Theme 2: The Fundamental Unit of Life

Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Cells - cells and organelles of cells, functions of different organelles of cells
- Movement across the cells - osmosis, hypertonic/hypotonic/isotonic solutions, permeable/semi-permeable membranes

Zoom out Zoom in!

Imagine you are standing one metre away from a 10 storey building. What do you think would be the height of a building of this size? Most of the modern architectures have a standard height of 10 feet (around 3 metres) for each floor. Going by this estimate, the approximate height of this building would be around 30 metres. Can you see the entire building from where you are standing? What if you go away from the building? If you continue to move away from a building and nothing blocks your view of the building, what is the height of the tallest building that your eyes can see?

Fig. 2.1, Burj Khalifa, an 828 m tall building located in Dubai; Image by King of Hearts via Wikipedia

Now let us do the reverse. Imagine standing in front of Burj Khalifa in Dubai such that you can see the entire building. If the building got replaced by a giant ruler, you would see a ruler, which is almost a kilometre long, standing vertically. If you move closer to this ruler, what would be the length of the ruler you will be able to see if you stood one metre away from it? If you move closer and closer, what would be the smallest length that you will be able to see with your naked eye?

It is said that healthy human eyes can see objects as small as 0.1 mm without the support from any other instruments/tools. In practice, most human eyes would struggle to see anything smaller than 0.5 mm, which is 500 micrometres. If we want to see anything within the range of 1 micrometre, then we need microscopes.

Case Study A - Magnification of a Microscope

Fig. 2.2 shows the microscopic view of a plant skin. You may notice thick black lines forming square shapes around the cells. A grid of square shapes printed on a transparent sheet (see Fig. 2.3) has been fixed behind the lens of a simple (single lens) microscope (see Fig. 2.4) so that the structures viewed through the microscope show these squares around the microscopic structures. This can help in estimating the size of the structures.

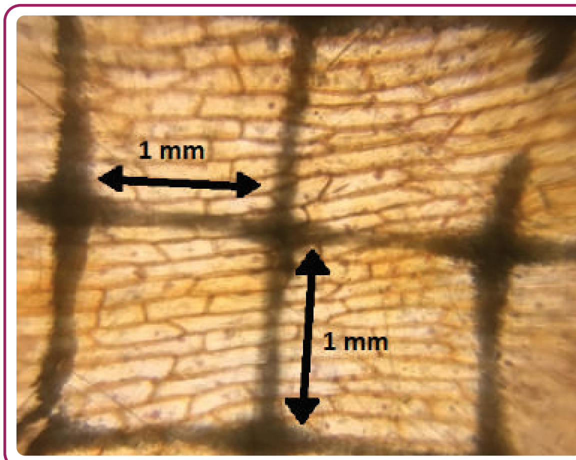


Fig. 2.2, Plant epidermal cells viewed through a microscope with a measurement grid of 1 mm x 1 mm stuck outside the microscope's lens

Question 1

i. If the size of each square of the grid is 1 mm x 1 mm, estimate the size of each cell and pick the option from below which matches the best. The first number in each option given below represents the height and the second represents the width. Note that 1000 µm = 1 mm and 1000 nm = 1 µm.

a. 100 nm x 300 nm	b. 300 μm x 100 μm	Answer
c. 100 μm x 300 μm	d. 0.5 μm x 1.5 μm	

