ARTHUR JARVIS UNIVERSITY

BIO 211 GENERAL PHYSIOLOGY

PROF. ANI NKANG

DEPT. OF BIOLOGICAL SCIENCES, ARTHUR JARVIS UNIVERSITY

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Physiology is the study of the **physical and chemical processes** that take place in living organisms during the performance of life functions. It is concerned with such basic activities as reproduction, growth, metabolism, excitation, and contraction as they are carried out within the fine structure, the cells, tissues, organs, and organ systems of the organism.

It investigates biological mechanisms with the tools of physics and chemistry. Three broad divisions are recognized: general physiology, concerned with basic processes common to all life forms; the physiology and functional anatomy of humans and other animals, including pathology and comparative studies; and plant physiology, which includes photosynthesis and other processes pertinent to plant life. Therefore, physiological processes are the ways in which organ systems, organs, tissues, cells, and biomolecules work together to accomplish the complex goal of sustaining life.

Water Potential

The plant cell, when placed in pure water, swells but does not burst. The osmotic potential of the vacuolar sap is negative resulting in water moving into the cell. This causes the plasmalemma to be pressed against the cell wall. The actual pressure that develops and pushes the membrane against the cell wall is the **turgor pressure**. The cell wall, being rigid, exerts an equal and opposite pressure, called the **wall pressure**. If the cell is placed in a more negative solute potential (i.e. a solution more concentrated than the vacuolar sap), water will leave the cell, the protoplast will shrink away from the cell wall, and the cell is said to be plasmolysed.

Practical Exercises / Progress Checks

(a) A piece of colored onions was placed in boiling water for two minutes. An epidermal strip was removed and mounted in M sucrose and observed for plasmolysis. Sketch the appearance of one of the cells. Explain what could have happened.

(b) A piece of coloured onions epidermis was placed in chloroform for two minutes. It was then removed and mounted in M sucrose and examined microscopically for plasmolysis. Does the appearance of the cells differ from that of (a) above? Explain.

(c) Distinguish between hydrophilic and hydrophobic substances. Give two examples of each.

ENERGY AND NUTRIENTS

Summary of respiratory pathways

If pyruvate is further oxidized in the presence of oxygen in the mitochondria, 34 ATP molecules produced by oxidative phosphorylation are added to the 4 ATP from substrate level phosphorylation. This gives an estimated 38 ATP from oxidation of a glucose molecule.

Practical Exercises / Progress checks

(a) Where does each step of the general processes of respiration (glycolysis, TCA cycle or electron transport chain) occur within the cell?

(b) Summarize the steps in glycolysis

(c) When 0_2 is available, substrates from glycolysis will be used by the TCA cycle. What happens when 0_2 is not available?

(d) How much energy is available from glycolysis (anaerobic respiration) as opposed to full aerobic respiration?

Evaporative cooling/Transpiration

Liquid molecules stay together because they are attracted to each other (cohesion). Molecules moving fast enough to overcome these attractions transform from the liquid to the gas phase, a process called vaporization or evaporation. Some evaporation occurs at any temperature. If a liquid is heated, the average kinetic energy of molecules increases and the liquid evaporates more rapidly.

Heat of vaporization is the quantity of heat a liquid must absorb for 1g of it to be converted from the liquid to the gaseous state. Water has a high heat of vaporization. The High heat of vaporization is also due to hydrogen bonding which must be broken before the molecules can make their exodus from the liquid. As a liquid evaporates, the surface of the liquid that remains behind cools down. This evaporative cooling occurs because the "hottest" molecules, with the greatest kinetic energy, are the most likely to leave as gas. Evaporative cooling provides a mechanism that prevents terrestrial organisms from overheating. Evaporation of water from the leaves of a plant helps keep the tissues from becoming too warm in the sunlight.

Stomatal Transpiration involves the evaporation of water from the cell surfaces bordering the intracellular air spaces, and the diffusion of the resultant water vapor from the intercellular spaces into the atmosphere by way of the stomata. The evaporated water is replaced by water from within the cell. Dry air has a great capacity to hold (or pull from leaves via stomata) water vapor. As the relative humidity of air falls below 100% its affinity for water increases dramatically.

Practical Exercises/ Progress Checks

Three similar potted plants (of the same species and size) were watered and their pots wrapped in polythene sheet (to prevent evaporation from the soil and pot). The lower surface of the leaves of one (A) were coated in Vaseline, the upper surfaces of the leaves of another (B) were coated with Vaseline, and While C was left untreated. The potted plants were weighted and then placed outside on a warm, sunny day. The plants were weighed again 12 hours later. The following results were obtained:

Time	Weight of potted plant (gms)		
	A	B	C
Initial Weight	256	274	285
12 hours later	251	264	265

Calculate the transpiration rate of each plant (gm water lost per hour).

