Reproduction and Heredity

In biological terms, life's purpose is to maintain homeostasis long enough for a species to reproduce. An individual organism does not have to reproduce to survive, but for a species to survive, some of its members must reproduce. Species are groups of organisms capable of interbreeding naturally and producing fertile offspring. Species survive or transcend only if they consistently produce enough offspring to replace organisms that die due to disease, predation, aging, or accidents. The genetic information of individual organisms is transferred to new generations by reproduction.

Reproduction Basics

When an organism reproduces, cell structures called chromosomes carry genetic information to the next generation. Chromosomes are made of segments called genes. Each gene segment contains coded information that directs the production of protein. Therefore, genes control the types of proteins an organism makes. Proteins produced by an organism determine its traits.

The body cells of an organism are diploid; they contain pairs of chromosomes, or 2n. The two chromosomes in each pair are called homologous chromosomes because they carry genes for the same traits. The sequence of genes on homologous chromosomes is the same. The alternate form of each gene on homologous chromosomes is called an allele. Figure 5.1 shows a pair of homologous chromosomes and alleles found in garden peas.

Types of Reproduction

There are two types of reproduction that pass genetic information to future generations—asexual reproduction and sexual reproduction. Some organisms reproduce asexually. In asexual reproduction, one parent produces offspring.

![Homologous Chromosome 4]

Figure 5.1 In garden peas, chromosome 4 contains genes for flower position, pod shape, and plant height. On a plant, flowers only are located along the stem—axial—or flowers only are clustered at the tip of stems—terminal. Pod shape is either inflated or constricted; and plant height is either tall or short.
The offspring are genetically identical to each other and the parent because all the genetic information comes from one parent. Other organisms reproduce sexually. In sexual reproduction, two parents produce offspring that have a combination of genes usually with half the genetic information contributed by each parent. The genetic information is in each parent's specialized sex cells called gametes or eggs in females and sperm in males.

**Cell Division**

All types of reproduction are by cell division that includes the division of the nucleus either by mitosis or meiosis. During cell division, chromosomes of a cell are copied and distributed to new cells known as daughter cells.

**Mitosis** and cell division of a body cell produce two daughter cells, each with a complete set of chromosomes. Mitosis and cell division produce new diploid cells for growth, repair, reproduction, and development. During mitosis, chromosomes in a parent cell's nucleus are copied, and then are equally distributed to two new cells. The resulting cells have the same numbers and kinds of chromosomes as the parent cell. Mitosis is illustrated in Figure 5.2.

**Meiosis** and cell division of a body cell produces four sex cells. Each new cell contains half the number of chromosomes as the body cell. This condition is called haploid or \( n \). During meiosis, chromosomes from a body cell are copied, and then align along the center of the cell as homologous pairs. In the first meiotic cell division, pairs of chromosomes move apart, and in the second division, copied chromosomes separate from each other. These two divisions distribute the chromosomes into four haploid gametes each with one chromosome from each homologous pair, therefore, one allele for each trait. These gametes are not genetically identical. The process of meiosis is illustrated in Figure 5.3.

**CHECK FOR UNDERSTANDING** Compare and contrast mitosis and meiosis.

**Asexual Reproduction**

In asexual reproduction, one parent passes copies of all of its chromosomes to each of its offspring. The offspring are genetically identical to each other and to the parent unless a gene mutation—a change in genetic code—occurs. In some organisms, asexual reproduction is merely an extension of growth. A group of new cells produced by mitosis and cell division separates from the parent to form offspring. Asexual reproduction can be a type of cloning—the production of identical genetic copies of an organism. Table 5.1 on page 57 shows types of asexual reproduction.

Asexually reproducing organisms may create offspring rapidly and in large numbers. In an unchanging environment, asexual reproduction is advantageous because successful parents will produce successful offspring. But, if organisms are not well adapted to a changing environment, asexual reproduction may not provide new varieties of organisms that can survive and reproduce.
CHECK FOR UNDERSTANDING Suppose a bacterium reproduced for 16 generations and formed a colony of thousands of cells. When a scientist examined the colony, she noted that all of the cells had identical characteristics. Explain why this is possible.

Sexual Reproduction
Cells produced by meiosis usually do not grow into new organisms. To produce an offspring, two haploid gametes must fuse during the process of fertilization to form a fertilized egg called a zygote. Fertilization results in a cell with the diploid (2n) chromosome number like that of body cells. The zygote then undergoes cell divisions and development to form a new organism.

