UNIT C – EVOLUTION

The collectors of organisms of yesteryear like Linnaeus and Darwin would have marveled if they could have had a glimpse of our present knowledge of chromosomes, cell division, what proteins are and how they are made in cells. Their conjectures and ideas would have become more concrete. In those days, however, their jobs were more difficult and their theories less accepted because the study of genetics did not exist. DNA had not yet been identified. The source of inheritance patterns and the barriers to breeding between species were unknown.

Since the structure of DNA was determined in 1953, biologists have been working with this huge molecule to unravel its mysteries. Certainly now, with so much knowledge available, our understanding of the concepts of adaptation and evolution is much greater than it was for the pioneers of this branch of biology.

DNA is the topic for the first part of this unit where its structure and functions are briefly considered. From here, the unit delves into the role of DNA in evolution, and the causes, patterns and rate of evolutionary changes.

DNA – THE MASTER MOLECULE

Fundamental to an <u>organism's</u> survival is its ability to grow, repair damage to itself, and replace lost cells such as blood and skin cells. Fundamental to the survival of a <u>species</u> is the reproductive ability of the individuals in the species. Both of these abilities require cell division. The production of identical cells requires **mitosis**, whereas **meiosis** is required for sexual reproduction. **Daughter cells**, the new cells produced by cell division, must have the correct genetic information in order to function properly.

Understanding cell division and the genetic basis of evolution require knowledge of deoxyribonucleic acid (**DNA**), the molecule that comprises chromosomes. A single DNA molecule is generally referred to as a **chromatid**. It is a huge double-stranded, spiral-shaped complex of structural units called **nucleotides**. Each nucleotide consists of three parts: **phosphoric acid**, a sugar (**deoxyribose**), and one of four different **nitrogenous bases**. There are two different types of bases. **Purines** are larger, double ring structures. **Adenine** (A) and **Guanine** (G) are the names of the two purines. **Pyrimidines** are smaller, single ring structures. **Cytosine** (C) and **Thymine** (T) are pyrimidines. The nucleotides of DNA are attached together by bonds between the sugar of one nucleotide and the phosphate of another, making up a repeating sugar-phosphate-sugar-phosphate pattern for the backbone of each of the two strands that make up a single molecule. The two strands are held together by weak chemical bonds called **hydrogen bonds** (H-bonds) between the bases that extend out from the backbone structures. Because of the chemical structure of the bases, each base only ever bonds to one other specific base. In this way, Adenine is **complementary** to Thymine, and Cytosine is complementary to Guanine.

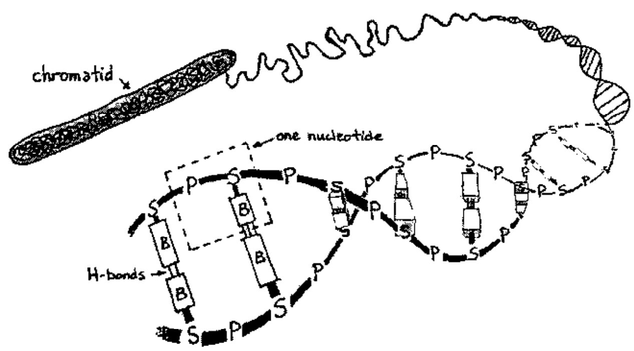

Figure C-1. Structure of DNA. *DNA makes up the genetic part of a chromosome. It is a double-stranded, helical polymer of nucleotides.*

DNA is the "master molecule" in cells. Segments of it, sometimes hundreds of nucleotides long, are called **genes**. Each gene gives the cell the ability to make a certain protein, such as an **enzyme**. Metabolic reactions in cells are enzymatic, therefore DNA's ability to synthesize required proteins is very important. The genetic condition of a cell (or organism) is referred to as its genotype. As a result of gene activity, cells (or organisms) have certain physical features, which are called phenotypes.

Beyond the scope of regular cellular activities, DNA has other significances. Because many cells divide, DNA also has to be able to **replicate** (make copies of itself) to provide daughter cells with the right genetic information. Any error in this process would technically be a **mutation** and might provide a daughter cell with an incorrect genetic sequence resulting in the inability to make a certain protein.

THE ROLE OF DNA IN EVOLUTION

DNA is the chemical code of life. It is made up of sections called genes. An **allele** is a variation of a particular gene. Each organism has a characteristic set of alleles that make up its **genome**. A genome contains all the genetic information required to reproduce an organism. This topic can be extrapolated to the population level, or to that of an entire species.

