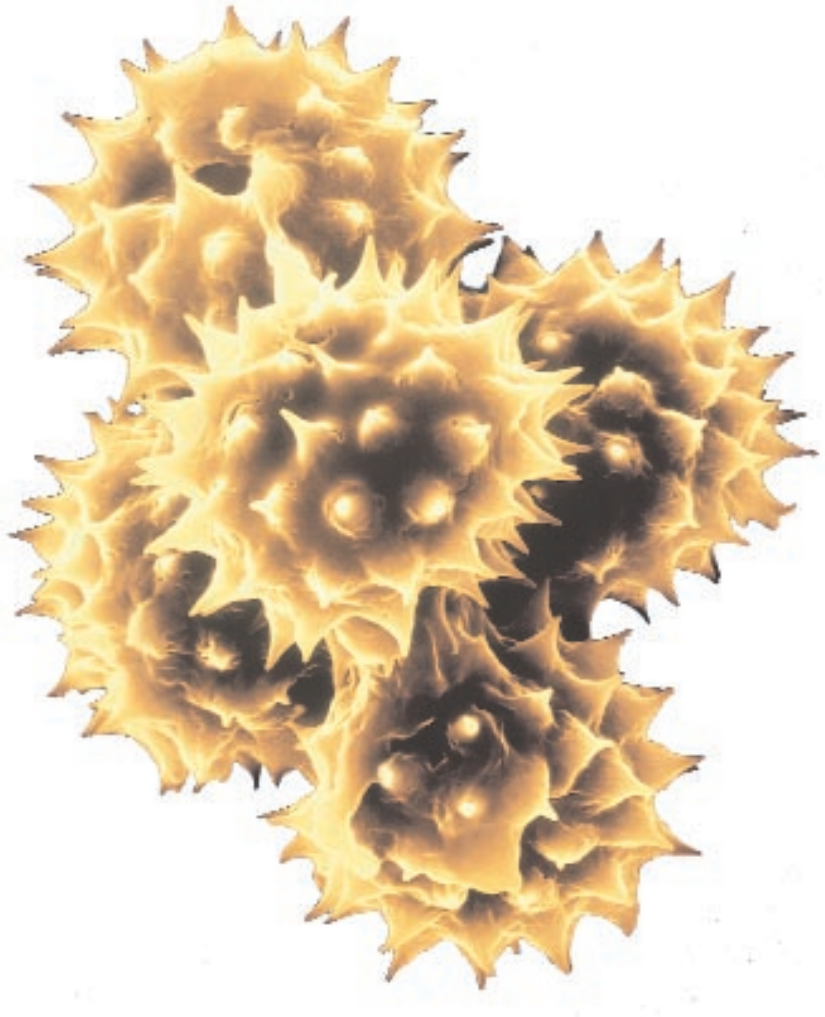
CHAPTER

7 Sexual Reproduction and the Diversity of Life

Getting Started

1 During the summer months it is rare to find a male aphid. Female aphids reproduce asexually and give birth to female aphids. In fact, the young aphids are born already pregnant.

However, something quite incredible happens in the autumn. Some females become males, and the aphids can then reproduce sexually. What advantages do aphids gain by reproducing two different ways? Why do plants and animals reproduce in so many different ways? Are there advantages to reproducing sexually rather than asexually?



2 In many plants, sexual reproduction occurs in the flower. Unlike humans, the male and female sex cells in many plants are found in the same individual. What are sex cells? Where are the sex cells located within the flower? Where are they found in male and female humans? Do any animals contain both male and female sex cells?

3 You may have heard of genetic screening. Various procedures are available to expecting parents to discover if a developing fetus has a genetic disorder, or what sex the child will be. Doctors can determine the answers to such questions simply by looking at the chromosomes of one cell. How do they do this? What are they looking for? How do chromosomes influence the development of organisms? What are the ethical implications of such tests?

Reflecting

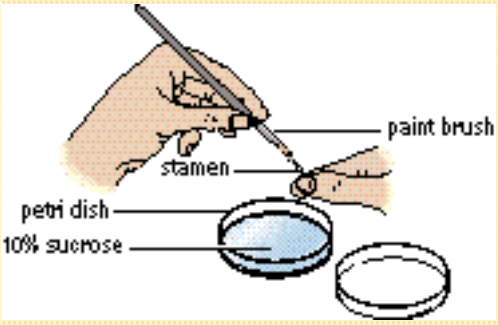
Think about the questions in 1, 2, 3. What ideas do you already have? What other questions do you have about sexual reproduction? Think about your answers and questions as you read the chapter.

Try This Examining Pollen

Pollen are the male sex cells of the flower. Like the sperm cells of animals, pollen cells fertilize egg cells. Collect pollen from a flower by removing a stamen (the pollen-producing organ). Using a paint brush, sweep some of the pollen into an open petri dish that contains a 10% sucrose solution. Check the pollen grains at the end of the class and 24 h later. You could use pollen from several different flowers, using a separate petri dish for each one.

Caution: Students who are sensitive to pollen should breathe through a disposable mask.

1. Describe what happens to the pollen grains.
2. Draw a diagram of the changes 6C that you observe.



Reproductive Strategies

In previous chapters you studied asexual reproduction. In this chapter you will study sexual reproduction. In general, less complex organisms produce offspring by asexual reproduction, while more complex organisms reproduce sexually (**Figure 1**), although there are many exceptions.

In the simplest form of asexual reproduction, a single cell, the mother cell, duplicates genetic information and becomes two daughter cells, but in all forms of asexual reproduction the offspring have the same genes as the parent. These genes will allow the offspring to meet any environmental challenges as well as the parent did, but it's not likely they would do any better.

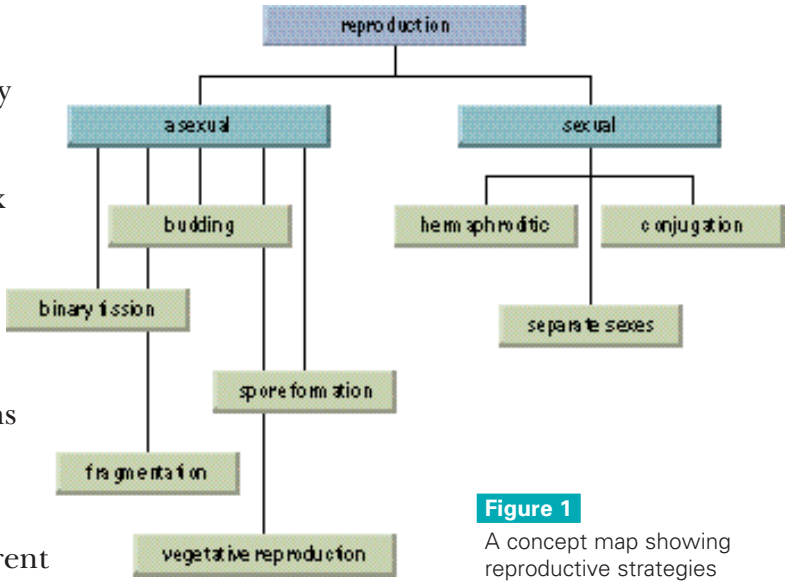
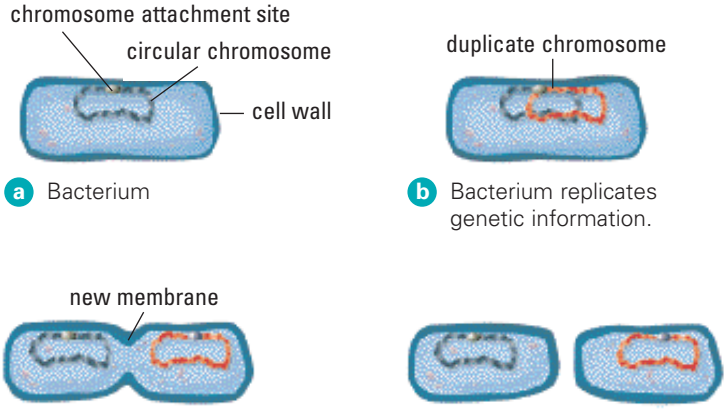


Figure 1
A concept map showing reproductive strategies

(a) In **Figure 2**, which of the cells would you label the mother and which would you label the daughter cells?

(b) In what ways would the new cells that are produced by asexual reproduction resemble the original cell?

Figure 2
Binary fission in bacteria is a form of asexual reproduction.



a Bacterium

b Bacterium replicates genetic information.

c Circular chromosomes attach to different areas, and new membrane and wall begin to form.

d Cell membrane and cell wall cleave, and two new cells are formed.

Sexual Reproduction

Sexual reproduction is common among multicellular organisms. In sexual reproduction, genetic information from two cells is combined to form the genetic code for a new organism. In complex animals, this usually involves two specialized sex cells, a sperm and an egg, that combine to form a zygote.

Offspring are not identical to either parent, or even to each other. Sexual reproduction produces new combinations of genes that may allow organisms to adapt better to a given environment.

(c) How do the offspring produced by sexual reproduction resemble the original organisms?

(d) How is sexual reproduction different from asexual reproduction?

(e) Explain why the offspring of an organism that reproduces sexually might be able to adapt better to a new environment than offspring of an organism that reproduces asexually.

Conjugation

Most of the time bacteria reproduce asexually by binary fission (**Figure 2**), but they also reproduce sexually in a process called conjugation (**Figure 3**). In **conjugation**, two cells come in contact with each other and exchange small pieces, but rarely all, of their genetic information.

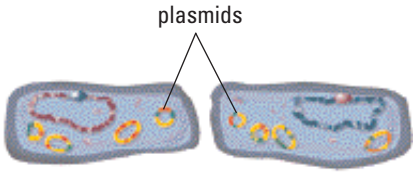
If the genetic material that is exchanged includes genes that allow the bacteria to survive in a new environment, both of the cells will now be able to survive in the environment, and so will all the descendants they create through asexual reproduction. Conjugation increases the diversity of bacteria species.

(f) Explain how conjugation provides greater diversity among bacteria.

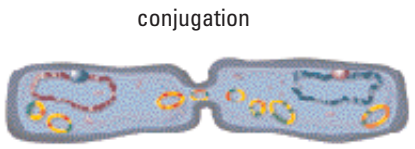
(g) List the ways in which conjugation differs from what you know about the way humans reproduce.

Figure 3

Conjugation, a form of sexual reproduction, is used by bacteria to exchange genetic information. Unlike human cells, bacteria do not have nuclei. Their DNA floats in the cytoplasm. It usually consists of one large ring and several smaller ones, called plasmids.



a Plasmids are small segments of genetic information.



b A bridge is formed between two bacterium cells, and plasmids are exchanged between the cells.

Hermaphrodites

Sexual reproduction presents special problems for organisms that have restricted movement. Animals and plants that are attached to a spot, such as sponges or tomatoes, will not come in contact with another member of their species. Some burrowing animals, such as worms, may contact only a few other members of their species. If worms were either male or female, as humans are, it would restrict their chance of reproducing. One solution to these problems is hermaphroditic reproduction. An organism that creates both male and female sex cells is referred to as a **hermaphrodite**.

Individual sponges, earthworms, and tomato plants are both male and female. They contain male sex organs that produce sperm and female sex organs that produce eggs. They can reproduce with any other member of their species.

In some cases, two hermaphrodite animals can join together, and each deposits sperm into the other animal, as shown in **Figure 4**. Some animals that live in water simply release their sex cells into the water. This usually happens at a certain time of year, so all the animals of one species release their sex cells at the same time. Land plants, many of which are hermaphrodites, have a similar strategy.

(h) What advantage is gained from fertilizing the eggs of another worm, rather than the worm's own eggs?

(i) Explain how hermaphroditic reproduction helps the earthworm to reproduce.

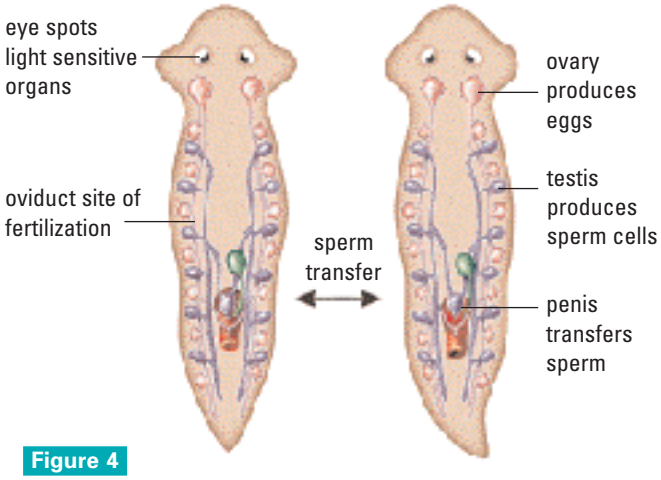


Figure 4

Sperm is transferred between two flatworms. Each flatworm acts as a male by releasing sperm and as a female by receiving the sperm to fertilize egg cells. Once fertilized, the egg cells are released inside a capsule.

Separate Sexes

Most complex animals and some plants have separate sexes, males and females. Males produce sperm cells and females produce egg cells.

Of course, if an organism has separate sexes, something has to determine which individuals are males and which are females. For example, in humans this is determined by two chromosomes, called the X and Y (**Figure 5**). Females have a pair of X chromosomes in each cell (one from each parent). Males have a single X chromosome (from their mother) and a much smaller Y chromosome (from their father) in each cell.