Sexual reproduction usually involves two parents. Each offspring inherits chromosomes from both of its parents when their gametes fuse. Simply stated, the offspring will receive half of its chromosomes from its father's sperm and half of its chromosomes from its mother's egg. At fertilization, the full complement of chromosomes is restored with the formation of the zygote.

<table>
<thead>
<tr>
<th>Table 5.1</th>
<th>Some Types of Asexual Reproduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Example</td>
</tr>
<tr>
<td>Binary fission</td>
<td>A one-celled organism divides evenly to form two one-celled offspring.</td>
</tr>
<tr>
<td>Budding</td>
<td>A cell or group of cells pinches off from the parent to form a new individual.</td>
</tr>
<tr>
<td>Spore formation</td>
<td>Parent produces reproductive cell with a hard outer coat. This cell forms a new organism without the fusion of gametes.</td>
</tr>
<tr>
<td>Regeneration (animals)</td>
<td>A new organism is produced through the replacement or regrowth of body parts.</td>
</tr>
<tr>
<td>Vegetative propagation (plants)</td>
<td>A new plant is produced from existing roots, stems, or leaves.</td>
</tr>
</tbody>
</table>
A zygote contains all the information necessary for growth, development, and eventual reproduction of an offspring. The zygote will develop into an offspring that is similar, but not genetically identical to its parents.

The variety of offspring produced by sexual reproduction is a result of both meiosis and fertilization as shown in Figure 5.4. Meiosis produces different types of gametes with different chromosomes and different genes. The fusion of gametes during fertilization can create a variety of zygotes.

Sexual reproduction is advantageous because it produces a variety of offspring. This variety increases the chance that at least a few offspring will be better adapted to changing environmental conditions. The variability that results from sexual reproduction reduces the chance that species will become extinct.

All organisms that reproduce sexually experience the same environmental problem—having male gametes reach female gametes. For animals that have external fertilization, like fish and frogs, reproduction occurs in watery environments where the sperm can swim to the egg. Terrestrial animals, including reptiles, birds, and mammals, rely on internal fertilization where the sperm are introduced into the female’s moist reproductive tract. Seed plants produce male gametes in tiny pollen grains that are transported to the female reproductive organ(s) of the plant by wind or animals. Non-seed plants, such as mosses and ferns, require moist conditions for the transfer of sperm to eggs.

**CHECK FOR UNDERSTANDING** Sexual reproduction produces a variety of offspring. Why is this an advantage?

**Development**

The changes that take place throughout the lifetime of an organism are called development. It is a highly regulated process involving mitosis, cell division, and differentiation. Mitosis and cell division increase the number of living cells.

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**Figure 5.4** In sexual reproduction, the doubling of the chromosome number that results from fertilization is balanced by the halving of the chromosome number that results from meiosis.
Differentiation is the process by which these new cells specialize and become different from one another. Differentiation produces different kinds of cells, tissues, and organs that perform specific functions.

The early stages of development in many animals are similar. First, the zygote undergoes rapid mitotic cell divisions to produce a ball or disk of cells. As mitotic cell divisions continue, the ball pinches in and forms three embryonic layers, as shown in figure number eleven of the diagram in Regents Exam Strategies for Success. Then these layers differentiate to form the specialized tissues, organs, and systems of a developing embryo.

**Differentiation**

The many body cells in an individual can be different from one another, even though they all are descended from a single diploid cell—the fertilized egg—and have identical genetic instructions. This is because different parts of these instructions are used in different types of cells and are influenced by the cell’s environment and history. Differentiation occurs in different types of cells when certain genes are expressed or turned on and others are not expressed or turned off.

For development to occur, an embryo must have a watery environment, an adequate food supply, and protection. For some aquatic animals, external development outside of the mother is possible. Some terrestrial animals, such as birds, have external development in an egg that provides protection, moisture, and nutrients. Most mammals, such as humans, have internal development in which the embryo is protected and nourished inside the mother’s body.

