosis**

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Menopause

- After about 500 cycles, human females undergo **menopause**, the cessation of ovulation and menstruation
- Menopause is very unusual among animals
- Menopause might have evolved to allow a mother to provide better care for her children and grandchildren

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Menstrual Versus Estrous Cycles

- Menstrual cycles are characteristic only of humans and some other primates
  - The endometrium is shed from the uterus in a bleeding called menstruation
  - Sexual receptivity is not limited to a time frame

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- **Estrous cycles** are characteristic of most mammals
  - The endometrium is reabsorbed by the uterus
  - Sexual receptivity is limited to a "heat" period called estrus
  - The length and frequency of estrous cycles vary from species to species

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Human Sexual Response

- Two reactions predominate in both sexes
  - Vasocongestion, the filling of tissue with blood
  - Myotonia, increased muscle tension
- The sexual response cycle has four phases: excitement, plateau, orgasm, and resolution
- Excitement prepares the penis and vagina for coitus (sexual intercourse)

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- Direct stimulation of genitalia maintains the plateau phase and prepares the vagina for receipt of sperm
- Orgasm is characterized by rhythmic contractions of reproductive structures
  - In males, semen is first released into the urethra and then ejaculated from the urethra
  - In females, the uterus and outer vagina contract

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- During the resolution phase, organs return to their normal state and muscles relax

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Concept 46.5: In placental mammals, an embryo develops fully within the mother's uterus

- An egg develops into an embryo in a series of predictable events

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Conception, Embryonic Development, and Birth

- **Conception**, fertilization of an egg by a sperm, occurs in the oviduct
- The resulting zygote begins to divide by mitosis in a process called cleavage
- Division of cells gives rise to a **blastocyst**, a ball of cells with a central cavity

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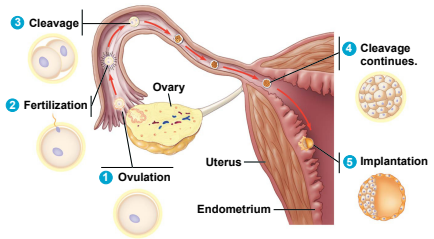
Figure 46.15



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- After blastocyst formation, the embryo implants into the endometrium
- **Pregnancy**, or **gestation**, is the condition of carrying one or more embryos in the uterus
- Duration of pregnancy in other species correlates with body size and maturity of the young at birth
- The roughly nine months of human gestation are divided into three trimesters of equal length

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First Trimester

- The first trimester is the time of most radical change for both the mother and the embryo
- The implanted embryo secretes hormones that regulate the mother's reproductive system
- One such hormone, human chorionic gonadotropin (hCG) maintains secretion of progesterone and estrogens during early pregnancy

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- Not all embryos are capable of completing development
- Many spontaneously stop due to chromosomal or other developmental abnormalities
- Rarely, a fertilized egg lodges in the fallopian tube, resulting in an ectopic pregnancy

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- During its first 2 to 4 weeks, the embryo obtains nutrients directly from the endometrium
- The outer layer of the blastocyst, called the **trophoblast**, mingles with the endometrium and eventually forms the **placenta**
- Blood from the embryo travels to the placenta through arteries of the umbilical cord and returns via the umbilical vein

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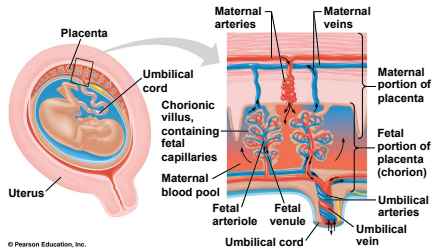
Figure 46.16



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- Splitting of the embryo during the first month of development results in genetically identical (monozygotic) twins
- Release and fertilization of two eggs result in fraternal and genetically distinct (dizygotic) twins

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- The first trimester is the main period of **organogenesis**, development of the body organs
- All the major structures are present by 8 weeks, and the embryo is called a **fetus**