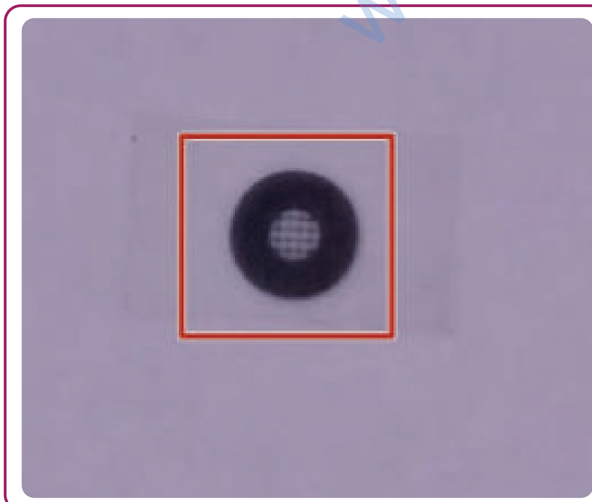


Fig. 2.3, Grid of square shapes printed on a transparent sheet

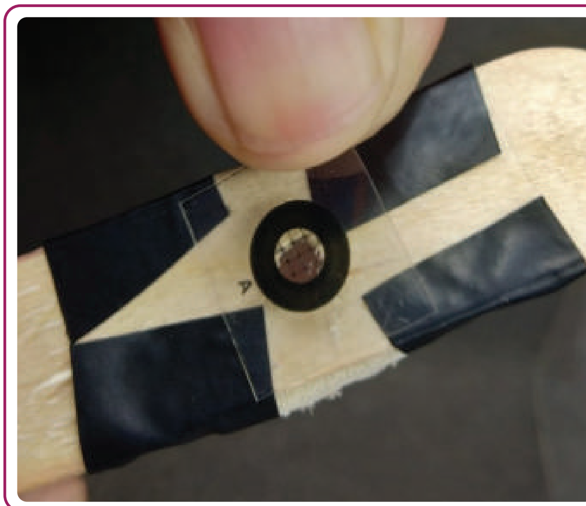


Fig. 2.4, Grid fixed behind the lens of microscope

ii. When the 1 mm x 1 mm squares are viewed through the microscope, they look bigger. What we see through the microscope is called the image of the square. As seen in Fig. 2.2, the size of the image of these squares is 3 cm x 3 cm. What is the magnification provided by this microscope? Refer to the given formula to calculate the magnification and write your answer in the space provided.

$$\textit{Magnification} = \frac{\textit{Size of the image of the object}}{\textit{Actual size of the object being viewed}}$$

Answer

Case Study B - Mitochondria

It is hard for the human eye to clearly see anything smaller than 0.5 mm. The size of the cells is in the µm range (around 100 times smaller than what our eyes can discern). What is inside the cells is even smaller. One of the organelles of a cell are mitochondria (singular: mitochondrion), which use oxygen to burn glucose and produce energy required by the cells. This is why they are also called the powerhouse of the cell.

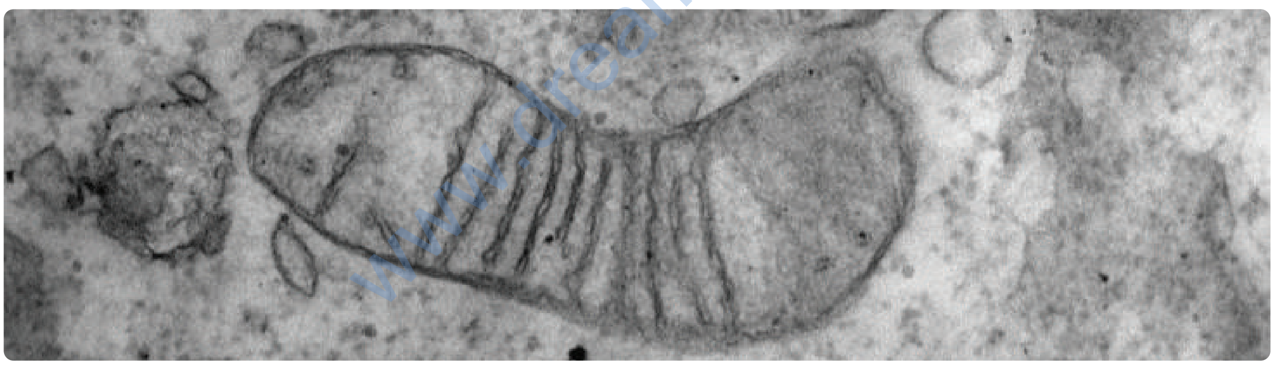


Fig. 2.5, Smiley face mitochondrion; Image cropped from image shared by Serge Golyshev via Flickr.com

Question 2

For i to iii, write the answer in the space provided after each.

i. Fig. 2.5 shows the image of a mitochondrion, magnified 25000 times through a microscope. The length of the image is 75 mm. What is the actual size of the mitochondrion?