The environment can affect reproduction and development. An example of this happened when DDT, a pesticide, spilled into a lake in Florida. Years later, biologists discovered that alligator hatchlings were abnormal in the environment surrounding the lake. One abnormality was that the males had poorly developed reproductive organs. Further research showed that chemicals from the pesticide had interfered with the natural development of alligator reproductive organs. There is much concern today of the environmental impact of chemicals on human reproduction and development.
Quick Review

1. After mitosis, the number of chromosomes in a newly formed cell is
   (1) double the number of the parent cell
   (2) half the number of the parent cell
   (3) equal to the number of the parent cell
   (4) double the number of both parent cells

2. If a cell with 36 chromosomes undergoes mitosis, each new cell will have
   (1) 36 chromosomes
   (3) 18 chromosomes
   (2) 2 chromosomes
   (4) 9 chromosomes

3. What are homologous chromosomes?

4. Mitosis and meiosis have many things in common. Which of the following statements is NOT common to both processes?
   (1) DNA is duplicated before the process begins.
   (2) Daughter cells come from one parent cell.
   (3) Prophase, metaphase, anaphase, and telophase occur.
   (4) Identical daughter cells are produced.

5. When you get a paper cut, your skin cells help to repair the injury. They do this by using the process of _________.

6. __________________ includes two cell divisions and results in four daughter cells.

DNA, Reproduction, and Traits

The year 2003 marked the fiftieth anniversary of the discovery of the DNA molecule’s structure. Today, DNA—deoxyribonucleic acid—is the topic of many TV news programs and newspaper and magazine articles. Understanding the structure of the DNA molecule is important because the coded instructions that specify the characteristics of all organisms are carried in each organism’s DNA.

Coded information in DNA does two things. First, during the lifetime of all organisms, the DNA code controls the production of proteins that determine the structure and function of an organism. Second, during reproduction, the DNA code is replicated or copied and passed to the new generation. Investigations into the chemical and structural properties of the DNA molecule have helped scientists understand how genetic information is encoded in genes and replicated during reproduction.

Over the years, collaborations by many scientists have led to a greater understanding of this genetic code. Understanding the genetic information in DNA has revolutionized biology, medicine, and industry. Scientists have translated parts of the code and used this information to detect genetic diseases, to design medicines, and to study the evolutionary history of life. They also have learned how to engineer new kinds of plants and animals by changing the code or transferring DNA from one organism to another. Concerns and questions about the ethical, legal, and social implications also are products of the DNA revolution. Understanding these concerns and questions, in the light of genetics and DNA information, helps all of us make informed decisions about the use of DNA technology.

DNA Function

Every organism requires a set of coded instructions for specifying its traits. The hereditary code is written in DNA molecules. For offspring to resemble their parents, there must be a reliable way to transfer hereditary information from one generation to the next.

Recall that for organisms that have nucleated cells, the genetic information is contained in the chromosomes found in the nucleus of each of its cells, as shown in Figure 5.5. Bacteria do not have nuclei, but they do have genes and DNA. Chromosomes contain thousands of genes, and genes are segments of DNA molecules.

DNA Structure

Each chromosome is a long, spiral, ladderlike molecule of DNA called a double helix. Figure 5.6 shows a small section of a DNA molecule. DNA is made of subunits called nucleotides. Each nucleotide consists of a sugar-phosphate molecule bonded to one of four nitrogenous bases—adenine, cytosine, guanine, or thymine. In DNA, the nitrogenous bases of nucleotides only bond as either adenine—thymine (A–T) or cytosine—guanine (C–G). A and T are called complementary bases, as are C and G. These are the rungs of the ladder. Sugar-phosphate molecules make up the supporting uprights of the ladder.

✔ CHECK FOR UNDERSTANDING What is the complementary base sequence to the portion of a DNA strand with this sequence of bases—A-T-C-G-T-A?

Just as the sequence of letters in the English alphabet are arranged into words and sentences
that have meaning, so is the sequence of DNA bases. The alphabet of bases—A, C, G, and T—is arranged into three-letter words each of which can be translated into the code for an amino acid, the building block of proteins. A long sentence composed of these three-letter words is a gene that specifies the order of amino acids in one protein molecule. A chromosome is like a chapter of many protein sentences. These proteins control cellular chemistry and contribute to cell structure and functions that specify our traits such as eye color and blood type. During reproduction, an organism’s chromosome chapters are replicated and transferred to its offspring.

**DNA Replication**

Accurate replication of the sequence of DNA bases contained in genes must occur during reproduction. DNA is replicated when chromosomes are copied during both mitotic and meiotic cell divisions.