Animals with separate sexes use one of two different methods of fertilization. For example, in fish the female releases her egg cells, and the male releases sperm. The sex cells unite outside the female's body. This process is called **external fertilization**.

In most land animals, including humans, the male deposits sperm inside the body of the female, where it fertilizes her eggs. This process is called **internal fertilization**.

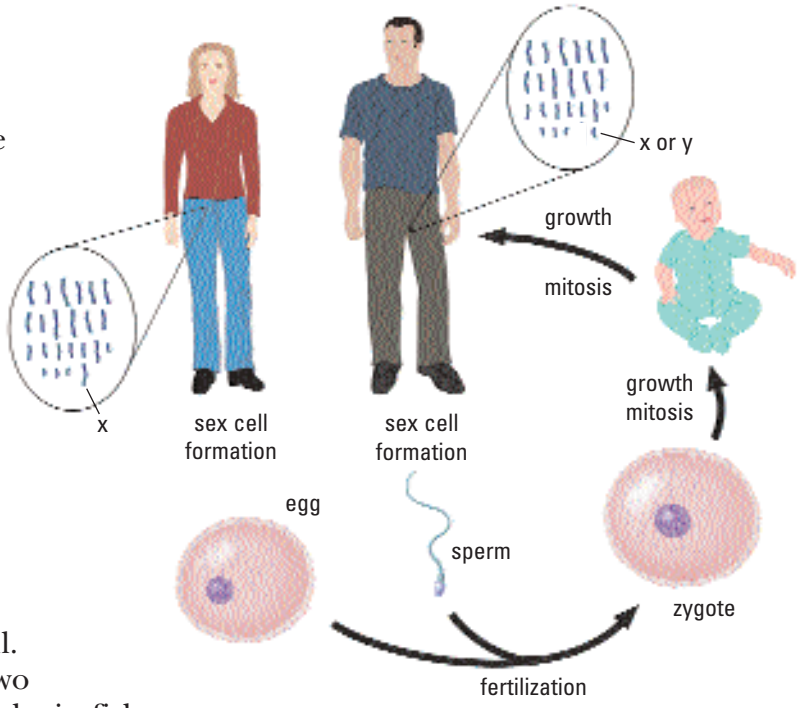


Figure 5
Humans contain organs that produce either egg cells or sperm cells.

(j) How do the reproductive strategies used by humans differ from those used by earthworms?

(k) How do internal and external fertilization differ?

Chromosome Number and the Formation of Sex Cells

Human cells contain 46 chromosomes. Imagine what would happen if a human cell containing 46 chromosomes fertilized another cell with 46 chromosomes. The resulting cell would contain 92 chromosomes! If cells with 92 chromosomes united, the following generation would have 184 chromosomes, and so on. For sexual reproduction to occur, there must be a way to reduce the number of chromosomes. This is why sex cells are formed. Sex cell formation differs from normal cell division.

The process that forms sex cells is called **meiosis**. During meiosis the chromosome number is reduced by half. A human cell containing 46 chromosomes undergoes meiosis to produce sex cells that have 23 chromosomes. The 46-chromosome number is referred to as the diploid chromosome number. It is written as $2n$. The 23-chromosome number is referred to as the haploid chromosome number and is given the symbol n.

The union of a haploid sperm cell and a haploid egg cell creates a diploid zygote.

(l) Which cells in **Figure 5** would contain 23 chromosomes? 46 chromosomes?

Aphids: Both Asexual and Sexual

If you look at the underside of new leaves or the buds of plants in the summer, you may observe a mass of tiny green or brown organisms. These are aphids, which survive by sucking the juices from the plant. You may notice large aphids surrounded by little aphids—this is evidence of an unusual life cycle (**Figure 6**). During the summer, female aphids reproduce asexually, giving birth to live female aphids. The newborn aphids contain unfertilized eggs that start developing into female aphids. It's as if summer aphids are born pregnant. This process allows their population to grow explosively if they find a good source of food.

(m) Explain why the offspring in the summer are clones of the mother.

(n) Would it be possible for a female aphid to produce a male aphid by asexual reproduction?

In the fall, when the days get shorter and evenings cooler, some of the female aphids become male. It's not really known how this change occurs, but the change allows the aphids to switch strategies. Now they reproduce sexually, and the females lay eggs that survive over the winter. These offspring, produced through the fertilization of sperm and egg, carry a combination of genetic information from both parents.

(o) What advantage do aphids gain from reproducing sexually?

(p) Speculate as to why aphids reproduce asexually in the summer and sexually in the fall.

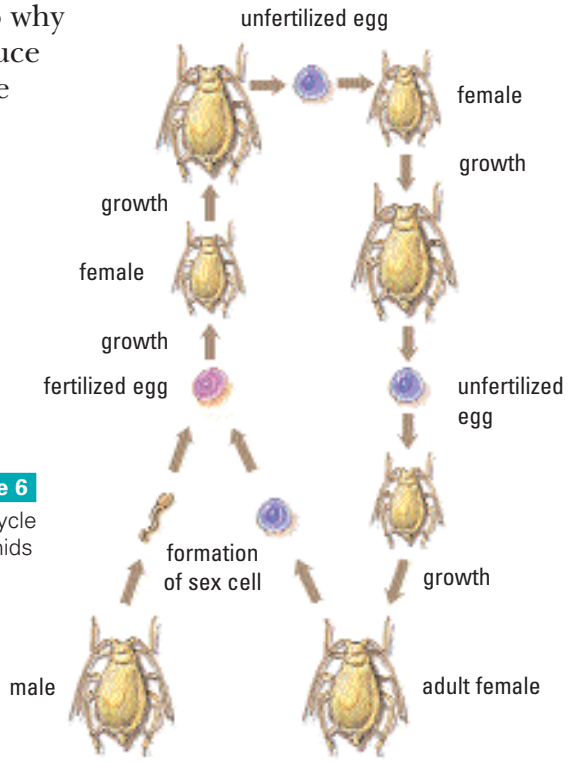


Figure 6
Life cycle of aphids

Understanding Concepts

1. What is a zygote?
2. Describe the process of conjugation.
3. What is hermaphroditic reproduction?
4. Give three examples each of animals that reproduce using
   (a) internal fertilization
   (b) external fertilization
5. In terms of chromosomes, how do female mammals differ from male mammals?
6. A muscle cell from a mouse has 22 chromosomes. How many chromosomes would you expect in
   (a) an unfertilized egg cell?
   (b) a zygote?
   (c) a brain cell?
   (d) a sperm cell?
7. What evidence do you have that suggests that people do not reproduce by conjugation?

Making Connections

8. What advantage is gained by bacteria that can reproduce both asexually and sexually?
9. What is the advantage of hermaphroditic reproduction in
   (a) plants?
   (b) animals?

7.2

Meiosis

Organisms that reproduce sexually show a greater range in their characteristics than those that reproduce asexually. Because the male and female sex cells come from different individuals in most species, sexual reproduction ensures a recombination of genes. Offspring carry genetic information from each parent. That may explain why you have thick hair like your father's, while your brother has thin hair like your mother's.

Although you may look more like one parent than the other, you receive the same amount of genetic information from each parent: a set of 23 chromosomes. Your father gives you a chromosome that contains genes that code for the thickness of your hair, but so does your mother. Each of the 23 chromosomes that you receive from your father is matched by one of 23 chromosomes from your mother. Chromosomes that are similar in shape, length, and gene arrangement are called homologous chromosomes (**Figure 1**). Your appearance is determined by the way the genes from your homologous chromosomes interact.

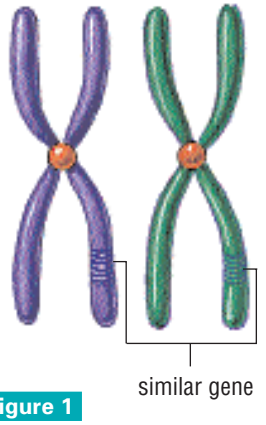


Figure 1
Homologous chromosomes carry genes that code for the same trait, in the same position on the chromosome. One of these chromosomes came from the mother, the other from the father.

Stages of Meiosis

Organisms that reproduce sexually contain two types of cells. Cells that reproduce only by normal cell division and mitosis are called **somatic cells**. Skin cells and muscle cells are examples. When these cells divide, each of the daughter cells is identical to the mother cell and has the

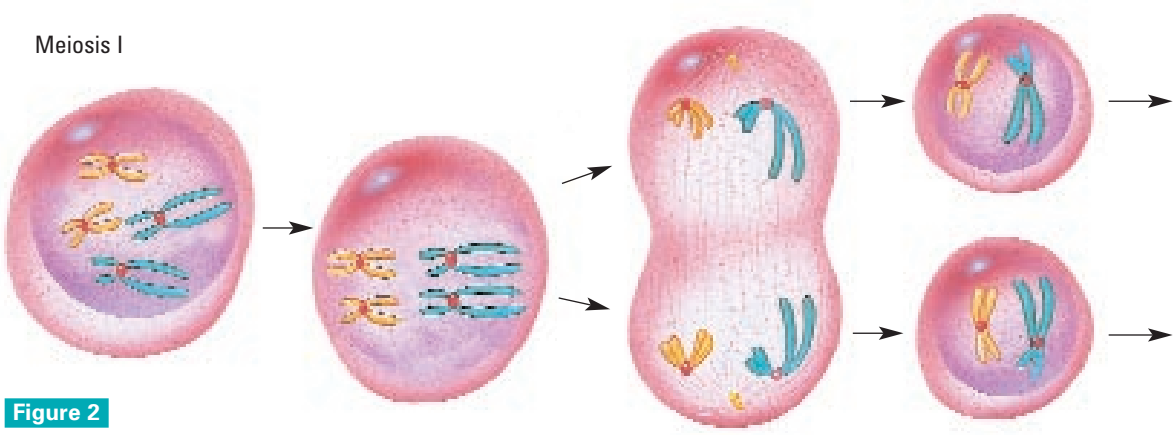


Figure 2
The process of meiosis requires two cell divisions. During the first division, the chromosome number is reduced. During the second division, the chromosomes divide and move to opposite poles.

same number of chromosomes. However, this is not true of the cells that produce sex cells. **Reproductive cells** produce sex cells that contain only half the number of chromosomes through the process of meiosis.

Meiosis involves two cell divisions that produce four haploid cells (**Figure 2**). During the first division, called meiosis I, homologous chromosomes move to opposite poles of the dividing cell. During this division a diploid cell ($2n$) becomes two haploid cells (n).

In the second phase, meiosis II, the chromosomes are divided.

Try This — A Dynamic Model of Meiosis

In Chapter 5, you may have built a model of mitosis. To help you understand the differences between meiosis and mitosis, work with your partner to modify your model so it can show the events of sex cell formation. Be sure that you can show both meiosis I and meiosis II with your model.

Understanding Concepts

1. How do somatic cells and reproductive cells differ from each other? How are they similar?
2. What are homologous chromosomes?
3. Describe the two divisions of meiosis.
4. Use **Figure 3** to compare meiosis and mitosis.

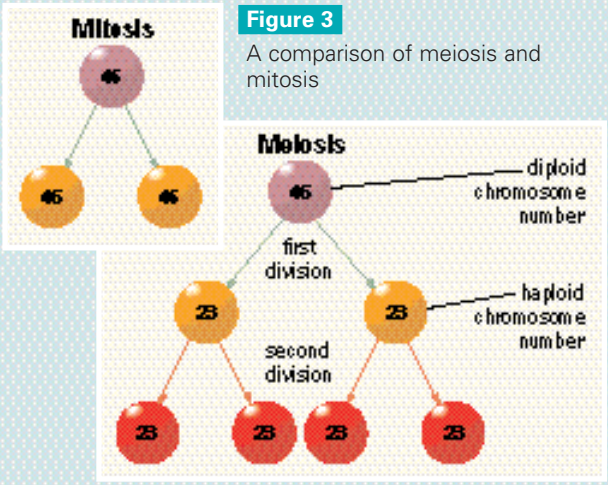
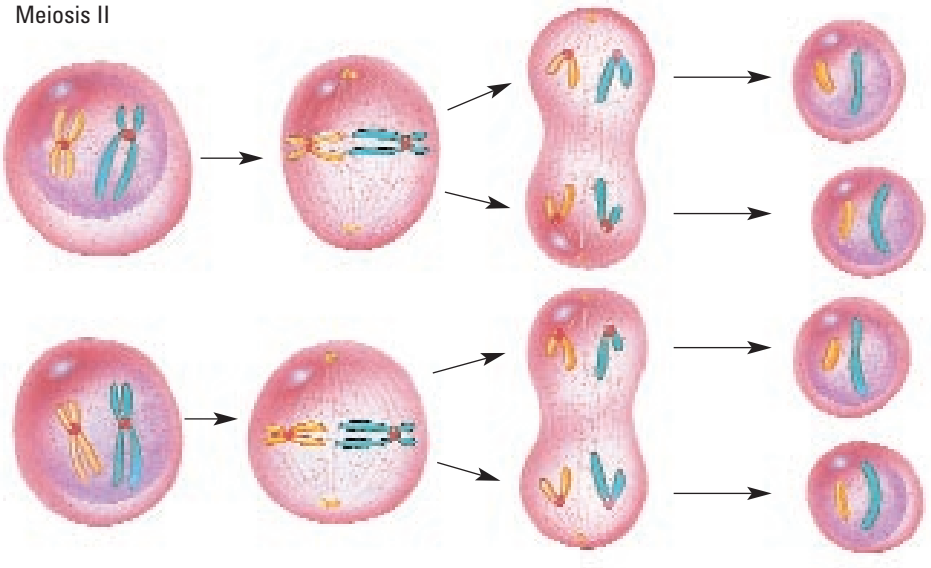


Figure 3
A comparison of meiosis and mitosis

5. Why is meiosis necessary?
6. A dog has 78 chromosomes in each somatic cell. How many chromosomes would you find in each of its sex cells?
7. Do homologous chromosomes have the same number of genes? Explain why or why not.
8. Do homologous chromosomes have identical genes? Support your answer.