Discuss briefly your results.

BASICS OF PHOTOBIOLOGY

Photosynthesis nourishes almost all the living world directly or indirectly. An organism acquires the carbon compounds it uses for energy and carbon skeletons by one of two major modes: Autotrophic or heterotrophic nutrition. Autotrophs make their organic molecules from inorganic raw materials obtained from the environment. It is for this reason that biologists refer to autotrophs as the producers of the biosphere. Heterotrophs obtain their organic material from other organisms. They are the biosphere's consumers. Some heterotrophs consume the remains of dead organisms. These are known as decomposers.

Determining an Absorption Spectrum

Substances that absorb light are called pigments. Different pigments absorb light of different wavelengths. The wavelengths absorbed disappear, while the wavelengths that are not absorbed pass (or are transmitted) through the pigment. The ability of a pigment to absorb various wavelengths of light can be measured by placing a solution of the pigment in a spectrophotometer.

Spectrophotometers are among the most widely used research instruments in biology. A spectrophotometer measures the relative amounts of light of different wavelengths absorbed and transmitted by a pigment solution. White light is separated into colors (wavelengths) by a prism located inside the spectrophotometer.

These different colors of light are then passed through the sample one by one. The transmitted light strikes a photoelectric tube, which converts light energy to electricity, and the electrical current is measured by a meter.

Each time the wavelength of light is changed, the meter indicates the fraction of light transmitted through the sample or, conversely, the fraction of light absorbed. A graph that shows the absorption of the pigment at different wavelengths is called an absorption spectrum. The absorption spectrum for *chlorophyll a*, the form of chlorophyll most important in photosynthesis, has two peaks, corresponding to Blue and Red light. These are the colors *chlorophyll a* absorbs best.

Transmittance and absorbance in absorption photometry

The visible distinguishing characteristic of dissolved substances is their color. Every color corresponds to a definite range of wavelengths of light. Solutions of substances appear colored when they absorb certain fractions of white light and are transparent to radiation corresponding to their colour. When the concentration of a solution rises linearly, the intensity of the emergent beam of light falls off. However, absorbance is linearly proportional to the concentration and for simplicity is defined as follows:

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Practical Exercise/Progress Checks

Prepare pigment extract from *Gmelina arborea* leaves by grinding (homogenizing) a small quantity of the leaf (0.5 g fresh weight) in 80% acetone. Filter the pigment extract into a stoppered flask and keep in darkness (until used). A clear extract can also be obtained by centrifugation. Determine the absorption spectrum of the clear extract in the visible spectrum (400-750nm).

Wavelength (nm)	Absorbance
400	
450	
475	
500	
525	
550	

575	
600	
625	
650	
675	
700	
725	

Plot the absorbance readings against wavelength.

(i) Can you identify the wavelengths best absorbed by photosynthetic pigments?

(ii) What lighting would you recommend to grow a plant indoors?

(iii) Why do plants vary in their photosynthetic absorption spectra? [For example, plants in different levels of a forest canopy have different concentrations and types of accessory pigments].

ENZYMOLOGY

Enzymes are large biological molecules responsible for the thousands of chemical interconversions that sustain life. They are highly selective catalysts, greatly accelerating both the rate and specificity of metabolic reactions, from the digestion of food to the synthesis of DNA. Most enzymes are proteins. Enzymes adopt a specific three-dimensional structure, and may employ organic (e.g. biotin) and inorganic (e.g. magnesium ion) cofactors to assist in catalysis.

In enzymatic reactions, the molecules at the beginning of the process, called substrates, are converted into different molecules, called products. Almost all chemical reactions in a biological cell need enzymes in order to occur at rates sufficient for life. Since enzymes are selective for their substrates and speed up only a few reactions from among many possibilities, the set of enzymes made in a cell determines which metabolic pathways occur in that cell.