DNA replication occurs in a series of steps. Many enzyme molecules act as helpers in the process of replication. First, with the help of an enzyme, the weak bonds between paired nucleotides break. The A nucleotides pull away from their complementary Ts, and the Cs pull away from their complementary Gs. This process—often referred to as “unzipping”—forms two strands of DNA. Next, the separated strands act as templates or patterns for two new DNA molecules. The unpaired nitrogenous bases attract other free nucleotides. Once again, A bonds with T, and C bonds with G. Finally, the sugar-phosphate molecules of the newly attached nucleotides link together to form the sides of the ladder. Replication results in two DNA ladders that are identical to each other and to the original.
CHECK FOR UNDERSTANDING Using the following terms, DNA, template, chemical bonds, C, T, A, G, parental, unzips, daughter strands, enzymes, replication, weak, sugars, phosphates, molecules, complementary, and bases, describe how DNA produces new copies of itself.

DNA and Protein Production
Everything an organism is or does depends on the thousands of types of proteins that it makes. Proteins are long chains of twenty different amino acids. Each protein is composed of hundreds of amino acids bonded together in a unique order that determines its specific shape. The protein factories in the cell are ribosomes. They assemble amino acids in the correct order to form a protein. The coded instructions in DNA contain directions on how to arrange and fold the amino acids to make all of a cell’s proteins. Therefore, if genes code for proteins, and proteins make us what we are, then how are proteins made from DNA?

DNA contains messages for making proteins. Each message is read or transcribed by another nucleic acid—RNA. RNA is made on a DNA template, as shown in Figure 5.7. RNA’s nucleotides have a different sugar base and RNA has the nitrogenous base uracil (U) instead of thymine that bonds with adenine. The process of making RNA from a DNA strand is called transcription.

Each transcribed message is transported from the nucleus as messenger RNA—mRNA—into the cytoplasm, and then is read by ribosomes and translated. Part of the translation involves a third type of nucleic acid, transfer RNA—tRNA. Each tRNA molecule transfers a specific amino acid from the cytoplasm to a ribosome, as shown in Figure 5.7. Within the ribosome, proteins are built according to the code in the original DNA message.

Proteins and Traits
Different kinds of molecules carry out the work of the cell. Most of these molecules are proteins that the cell makes or synthesizes. Many proteins

Figure 5.7 Protein production involves DNA, mRNA, tRNA, amino acids, and ribosomes.
are enzymes that make specific cellular chemical reactions possible. Other types of proteins are used in building cell structures.

Offspring resemble their parents because they inherit similar genes that code for the production of similar proteins, which form similar structures and perform similar functions. Each type of protein has a different amino acid sequence, which determines the protein's three-dimensional shape. The shape of each type of protein, in turn, determines its function. Protein function results in the traits of an organism. Figure 5.8 illustrates the relationship between DNA and traits of an organism and its offspring.

CHECK FOR UNDERSTANDING What determines the shape of a protein molecule?

A gene and the protein it produces might control just one trait. For example, some thumbs naturally bend back at the joint, as shown in Figure 5.9 on page 64. This is called hitchhiker's thumb and is a dominant trait. A person showing this trait inherited at least one dominant allele for this trait. To have a straight thumb, the recessive trait, a person must inherit a recessive allele from each parent. This means that the parents must have inherited their alleles from their parents, who inherit them from their parents, and so on. Because a straight thumb is a recessive trait, a human can inherit the trait without it being shown, unlike a dominant trait. By observing and recording traits in several generations and throughout the extended family, we can discover some of the genes that individuals inherit.
Figure 5.9 If an individual inherited two recessive alleles (bb), thumbs are straight. When an individual inherits at least one dominant allele (BB or Bb), hitchhiker’s thumbs are present.

Some traits are the result of the interaction of several genes that produce several proteins. For example, several genes control human height. Each of these genes makes a protein that is involved in growth. The height of an individual is determined by the type and number of growth proteins that are coded for in his or her genes.

Some genes produce a protein that affects more than one chemical reaction or cell structure. This can result in one gene affecting many traits. For example, the gene that produces the protein fibrillin affects many body functions and structures. One abnormal fibrillin gene can produce weak tendons, ligaments, and other connective tissues in the body, including the make up of the arteries. This one defective gene has a “domino effect” on many body processes and structures.

Gene Expression
Genes are like light switches; they can be turned off or turned on by a variety of mechanisms that are dependent on the environment and history.

