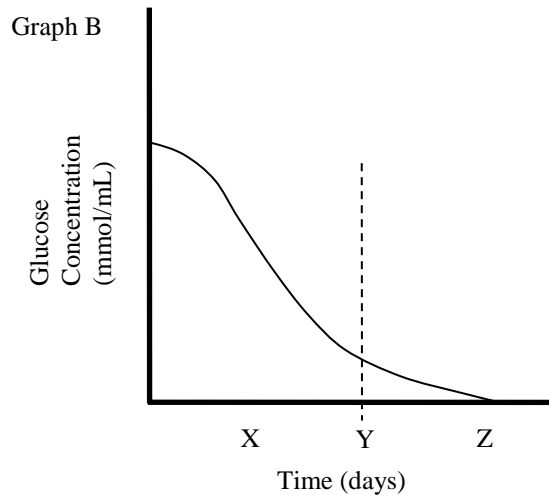
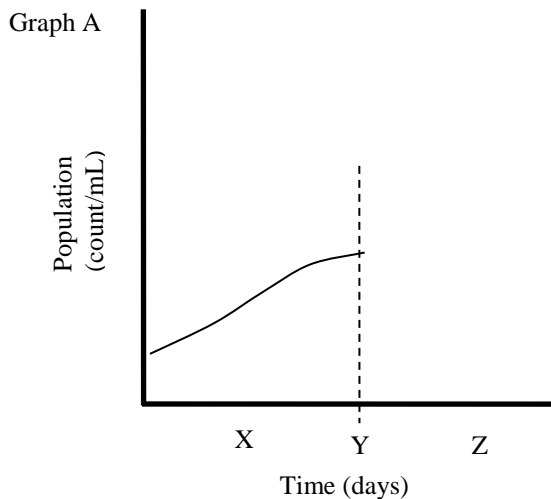
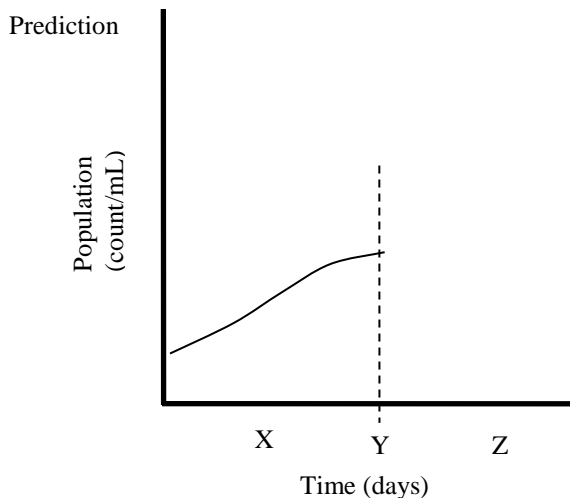


## Big Idea 2 Free Response Practice

1. A population of a single-celled heterotrophic organism in a flask of glucose solution was measured over time. Oxygen was bubbled through the solution and carbon dioxide was absorbed but no other substances were added or removed. Graph A shows the population of the organism. Graph B shows the concentration of glucose solution in the flask.



- Describe the population growth of the organism in terms of entropy and glucose use.
- Predict the shape of the population curve from Y to Z. Draw your prediction in the space provide below. Justify your response.
- Describe the changes in population and glucose concentration in terms of changes in free energy.



**Key 1:**

- a. *The second law of thermodynamics states that the entropy of the universe tends to increase. The process of life, despite itself imposing greater organization on the living things themselves, does so at a net increase in entropy, as order is removed from the environment to make this happen. In the case of the flask containing organisms, as the population grows, and more organisms arise, glucose is used to drive this process. The organization of the glucose molecule is decreased through metabolism. There is a net increase in entropy in this situation because the metabolic processes involved in respiration are not 100% efficient and result in heat production.*
- b. *We should see a decline in population to zero around time  $z$ . Glucose is the food source for the organism and required to drive all metabolic processes. Because glucose concentration is decreasing, organisms will compete for this food supply, with all organisms ultimately dying off as the glucose concentration reaches zero.*
- c. *Metabolic processes in the organisms result from the coupling of endergonic (molecule building) and exergonic (ATP breaking) reactions. The net result is an increase in  $G$  within the organism. This is true as the population of the organism grows. However, the exergonic reactions occurring in the organism rely on ATP, a substance generated through the oxidation of glucose in respiration. Respiration itself is an exergonic reaction resulting in the production of ATP and heat and accordingly a decrease in  $G$ . When taken together, the increase in free energy occurring in the living cell plus the decrease in free energy during glucose oxidation results in an overall decrease in free energy in the total system. As the population expands and the glucose concentration decreases,  $G$  decreases. Once the glucose concentration reaches zero, there can be no longer a flow of free energy into the organisms and the endergonic reactions within the organism can no longer be sustained, resulting in death of the cells.*