Did You Know

Have you ever noticed how some blueberries in grocery stores are almost twice as large as those found in the wild? These blueberries have four sets of chromosomes. The $4n$ condition is called polyploidy. Other fruits like plums, cherries, and grapes can also have more than the usual $2n$ chromosome number.

7.3

Reproduction in Flowering Plants

A plant's flowers contain its reproductive cells. Many plants have both male and female sex organs, and hence are hermaphrodites. Some of these have separate male and female flowers, while others have both sex organs in the same flower. A few plants, such as poplar trees, have separate sexes. Poplars have male flowers or female flowers, but not both on the same plant.

The male sex cells of the flower, the **pollen**, are produced in the **anthers**, which are the tips of the **stamens**. Female sex cells, called **eggs**, are located in a structure called the **ovary**, which is at the base of the **pistil**.

Pollination

Pollination is the process by which the pollen is moved from the anther to the female eggs cells and fertilizes those cells. In some plants, the pollen can fertilize the eggs in the same flower. However, in many plants the pollen has to travel to another flower before it can fertilize an egg cell. Wind often carries pollen. Many people are bothered by wind-carried pollen, such as from ragweed or oak. If you have hay fever, it may well be caused by pollen.

Plants that have brilliantly coloured, fragrant flowers, and a sugary nectar attract animals to pollinate them. Most pollinators are insects, but bats and hummingbirds also pollinate flowers. As the animal crawls into the flower to collect the nectar, pollen from the anther falls on its body. When it moves to the next flower in search of more nectar, some of the pollen brushes off onto the pistil. Animals may deposit pollen over a wide area.

Once a pollen grain arrives at the pistil, it may unite with and fertilize an egg.

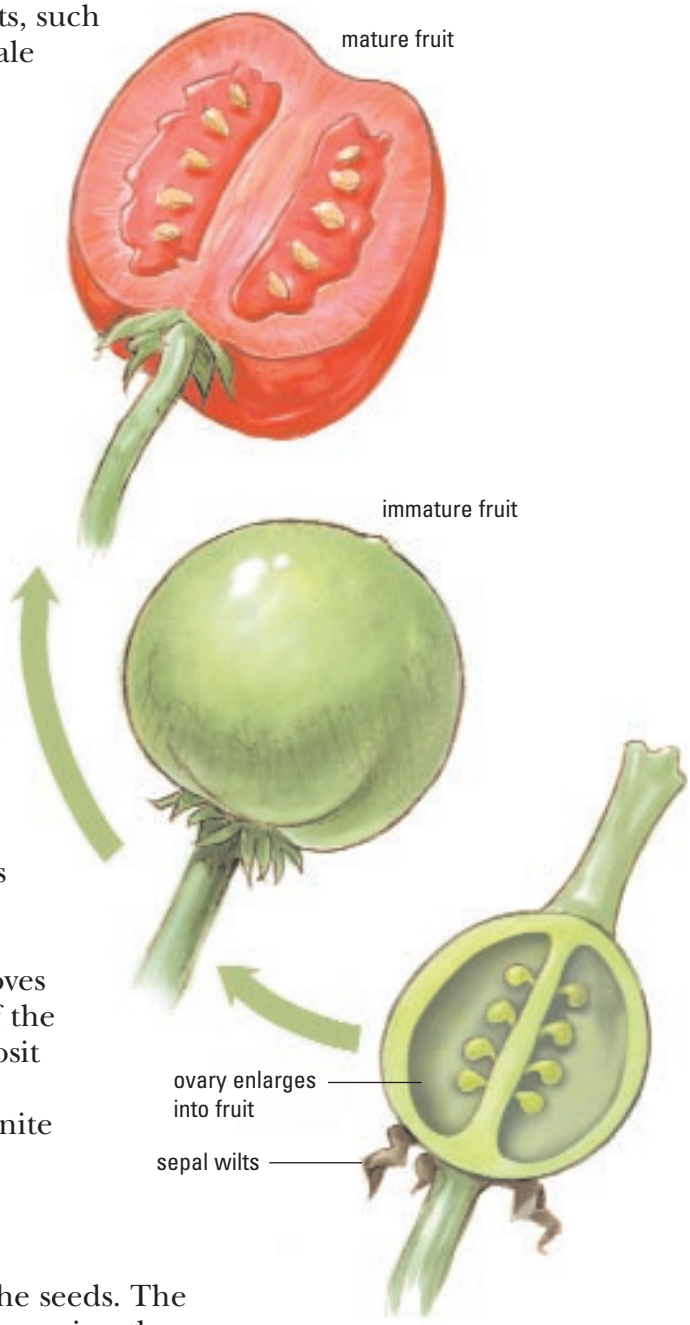
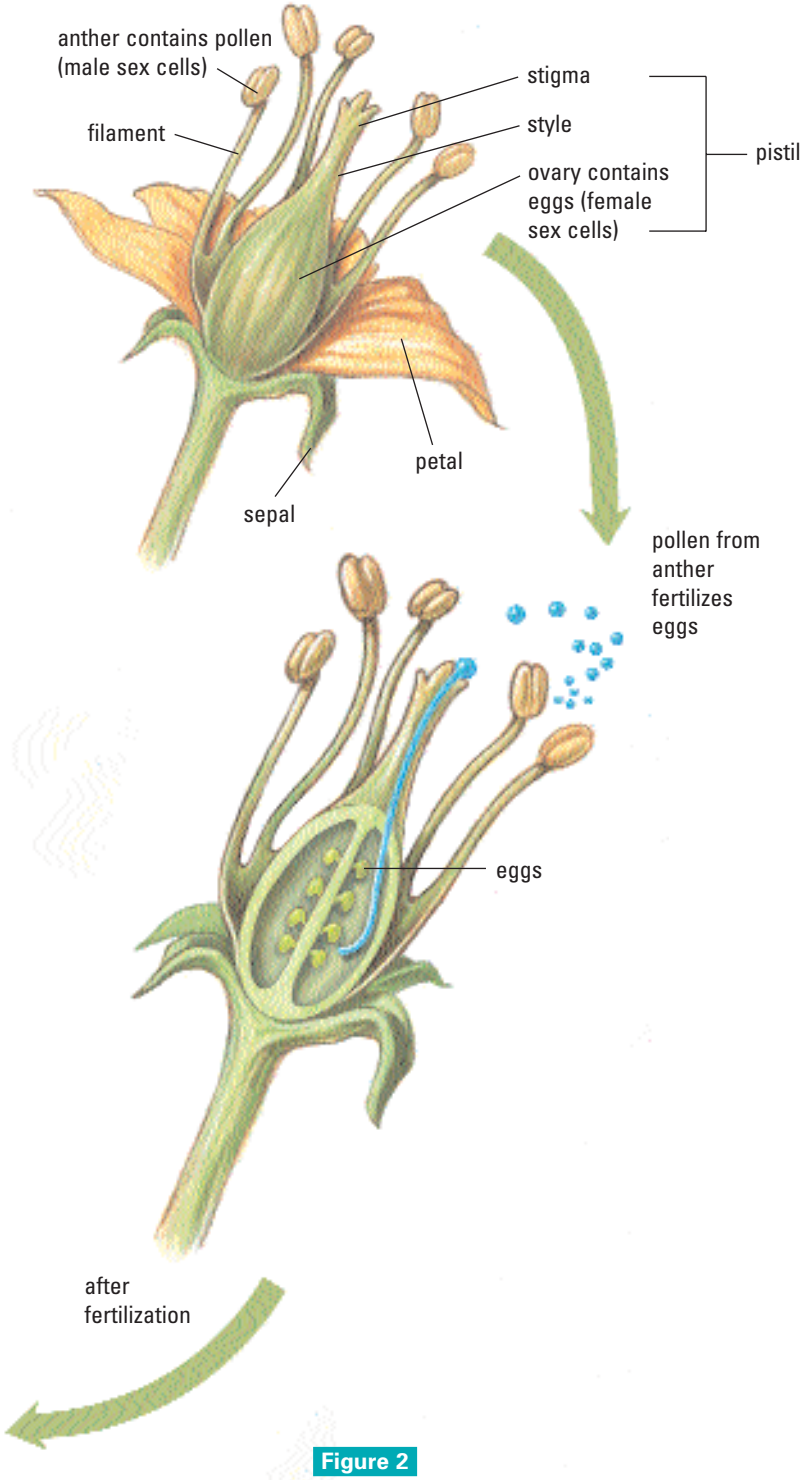


Figure 1
The life cycle of the tomato plant. After the pollen has fertilized the female eggs, the ovary develops into the fruit.

Seed and Fruit Formation

The fertilized eggs (zygotes) of the flower become the seeds. The petals slowly shrivel and fall from the plant. In some species, the ovary surrounding the zygotes develops into the fruit. Fruits help protect and disperse the seeds.

There are many different types of fruits, from pea pods to apples. Many birds and animals eat fruits and scatter the seeds, often in their droppings. The life cycle of one plant, the tomato, is shown in **Figure 1**.



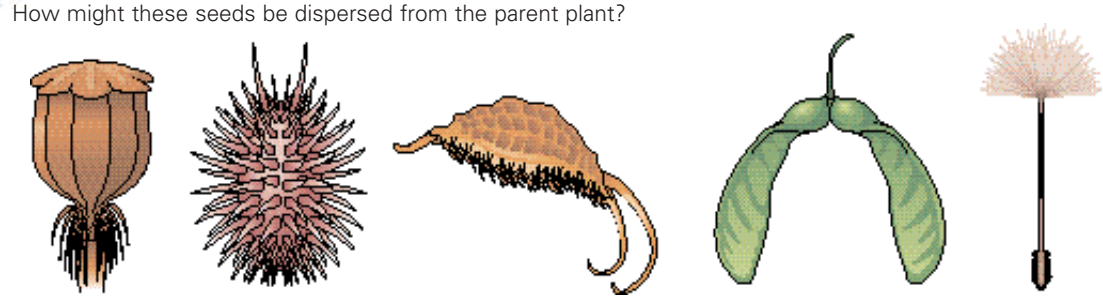
Understanding Concepts

1. Many plants are hermaphrodites. Explain.
2. Name the male and female sex cells of the flower.
3. What is pollination? How does it occur?
4. Explain how fruit is formed.
5. Many seeds have specialized adaptations for dispersal. Some seeds have structures that allow them to be carried by the wind. Other seeds can cling to animal fur. Examine the seeds in **Figure 2**. Do you think they are carried by the wind or animals? What special structures do each of the seeds have that help them travel away from the parent?
6. Speculate about how fruit formation helps plants spread their seeds. Use several different fruits as examples.

Exploring

7. Have you ever noticed that hummingbirds are attracted to red trumpet-shaped flowers? The long beak and hovering flight of the hummingbird make it ideally suited for getting nectar from these flowers. In the process, they pollinate the plants. Provide other examples of how flowers and animals have developed special structures to ensure pollination.

Figure 2
How might these seeds be dispersed from the parent plant?



a poppyseed capsule
b burdock
c unicorn capsule
d maple
e dandelion

7.4 Investigation

SKILLS MENU
○ Questioning ● Conducting ● Analyzing
● Hypothesizing ● Recording ● Communicating
○ Planning

Flower Anatomy

In this investigation you will examine different flowers to see which structures they have in common and which are different. You will also look at the functions of the parts of a flower.

Question

How do flowers differ from each other?

Hypothesis

1 Create a hypothesis for this question.

Materials

- whole flowers (various kinds)
- coloured pencils
- small paint brush
- hand lens or dissecting microscope
- tweezers
- small knife

Caution: Exercise caution when using a knife. Students who are sensitive to pollen should breathe through a disposable mask.