Answer

ii. How many mitochondria of this size can you line up end to end between two of the mm marks on your ruler?

Answer

iii. While all living organisms are made up of cells, depending on the function performed by an organ, it is made up of different types of cells. Eg: the cells which communicate messages across the body, called the nerve cells, have a different design and internal structure when compared to the elastic muscle cells which make up parts, like the arm biceps or the pumping machine, our heart.

A study was conducted to find a correlation between the number of mitochondria present in a cell and the cell type. The graph shown in Fig. 2.6 captures this data for five different cell types. What can you infer about the energy requirement of cell type E when compared to other cell types? Justify your answer.

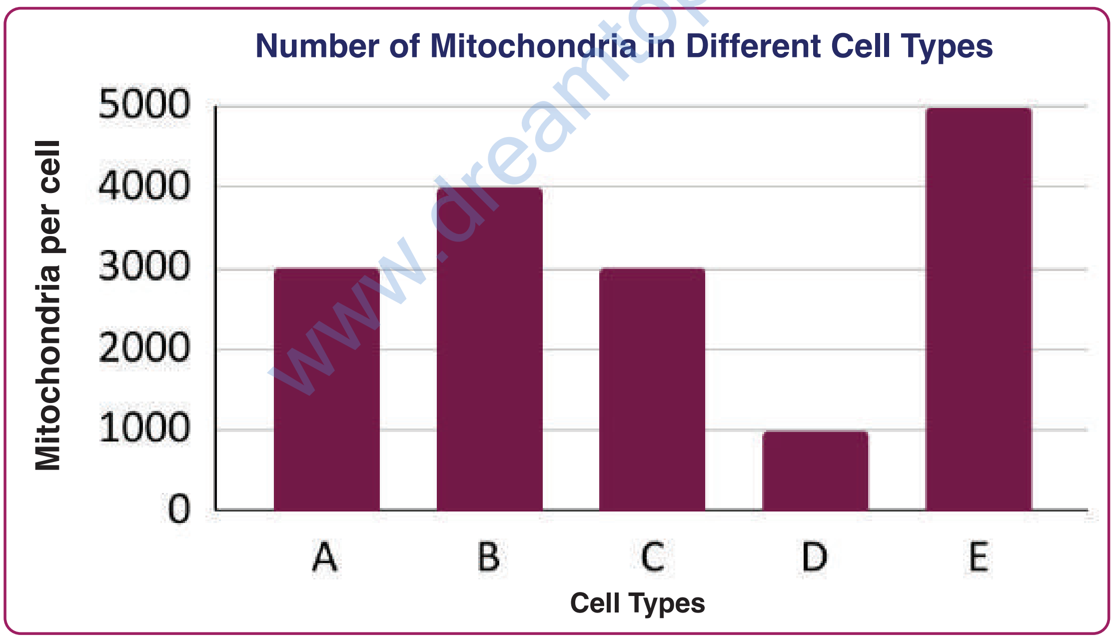


Fig. 2.6, Bar chart showing number of mitochondria per cell for different cell types.

Answer

Case Study C - Cell Fractionation

Cell fractionation is a technique for separating the components of a cell while preserving the functionality of each component. The process involves the following stages:

1. A tissue sample is first broken into small parts through chopping, grinding, etc., and placed in a medium, which can provide enough nutrition to the cells. This medium is cold and isotonic in nature.
2. After this, the solution with the cells is placed in a centrifuge, which is made to rotate at controlled speeds.

A centrifuge throws denser particles of the mixture further away (more than the lighter particles) from the centre of the circle around which it rotates. This leads to the separation. If the mixture was left undisturbed for a long time, the denser particles would sediment at the bottom due to the Earth's gravitational pull. By centrifuging, we speed up the process of sedimentation. Higher the speed with which the centrifuge rotates, faster is the sedimentation. When run at low speed, the macroscopic debris gets separated but the cells remain intact. The smaller organelles of the cell get separated only when the centrifuge is run at high speeds and further smaller ones get separated when centrifuged at very high speeds for a longer duration.