A **gene pool** is the ratio of all the alleles of all the genes of a species (population) when they are considered pooled together. The genetic make-up of a species can be expressed as the ratio of genes in the gene pool. This ratio is at the mercy of the activities of the members of the species. Events such as reproduction and death have the potential to affect the ratio of genes in the species' gene pool. Evolution occurs when the ratio of genes in the gene pool changes. Evolution is a change in the genetics of a species. Evolutionary changes are more likely to occur to a species with few members than to one with a greater number of members.

C-1. CONCEPT CHECK-UP QUESTIONS:

1. a. If a DNA segment with 300 nucleotides contains 100 Guanine molecules, how many Cytosine molecules will there be?
   b. How many Adenine molecules will the same DNA segment have?
2. How do genes determine the characteristics of cells (or organisms)?
3. a. Define gene pool.
   b. Relate "evolution" to your definition in 3a.

AGENTS OF EVOLUTION

There are several mechanisms through which evolution occurs. These are often referred to as agents of evolution. Each one is explained below.

1. **Natural Selection**. Observing organisms living in nature allows one to realize that not all members of a given population are equally suited for survival. For example, butterflies with slightly larger wings relative to their mass may be less able to survive in a windy area than butterflies of the same population with a smaller wing surface area to mass ratio. Given that wing size and body mass in butterflies are genetic, some members of the butterfly species could have a disadvantage because their genetics gives them a poorer chance of survival. This is a measure of biological **fitness**. Some gene combinations in the population may, perhaps, be removed from the population due to the demise of the less fortunate, less fit organisms. Overall, a species seems well suited or well adapted to its environment because those members of the species that are not suited do not survive.

Charles Darwin

Charles Darwin was the first to document and promote knowledge of Natural Selection. Born about 100 years after Linnaeus, he was one of the world's last great "collectors". The British government hired him as a naturalist. In this capacity, he spent several years sailing to distant parts of the world such as South America and the Galapagos Islands collecting, identifying, and documenting organisms. Darwin strove to understand and explain obvious similarities and differences among organisms and their distribution patterns. He realized that the environment, complete with living and non-living components, must impact the survival of organisms. Changes to a species over long periods of time could be attributed to the reproductive advantage that certain phenotypes had. Taken over expanses of time, it becomes easy to realize how organisms have changed, or evolved. It took Charles Darwin about 20 years to ponder and refine his theory of Natural Selection, before he published it. Natural Selection is now widely accepted in explaining evolutionary changes to organisms.

The selective pressure on a population due to the environment can impose different types of changes on the population. **Directional selection** causes a change in a constant direction – such as increasing size. **Stabilizing selection** removes the members of the species that display extreme **variations** thus reinforcing the average phenotype. **Disruptive selection** occurs when the selective pressure negatively affects the individuals that display the most typical features thus promoting different phenotypic variations within the population or species. This results in a **bimodal distribution**.

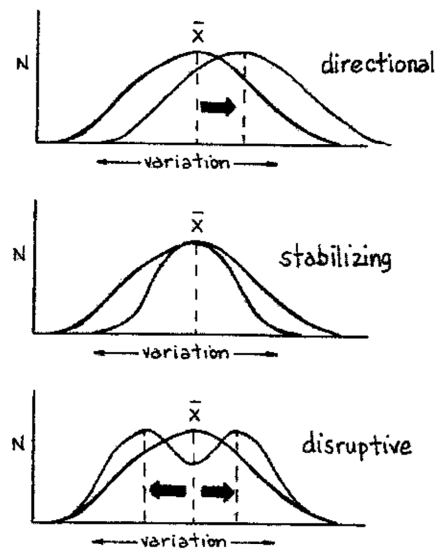

Figure C-2. Types of Natural Selection. *Selective pressures from the environment can force the evolution of a genetic physical feature in one of three different ways. Whenever there is a shift in the average frequency of genes for a particular trait (variation), evolution has occurred.*

2. **Artificial Selection**. Some organisms have evolved because of the effects of human interference with nature. Humans have, for centuries, bred domestic animals for their own benefit. Whether the goal was to develop better milk cows, faster racehorses, or breeds of dogs that don't bark, humans have interfered with what otherwise would be Natural Selection. Artificially inseminating livestock, protecting endangered species, developing hybrid food crops and genetically altered fruit are all examples of this **selective breeding**. This non-random mating is characterized by the identification of desired traits in organisms and promoting their development at the expense of what may have occurred otherwise.