Essential knowledge 2.A.1: All living systems require constant input of free energy.

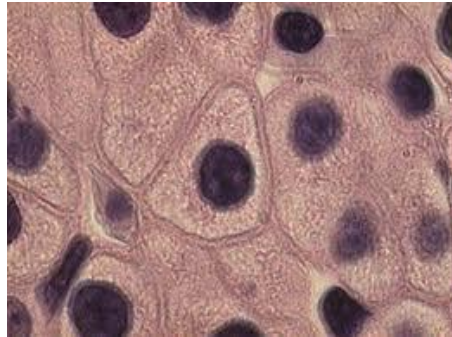
Learning Objectives:

LO 2.1 The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow and to reproduce. [See SP 6.2]

LO 2.3 The student is able to predict how changes in free energy availability affect organisms, populations and ecosystems.  
[See SP 6.4]

2. During microscopic examination of human tissue samples, a student observed the following at different magnifications. In some cases, individual cells were clearly visible (A and B). In others, the magnification was too low to clearly visualize individual cells although the dark patches of nuclei are visible in fig C.

Fig. A



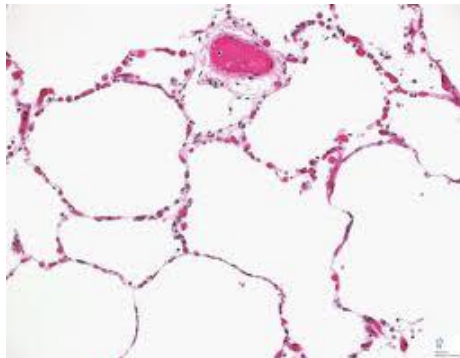
← 100 $\mu$ m →

Fig. B



← 200 $\mu$ m →

Fig. C



← 300 $\mu$ m →

Fig. D



← 1000 $\mu$ m →

- Identify the image that contains a cell or cells with the lowest surface area to volume ratio. Explain your reasoning and provide a sample calculation to illustrate this.
- Identify an image that shows a tissue that is ideally suited for the exchange of materials with the environment. Justify your response and suggest the role this tissue may have in the organism.
- Explain how surface area to volume ratio can place a limit on the maximum size of a cell.
- Describe how you could model that the rate of exchange of materials is affected by surface area to volume ratio. (Option – support your written response with clearly labeled diagrams).

**Key 2:**

- a. *Fig. B. The field of view is 200 microns, the cell is therefore about 100 microns across. The closest to this is fig. A in which the cells are approximately 20-30 microns. Assuming the cells are all roughly the same shape, the cell with the largest volume will have the lowest surface area to volume ratio. Many possible answers – check for accuracy in calculation. e.g. for a spherical cell in which the radius is  $r$ , the volume ( $v$ ) is  $4/3\pi r^3$  (check answer) The surface area ( $sa$ ) is  $4\pi r^2$ . Ratio is  $sa/v$ . Accept answers for rectangular and cuboidal cells. Student must compare two cell sizes and show how  $sa:v$  ratio drops as size decreases.*
- b. *Fig. C or D are appropriate responses. These tissues indicate a large surface area/volume ratio. Their structure facilitates exchange of material with the environment, maximizing the area through which substances can move into the cell while minimizing the distance these substances have to move to perfuse the cell fully. Fig. C is alveolar tissue and fig. D is jejunal villi. Accept reasonable answers for tissue and function.*
- c. *Rapid exchange of materials such as oxygen, carbon dioxide, and glucose with the environment is crucial for effective metabolism and the maintenance of homeostasis. A low  $sa:v$  ratio in a large cell in effect decreases the speed at which materials can fully perfuse and leave the cell. This makes exchange slow, increasing concentration of waste products and decreasing the rate at which nutrients can enter. A cell beyond a particular size is therefore unable to operate basic life processes because of this limitation.*
- d. *Responses are acceptable if the model and measurement method seem reasonable. For example, create blocks of agar/phenolphthalein/base of different sizes. Immerse in acid for set length of time. Retrieve blocks, cut open and measure distance of diffusion. Diffusion of the acid in smaller block will fill the block indicating a correlation between higher  $sa:v$  ratio and an object being fully perfused quicker. Note that in this method, the movement of acid is the same in each block, limiting how much of a larger block can be filled in a given time.*