What gets collected at the bottom after centrifugation is often called the pellet. Table 2.1 shows different speeds at which a centrifuge is rotated during fractionation and the pellet contents, which get separated at each of those speeds.

Centrifuge Speed (G)	Pellet Content
Low speed (centrifuged for 10 mins)	Nuclei, cell debris
Moderate speed (for 20 mins)	Mitochondria, chloroplasts, lysosomes
High speed (for 60 mins)	Plasma membrane, pieces of endoplasmic reticulum
Very high speed (for 120 mins)	Ribosomes, some soluble enzyme complexes

Table 2.1, Centrifuge speed and pellet content at respective speed

Question 3

i. Based on the data given in Table 2.1, arrange the following organelles of a plant cell in the decreasing order of their size. Assume that the density of cell organelles is closely related to the size.

A. Chloroplast	B. Ribosomes
C. Plasma membrane	D. Nucleus

______________ > ______________ > ______________ > ______________

ii. Based on the data in Table 2.1, name any two cell organelles which have a similar size. Write your answer in the space provided.

Answer

Question 4

The case study section on cell fractionation specified some properties of the medium in which the tissue sample is placed. If these properties are not kept in mind, the objectives of cell fractionation may not be met. What do you think will happen if the medium was hypotonic? Why? Recall that a hypotonic solution will have a fewer number of solutes dissolved in it compared to the solute concentration inside the cells.

a. Cell organelles may get damaged because water may exit from the cell

b. Separation of organelles won't be possible since cells will start multiplying as water from the medium enters the cells

c. Cell organelles may get damaged due to water from the medium entering the cell

d. Centrifugation requires a liquid medium, but since water will exit from the cells, centrifugation and hence the separation of organelles won't be possible

Answer

Case Study D - Osmosis

The difference between the concentration of solutes inside a cell and that in its environment plays a major role in the movement of fluid and nutrition into and from a cell. This movement of fluid is called osmosis, which happens across a layer with small holes. The holes are small enough for the solute to not pass through but big enough for the solvent. This means if you had a bag containing sugar water where the pores (holes) in the bag are small enough to prevent sugar molecules from coming out, then sugar won't move out easily. However, if the pores are big enough for the smaller molecules of water to pass through, then water will move across the bag. When such a bag is placed in plain water, more molecules of water will move into the bag from outside compared to those moving out from the bag. Eventually the bag will have more water than before. In this case, the bag is acting as what is known as a semipermeable membrane, since it is permeating water to come in but not the sugar molecules to go out.

A plant cell has a cell membrane as well as a cell wall outside the membrane. The cell wall gives regular shape and rigidity to the cell. It has big pores and is considered fully permeable.

Question 5

A plant tissue sample is placed in distilled water. Predict if any water movement will happen into/outside the cells. Also identify the permeability of the layers relevant here, through which water will / will not pass through.

a. Water will enter the cells; cell wall and cell membrane are both fully permeable

b. Water will enter the cells; cell wall is fully permeable and cell membrane is semipermeable

c. Water will come out of the cells; cell wall and cell membrane are both fully permeable

d. Water will come out of the cells; cell wall is fully permeable and cell membrane is semipermeable

Answer

Case Study E - Explore Osmosis

The following experiment setup was prepared to understand osmosis.