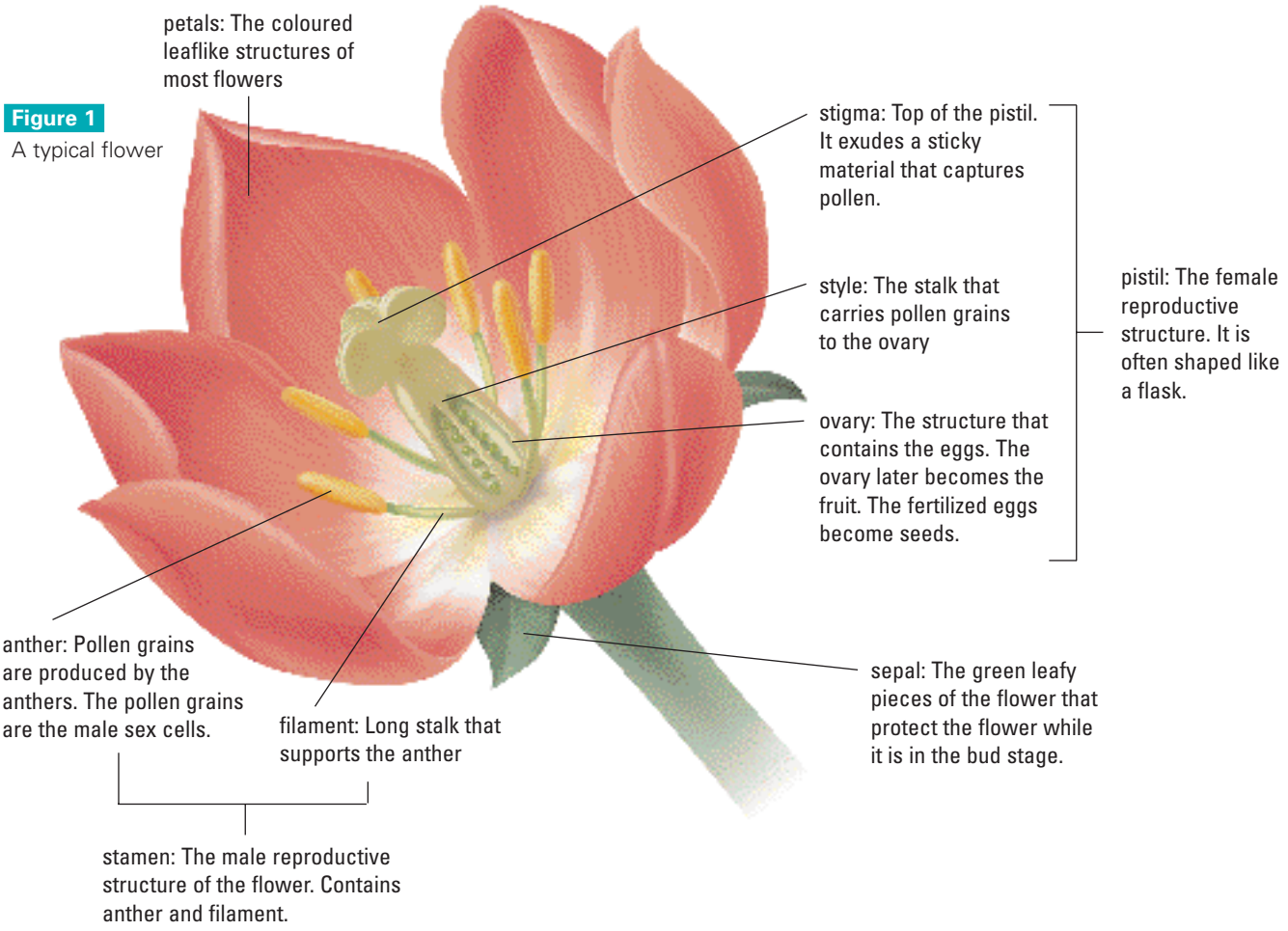


Figure 1
A typical flower

SKILLS HANDBOOK: 6D Creating Data Tables

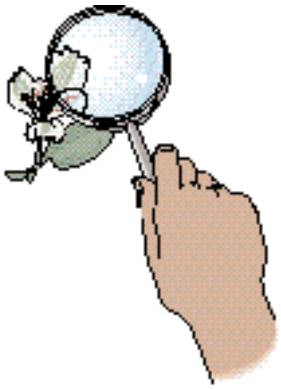
Procedure

2 Examine **Figure 1** and read the descriptions of the various parts. Not all flowers are alike. Your flowers may differ from the diagram.

3 Obtain two flowers and examine them closely with a hand lens or under a dissecting microscope.

(a) Record the number of petals, sepals, and stamens on each flower. Leave space on your data table for the data from more flowers. (6D)

Step 3



4 Compare the number of petals, sepals, and stamens on your flowers with those of similar and different flowers being examined by other groups.

(a) Do similar flowers have the same number of petals, sepals, and stamens?

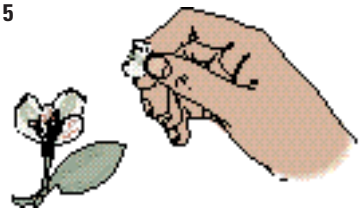
(b) Do different flowers have the same number of petals, sepals, and stamens?

5 Remove a few adjoining petals and sepals. Examine the inside of the flower carefully.

(a) How many pistils do you see?

(b) Draw a diagram of your flowers and label the parts. Identify which parts are the female reproductive system and which are the male reproductive system. (6C)

Step 5



6 Carefully cut vertically through the pistil of each flower.

(a) Draw a diagram of the inside of the pistil and label the structures.

Caution: Exercise care when using a knife.

Analysis and Communication

7 Compare the flowers you examined by answering the following questions:

(a) Why do you think the flowers were different? (Hint: Find out what type of flower each is, how it is pollinated, and how its seeds are dispersed.) (3A)

(b) Why do you think the similar parts of your flowers were similar?

(c) Did any flowers you examined lack one or more of the parts shown in **Figure 1**?

(d) What happens when the pollen reaches the egg?

(e) In what part of the flower do seeds form?

(f) How do insects and birds help with the process of pollination?

Exploring

1. Bees collect nectar from plants. Predict which part of the flower contains nectar. Give reasons for your prediction.
2. Explain why unripe fruit is often green and bitter, whereas ripe fruit is usually sweet and colourful.

Reproduction of Plants for Food

Imagine your school lunchroom with twice as many people but the same amount of food. The lunchroom would have two problems: the amount of space and the amount of food for each person. The problems facing world agriculture are similar.

Approximately 6 billion people inhabit 145 000 000 km^2 of planet Earth. Scientists estimate that the population will grow to about 10 billion within 50 years. The most dramatic increases will occur in areas already identified as crowded. Increased food production is essential to feed the extra people, but only about 11% of Earth's land is suitable for growing crops (**Figure 1**). Many experts suggest that technology will probably not be able to increase the area of agricultural land. Unfavourable climatic conditions make tundra areas and deserts inappropriate for growing food.

Figure 1
Of the world's 13.1 billion ha, only about 1.4 billion ha can be used for cropland.

Strategies for Increasing Food Production

Selective Breeding

Plants with desired characteristics are identified and crossbred with other plants that have different desirable characteristics. During **crossbreeding**, pollen is taken from one plant and used to fertilize the eggs of another. Some of the offspring will have the best characteristics of both parents, but others may have the worst characteristics. All the seeds are planted, and the plants showing the desired characteristics are bred again. After several generations of **selective breeding**, all the offspring have the desired characteristics.

Sir Charles Saunders, a Canadian scientist, developed Marquis wheat by crossbreeding the Red Calcutta and Red Fife varieties of wheat. Red Fife was once the most common variety of wheat in Canada. Its hardy qualities were well suited for the Canadian prairie, but it matured slowly, and therefore was susceptible to frost damage. Red Calcutta wheat was less hardy and produced poor yields, but developed more quickly. Saunders crossbred the two varieties and selected the offspring that showed the characteristics he wanted. His new variety, Marquis wheat, had the good yields and hardy qualities of Red Fife, but matured approximately two weeks earlier (**Figure 2**).

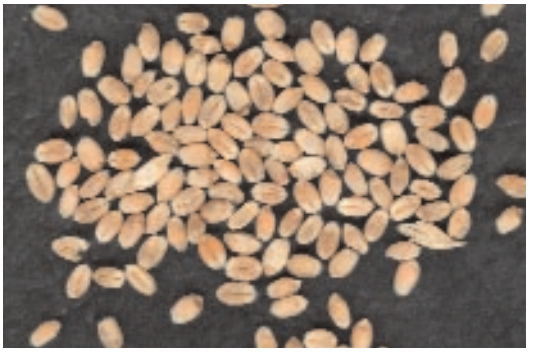


Figure 2
Marquis wheat was developed by crossbreeding Red Calcutta and Red Fife wheat.

Cloning

In cloning plants for food, cuttings are taken from a plant with desired characteristics (**Figure 3**). Because cloning is a type of asexual reproduction, all of the offspring are exact duplicates of the parent.

Figure 3

Grafting

Many fruit trees are grown by grafting, rather than planting from seed. Some varieties produce excellent roots but poor fruit, while other varieties have excellent fruit but their roots are susceptible to winter damage. Branches from trees with excellent fruit are grafted onto trees with excellent roots. The resulting tree produces good fruit and survives the winter well.

Did You Know

McIntosh apples are all produced from grafted branches descended from one tree in Ontario. This is because the seeds inside McIntosh apples do not germinate to produce true McIntosh trees.

The Risks of Low Diversity

Historically, humans have used about 700 different species of plants. Today we rely heavily on only about 20 species. Wheat, rice, barley, corn, and sorghum are the most important crops in the world. Although these food species are reproduced sexually, they have been bred carefully so that each plant is very similar to the others, to ensure a good yield.

When large areas of agricultural land are planted with just one variety of food crop, it is called a monoculture. This has been a good strategy for farmers because the variety chosen can be perfect for the soil and the climate. However, because there is little diversity among the plants, few of the plants would be resistant to a new pest or disease, making the crop vulnerable.

What can make this situation even worse is that most land is not well suited for monocultures of cereal grains, such as wheat and barley. The soil requires added nutrients. In some areas, a few seasons after planting, the soil no longer supports the growth of crops. Have long-term needs been sacrificed for short-term gains?

Converting a natural ecosystem to an artificial ecosystem has many implications. Should we drain a marsh to plant rice? Should we irrigate a desert to plant wheat or cotton? Once it has been done, and the native plants have been destroyed, can it be undone?

Figure 4

The tropical rain forests hold the greatest diversity of life on the planet. Many plants and animals living there have not been "discovered" by scientists. Unfortunately, they are being destroyed as the forests are burned to clear land for crops.

Understanding Concepts

1. Why is increasing food production such a great concern?
2. How might grafting and selective breeding help increase food production?
3. How do cloning and grafting limit biodiversity?

Making Connections

4. Why might it be dangerous to reduce the number of plants used by people?
5. Many farmers grow a single crop on large areas of farmland. What are the advantages and disadvantages of this practice?

Reflection

6. Many people living in Central and South America have cut down forests to increase cropland (**Figure 4**). Explain why such a practice provides only a short-term solution to food shortages.

Challenge

Farmers may know more about reproductive technologies for food plants than people who live in cities. Having that knowledge could influence their opinions. Surveys may give inaccurate results if the sample of people is not broad enough. How will you decide who to interview with your survey?

7.6

Sex Cell Development in Males

In the last few sections you have been looking at the production of sex cells and the formation of the zygote in plants. Animals also have sex cells, but what do they look like, and where and how are they produced?

Structure of Sperm

The sperm cell, shown in **Figure 1**, is well designed for its purpose. Built for motion, the sperm cell is streamlined. The sperm cell carries little excess weight; a small amount of cytoplasm surrounds the nucleus. Although reduced cytoplasm is beneficial for a cell that must move, it also presents a problem. Limited cytoplasm means a limited energy reserve.

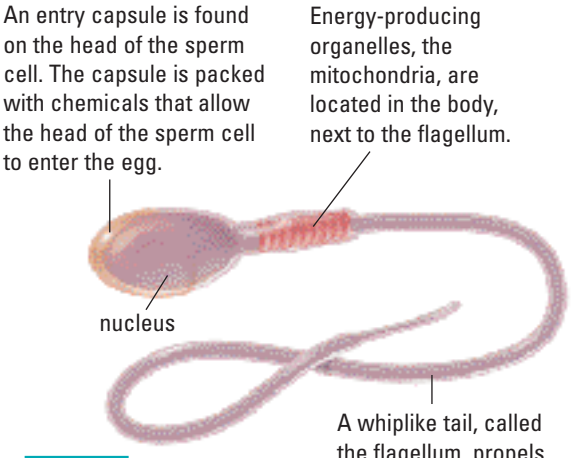


Figure 1
Human sperm cell

Sperm Production and Development

The **testis** (plural testes) is the primary reproductive organ of the male mammal. It is responsible for producing and nourishing sperm as they mature. The insides of the testes are filled with tiny, twisting tubes. These **seminiferous tubules** are lined with reproductive cells that produce sex cells by meiosis (**Figure 2**). Human reproductive cells contain a full complement of 46 chromosomes. Mature human sperm cells contain 23 chromosomes.

As the sperm cells develop from the immature, shapeless form, they begin to grow a flagellum and reduce the amount of cytoplasm inside the cell. As the sperm mature, they move slowly into the epididymis, an organ that lies near the testis (**Figure 2**), where they complete their development.

Sperm are not built to last. Those not released for reproduction die within a few days and are replaced by newer cells from the testes. Scavenging white blood cells scour the epididymis, removing older sperm cells and those that have died.