   At times human activity has also resulted in **accidental selection**, where the survival of some organisms has been put in jeopardy unintentionally. Modern day examples of this include disasters like oil spills, the use of certain herbicides and pesticides to protect crops and other activities with negative ecological impacts.

   Historically, the most documented examples of accidental selection were a result of the industrial revolution, which occurred in many countries in the middle portion of the 19th century. The air and soot pollution from the coal-burning factories of the era had significant environmental impacts. Surfaces were covered, and the food source and camouflage of some organisms (the product of eons of adaptation) were affected. Predator species easily caught and consumed prey that was previously harder to see. This new selective pressure caused a shift in the ratio of genes in the gene pools of the prey species. This is what happened to *Biston betularia*, the peppered moth of England that went from predominantly a light color to a dark color in a span of 100 years (generations). Pollution from the factories provided the environmental change that allowed predator birds to consume the light coloured moths in a greater proportion forcing the evolution of the moths. This phenomenon has become known as **industrial melanism**. (Melanin is a pigment molecule in the skin of many animals.) With improved pollution standards worldwide, it is anticipated that some of these evolutionary changes will reverse themselves.

   Another instance of human impact was the development and marketing of the pesticide, **DDT** after World War II. At that time, it was not understood that surviving organisms did not metabolize this chemical toxin. Instead, it accumulated in the tissues of animals like birds that ate insects containing the pesticide. Part of the diet of predatory birds (**raptors**) is smaller birds. When these large birds ate birds with traces of DDT in them, they too accumulated the pesticide in their tissues. The more they ate, the higher the pesticide concentration became. This phenomenon is known as **biological magnification**. With elevated concentrations of this chemical in their systems, these birds were unable to lay eggs with shells hard enough to survive nesting. Within two decades, the world noted a significant decline in the population sizes of predatory birds (eagles, falcons, etc.), and many of them were being named to the endangered species lists. The use of DDT in North America was banned decades ago. Many of these bird species have almost fully recovered.

3. **Mutation**. One of the beautiful things about DNA, the master molecule of genetic features of organisms, is that it can be altered. Changes to DNA are called mutations, and the agents of these changes are called mutagens. Typically, mutagens are either chemical or an effect of radiation.

   Gene mutations can occur when DNA is making copies of itself for cell division. This process, called DNA replication is under enzymatic control. It is well known that enzyme activity is affected by environmental influences. The presence of certain chemicals can interfere with the normal metabolic reactions such as replication. Radiation, which affects energy levels in cells, can also affect the outcome of replication. In either case, daughter cells may inherit altered DNA.

Typically, mutations are thought of as "bad" because the changed DNA would be unable to produce a required protein that the cells normally produce. At the organism level, the individual may have some metabolic deficiency due to the lack of an enzyme, for example. In nature, an organism with a metabolic deficiency may not survive. Another possibility exists, however. The changed DNA may allow the cell (and organism) to make a new protein or have a new characteristic that is otherwise unknown in the population and give that individual a survival advantage! In time, individuals with this new genetic trait would survive better than their counterparts. A change in the gene pool would result, which is evolution.

4. **Genetic Drift**. As this term implies, the genetic composition of a species can undergo random changes that do not have any major identifiable cause. It is easiest to recognize these changes by considering a small, isolated population - on an island for example, where mate selection and breeding occurs only among the members of the population on the island. In this type of situation, factors such as the sexual activities and viability of individuals, and the gender ratio in the population take on a new significance. Consider the effect of one male that parents twenty surviving offspring, where another male has half of that number. Obviously, the more offspring an individual has, the more that individual's alleles will become represented in the gene pool. What if, using the island example, there are relatively few breeding females? By the same reasoning, the genetics of those females would have greater representation in subsequent generations. Both of these examples illustrate evolutionary changes and can be applied to large populations, however, their impacts are obviously diminished as larger populations are considered.
5. **Gene Flow**. Gene flow can be used to explain changes in the gene frequencies of isolated populations of a species. Isolated populations have their own particular genetics. In event that a member of a different population immigrates and joins a given population, he or she may introduce gene alleles into the population that may not have been present before. The result is a passage of genetic information into the gene pool of one population from another. Over time, the genetic distance between the two populations may become lessened.