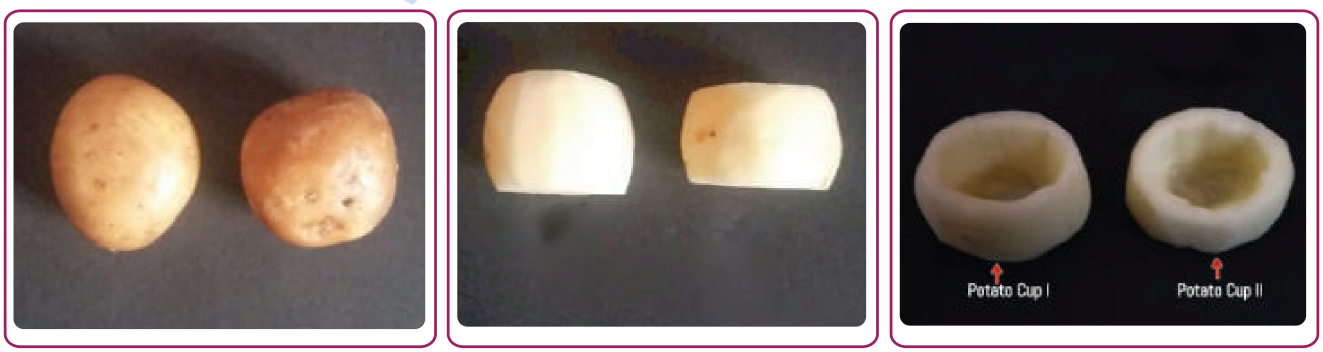


Fig. 2.7, A potato is taken and cut in half after removing the peel.
A cup shaped cavity is carved in the middle of each potato half.

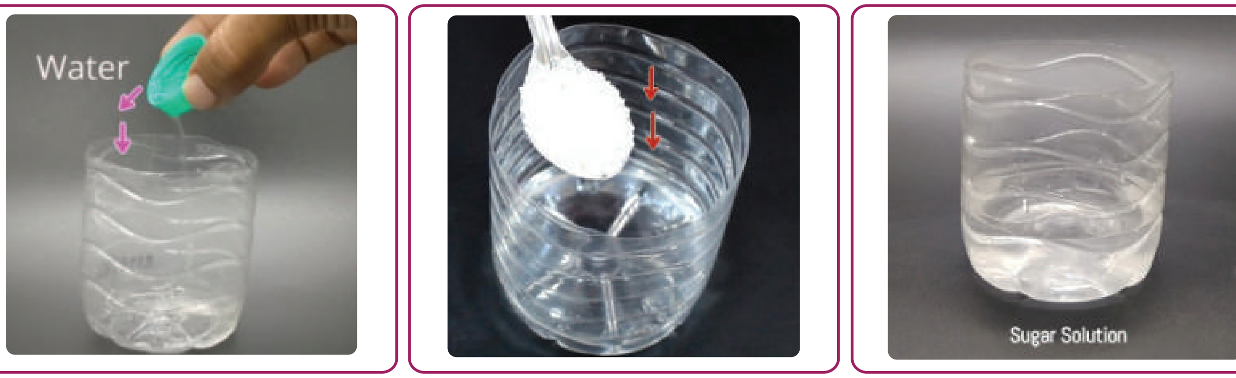


Fig. 2.8, 50 ml of sugar solution is prepared with 7% concentration, i.e. 3.5 g sugar dissolved in 50 ml water

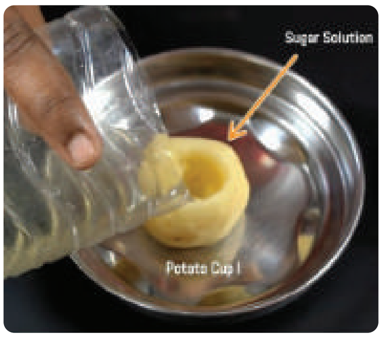


Fig. 2.9, Sugar solution poured in the cavity of Potato Cup I

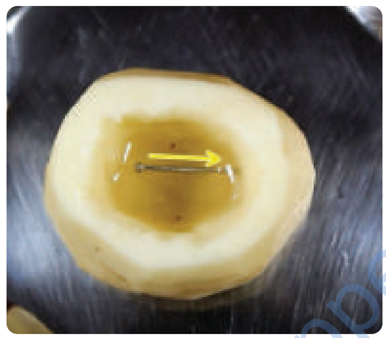


Fig. 2.10, Level of sugar solution marked using a paper pin

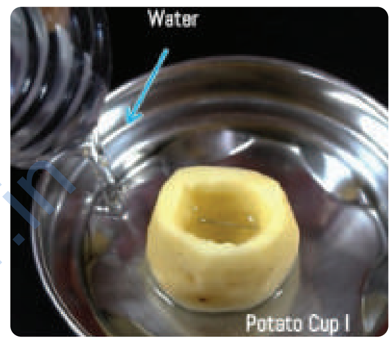


Fig. 2.11, Plain drinking water poured outside Potato Cup I. This is **Setup A**.