Essential knowledge 2.A.3: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

**Learning Objectives:**

LO 2.6 The student is able to use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion. [See SP 2.2]

LO 2.7 Students will be able to explain how cell size and shape affect the overall rate of nutrient intake and the rate of waste elimination. [See SP 6.2]

LO 2.9 The student is able to represent graphically or model quantitatively the exchange of molecules between an organism and its environment, and the subsequent use of these molecules to build new molecules that facilitate dynamic homeostasis, growth and reproduction. [See SP 1.1, 1.4]

- 3. Statement: “Organisms respond to changes in their external environment through physiological and/or behavioral mechanisms.” Choose one of the following examples given and answer the questions below:**
- i. Photoperiodism and phototropism in plants
  - ii. Hibernation and migration in animals
  - iii. Taxis and kinesis in animals
  - iv. Chemotaxis in bacteria
  - v. Sexual reproduction in fungi
  - vi. Nocturnal and diurnal activity: circadian rhythms
  - vii. Shivering and sweating in humans
- a. State the choice you have made and explain the basic biological concept involved.
  - b. Design and outline a realistic scientific investigation that will collect data to confirm or refute this behavioral or physiological mechanism. Be specific enough in your response to allow an investigator to begin this work using your outline. Discuss sample size and length of investigation period.
  - c. Identify the type of data you will be collecting in this investigation. State specifically how you will collect these data. Provide an outline of data table or graph if appropriate.
  - d. State your hypothesis for this investigation. State what the data would show if your hypothesis is confirmed.

**Key 3:**

*Each example must be judged by the following criteria*

- a. Accurate explanation of the concept*
- b. Detailed and scientifically appropriate and realistic investigation. May be lab based or observational field work.*
- c. Data must be specific and method of collection realistic. Data table or graph make sense and are clear.*
- d. Hypothesis is stated and reasonable, hypothetical data would support hypothesis.*

Essential knowledge 2.C.2: Organisms respond to changes in their external environments.

Learning Objective:

LO 2.21 The student is able to justify the selection of the kind of data needed to answer scientific questions about the relevant mechanism that organisms use to respond to changes in their external environment. [See SP 4.1]

4.  $\beta$ -globin is a protein subunit of hemoglobin found in mammals. DNA is extracted from nuclei of certain tissues of a mouse and denatured. A single stranded DNA probe engineered to complement the  $\beta$ -globin gene is added to the mouse DNA sample. Data is collected to determine whether the probe has bound to the  $\beta$ -globin gene. This procedure is repeated with mRNA extracted from the same mouse tissue types. The data collected is shown in Table 1.

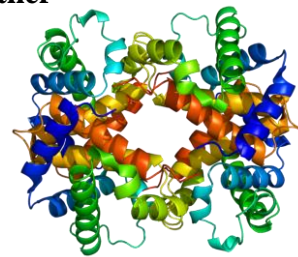


Diagram of  $\beta$ -globin

Nucleic Acid	Binding of $\beta$ -globin Gene Probe in Certain Tissues		
	Neural	Muscle	Blood/Bone Marrow
Nuclear DNA	Binds	Binds	Binds
Cytoplasmic mRNA	No Binding	No Binding	Binds

**Table 1**

- In terms of gene expression, explain why the pattern of binding shown in Table 1 makes sense.
- Assuming you had muscle cells in culture, describe what factors must be present to initiate the production of  $\beta$ -globin in these cells.
- The tissues examined in this scenario are fully differentiated. Describe two key processes by which this differentiation occurs in an organism beginning with the zygote. Provide an illustrative example of each.