Like all catalysts, enzymes work by lowering the activation energy (E_a) for a reaction, thus dramatically increasing the rate of the reaction. As a result, products are formed faster and reactions reach their equilibrium state more rapidly. Most enzyme reaction rates are millions of times faster than those of comparable un-catalyzed reactions. As with all catalysts, enzymes are not consumed by the reactions they catalyze, nor do they alter the equilibrium of these reactions. However, enzymes do differ from most other catalysts in that they are highly specific for their substrates. Enzymes are known to catalyze about 4,000 biochemical reactions. A few RNA molecules called ribozymes also catalyze reactions, with an important example being some parts of the ribosome. Synthetic molecules called artificial enzymes also display enzyme-like catalysis. Enzyme activity can be affected by other molecules. Inhibitors are molecules that decrease enzyme activity; activators are molecules that increase activity. Many drugs and poisons are enzyme inhibitors. Activity is also affected by temperature, pressure, chemical environment (e.g., pH), and the concentration of substrate. Some enzymes are used commercially, for example, in the synthesis of antibiotics. In addition, some household products use enzymes to speed up biochemical reactions (e.g., enzymes in biological washing powders break down protein or fat stains on clothes; enzymes in meat tenderizers break down proteins into smaller molecules, making the meat easier to chew).

Enzymes are in general globular proteins. A small number of RNA-based biological catalysts exist, with the most common being the ribosome; these are referred to as either RNA-enzymes or ribozymes. The activities of enzymes are determined by their three-dimensional structure.

Most enzymes are much larger than the substrates they act on, and only a small portion of the enzyme (around 2–4 amino acids) is directly involved in catalysis. The region that contains these catalytic residues, binds the substrate, and then carries out the reaction is known as the active site. Enzymes can also contain sites that bind cofactors, which are needed for catalysis. Some enzymes also have binding sites for small molecules, which are often direct or indirect products or substrates of the reaction catalyzed. This binding can serve to increase or decrease the enzyme's activity, providing a means for feedback regulation.

Like all proteins, enzymes are long, linear chains of amino acids that fold to produce a three-dimensional product. Each unique amino acid sequence produces a specific structure, which has unique properties. Individual protein chains may sometimes group together to form a protein complex. Most enzymes can be denatured—that is, unfolded and inactivated—by heating or chemical denaturants, which disrupt the three-dimensional structure of the protein. Depending on the enzyme, denaturation may be reversible or irreversible.

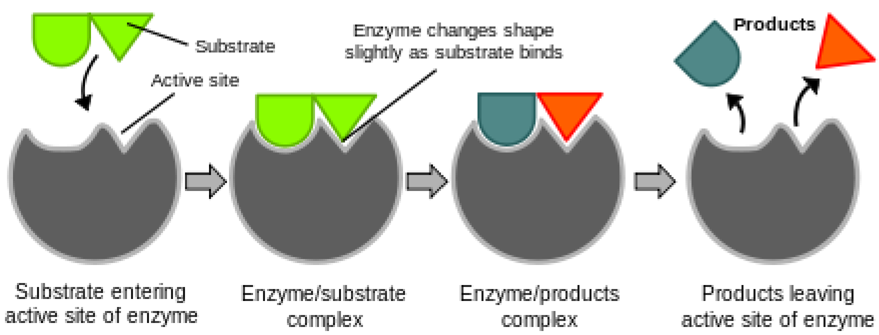
Specificity

Enzymes are usually very specific as to which reactions they catalyze and the substrates that are involved in these reactions. Complementary shape, charge and hydrophilic/hydrophobic characteristics of enzymes and substrates are responsible for this specificity. Enzymes can also show impressive levels of stereospecificity, and chemoselectivity.

Some of the enzymes showing the highest specificity and accuracy are involved in the copying and expression of the genome. These enzymes have "proof-reading" mechanisms. Here, an enzyme such as DNA polymerase catalyzes a reaction in a first step and then checks that the product is correct in a second step. This two-step process results in average error rates of less than 1 error in 100 million reactions in high-fidelity mammalian polymerases. Similar proofreading mechanisms are also found in RNA polymerase, aminoacyl tRNA synthetases and ribosomes.

"Lock and key" model

Enzymes are very specific, and it was suggested by the Nobel laureate organic chemist Emil Fischer in 1894 that this was because both the enzyme and the substrate possess specific complementary geometric shapes that fit exactly into one another. This is often referred to as "the lock and key" model



Diagrams to show the induced fit hypothesis of enzyme action

In 1958, Daniel Koshland suggested a modification to the lock and key model: since enzymes are rather flexible structures, the active site is continuously reshaped by interactions with the substrate as the substrate interacts with the enzyme. As a result, the substrate does not simply bind to a rigid active site; the amino acid side-chains that make up the active site are molded into the precise positions that enable the enzyme to perform its catalytic function. In some cases, such as glycosidases, the substrate molecule also changes shape slightly as it enters the active site. The active site continues to change until the substrate is completely bound, at which point the final shape and charge is determined. Induced fit may enhance the fidelity of molecular recognition in the presence of competition and noise via the conformational proofreading mechanism.