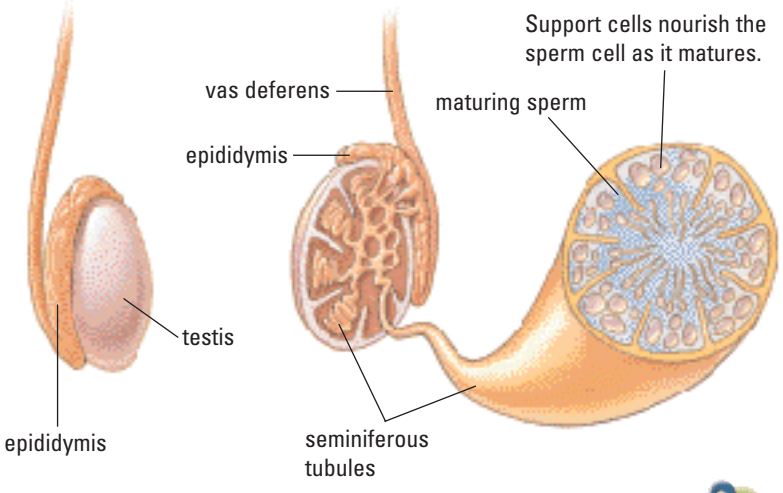


Figure 2
Male sex cells are produced in the testes.

Did You Know

The male sperm cell is dwarfed by the much larger female egg cell. In humans, the egg cell is 100 000 times larger than the sperm cell.

Did You Know

If you untwisted a seminiferous tubule, it would measure approximately 70 cm in length!

Fertilization

In mammals, fertilization is internal. Each egg is fertilized by one sperm. The sperm uses its store of chemicals to enter the egg, but the egg permits only the head to enter. The body remains outside. As soon as one sperm has entered, the egg puts up a barrier that other sperm cannot break through. Once inside the egg, the sperm's nucleus merges with the nucleus of the egg. In humans, the fertilized egg has 46 chromosomes: 23 from the egg, and 23 from the sperm.

Hormones and Male Sex Cell Production

Up until week seven following fertilization, human male and female embryos are identical in appearance. Then, a chemical messenger—a hormone—is sent from the brain to stimulate the development of sexual structures.

After birth, the reproductive organs of both males and females produce low levels of sex hormones. These sex hormones continue to influence the development of male and female characteristics. However, reproductive organs are not capable of producing mature sex cells until puberty.

Puberty is a period of rapid growth and sexual maturity. It usually takes place in humans between 9 and 15 years of age. During that time, humans display a wide variety of physical changes. In the males, the amount of testosterone, a hormone secreted by the testes, increases. Testosterone stimulates sperm development.

Two other hormones are important in sperm development. Both of these hormones are released by the pituitary gland in the brain. Luteinizing hormone (LH) causes special testes cells to produce testosterone. Follicle stimulating hormone (FSH) acts directly on the reproductive cells in the testes, causing them to divide and produce sperm. FSH also causes the reproductive cells to absorb testosterone. **Figure 3** shows how these hormones interact in a feedback system.

Testosterone secretion and sperm production usually continues for the rest of the male's life. Males over 90 years old have been known to father children.

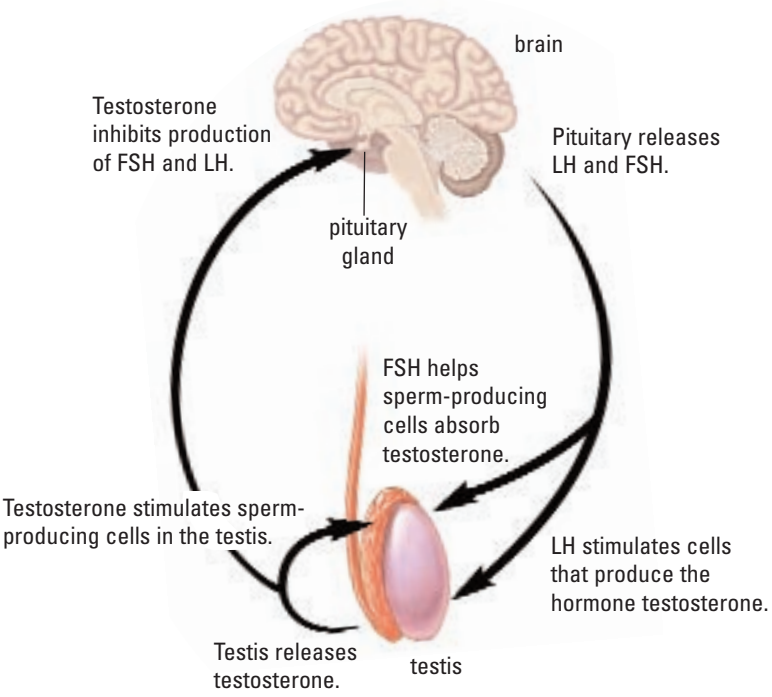


Figure 3
Hormones in the male reproductive system

Understanding Concepts

1. What features of the sperm cell make it well suited for movement?
2. What are seminiferous tubules?
3. Describe the development of sperm.
4. What are the functions of testosterone?
5. Describe the differences between mature sperm cells and reproductive cells.
6. Why do sperm die only a few days after they are produced?

Sex Cell Development in Females

The female reproductive system in mammals (**Figure 1**) is more complicated than that of the male, because it has an extra responsibility. Not only must the female produce sex cells (eggs), but she must also nurture the embryo once an egg is fertilized.

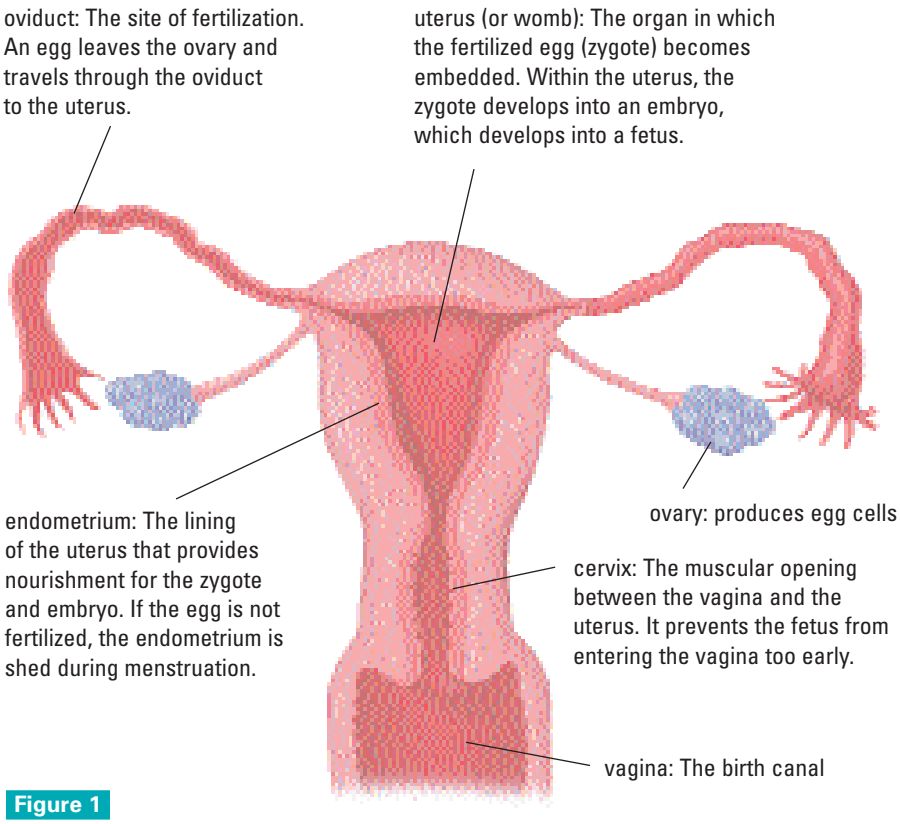


Figure 1
Frontal view of the female reproductive system

Structure of the Egg

Like the sperm, the egg is well designed for its purpose. The female sex cell is much larger than the sperm, and it is packed with nutrients, so that when it is fertilized it can divide rapidly. It is capable of building a barrier after fertilization to prevent sperm from entering. Unlike males, who manufacture millions of sperm cells every day, human females usually develop only one egg at a time.

Production and Development of the Egg

The primary reproductive organ of the female is the **ovary**. It is responsible for producing and developing egg cells. The ovary contains small groups of cells, called **follicles**. The follicles are composed of two types of cells: a reproductive cell that produces the egg and nutrient-producing cells. The nutrient-producing cells provide energy-rich chemicals to the developing egg.

Unlike the testis, the ovary does not generate new egg cells throughout adult life. The human ovary contains about 400 000 immature follicles at puberty, and the number continually decreases. Hundreds of the follicles begin to develop during each reproductive cycle, but usually only a single follicle is allowed to reach maturity in each cycle (**Figure 2**). The other follicles that had been developing deteriorate and are absorbed into the ovary.

As the follicle develops, the reproductive cell, which contains 46 chromosomes, undergoes meiosis. It forms one large, mature egg cell with 23 chromosomes, plus three tiny cells that disintegrate. Meanwhile, nutrient cells surrounding the egg-producing cell have been dividing to nourish the future egg. The nutrient cells surrounding the egg cell develop into a fluid-filled cavity. When the egg is ready, the ovary wall bursts and the egg cell is released into the **oviduct**. The release process is called **ovulation**.

Nutrient cells that remain within the ovary are transformed into a tissue called the **corpus luteum**. The corpus luteum secretes hormones essential for pregnancy. If pregnancy does not occur, the corpus luteum degenerates after about 10 days, and the cycle that leads to ovulation begins once again.

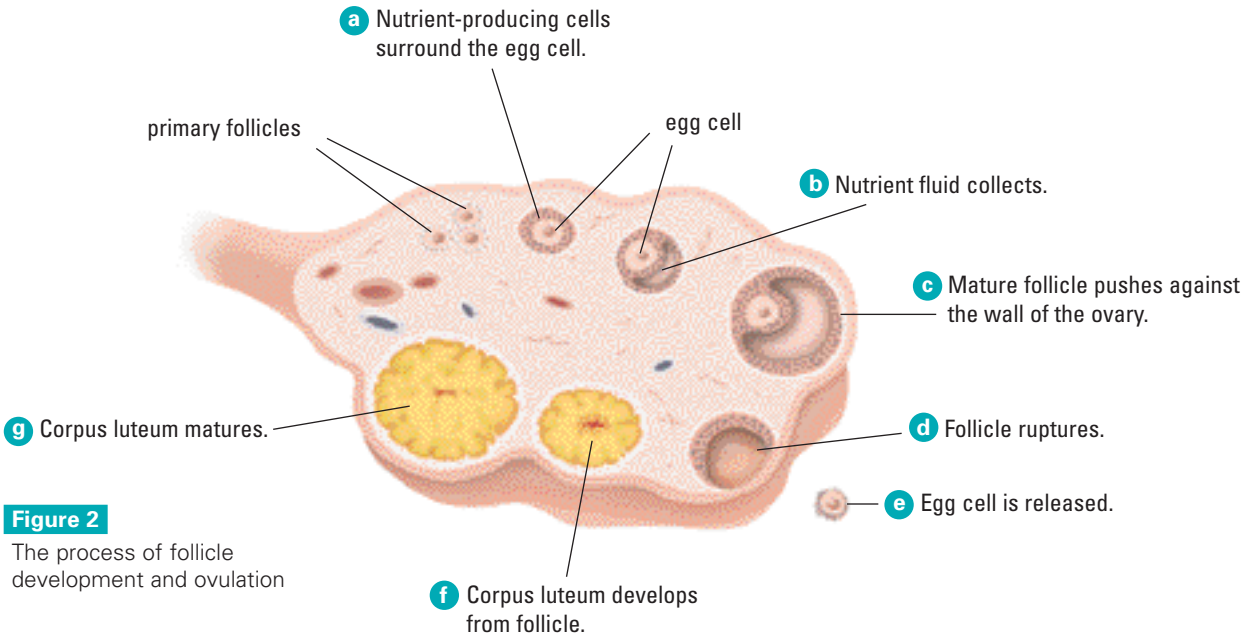


Figure 2
The process of follicle development and ovulation

Pregnancy

The oviduct moves the egg toward the **uterus**, the organ responsible for nourishing an embryo as it grows. If the egg has been fertilized by a sperm cell while moving through the oviduct, the zygote begins to divide by mitosis, becoming an embryo. The embryo embeds in the thick lining of the uterus, called the **endometrium**. The endometrium supports the developing embryo.

If the egg is not fertilized, the endometrium is shed in a process called **menstruation**.

The Role of Hormones

In females at puberty, the pituitary gland in the brain secretes two hormones, FSH and LH, which stimulate the changes that take place in the female's body. During puberty external and internal reproductive organs develop their mature form, and development of follicles can begin.

Estrogen

FSH also triggers the development of follicle cells in the ovary (**Figure 3**). As they develop, they begin to secrete another hormone, called estrogen. Estrogen is released into the blood and carried to the cells of the body. In the uterus, estrogen encourages the endometrium to thicken, in preparation for the zygote. As the follicles develop, estrogen concentrations in the blood increase.

Progesterone

Once the follicle cells begin to develop, LH is released into the blood. LH causes ovulation and the formation of the corpus luteum (**Figure 3**). The corpus luteum secretes both estrogen and another hormone, progesterone. Progesterone continues to stimulate the development of the endometrium and prepares the uterus for an embryo. In addition, progesterone inhibits further ovulation.