C-2. CONCEPT CHECK-UP QUESTIONS:

1. What is the role of nature in Natural Selection?
2. Develop an evolutionary story to explain why antelope are fast runners.
3. How is artificial selection different from Natural Selection?
4. How is artificial selection different from accidental selection?
5. Why are the effects of genetic drift and gene flow more significant in small populations?

PATTERNS OF EVOLUTION

Darwin was the first to document an explanation of how evolutionary changes give rise to a new species. Combining his notions with our knowledge of genetics and the modern definition of species, it is easy to explain the concept of **speciation**, the development of a new species.

Consider the situation where some members of a species (for some reason) become separated so that they are reproductively isolated from the rest of the species. Perhaps a volcanic eruption followed by an extensive lava flow destroys part of a habitat where field mice live. It could be that part of the field mouse population becomes separated from the rest of the species and the two groups will not encounter each other because of the lava bed that now separates them. Their once common gene pool no longer has the luxury of large numbers to moderate the impacts of the agents of evolution and prevent rapid evolution. These two groups of mice, though still the same species, continue to exist. Possibly, they evolve more rapidly in their own new, more restricted environments than they would have otherwise. In time, their gene pools will change independently of each other. If the gene pools change enough that breeding between the two populations is no longer possible, then, by definition, separate species exist.

When a species evolves, some aspect of its physical characteristics changes. Evolution is defined as changes to gene frequencies in a population (or species). Genes produce the physical features of organisms and it is these features that are at the mercy of the environment driving further evolutionary changes. Long term changes to the physical features of members of a species result in the species becoming either increasingly similar or dissimilar to another species. This is the difference between **convergent evolution** and **divergent evolution**. For example, consider colour patterns in moths and butterflies. The Viceroy moth and the Monarch butterfly look very similar to each other because of selective predation by birds. The moths that more closely resembled the butterfly were eaten less often, and over the eons of generations, the physical features of the two insect species have converged. They will never become the same species because other aspects of their genetics will always provide a barrier to interbreeding. The alternative, divergent evolution occurs because in becoming more similar to one species, an evolving species will also be becoming less similar to another.

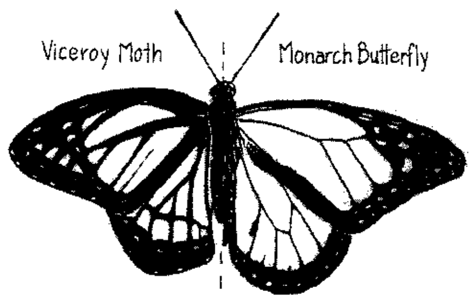

Figure C-3. Viceroy Moth vs. Monarch Butterfly. *The similarity in physical appearance of these two insects is not random. Birds prey on viceroy moths, but find the butterflies distasteful. The moths that are mistaken for butterflies are spared.*

THE TEMPO OF EVOLUTIONARY CHANGE

Throughout this consideration of evolution, two different models of evolutionary change have been used. The first involves slow changes over long periods of time (i.e., the moths affected by bird predation) and the other involves rapid changes brought about by some catastrophic event (i.e., the field mice affected by the lava flow).

Generally, nature tends to be fairly constant. As a result, the natural survival pressures on organisms do not change rapidly. Under these conditions, it is less likely that the environment will bring about many significant evolutionary changes. Any that did occur, would have occurred slowly. This is the **Gradual Change Model** of evolution.

Nature can change suddenly relative to geologic time. There is extensive data on earthquakes, volcanoes, plate tectonics, global warming, ice ages, tidal waves, etc., all of which have serious implications to organisms. Gradual evolution is interrupted by these events, namely by periods of time when rapid changes can occur, including **mass extinction**. Mass extinction is the relatively sudden death of large numbers of individuals, perhaps even entire populations or species. This model of evolution is called the **Punctuated Equilibrium Model**.

The role of extinction in evolution is interesting. When a species becomes extinct, it means that it was biologically unfit for continued survival in its environment. When extinction occurs, the genetics of that organism are removed from nature, never to reappear. The balance of nature is shifted. Food resources and habitats experience new demands. Surviving animals and plants have changed selective pressures. The old belief that ancient animals simply evolved into modern ones is no longer supported. The organisms that exist today are the descendents of the past. There have been countless extinctions and evolutionary changes along the way. Human records are short compared to geologic time and fossil records are incomplete, so we may never have a full understanding of the evolutionary changes that have occurred.