For example, the genes in a cell that have a code for functioning as a lung cell are in the “off” position in a stomach cell.

Your characteristics are determined not just by your genes but by the environment also. The internal and/or external environment of the organism can affect gene or protein action as shown in Figure 5.10.

Environmental conditions can influence the expression of a gene in humans also. A person may have genes that should result in his or her being very tall. But, if that person’s diet does not provide adequate nutrition for growth, the person may be shorter than his or her genes would predict. The expression of some inherited genes can be modified because of environmental conditions. A person might have a gene that makes him or her predisposed to heart disease. The person might reduce the risk of heart disease through exercise and a low fat diet.

Mutations
DNA is usually replicated accurately, but mistakes can occur. The result of a change in the DNA base sequence is called a gene mutation. Gene mutations can result from an addition of one or more bases, a deletion, a substitution, or a mismatch in a DNA molecule, as shown in Figure 5.11 on page 65. Any cell containing these errors will pass them to daughter cells. If the cell is a reproductive cell, the mutation can be inherited.

When a gene mutation occurs, the DNA message has a new meaning. Now, the code for making a protein might cause the cell to produce a different protein having a different shape and

Figure 5.10 An experiment on a Himalayan hare indicates how the environment affects gene expression. Without harming the hare, an ice pack was applied to a region of shaved hair on the hare’s back. It resulted in the growth of black hair instead of white hair.
function. This can lead to a change in the traits of offspring, just as a typographical error in an English composition can change, "He is here." to "He is there." In DNA, a mistake in the base sequence results in a mutation that can alter an organism.

Mutation also can occur during meiotic cell division when DNA is distributed to daughter cells. This type of mutation is called a chromosomal mutation. Offspring may inherit too many chromosomes or too few chromosomes. One example of this is Down syndrome. A person with Down syndrome has an extra chromosome 21, as shown in Figure 5.12. An individual with this chromosomal condition has distinctive facial features such as flat face, slanted eyes, and protruding tongue. Various body systems are weakened and intelligence varies greatly. Some individuals are mentally impaired while others may attend college. The odds of having a child with Down syndrome are about 1 in 700 live births. The odds of having a child with Down syndrome increase for older mothers—those over 40 years of age.

Some mutations occur spontaneously—they have no identifiable cause. Other mutations are known to be caused by environmental factors, such as chemicals or radiation, particularly X rays or UV (ultraviolet) rays. Mutations can have a range of effects on organisms from none to serious, such as cancer or inherited diseases. Mutations occur naturally, but we can decrease the chances for mutations by avoiding environmental hazards such as cigarette smoke, radiation, and high voltage electric fields, all known to trigger mutations.

Mutations usually are harmful, but sometimes, the alteration may be beneficial because it allows for variations in offspring that increase their chances for survival. These rare mutations can provide the variation in a species that help it evolve.

Human Genome Project
Mapping, sequencing, and identifying genes; storing and analyzing data; and addressing the ethical, legal, and social issues that may arise from availability of personal genetic information are some of the goals of the U.S. Human Genome Project (HGP). The ultimate goal of the HGP is to obtain the DNA sequence of the 3 billion bases—A-T and C-G—present in human DNA. In the months and years ahead, there will be great strides made in understanding chromosomes, genes, and the proteins produced from the code of life, DNA.

Figure 5.11 A mismatched base pair might occur during replication of DNA. In daughter cells, corresponding positions of replicated DNA will have different base pairs.

Figure 5.12 This karyotype reveals that the individual has three copies of chromosome 21 and will exhibit traits of Down syndrome.
7 Which statement best describes the relationship between the number of genes and the number of chromosomes in human skin cells?
(1) There are more genes than chromosomes in skin cells.
(2) There are more chromosomes than genes in skin cells.
(3) There are equal numbers of genes and chromosomes in skin cells.
(4) There are many genes and no chromosomes in skin cells.

8 The diagram below represents the organization of genetic information within a cell nucleus.

The circle labeled Z most likely represents
(1) amino acids  (2) chromosomes  (3) vacuoles  (4) molecular bases

9 New inheritable characteristics would least likely to result from
(1) mutations that occur in muscle cells and skin cells
(2) mutations that occur in male gametes
(3) mutations that occur in female gametes
(4) the sorting and recombination of existing genes during meiosis and fertilization

10 A molecule of DNA is composed of
(1) receptor enzymes
(2) ATP and enzymes
(3) amino acids and proteins
(4) paired bases (A, T, G, C)

11 Which statement provides the best evidence that the environment interacts with genes in the development and expression of inherited traits?
(1) Organisms produced asexually are genetically identical.
(2) People who have cancer can pass the defective gene to their offspring.
(3) Mutations happen randomly and may be harmful or helpful to organisms.
(4) Identical twins who have not been raised together show differences in height and weight.