Mechanisms

Enzymes can act in several ways, all of which lower $\Delta G^{\ddagger}$ (Gibbs energy):

- Lowering the activation energy by creating an environment in which the transition state is stabilized.
- Providing an alternative pathway. For example, temporarily reacting with the substrate to form an intermediate ES complex, which would be impossible in the absence of the enzyme.
- Increases in temperatures speed up reactions. Thus, temperature increases help the enzyme function and develop the end product even faster. However, if heated too much, the enzyme's shape deteriorates and the enzyme becomes denatured. Some enzymes like thermolabile enzymes work best at low temperatures.

GROWTH HORMONES

Plant hormone

Plant hormones (also known as **phytohormones**) are chemicals that regulate plant growth. Plant hormones are signal molecules produced within the plant, and occur in extremely low concentrations. Hormones regulate cellular processes in targeted cells locally and, when moved to other locations, in other locations of the plant. Hormones also determine the formation of flowers, stems, leaves, the shedding of leaves, and the development and ripening of fruit. Plants, unlike animals, lack glands that produce and secrete hormones. Instead, each cell is capable of producing hormones. Plant hormones shape the plant, affecting seed growth, time of flowering, the sex of flowers, senescence of leaves, and fruits. They affect which tissues grow upward and which grow downward, leaf formation and stem growth, fruit development and ripening, plant longevity, and even plant death. Hormones are vital to plant growth, and, lacking them, plants would be mostly a mass of undifferentiated cells. So they are also known as growth factors or growth hormones.

Plant hormones are naturally produced within plants, though very similar chemicals are produced by fungi and bacteria that can also affect plant growth. A large number of related chemical compounds are synthesized by humans. They are used to regulate the growth of cultivated plants, weeds, and in vitro-grown plants and plant cells; these manmade compounds are called **Plant Growth Regulators** or **PGRs** for short.

Plant hormones are not nutrients, but chemicals that in small amounts promote and influence the growth, development, and differentiation of cells and tissues. The biosynthesis of plant hormones within plant tissues is often diffuse and not always localized. Plants lack glands to produce and store hormones, because, unlike animals — which have two circulatory systems (lymphatic and cardiovascular) powered by a heart that moves fluids around the body — plants use more passive means to move chemicals around the plant. Plants utilize simple chemicals as hormones, which move more easily through the plant's tissues. They are often produced and used on a local basis within the plant body. Plant cells produce hormones that affect even different regions of the cell producing the hormone.

Hormones are transported within the plant by utilizing four types of movements. For localized movement, cytoplasmic streaming within cells and slow diffusion of ions and molecules between cells are utilized. Vascular tissues are used to move hormones from one part of the plant to another; these include sieve tubes or phloem that move sugars from the leaves to the roots and flowers, and xylem that moves water and mineral solutes from the roots to the foliage.

Plants need hormones at very specific times during plant growth and at specific locations. They also need to disengage the effects that hormones have when they are no longer needed. The production of hormones occurs very often at sites of active growth within the meristems, before cells have fully differentiated. After production, they are sometimes moved to other parts of the plant, where they cause an immediate effect; or they can be stored in cells to be released later. Plants use different pathways to regulate internal hormone quantities and moderate their effects. They can store them in cells, inactivate them, or cannibalise already-formed hormones by conjugating them with carbohydrates, amino acids, or peptides. Plants can also break down hormones chemically, effectively destroying them.

Classes of plant hormones

In general, it is accepted that there are five major classes of plant hormones, some of which are made up of many different chemicals that can vary in structure from one plant to the next. The chemicals are each grouped together into one of these classes based on their structural similarities and on their effects on plant physiology. Other plant hormones and growth regulators are not easily grouped into these classes; they exist naturally or are synthesized by humans or other organisms, including chemicals that inhibit plant growth or interrupt the physiological processes within plants. Each class has positive as well as inhibitory functions, and most often work in tandem with each other, with varying ratios of one or more interplaying to affect growth regulation.

The five major classes are:

Abscisic acid

Abscisic acid (also called ABA), was discovered and researched under two different names before its chemical properties were fully known, it was called *dormin* and *abscicin II*. Once it was determined that the two compounds are the same, it was named abscisic acid. The name "abscisic acid" was given because it was found in high concentrations in newly abscised or freshly fallen leaves.