If no embryo is embedded in the endometrium, the corpus luteum stops making estrogen and progesterone. The endometrium stops developing and instead begins to break down. Menstruation starts, and a new set of follicles can develop in the beginning of the next reproductive cycle.

Understanding Concepts

1. Where are egg cells produced?
2. What is the site of fertilization?
3. In which structure does the embryo develop?
4. What are the two types of follicle cells found in the ovary? Explain the function of each of the cell types.
5. Describe ovulation.
6. How is the corpus luteum formed? Explain its function.

Making Connections

7. If the ovaries of a woman are removed, would she be able to give birth to a baby? Support your answer.
8. Ectopic pregnancies occur when the embryo becomes implanted in the oviduct rather than the uterus. Speculate about some of the difficulties that would be experienced by such a pregnancy.

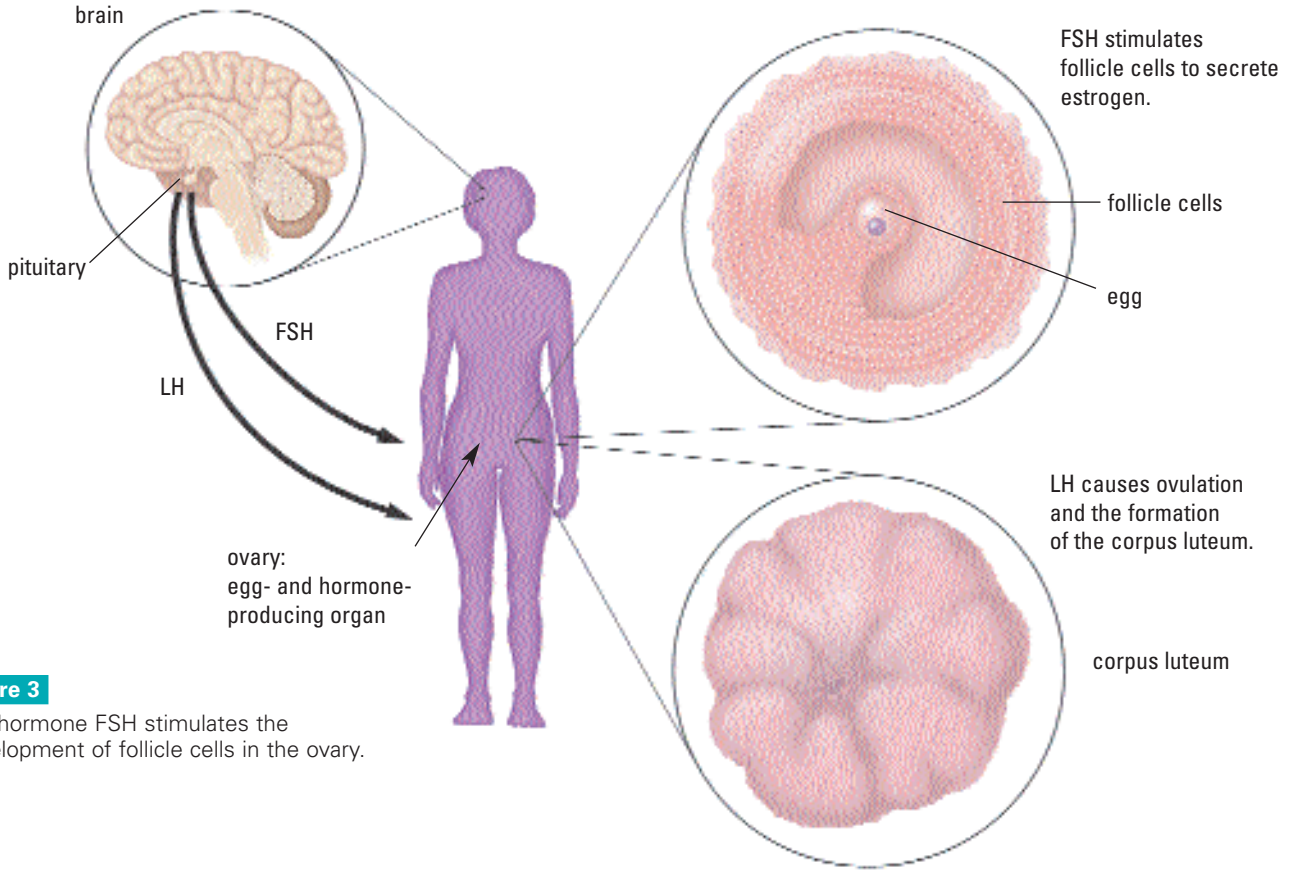


Figure 3
The hormone FSH stimulates the development of follicle cells in the ovary.

Career Profile

Fertility Specialist

For more than 30 years, Dr. Albert Yuzpe has been a trailblazer in the field of reproductive medicine. After obtaining an M.Sc., with a major in medical research/endocrinology, from the University of Western Ontario, Dr. Yuzpe trained as a medical doctor specializing in obstetrics and gynecology. He also became a fellow of the Medical Research Council of Canada, focusing on drugs that cause the ovaries to release eggs for fertilization. He helped develop laparoscopy—a kind of exploratory surgery that involves making a small incision in the body and inserting a tiny flexible microscope, or laparoscope. Less invasive (requiring a smaller cut) than other kinds of surgical techniques, it is used to diagnose a wide variety of ailments.

> "Medicine has enabled me to take my knowledge and experience abroad."

Throughout his career, Dr. Yuzpe has continued to teach and do research. He has been chief of Reproductive Medicine at University Hospital in London, Ontario, and a professor at Western's Faculty of Medicine, where he is now Professor Emeritus. He has taught courses in reproductive medicine and worked as a consultant for the World Health Organization in several countries.

Dr. Yuzpe is cofounder of the Genesis Fertility Centre, Inc., in Vancouver, where he now works with a team of specialists assisting patients with fertility problems. "The most rewarding thing is when people get pregnant," but the most difficult part of his job is to help some couples accept the fact that they simply cannot get pregnant.

Teaching has been a very important part of Dr. Yuzpe's career. His proudest moments come from seeing "the evolution of people I had a hand in training."

Exploring

1. The training to become a specialized medical doctor is long and demanding. Choose a specialty and research the various stages of training required.
2. Research the development of the laparoscope (3A) and its benefits.
3. Why is it important for university teachers to be researchers and vice versa?

Hormones and the Reproductive Cycle

The female reproductive cycle, also called the menstrual cycle, continues through a woman's life from puberty until about the age of 50 years, when no more follicles remain in her ovaries, so no more eggs can develop. This stage of life is referred to as menopause. Until menopause, however, the menstrual cycle (**Table 1** and **Figure 1**) repeats on average every 28 days, although this number varies widely in women, and may change over the life of the woman. The menstrual cycle can be divided into four distinct events: flow phase, follicular phase, ovulation, and a luteal phase.

(a) A man into his 70s or 80s can still produce sperm cells. Would a woman of the same age also be able to produce egg cells? Give your reasons.

(b) If a woman reaches puberty at age 13 and reaches menopause at 50, calculate the number of egg cells she will ovulate. (Assume one egg cell per ovulation and no pregnancies.)

(c) Why would it be impossible for a woman to give birth to that many children?

Table 1 **Summary Table: Female Menstrual Cycle**

Phase	Description of events	Hormone produced	Days
flow	Menstruation		1–5
follicular	Follicles develop in ovaries. Endometrium is restored.	Estrogen produced by follicle cells	6–13
ovulation	Egg cell bursts from ovary.		14
luteal	Corpus luteum forms, endometrium thickens.	Estrogen and progesterone produced by corpus luteum	15–28

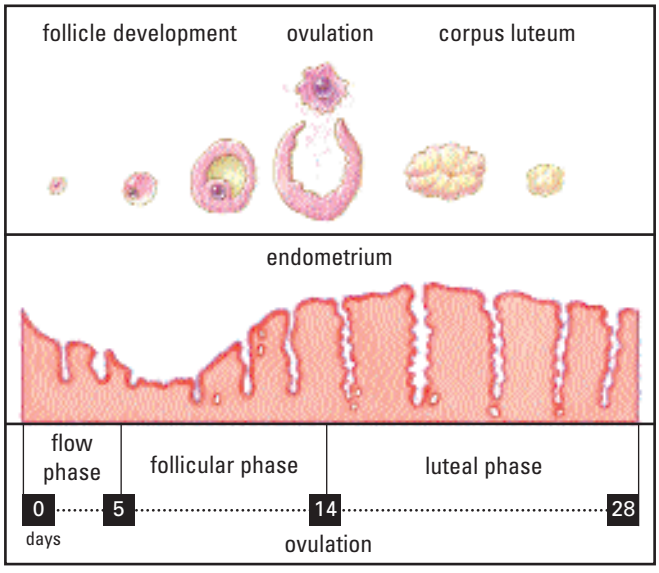


Figure 1
This graph summarizes how events in the ovary and uterus are related during the menstrual cycle.

Flow Phase

The flow phase is marked by the shedding of the endometrium, or menstruation. This is the only phase of the menstrual cycle that can be determined externally. For this reason, the flow phase is used to begin the menstrual cycle. It lasts about five days.

(d) Where is the endometrium located?

(e) What is the function of the endometrium?

Follicular Phase

During the follicular phase, the follicles within the ovary develop and begin to secrete the hormone estrogen. As follicles continue to develop, estrogen levels in the blood increase. In a 28-day cycle, the follicular phase normally takes place from days 6 to 13.

(f) In which organ do the follicle cells develop?

Ovulation

Ovulation, the shortest phase of the menstrual cycle, marks the end of the follicular phase. The egg bursts from the ovary and begins to travel through the oviduct to the uterus. About four or five days after ovulation, if the egg has not been fertilized, it dies.

(g) Explain why progesterone levels only begin to rise after ovulation.

Table 2

Event	Hormone responsible	Days of the cycle
a. follicle is stimulated	?	?
b. endometrium begins to develop	?	?
c. ovulation	?	?
d. endometrium continues to develop	?	?
e. menstruation	?	?

Table 3

	Temperature (°C)	
Days	Ovulation occurs	No ovulation
5	36.4	36.3
10	36.2	35.7
12	36.0	35.8
14	38.4	36.2
16	37.1	36.1
18	36.6	36.0
20	36.8	36.3
22	37.0	36.3
24	37.1	36.4
28	36.6	36.5

The Luteal Phase

The development of the corpus luteum in the follicle marks the beginning of the luteal phase. Estrogen levels begin to decline when the egg leaves the ovary but are restored somewhat when the corpus luteum forms. The corpus luteum secretes both estrogen and progesterone. Progesterone continues to stimulate the endometrium and prepares the uterus for an embryo. In addition, progesterone inhibits further ovulation to prevent another egg being released during pregnancy.

(h) Birth control pills contain high concentrations of progesterone. Explain how they prevent pregnancy.

(i) What might happen if an egg were released into the oviduct during a pregnancy?

Understanding Concepts

1. Copy **Table 2** in your notes and use it to summarize the events that take place in the menstrual cycle.
2. Body temperature was monitored during the menstrual cycle of two women. One ovulated and the other did not.
   - **(a)** Graph the data provided in **Table 3**. Plot changes in temperature along the *y*-axis (vertical axis) and the days of the menstrual cycle along the *x*-axis (horizontal axis). (7B)
   - **(b)** Assuming the menstrual cycle is an average 28-day cycle, label ovulation day on the graph.
   - **(c)** Describe changes in temperature prior to and during ovulation.
   - **(d)** Compare body temperatures with and without a functioning corpus luteum.
3. **Figure 2** shows changes in the thickness of the endometrium throughout the menstrual cycle. (7A)
   - **(a)** Identify the events that occur at the times labelled X and Z.
   - **(b)** Identify the letter-label in which follicle cells produce estrogen.
   - **(c)** Identify the letter-label in which the corpus luteum produces estrogen and progesterone.

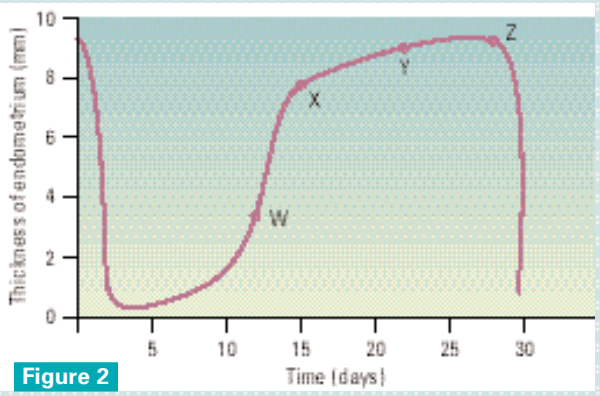


Figure 2

4. Predict the consequences if a 46-chromosome, immature cell were released from the ovary rather than a 23-chromosome egg.

Challenge

If the questions are too personal, an interview about reproductive issues may touch on some pain in a person's life. How can you craft your survey questions so they prompt answers about the issue but also protect your respondents?

Atypical Meiosis

Most processes of the body can go wrong, including cell division. If errors occur during division of a somatic cell, such as a skin cell or a liver cell, it may not harm the organism, which has many other cells. However, if something goes wrong during meiosis in a reproductive cell, the resulting embryo is in serious trouble: all of its cells will be affected.