12 A characteristic of mutations is that they usually
(1) are caused only by events in mitosis
(2) do not occur at random
(3) result in different genetic sequences
(4) occur to meet the needs of a species

13 Exposure to cosmic rays, X rays, ultraviolet rays, and radiation from radioactive substances may promote
(1) the production of similar organisms
(2) diversity among organisms
(3) an increase in the population size
(4) a change from sexual to asexual reproduction

14 When a person's teeth are being x-rayed, other body parts of this person are covered with a protective lead blanket to prevent
(1) loss of hair
(2) increase in cell size
(3) changes in DNA molecules
(4) changes in glucose structure
1 Which statement best explains the significance of meiosis in helping to maintain continuation of a species?

(1) Meiosis produces eggs and sperm that are alike.
(2) Meiosis provides for chromosomal variation in the gametes produced by an organism.
(3) Equal numbers of eggs and sperm are produced by meiosis.
(4) The gametes produced by meiosis ensure the continuation of any particular species by asexual reproduction.

2 Which diagram best represents part of the process of sperm formation in an organism that has a normal chromosome number of eight?

3 Which statement best explains the significance of meiosis in the process of evolution within a species?

(1) The gametes produced by meiosis ensure the continuation of any particular species by asexual reproduction.
(2) Equal numbers of eggs and sperm are produced by meiosis.
(3) Meiosis produces eggs and sperm that are alike.
(4) Meiosis provides for variation in the gametes produced by an organism.

4 Which phrases best identify characteristics of asexual reproduction?

(1) one parent, union of gametes, offspring similar to but not genetically identical to the parent
(2) one parent, no union of gametes, offspring genetically identical to parent
(3) two parents, union of gametes, offspring similar to but not genetically identical to parents
(4) two parents, no union of gametes, offspring genetically identical to parents

5 Which characteristic of sexual reproduction has specifically favored the survival of animals that live on land?

(1) fusion of gametes in the outside environment
(2) male gametes that may be carried by the wind
(3) fertilization within the body of the female
(4) female gametes that develop within ovaries

6 The diagram below shows two different structures, 1 and 2, that are present in many single-celled organisms. Structure 1 contains protein A, but not protein B, and structure 2 contains protein B, but not protein A.

Which statement is correct concerning protein A and B?

(1) Proteins A and B have different functions and different amino acid chains.
(2) Proteins A and B have different functions but the same amino acid chains.
(3) Proteins A and B have the same function but a different series of bases (A, C, T, and G).
(4) Proteins A and B have the same function and the same sequence of bases (A, C, T, and G).
7 A certain mutant bacterial cell cannot produce substance X. The mutation was most likely the result of a change in the 
(1) structure of the cell membrane 
(2) ability of the DNA to replicate 
(3) amino acid sequence of DNA 
(4) gene that codes for a specific protein 

8 During warm temperatures of summer, the arctic fox produces enzymes that cause its fur to become reddish brown. During the cold temperatures of winter, these enzymes do not function. As a result, the fox has a white coat that blends into the snowy background. This change in fur color shows that 
(1) the genes of a fox are made of unstable DNA 
(2) mutations can be caused by temperature extremes 
(3) random alteration of DNA can occur on certain chromosomes 
(4) the expression of certain genes is affected by temperature 

9 Flower color in primrose plants is controlled by an individual gene. The sudden appearance of one white flowering primrose in a plant breeder’s field of red primrose plants is most likely due to 
(1) a change in the amount of glucose produced during photosynthesis 
(2) the use of a new natural fertilizer on the field 
(3) rapid mitotic divisions within the developing seeds 
(4) a random change in the structure of DNA during meiosis 

10 Mutations can be considered as one of the raw materials of evolution because they 
(1) contribute to new variations in organisms 
(2) are usually well-adapted to the environment in which they appear 
(3) are usually beneficial to the organism in which they appear 
(4) are usually harmful and cause species of organisms to become extinct 

11 The presence of DNA is important for the cellular metabolic activities because DNA 
(1) directs the production of enzymes 
(2) is a structural component of cell membranes 
(3) directly increases the solubility of nutrients 
(4) is the major component of cytoplasm 

12 Which event occurring in the life cycle of a bacterium most directly involves the replication of DNA? 
(1) The bacterium copies its single chromosome. 
(2) As the cell grows, the two copies of the chromosome separate. 
(3) The cell divides as a partition separates it into equal halves. 
(4) Each new cell receives one copy of the chromosome. 