**Key 4:**

- a. *Binding of the probe to nuclear DNA indicates that the gene for  $\beta$ -globin must be present in each tissue type. However, the transcription of this gene to mRNA happens only in blood cells. Therefore, the probe is only binding to mRNA in blood cells. This is because the mRNA transcript does not exist in the other tissues as it is not expressed in these.*
- b. *To cause the expression of the gene in the other tissues, an external signal to turn on this gene must be added to the mix. In addition, the appropriate transcription factor must be present in the cytoplasm of the cell. The presence of both of these will turn on the appropriate gene.*
- c. *Students may choose from 1) cytoplasmic segregation; differential distribution of certain factors in the embryo to produce polarity, e.g. the creation of distal and proximal ends of limbs, 2) induction; the process by which chemical signals are passed from one cell to another to stimulate differentiation of tissues in a particular structure, e.g. components of the eye, and 3) apoptosis; the process by which certain cells are programmed to die, allowing the tissue and/or structure to take its final form, e.g. finger webs in humans disappearing.*

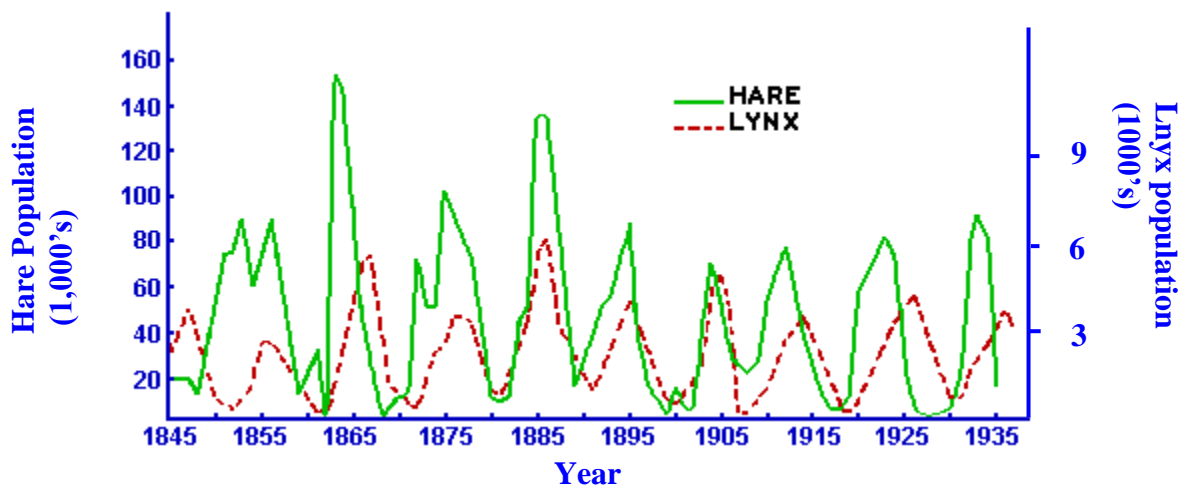
Essential knowledge 2.E.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms.

Learning Objective:

LO 2.32 The student is able to use a graph or diagram to analyze situations or solve problems (quantitatively or qualitatively) that involve timing and coordination of events necessary for normal development in an organism. [See SP 1.4]



5. Graph 1 represents a classic study of snowshoe hare and Canadian lynx populations based on the number of pelts brought in by hunters and trappers over 90 years.



Graph 1

- Describe the similarities and differences in trends in the populations of the snowshoe hare and the lynx.
- Make one inference from these trends regarding the interaction between the two species. Justify your response.
- Foxes hunt mice, rabbits and hares. Hypothesize what would happen to the population cycle of lynx if foxes were introduced into the Canadian ecosystem. Justify your response.

**Key 5:**

- a. *The hare population is much larger than that of the hare although both show rises and falls in approximately 10 year cycles. Rises in hare populations precede rises in lynx populations and drops in lynx populations come after those in hare populations.*
- b. *Answers may vary but the basic idea is that these data represent a predator prey relationship. When hare populations are high, lynx have more food. This extra energy availability allows lynx populations to flourish. As the lynx increase in number, they reduce the hare population eventually causing a decline in available energy that causes their own populations to decrease. This promotes growth in the hare population who flourish in the absence of fewer predators and so on into the next cycle.*
- c. *The fox is another predator of hares. It would be a direct competitor to the lynx and reduce the energy available to it. This would cause both hare and lynx populations to drop to lower overall levels, although the cycle may be unchanged in period.*

Essential knowledge 2.D.1: All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy.