Nondisjunction (failure to separate) is an error that occurs when two homologous chromosomes move to the same pole during meiosis (**Figure 1**). As a result, one of the daughter cells is missing a chromosome, while the other has an extra chromosome. Cells that lack genetic information or have too much information will not function properly.

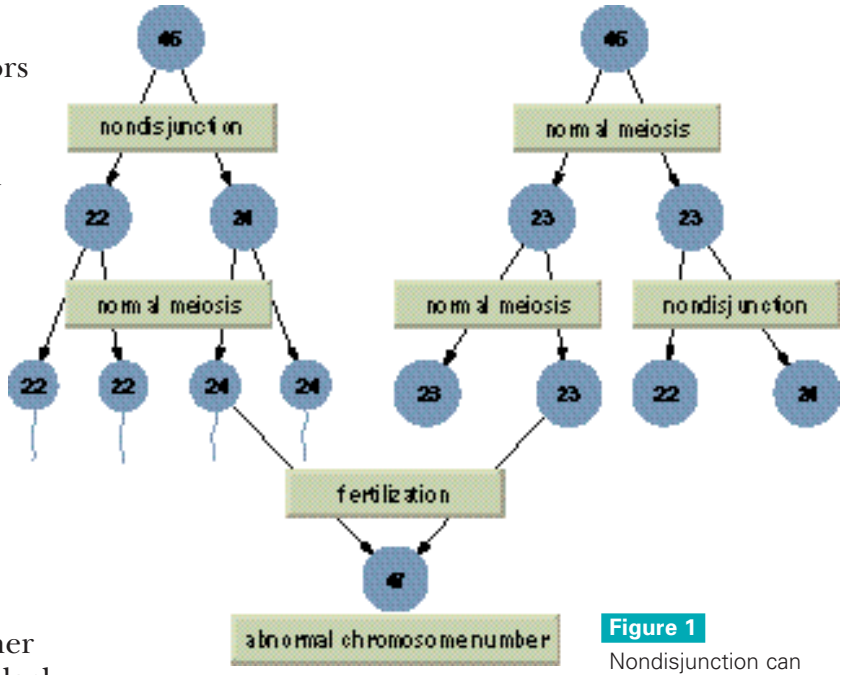


Figure 1
Nondisjunction can occur at meiosis I or meiosis II stage.

In humans, nondisjunction can produce sex cells with 22 or 24 chromosomes. The sex cell with 24 chromosomes has both chromosomes from one of the homologous pairs. If that sex cell joins with a normal sex cell with 23 chromosomes, the zygote will have 47 chromosomes, rather than 46. One homologous pair of chromosomes will have an extra chromosome and be a triplet. If a sex cell containing 22 chromosomes joins with a normal sex cell, the resulting zygote will have 45 chromosomes.

When a fertilized egg with an abnormal chromosome number divides, each cell of the body will also have the abnormal number of chromosomes. In most cases, the zygote dies, because there is either too much or not enough information in each cell. In a few cases, a person with a nondisjunction disorder is born.

Nondisjunction Disorders

Down syndrome is a genetic disorder produced by nondisjunction (**Figures 2** and **3**). Most people with Down syndrome have an extra chromosome for chromosome pair 21—too much genetic information. Children with Down syndrome may have a mental disability, although a wide range of mental abilities is possible.

Turner syndrome occurs when sex chromosomes undergo nondisjunction in either the male or the female parent, producing a female with a single X chromosome instead of two (**Figure 4**). Females

Figure 2
It has been estimated that one baby in 600 is born with Down syndrome. Researchers believe that the nondisjunction occurred when the egg was produced.

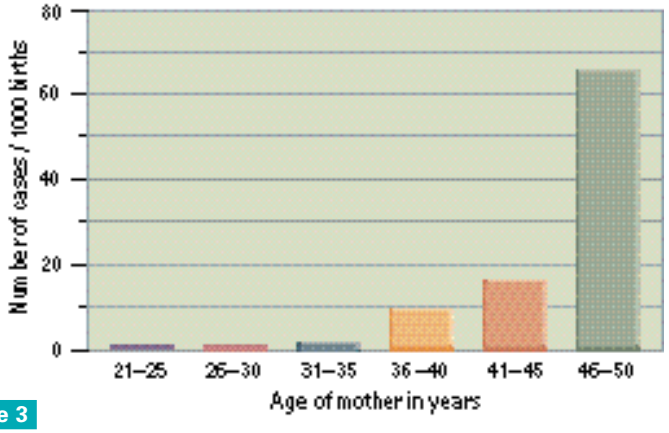


Figure 3

The incidence of birth of babies with Down syndrome increases with the age of the mother.

with Turner syndrome do not mature sexually and are shorter in height. About one in every 10 000 births is a Turner syndrome baby.

Klinefelter syndrome is also caused by nondisjunction in either the sperm or egg. The child inherits two X chromosomes plus a single Y chromosome. The child is a male, however, as he enters puberty, he begins producing high levels of female sex hormones. Males with Klinefelter syndrome cannot father children. This disorder occurs in about one in every 1000 births.

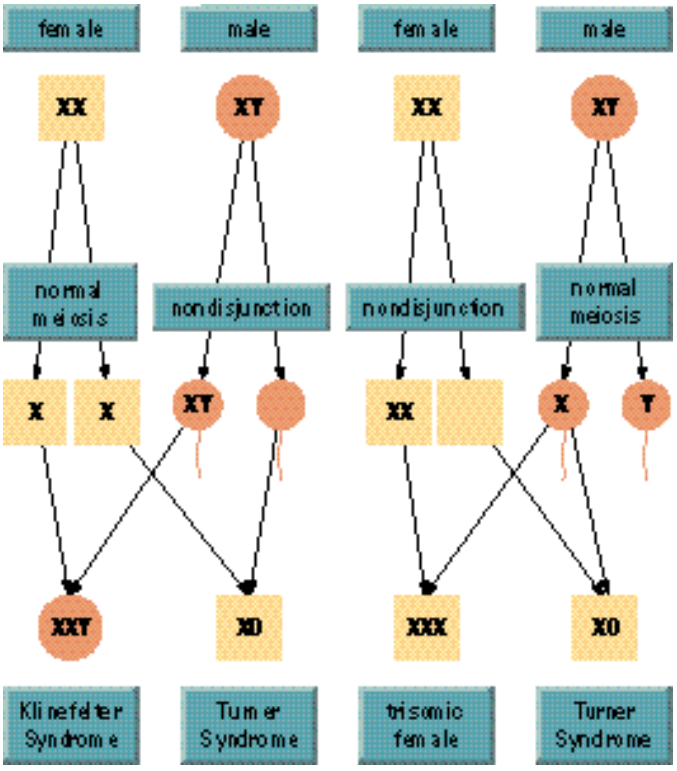


Figure 4

Disjunction disorders that involve sex chromosomes

Understanding Concepts

1. What causes nondisjunction?
2. Draw diagrams to show how nondisjunction could occur during
   - **(a)** meiosis I
   - **(b)** meiosis II
3. Explain how a human cell could have 47 chromosomes.
4. If a zygote contains 45 chromosomes, how many chromosomes would you expect to find in nerve cells as they develop? Give reasons for your answer.
5. Use the diagram of nondisjunction in **Figure 5**.
   - **(a)** How many chromosomes would be found in cells "A" and "B"?
   - **(b)** Which cells in the diagram have a normal diploid chromosome number?

Making Connections

6. Provide a hypothesis that might (4A) explain why older women are much more likely to give birth to a child with Down Syndrome.

Exploring

7. Using library or Internet sources, (3A) research another nondisjunction disorder, such as Patan or Edward syndromes.

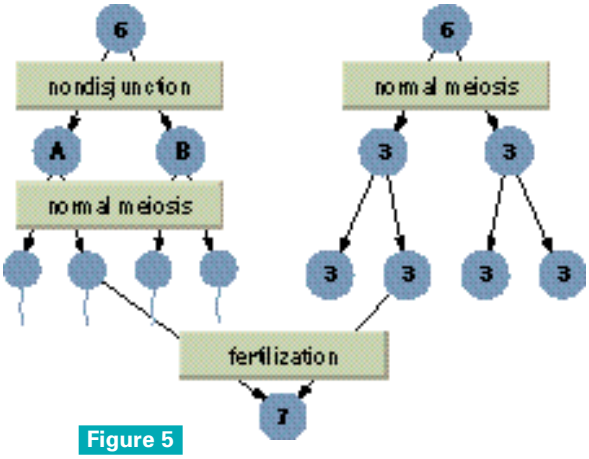


Figure 5

Genetic Screening

Many genetic disorders, such as Down syndrome, can be detected before the baby is born. By using ultrasound (**Figure 1**), physicians can locate the position of the developing fetus in the uterus of the mother. Using a second technique called amniocentesis, the doctor uses a syringe to draw fluid from a sac that surrounds the fetus. The fluid, called amniotic fluid, contains cells from the fetus. By treating the cells with special stains, the tiny chromosomes can be made visible for microscopic examination.

The physician uses a camera mounted on the microscope to take a picture of the chromosomes. The chromosomes in the digital image are identified and arranged in a karyotype chart (**Figure 2**). The karyotype compares the number, size, and shape of homologous chromosomes. A chromosome count of 47 would indicate a nondisjunction disorder. By comparing the homologous chromosomes, the specific disorder can be identified. This whole process is called genetic screening.

Figure 1
Sound waves are used to create an image of the fetus.

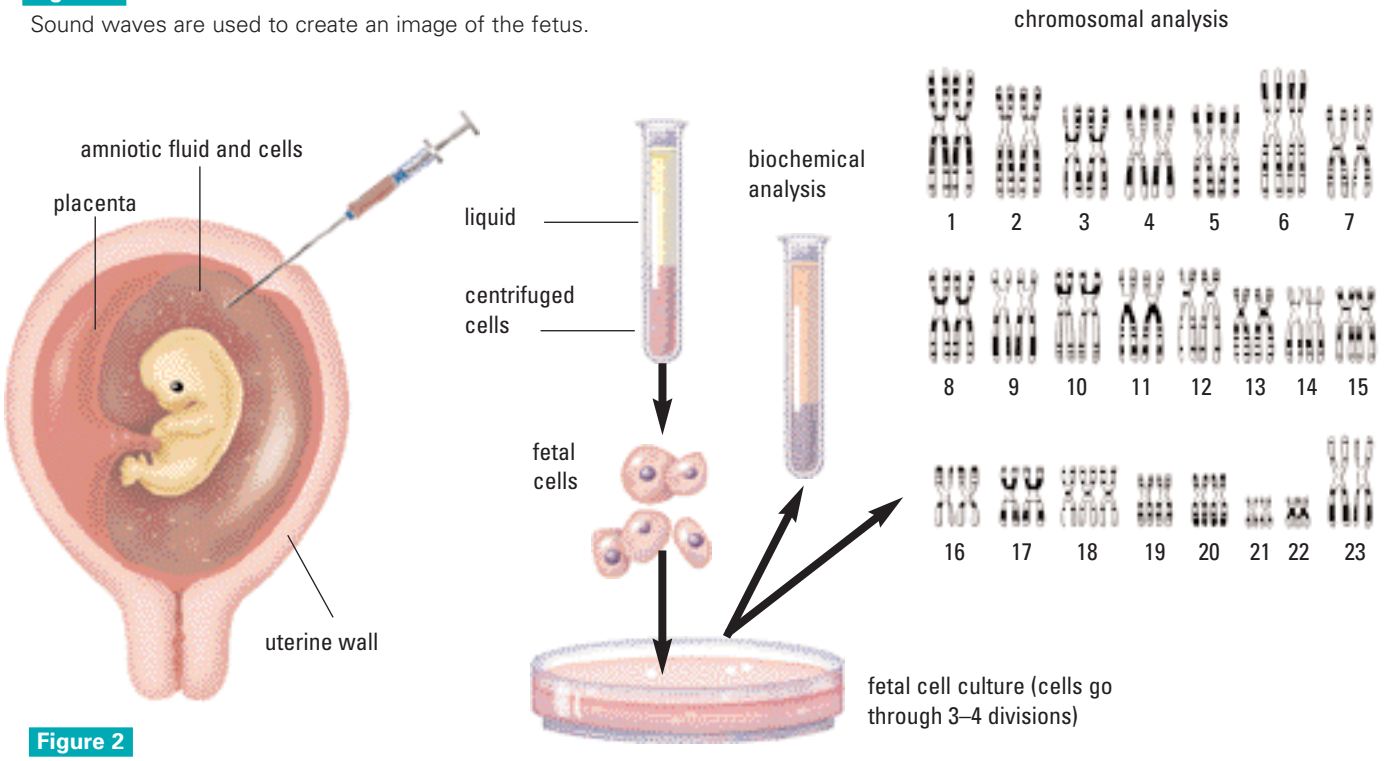


Figure 2
A karyotype is created using fetal cells drawn from the amniotic fluid.

This entire procedure of determining whether a fetus has a genetic disorder, like many other advancements in reproductive technology, raises many ethical questions. Might diagnosing genetic disorders prior to birth lead to pregnancies being terminated? Although most often the screening confirms that the baby does not carry a genetic disease, some disorders are identified. The screening also allows the physician to determine the sex of the baby. Some people fear that the technique could be used to select the sex of the offspring.