13 Heavy cigarette smoking and use of alcohol throughout pregnancy usually increase the likelihood of 
(1) the birth of twins 
(2) the birth of a male baby 
(3) a baby being born with a viral infection 
(4) a baby being born with medical problems 

14 Which diagram illustrates fertilization that would most likely lead to the development of a normal human female? 

```
(1) X + X  
(2) XX + X  
(3) X + XY  
(4) X + Y  
```
Part B

15 Meiosis occurs in the development of sex cells. Mitosis occurs in most other cells. Identify two additional differences between these processes.

16 The chart below shows information about the relationship between the age of the mother and the occurrence of Down syndrome in the child.

<table>
<thead>
<tr>
<th>Age of Mother</th>
<th>Occurrence of Down Syndrome per 1000 Births</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.8</td>
</tr>
<tr>
<td>30</td>
<td>1.0</td>
</tr>
<tr>
<td>35</td>
<td>3.0</td>
</tr>
<tr>
<td>40</td>
<td>10.0</td>
</tr>
<tr>
<td>45</td>
<td>30.0</td>
</tr>
<tr>
<td>50</td>
<td>80.0</td>
</tr>
</tbody>
</table>

State one conclusion that can be drawn from the chart concerning the relationship between the age of the mother and the chance of her having a child with Down syndrome.

17 Using one specific example, identify one action taken by a mother that could have a negative effect on the embryonic development of her baby.

18 Hemoglobin is a complex protein molecule found in red blood cells. Hemoglobin with the normal sequence of amino acids is able to carry oxygen to body cells effectively. In the disorder known as sickle cell anemia, one amino acid is substituted for another in the hemoglobin. One characteristic of this disease is poor distribution of oxygen to the body cells. Explain how the change in amino acid sequence of this protein could cause the results described.

19 To help them understand inherited genetic diseases, scientists study the structure and function of both DNA and protein molecules.

a Use your understanding of biology to complete the following chart that compares DNA and protein molecules.

<table>
<thead>
<tr>
<th>Building blocks or subunits</th>
<th>DNA molecules</th>
<th>Protein molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One function</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b Describe the relationship between DNA molecules and protein molecules.
The Mystery of Deformed Frogs

Deformities, such as legs protruding from stomachs, no legs at all, eyes on backs, and suction cup fingers growing from sides, are turning up with alarming frequency in North American frogs. Clusters of deformed frogs have been found in California, Oregon, Colorado, Idaho, Mississippi, Montana, Ohio, Vermont, and Quebec.

Scientists in Montreal have been studying frogs in more than 100 ponds in the St. Lawrence River Valley for the past 4 years. Normally, less than 1% of frogs are deformed, but in ponds where pesticides are used on surrounding land, as many as 69% of the frogs were deformed.

A molecular biologist from the University of California believes that the deformities may be linked to a new generation of chemicals that mimic growth hormones. The same kinds of deformities found in the ponds have been replicated in laboratory experiments.

Some scientists have associated the deformities with a by-product of retinoid, which is found in acne medications and skin rejuvenation creams. Retinoids inside a growing animal can cause deformities. For this reason, pregnant women are warned not to use skin medications that contain retinoids. Recent laboratory experiments have determined that a pesticide can mimic a retinoid.

A developmental biologist from Hartwick College in Oneonta, New York, questioned whether a chemical could be the culprit because there were no deformed fish or other deformed animals found in ponds where deformed frogs were captured. He believes parasites are the cause. When examining a three-legged frog from Vermont, the biologist found tiny parasitic flatworms packed into the joint where a leg was missing. In a laboratory experiment, he demonstrated that the invasion of parasites in a tadpole caused the tadpole to sprout an extra leg as it developed. Scientists in Oregon have made similar observations.