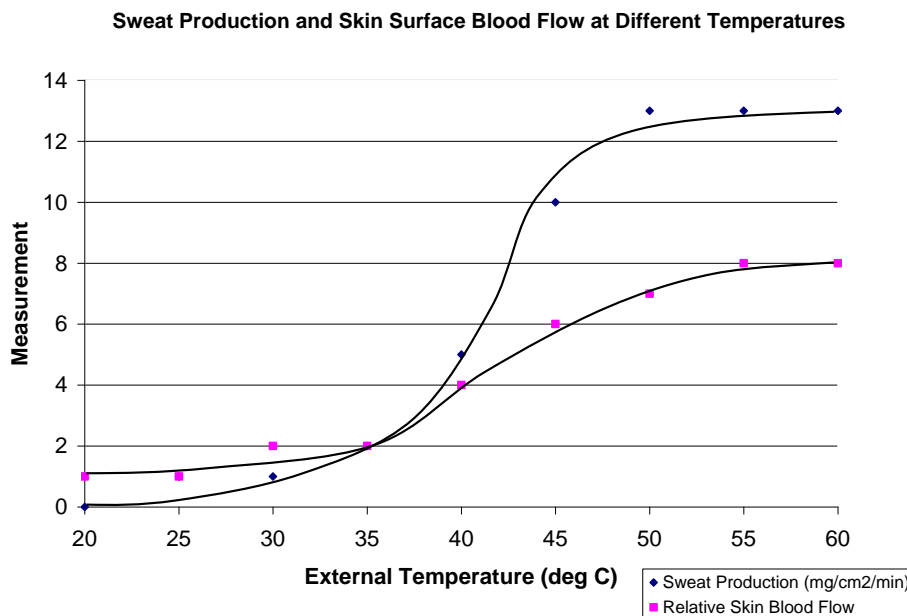
Essential knowledge 2.D.3: Biological systems are affected by disruptions to their dynamic homeostasis.

Learning Objective:

LO 2.24 The student is able to analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system (cells, organisms, populations, communities or ecosystems). [See SP 5.1]

LO 2.28 The student is able to use representations or models to analyze quantitatively and qualitatively the effects of disruptions to dynamic homeostasis in biological systems. [See SP 1.4]

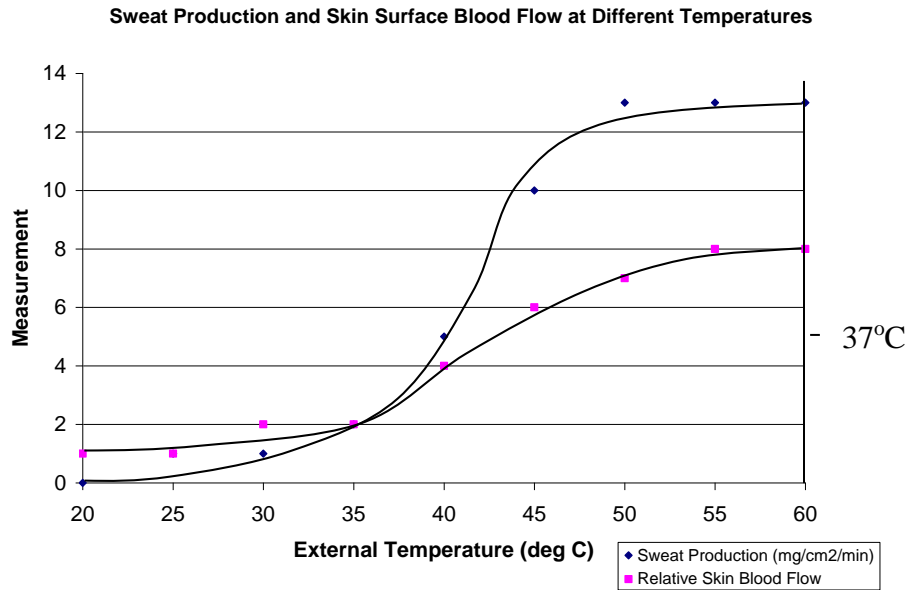
6. Temperature regulation is crucial in animals to optimize biological functions and maintain life processes. To explore thermoregulation in humans, a student conducted the following investigation on several of her classmates. Individually, each subject was seated comfortably in a t-shirt and shorts in a small room whose temperature and humidity could be controlled (i.e. a sauna). The subject was fitted with a probe to measure the flow of blood at the skin's surface on the left forearm. A 16cm<sup>2</sup> rectangular piece of absorbent gauze was taped to the right forearm and covered with an impermeable layer of tape. The temperature in the room was increased from 20°C at 2 degree intervals up to 40 °C. Each temperature was maintained for 5 minutes. At the end of each 5 minute period, the absorbent gauze was replaced with a fresh piece. The used gauze was weighed and the amount of sweat absorbed by it was calculated. This weight was converted into a sweat production figure measured in mg/ cm<sup>2</sup>/min. The data from each subject was tabulated, averaged and plotted (see graph 1). The body temperature of the subject was also measured and recorded at the beginning of the experimental period and subsequently at the end of every 5 minute temperature interval. The humidity of the room was held at 30%.