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- Changes occur in the mother
  - Mucus plug to protect against infection
  - Growth of the placenta and uterus
  - Cessation of ovulation and the menstrual cycle
  - Breast enlargement
  - Nausea is also very common

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Figure 46.17

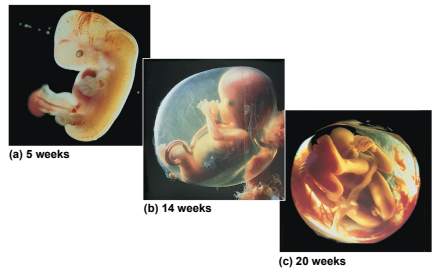

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Figure 46.17a

(a) 5 weeks

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Figure 46.17b

(b) 14 weeks

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Figure 46.17c

(c) 20 weeks

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Video: Ultrasound of Human Fetus 1

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Video: Ultrasound of Human Fetus 2

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Second and Third Trimesters

- During the second trimester
  - The fetus grows and is very active
  - The mother may feel fetal movements
  - The uterus grows enough for the pregnancy to become obvious

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- During the third trimester, the fetus grows and fills the space within the embryonic membranes
- Childbirth begins with labor, a series of strong, rhythmic uterine contractions that push the fetus and placenta out of the body
- Labor is regulated by prostaglandins and hormone such as estradiol and oxytocin

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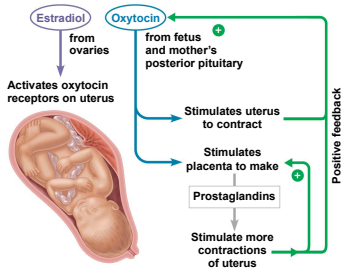
Figure 46.18



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- Labor typically has three stages
  - Thinning and opening of the cervix, or dilation
  - Expulsion or delivery of the baby
  - Delivery of the placenta
- Postnatal care in mammals includes lactation, the production of mother's milk

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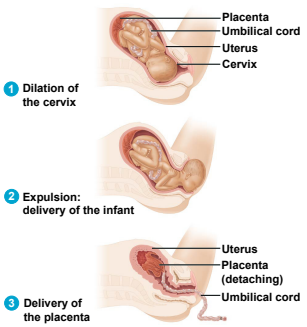
Figure 46.19



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Maternal Immune Tolerance of the Embryo and Fetus

- A woman's acceptance of her "foreign" offspring is not fully understood
- It may be due to suppression of the immune response in her uterus

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Contraception and Abortion

- **Contraception**, the deliberate prevention of pregnancy, can be achieved in a number of ways
- Contraceptive methods fall into three categories
  - Preventing release of eggs and sperm
  - Keeping sperm and egg apart
  - Preventing implantation of an embryo

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Figure 46.20

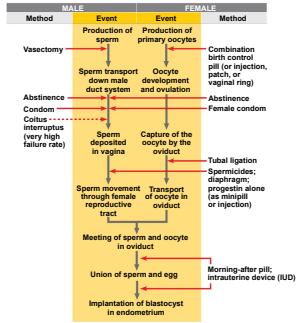

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Figure 46.20a

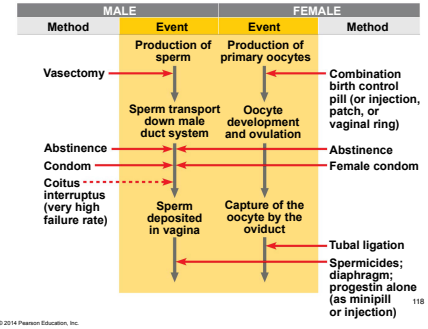

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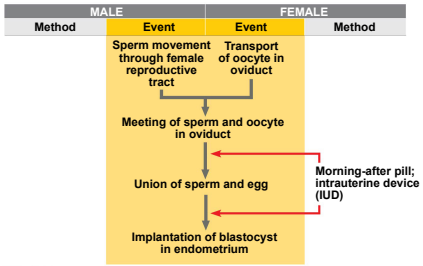
Figure 46.20b