In general, it acts as an inhibitory chemical compound that affects bud growth, and seed and bud dormancy. It mediates changes within the apical meristem, causing bud dormancy and the alteration of the last set of leaves into protective bud covers. Without ABA, buds and seeds would start to grow during warm periods in winter and be killed when it froze again. Since ABA dissipates slowly from the tissues and its effects take time to be offset by other plant hormones, there is a delay in physiological pathways that provide some protection from premature growth. It accumulates within seeds during fruit maturation, preventing seed germination within the fruit, or seed germination before winter. Abscisic acid's effects are degraded within plant tissues during cold temperatures or by its removal by water washing in out of the tissues, releasing the seeds and buds from dormancy.

Plants start life as a seed with high ABA levels. Just before the seed germinates, ABA levels decrease; during germination and early growth of the seedling, ABA levels decrease even more. As plants begin to produce shoots with fully functional leaves, ABA levels begin to increase, slowing down cellular growth in more "mature" areas of the plant.

Auxins

The auxin indole-3-acetic acid (IAA)

Auxins are compounds that positively influence cell enlargement, bud formation and root initiation. They also promote the production of other hormones and in conjunction with cytokinins, they control the growth of stems, roots, and fruits, and convert stems into flowers. Auxins were the first class of growth regulators discovered. They affect cell elongation by altering cell wall plasticity. Auxins act to inhibit the growth of buds lower down the stems (apical dominance), and also to promote lateral and adventitious root development and growth. Auxins in seeds regulate specific protein synthesis, as they develop within the flower after pollination, causing the flower to develop a fruit to contain the developing seeds.

Cytokinins

The cytokinin zeatin, the name is derived from *Zea*, in which it was first discovered in immature kernels.

Cytokinins or CKs are a group of chemicals that influence cell division and shoot formation. They were called kinins in the past when the first cytokinins were isolated from yeast cells. They also help delay senescence or the aging of tissues, are responsible for mediating auxin transport throughout the plant, and affect internodal length and leaf growth. They have a highly synergistic effect in concert with auxins, and the ratios of these two groups of plant hormones affect most major growth periods during a plant's lifetime. Cytokinins counter the apical dominance induced by auxins; they in conjunction with ethylene promote abscission of leaves, flower parts, and fruits.

Ethylene

Ethylene is a gas that forms through the breakdown of methionine, which is in all cells. Ethylene has very limited solubility in water and does not accumulate within the cell but diffuses out of the cell and escapes out of the plant. Its effectiveness as a plant hormone is dependent on its rate of production versus its rate of escaping into the atmosphere. Ethylene is produced at a faster rate in rapidly growing and dividing cells, especially in darkness. Ethylene affects cell growth and cell shape; when a growing shoot hits an obstacle while underground, ethylene production greatly increases, preventing cell elongation and causing the stem to swell. The resulting thicker stem can exert more pressure against the object impeding its path to the surface. If the shoot does not reach the surface and the ethylene stimulus becomes prolonged, it affects the stem's natural geotropic response, which is to grow upright, allowing it to grow around an object. Ethylene affects fruit-ripening: Normally, when the seeds are mature, ethylene production increases and builds-up within the fruit, resulting in a climacteric event just before seed dispersal.

Gibberellins

Gibberellins, or GAs, include a large range of chemicals that are produced naturally within plants and by fungi. They were first discovered when Japanese researchers noticed a chemical produced by a fungus called *Gibberella fujikuroi* that produced abnormal growth in rice plants. Gibberellins are important in seed germination, affecting enzyme production that mobilizes food production used for growth of new cells. Absorption of water by the seed causes production of GA. The GA is transported to the aleurone layer, which responds by producing enzymes that break down stored food reserves within the endosperm, which are utilized by the growing seedling. They promote flowering, cellular division, and in seeds growth after germination. Gibberellins also reverse the inhibition of shoot growth and dormancy induced by ABA.

Animals and Humans: What are Growth Hormones?

Growth hormone (GH) is a protein-based peptide hormone. It stimulates growth, cell reproduction and regeneration in humans and other animals. Somatotropin refers to the growth hormone produced naturally in animals, whereas the term somatropin refers to growth hormone produced by recombinant DNA technology, and is abbreviated "HGH" in humans.

Growth hormone is used in medicine to treat children's growth disorders and adult growth hormone deficiency. In recent years, growth hormone replacement therapies have become popular in the battle against ageing and obesity. In its role as an anabolic agent, HGH has been abused by competitors in sports since the 1960s, and it has been banned by the IOC.