**Graph 1**

a. Describe the trends in data shown in graph 1.

- b. Describe the purposes and mechanisms of action of the changes in sweat production and blood flow in thermoregulation.
- c. On graph 2, draw a line indicating the internal body temperature change you would expect to find in the subjects over the course of the experiment. Assume the average initial temperature was 37°C. Justify your response.



**Graph 2**

- d. In a variant of the investigation, subjects were returned to the room the next day and the humidity of the room was adjusted to 95%. Predict the effect this would have on each of the measurements. Illustrate your prediction by adding lines to the graph using an appropriate key. Justify your response.

**Key 6:**

- a. *Students should clearly and accurately describe the shapes of each curve, including the plateau at the upper end.*
- b. *The purpose of each mechanism is to increase cooling in order to maintain body temperature as external temperature rises. Skin surface blood flow is controlled by arterioles that feed capillaries. As temperature rises arterioles dilate allowing greater flow of blood to surface, increasing radiative cooling. Sweat glands are stimulated to produce sweat as temperature rises. A layer of liquid sweat on the skin removes energy from the skin's surface in order to vaporize producing evaporative cooling.*
- c. *Drawn line should be straight up to the point of each plateau and then rise. **Justification** - Homeostasis is maintained by radiative and evaporative cooling. However, once these mechanisms have reached their maximum limit (there is a fixed amount of sweat produced and blood shunted to the surface) the body can no longer keep a stable temperature. Temperature will then become elevated.*
- d. *Both sweat production and skin blood flow lines should be accelerated reaching a plateau sooner. Temperature should remain constant until the plateaus and therefore begin to rise at a lower temperature than before. **Justification** – the rise in humidity makes sweating less effective for evaporative cooling as evaporation is reduced. The upper limits of both cooling mechanisms does not change but the attenuated cooling effects of sweating mean that body temperature rises at a lower external temperature than when sweating is more effective at a lower humidity.*

Essential knowledge 2.C.1: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.

Essential knowledge 2.C.2: Organisms respond to changes in their external environments.

Learning Objective:

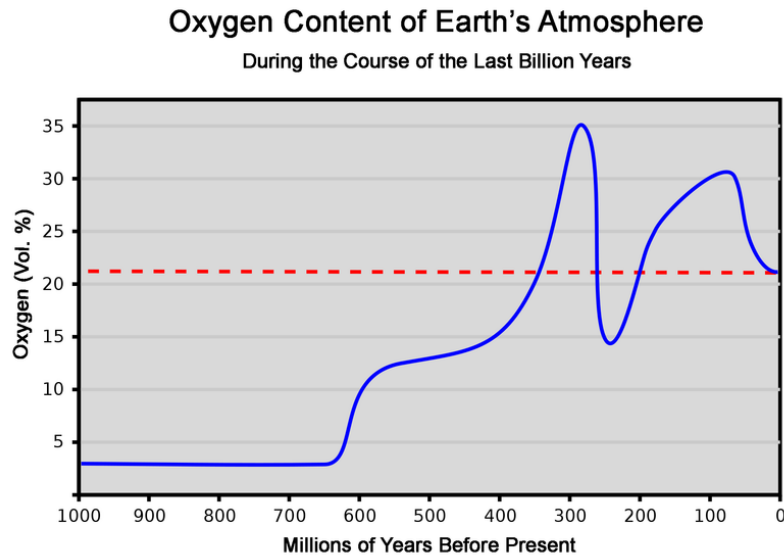
LO 2.15 The student can justify a claim made about the effect(s) on a biological system at the molecular, physiological or organismal level when given a scenario in which one or more components within a negative regulatory system is altered.