C-3. CONCEPT CHECK-UP QUESTIONS:

1. Define each of the following terms: a. species b. fitness
2. Contrast divergent evolution with convergent evolution
3. Describe a situation where an entire gene pool disappears.

CHECK YOUR UNDERSTANDING

MULTIPLE CHOICE:

1. Meiosis results in
   A. 2 diploid daughter cells.
   B. 4 diploid daughter cells.
   C. 2 haploid daughter cells.
   D. 4 haploid daughter cells.

2. Which pair of bases is **NOT** a complementary base pair?
   A. thymine, adenine.
   B. adenine, guanine.
   C. guanine, cytosine.
   D. cytosine, guanine.

3. Replication ensures daughter cells will have exact copies of
   A. chromosomes without any mutations.
   B. all the genetic information for the organism.
   C. suitable segments of DNA required for cell survival.
   D. the genes to be used by those particular cells.

4. Evolution of viceroy moths illustrates
   A. disruptive selection.
   B. accidental selection.
   C. stabilizing selection.
   D. directional selection.

5. Darwin is noted for the
   A. Gradual Change Model.
   B. Theory of Natural Selection.
   C. Discovery of DNA structure.
   D. Punctuated Equilibrium Model.

6. The **MOST ACCURATE** way to identify evolution is
   A. observing mutations.
   B. documenting changes in physical features over time.
   C. recording changes in gene frequencies in a gene pool.
   D. finding genotypes that don't change over time.

7. Industrial melanism is an example of
   A. artificial selection.
   B. disruptive selection.
   C. stabilizing selection.
   D. accidental selection.

8. The strands of DNA molecules are held together by H-bonds between
   A. sugars.
   B. phosphates.
   C. complementary bases.
   D. pairs of purines and pairs of pyrimidines.

9. Many predatory birds suffered due to human use of pesticides because
   A. all of the following.
   B. their food sources were dying off.
   C. the pesticides accumulated in their tissues.
   D. the pesticides affected their successful reproduction.

10. The evolutionary changes called "industrial melanism"
    A. may become reversed.
    B. have stopped completely.
    C. are continuing at a rapid rate.
    D. are examples of genetic drift.

11. A species is **BEST** defined as a set of organisms that
    A. live in the same area.
    B. is part of a population.
    C. successfully interbreed.
    D. have the same physical features.

12. Which is **NOT** an example of artificial selection?
    A. Bird watching.
    B. Breeding racehorses.
    C. Raising purebred dogs.
    D. Protecting endangered species.

13. The accumulation of toxins in the tissues of organisms is known as
    A. extinction.
    B. natural selection.
    C. disruptive selection.
    D. biological magnification.

14. A bimodal distribution of phenotypes could naturally result from
    A. artificial selection.
    B. disruptive selection.
    C. stabilizing selection.
    D. directional selection.

15. Natural selection does **NOT** require
    A. extinction.
    B. selective pressure.
    C. phenotypic variation.
    D. reproductive success.

16. Genetic drift is **MOST LIKELY** to occur in a
    A. large population due to selective pressures.
    B. small population due to selective pressures.
    C. large population without the influence of selective pressures.
    D. small population without the influence of selective pressures.

17. Variations of a specific gene are
    A. alleles.
    B. mutations.
    C. genotypes.
    D. phenotypes.

18. A rare allele in a population may become more common in a relatively short period of time due to
    A. genetic drift.
    B. adaptive radiation.
    C. divergent evolution.
    D. convergent evolution.

19. Individuals lacking specializations required for survival in a changing environment
    A. die.
    B. adapt.
    C. evolve.
    D. mutate.

20. The ability of an organism to pass on its genes to its offspring is part of
    A. fitness.
    B. radiation.
    C. evolution.
    D. adaptation.

WRITTEN ANSWERS:

1. Describe chromosome structure.
2. How is a gene different from a genome?
3. Explain how the DNA in a dog cell would differ from that in a cat cell?
4. List pros and cons of artificial selection.
5. Contrast each of the following:
   a. Accidental Selection vs. Natural Selection
   b. Gradual Change vs. Punctuated Equilibrium
6. Describe how our understanding of evolution has evolved.
7. What is the relationship between a gene pool and evolution?
8. (Research) What is *Biston betularia*? Describe the details of its evolution in the 19th century.