20 Pregnant women are advised not to use skin medicines containing retinoids because retinoid by-products
   (1) may cause fetal deformities
   (2) may cause parasites to invade developing frogs
   (3) are the main ingredient in most pesticides
   (4) reduce abnormalities in maternal tissue

21 Which statement is most likely true, based on the information in the passage?
   (1) Only a few isolated incidents of frog deformities have been observed.
   (2) If frog parasites are controlled, all frog deformities will stop.
   (3) Deformities in frogs are of little significance.
   (4) Factors that affect frogs may also affect other organisms.

22 A possible reason for the absence of deformed fish in the ponds that contained deformed frogs is that
   (1) fish can swim away from chemicals introduced into the pond
   (2) fish cannot develop deformities
   (3) parasites that affect frogs usually do not affect fish
   (4) frogs and fish are not found in the same habitat

23 Describe how pesticides could cause deformities in frogs.
24 Although human muscle cells and nerve cells have the same genetic information, they perform different functions. Explain how this is possible.

25 How would a baby's DNA sequence compare to the DNA sequence of its mother?

26 A family has three daughters with the same parents. State whether the girls would look alike or be different, then state at least one scientific fact that helps to support your answer.

Base your answers to questions 27 and 28 on the diagram below, which provides information related to heredity, and on your knowledge of biology.

27 The type of molecule in box A serves as a template. Explain what this means.

28 Which molecules are represented by box B?
   (1) bases
   (2) proteins
   (3) amino acids
   (4) simple sugars

Part C

29 A team of behavioral scientists claimed that genes exert a strong influence on eating patterns. The research team asked 10 adult monozygotic twins and 10 adult dizygotic twins to keep a week-long diary of their meals and snacks, as well as how hungry they felt before and after each meal. Monozygotic twins develop when one developing zygote splits to form two embryos. Dizygotic twins develop from two different zygotes.

a If the scientists' hypothesis is correct, which type of twin would be expected to have the most similar eating patterns? Support your answers with a biological explanation.
30 Proteins have many different functions in our bodies. By studying the detailed structures of protein molecules, scientists are better able to understand how proteins function normally and how some proteins with abnormal shapes can cause disease.

a Describe one function performed by a protein that your body produces.

b Explain how the production of a protein with an abnormal shape could lead to disease.

c State one example of an inherited disease that is caused by a change in the production of a protein.

31 In studying a link between genes and enzymes, scientists found that two normal parents could produce an infant with a genetic disease that causes affected individuals to produce urine that turns black on exposure to air. The diagram below compares the cells of a normal infant with the cells of an infant with the genetic disease. The scientists analyzed normal infants and infants afflicted with the hereditary condition. Analysis supported the realization that genes can specify the activity of enzymes.
Explain how a changed gene could result in the "black urine" trait in an infant with the genetic disease. Include the following information in your explanation:

- one type of DNA alteration that could result in the genetic disorder.
- how a DNA alteration affects the protein produced by an infant with the genetic disorder.
- how it is possible for two normal parents to produce an infant with the genetic disorder.

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**Part D**

Answer all questions in this part.

**Directions (33–37):** For those questions that are followed by four choices, circle the number of the choice that best answers the question. For all other questions in this part, follow the directions given in the question.

Chlorophyll from plant leaves can be separated using this chromatograph. A dot of chlorophyll extract is placed near one end of the filter paper or chromatograph paper. The strip is then placed in a solvent such as alcohol as shown below.

![Chromatograph](image)

32. What is the purpose of chromatography?

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33. Explain how chromatography works.

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**Directions (34–37):** Use your knowledge of DNA and protein synthesis to answer the following questions.

34. Which composes a molecule of DNA?
   - (1) amino acids and proteins
   - (2) ATP and enzymes
   - (3) paired nucleotides
   - (4) receptor enzymes
35 Describe the functions of the following types of RNA.

a mRNA

b rRNA

c tRNA

36 The diagram below shows a portion of a DNA molecule. The letters in the diagram represent four bases: adenine (A), thymine (T), guanine (G), and cytosine (C). Which sequence of bases do the question marks represent?

(1) C-A-C
(2) G-C-A
(3) G-A-C
(4) T-C-A

G G A T A C C T G
||| ||| ||| ||| ||| ||| ||| C C T A T G ???

37 In most organisms, the start of translation is signaled by an AUG codon. What is the first amino acid in most proteins?

(1) isoleucine
(2) leucine
(3) methionine
(4) praline