Should genetic screening be widely available? 8B

Statement

Genetic screening before birth should be used on very rare occasions, if at all.

Point

- Diagnosis of genetic disorders before birth could make people consider terminating pregnancies if "imperfect" children were identified.
- In China, ultrasound scanning is used to identify male children. Because the male child has been preferred and because of state restrictions on the number of offspring, many pregnancies have been terminated because the mother carried a female child.

Counterpoint

- In most cases, genetic screening confirms that the baby is all right. This reduces worry about the pregnancy. In addition, identifying a disorder doesn't mean that the pregnancy will be terminated. It may mean that the parents are better prepared.
- Screening for gender preference has not been a problem in Canada. In Canada, there is no legal limit on the number of offspring.

What do you think?

- In your group, discuss the statement and the points and counterpoints above. Write down additional points and counterpoints that your group considered.
- Decide whether your group agrees or disagrees with the statement.
- Search newspapers, a library periodical index, a CD-ROM 3A encyclopedia, and, if available, the Internet for information on genetic screening.
- Prepare to defend your group's position in a class discussion. 3B

Human Karyotypes

Scientists are still working to discover the causes of nondisjunction disorders. Irene Uchida, a Canadian scientist then working at the Children's Hospital in Winnipeg, did research that indicates that radiation may have an effect. Her study suggested that women who were exposed to X rays were more likely to have a child with a nondisjunction disorder. This finding may explain why the incidence of nondisjunction disorders increases according to the age of the mother. The older a woman is, the more likely it is that she will have been exposed to radiation.

Dr. Uchida used karyotype charts in her work. A karyotype chart is a picture of the chromosomes from a cell, arranged in homologous pairs. The chart can be used to diagnose nondisjunction disorders.

In this activity you will analyze a karyotype chart and create your own chart. Then you will diagnose the nondisjunction disorder of the cell described in the chart.

Materials

- human karyotype plate
- scissors
- blank paper
- transparent tape

Procedure

1 Examine the karyotype chart in **Figure 1**.

(a) Which characteristics are used to arrange the chromosomes in pairs?

(b) In what ways does chromosome pair 2 differ from pair 20?

(c) What is the sex of the individual whose chromosomes are shown in the chart?

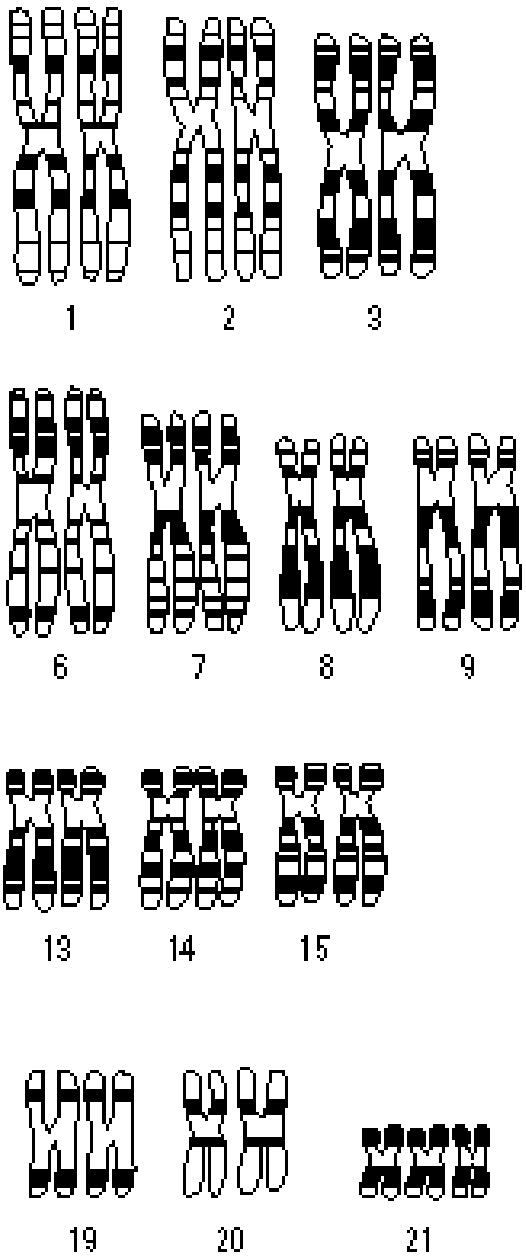


Figure 1
A karyotype chart

2 Obtain a karyotype chart from your teacher and carefully cut out each of the chromosomes.

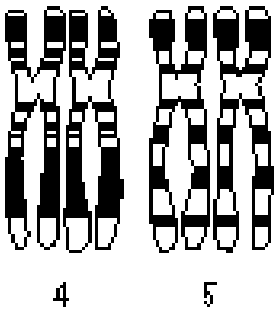
3 Match the paired chromosomes and prepare a karyotype chart by taping the chromosomes to the paper. Use the karyotype chart in **Figure 1** for reference.

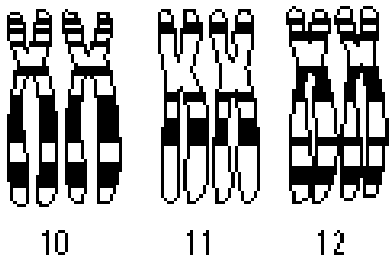
(a) How many chromosomes did you find?

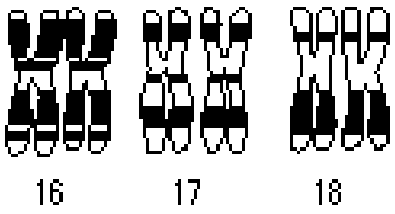
(b) What is the sex of the individual?

4 Study **Table 1** and **Figure 1**.

(a) Using the information shown in the karyotype chart, diagnose the nondisjunction disorder.







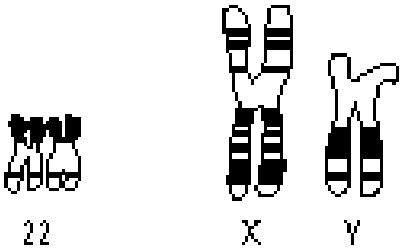


Table 1

Chromosome abnormality	Syndrome	Effect
XO	Turner	sterile female, 45 chromosomes, short stature
XXY	Klinefelter	sterile male, 47 chromosomes, often long arms and legs
three #21	Down	47 chromosomes, distinctive facial features

Understanding Concepts

1. How could a karyotype be used to identify gender?
2. Radiation can cause chromosomes to break apart. Would karyotyping be useful in identifying X-ray damage? Explain how.
3. Would the diagnosis of Turner syndrome in a single cell mean that every cell of the body contained 45 chromosomes? Explain your answer.
4. Is it possible for two people who have Down syndrome to have a child that doesn't have the syndrome? Explain your answer.
5. Would it be possible to produce a baby with 48 chromosomes? Explain your answer.

Making Connections

6. More males than females suffer from colour blindness. Speculate why females with Turner syndrome have a similar incidence of colour blindness as males do.

Chapter 7 Review

Key Expectations

Throughout this chapter, you have had opportunities to do the following things:

- Describe and give examples of types of sexual reproduction. (7.1, 7.3)
- Compare sexual and asexual reproduction. (7.1)
- Describe the production, structure, and function of sex cells. (7.3, 7.4, 7.6, 7.7)
- Describe how hormones influence development of sperm. (7.6)
- Describe how hormones influence development of the eggs and ovulation. (7.7, 7.8)
- Investigate the reproductive structures of flowering plants, and organize, record, analyze and communicate results. (7.4)
- Formulate and research questions related to reproductive technologies, and communicate results. (7.9, 7.10)
- Provide examples of how developments in reproductive biology have affected the identification of genetic disorders, and discuss the social implications of these developments. (7.9, 7.10, 7.11)
- Provide examples of how developments in reproductive biology have affected food production. (7.5)
- Describe Canadian contributions to research and technological developments in genetics and reproductive biology. (7.5, 7.11, Career Profile)
- Explore careers that require an understanding of reproductive biology. (Career Profile)

KEY TERMS

anther
conjugation
corpus luteum
crossbreeding
egg
endometrium
external fertilization
follicle
hermaphrodite
hormone
internal fertilization
meiosis
menstruation
ovary
oviduct
ovulation
pistil
pollen
pollination
reproductive cells
selective breeding
seminiferous tubules
somatic cells
sperm
stamen
testis
uterus

Reflecting

- "Sexual reproduction creates a diversity of species." Reflect on this idea. How does it connect with what you've done in this chapter? (To review, check the sections indicated above.)
- Revise your answers to the questions raised in Getting Started. How has your thinking changed?
- What new questions do you have? How will you answer them?

Understanding Concepts

1. Make a concept map to summarize the material you have studied in this chapter. Start with the words "sexual reproduction."
2. Using the life cycle of aphids, distinguish between sexual and asexual reproduction.
3. Explain how sexual reproduction provides genetic diversity.
4. Classify the following as either sexual or asexual reproduction:
   (a) A small piece of a cactus breaks off the original plant, falls to the ground, and begins to grow.
   (b) Pollen from a male poplar tree fertilizes sex cells on a female poplar tree.
   (c) Two earthworms each produce sperm and eggs and fertilize each other. Eggs are laid.
   (d) A flatworm is cut in half and grows into two flatworms.
5. How can two brothers with the same parents have different hair colour?
6. Compare meiosis with mitosis. Copy **Table 1** in your notebook and place a check mark in the correct box.

Table 1

Description	Meiosis	Mitosis
produces four cells	?	?
daughter cells are clones of mother cell	?	?
haploid cells produced	?	?
skin cells undergo this cell division	?	?
formation of sex cells	?	?
two stages of cell division	?	?

7. Describe how pollen cells fertilize egg cells in a flower.

8. Draw the flower shown and label the parts. Indicate which are male or female parts and which are neither.

9. Draw a diagram that shows how a child could inherit three number 21 chromosomes.

Applying Skills

10. Fruit flies normally have 8 chromosomes. **Figure 1** shows the events of meiosis.
    (a) In which parent did nondisjunction take place?
    (b) How many chromosomes would be found in zygotes D, E, and F?
    (c) What is happening during process X?
    (d) Which zygote would most likely be healthy?

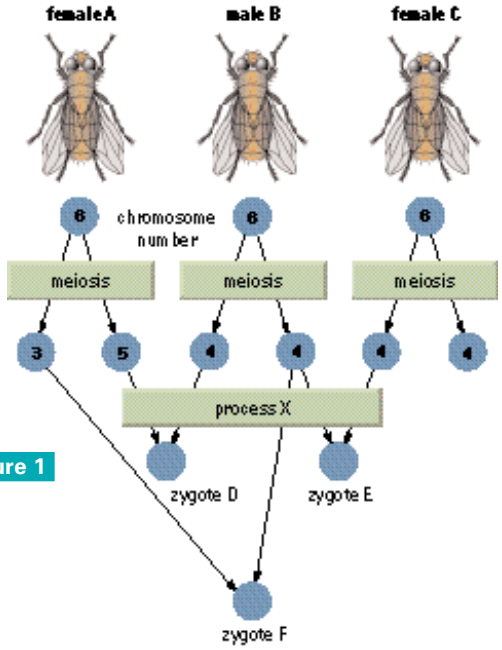


Figure 1

11. Use **Figure 2** to answer this question.
    (a) How many chromosomes were in the sperm cell?
    (b) Explain how this sperm cell could be produced from a cell that had 46 chromosomes.
    (c) How many chromosomes would be found in each cell following mitosis?

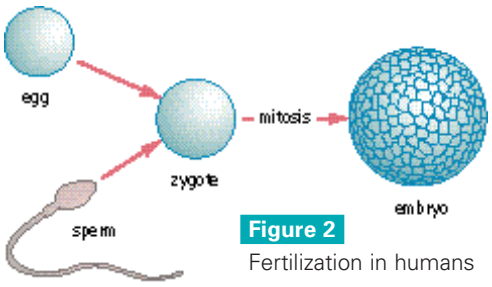
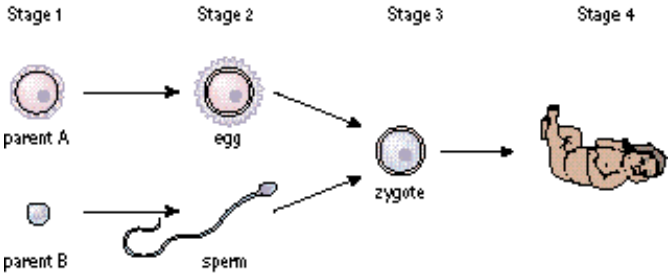


Figure 2
Fertilization in humans

Making Connections

12. Use **Figure 3** to answer the following questions:
    (a) At which stage would you find a haploid chromosome number?
    (b) What occurs at stage 3?
    (c) Would the change that occurs between stages 3 and 4 occur because of mitosis or meiosis? Explain why.
    (d) How many homologous pairs of chromosomes would be found in the baby if it was a female?

Figure 3



13. What advantage does cross-pollination provide flowering plants?

14. A male has cancer in one testis and has to have it removed. Speculate about how this will affect his ability to father children.

15. If a couple is planning to have a baby, on which days of a 28-day menstrual cycle is the female most fertile?