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- The rhythm method, or natural family planning, is to refrain from intercourse when conception is most likely; it has a pregnancy rate of 10–20%
- Coitus interruptus, the withdrawal of the penis before ejaculation, is unreliable
- Barrier methods block fertilization with a pregnancy rate of less than 10%
  - A condom fits over the penis
  - A diaphragm is inserted into the vagina before intercourse

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- Intrauterine devices (IUDs) are inserted into the uterus and interfere with fertilization and implantation; the pregnancy rate is less than 1%
- Female **birth control pills** are hormonal contraceptives with a pregnancy rate of less than 1%

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- Sterilization is permanent and prevents the release of gametes
  - **Tubal ligation** ties off the oviducts
  - **Vasectomy** ties off the vas deferens
- **Abortion** is the termination of a pregnancy
- Spontaneous abortion, or miscarriage, occurs in up to one-third of all pregnancies
- The drug RU486 terminates a pregnancy nonsurgically within the first 7 weeks

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Modern Reproductive Technologies

- Recent advances are addressing reproductive problems

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Detecting Disorders During Pregnancy

- Amniocentesis and chorionic villus sampling are invasive techniques in which amniotic fluid or fetal cells are obtained for genetic analysis
- Noninvasive procedures usually use ultrasound imaging to detect fetal condition
- Genetic testing of the fetus poses ethical questions and can present parents with difficult decisions
- Almost all detectable disorders are untreatable in the uterus; many cannot be corrected after birth

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Infertility and In Vitro Fertilization

- Causes of infertility are quite varied, with men and women equally affected
- Among preventable causes of infertility, STDs are most significant
- ***In vitro* fertilization (IVF)** mixes eggs with sperm in culture dishes and returns the embryo to the uterus at the eight-cell stage
- Sperm or sperm nuclei can also be injected directly into an oocyte

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Figure 46.21

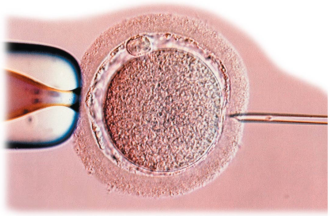

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Figure 46.UN01

Chromosome Set	Appearance of Genitalia	
	No Surgery	Embryonic Gonad Removed
XY (male)	Male	Female
XX (female)	Female	Female

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Figure 46.UN02

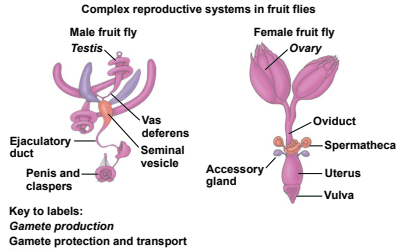

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Figure 46.UN03

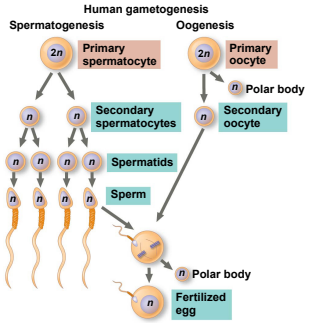

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Figure 46.UN04

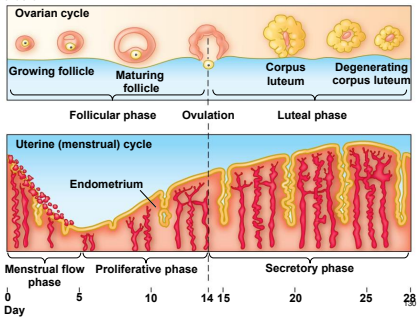

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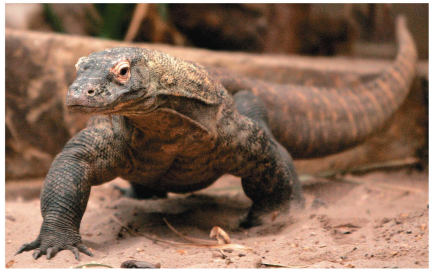
Figure 46.UN05



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