[See SP 6.1]

LO 2.16 The student is able to connect how organisms use negative feedback to maintain their internal environments. [See SP 7.2]

LO 2.18 The student can make predictions about how organisms use negative feedback mechanisms to maintain their internal environments. [See SP 6.4]

7. Over billions of years, the earth's atmosphere has changed composition due to various geological, climatological, and biological phenomena. The atmospheric concentration of oxygen over the last billion years can be seen in fig. 1.



**Fig. 1**

- Describe how the change around 600 million years ago in atmospheric oxygen was caused by an earlier change in the primary source of free energy for organisms on the earth.
- Explain how this change was accelerated by the compartmentalization of reactions in photosynthetic organisms.
- In the form of a flow chart, clear and labeled diagram, or well written paragraph, describe how electrons facilitate the production of oxygen in photosynthesis.

**Key 7:**

- a. *Prior to the evolution of photosynthesis, organisms used chemical free energy. They were either chemoautotrophic, relying on inorganic chemicals to produce food or later on, chemoheterotrophic, breaking down glucose and storing the energy in the form of ATP. Oxygen was not produced in either of these cases. With the advent of photosynthesis, light became the primary source of free energy. Its capture allowed the conversion of inorganic materials into glucose which could then be used to form ATP. Oxygen was produced in this process as water was hydrolyzed to replenish electrons removed from the enzyme complex critical to the photosynthetic process. As photosynthetic organisms flourished, the level of oxygen in the atmosphere increased. (note: initial free oxygen was spent in oxidizing iron and so levels of O<sub>2</sub> in the atmosphere did not begin to rise until much later than the evolution of photosynthetic bacteria.*
- b. *Chloroplasts are an efficient light capturing structure. Their double membranes make it possible to gather photons, and store this energy in ATP through a chemiosmotic process made possible only in the chloroplasts compartments. This is dependent upon a hydrogen ion gradient that is formed within the thylakoid structures of chloroplasts. The ATP generated (along with NADH) can then be used to power the production of glucose. The efficiency of this process requires the hydrolysis of water which releases oxygen as a by-product, adding much more free oxygen to the atmosphere than was possible before the advent of double-membrane based photosynthesis.*
- c. *Photon energy → stimulated electrons in PS I and II → resonance transfer of electron energy → ejection of electron from PS then:
  - i) → capture of electron energy by proton pump → capture of electron by NADP<sup>+</sup> and in parallel,
  - ii) water is hydrolyzed to produce an electron to replace that lost by the PS → oxygen (and H<sup>+</sup> and electrons) is produced as a result*

Essential knowledge 2.A.2: Organisms capture and store free energy for use in biological processes.

Essential knowledge 2.A.1: All living systems require constant input of free energy.

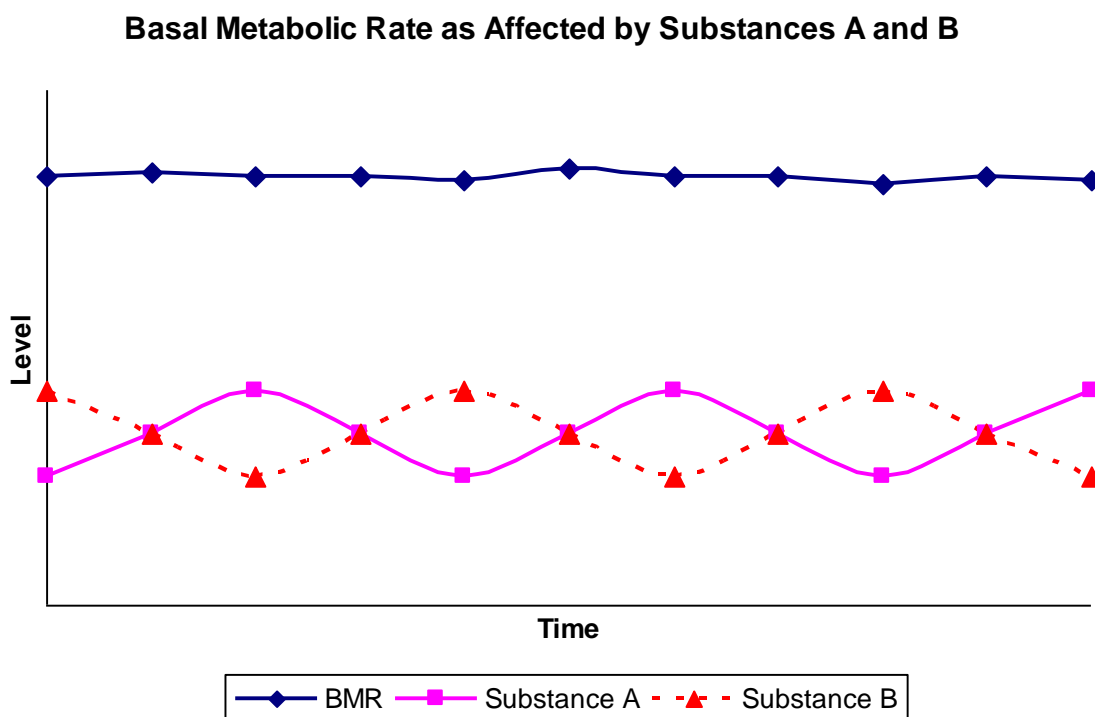
Essential knowledge 2.B.3: Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

Learning Objective:

LO 2.5 The student is able to construct explanations of the mechanisms and structural features of cells that allow organisms to capture, store or use free energy. [See SP 6.2]

LO 2.13 The student is able to explain how internal membranes and organelles contribute to cell functions. [See SP 6.2]

8. The basal metabolic rate (BMR) varies depending on the status of a complex series of enzymatic steps. In graph 1, the relationship between two substances in this system and BMR is shown. Substance A is a hormone that causes metabolism to speed up.



**Graph 1**

- Describe the relationship between substances A and B. How do you think B affects A?
- The body monitors the amount of A in the blood stream and adjusts levels of B accordingly. Assuming that levels of A and B are interdependent, predict what might happen if this monitoring system failed?
- Metabolic rate is one of many systems under allosteric control. Describe what allosteric control is and how it enables fine control of a complex system. Provide an example.



**Key 8:**

- a. *There is an inverse relationship between A and B. As rises as B falls and vice versa. B may cause a decrease in A so that when B is low, A is present in higher amounts and when B is high, A is reduced. This points to a negative feedback system.*
- b. *If it were not possible to monitor A correctly, the feedback loop would be broken. B would not be produced in response to high levels of A and would not have an inhibitory effect on it. Therefore, levels of A would rise without control. This would lead to an increase in metabolic rate.*
- c. *An allosteric mechanism is one in which in a series of enzymatically controlled events, a secondary substance modifies one of those acting in the primary series. This secondary substance, often a coenzyme, activates a primary enzyme allowing the latter to have its effect. Without the coenzyme, modification does not occur and the enzyme cannot act, bringing the cascade to a halt. Regardless of the amount of primary enzyme present, changes in the concentration of a coenzyme make this enzyme useful or not, thereby allowing fine control over the process. This type of control can be seen in the production of T3 by a series of reactions, the first of which is initiated in the presence of TSH, a coenzyme produced by the pituitary gland.*

Essential knowledge 2.C.1: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.

Learning Objective:

LO 2.15 The student can justify a claim made about the effect(s) on a biological system at the molecular, physiological or organismal level when given a scenario in which one or more components within a negative regulatory system is altered.

[See SP 6.1]

LO 2.16 The student is able to connect how organisms use negative feedback to maintain their internal environments. [See SP 7.2]