Fig. 2.12, Plain drinking water poured in the cavity of Potato Cup II

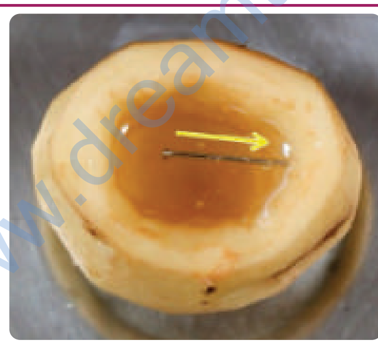


Fig. 2.13, Level of drinking water marked using a paper pin

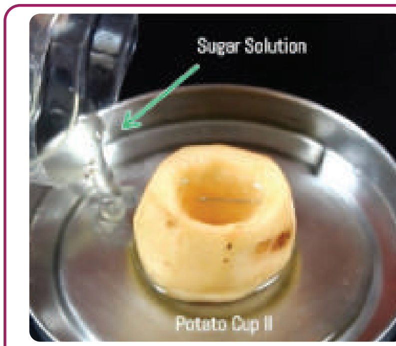


Fig. 2.14, Sugar solution poured outside Potato Cup II. This is **Setup B**.

Place both the setups aside for 3 hours and observe the level of water inside the cavity of the potato cups.

Question 6

i. Predict what will happen in Setup A after it is left aside for 3 hours.

a. Water goes below the pin level
b. Water goes above the pin level
c. Water level remains unchanged

Answer

ii. Predict what will happen in Setup B after it is left aside for 3 hours.

a. Water goes below the pin level
b. Water goes above the pin level
c. Water level remains unchanged

Answer

Question 7

What is the role of the paper pin in the osmosis experiment described in Fig. 2.7 to 2.13? Write your answer in the space provided. Also state the properties of the pin which make it suitable for this role.

Answer

Question 8

Another setup, which was the same as Setup B, was created. The only difference here was that the potato peel was not removed from the bottom of the potato before placing it in sugar solution. The results were different when compared to Setup A and B. It was observed that the water level remained unchanged after the setup was left undisturbed for 3 hours. Explain the results in the space provided.

Answer

Question 9

In one of the potato cup setups, it was observed that the water level inside the cavity goes above the level marked by the paper pin. The time taken for the water level to go above the paper pin was observed and recorded. The concentration of sugar solution was varied and in each case, the time taken to cross the paper pin level was observed. The graph shown in Fig.2.15 plots the time taken for different concentrations of sugar. The concentration of sugar was measured in terms of the number of grams of sugar dissolved in 100 ml of water.

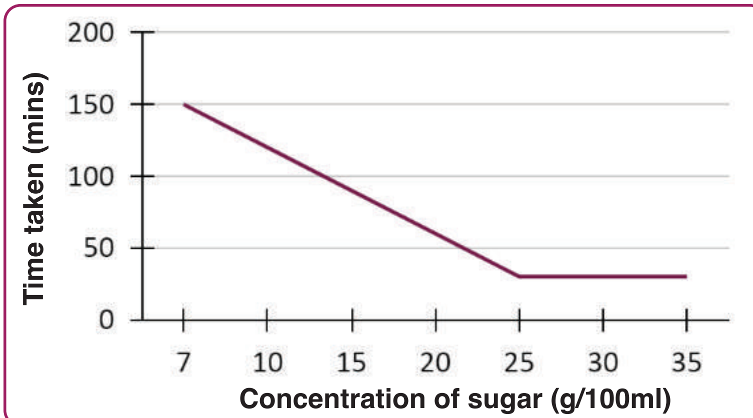


Fig. 2.15, Graph plotting concentration of sugar vs time taken for water level to go above the pin

What can you conclude about the impact of concentration of the solute on the rate of osmosis, based on this data? Pick the most suitable option out of the following.

a. Rate of osmosis decreases as the concentration of the solute is increased

b. Rate of osmosis decreases as the concentration is increased till a certain limit and remains constant after that

c. Rate of osmosis increases as the concentration of the solute is increased

d. Rate of osmosis increases as the concentration is increased till a certain limit and remains constant after that

Answer

Question 10

An onion peel, labelled as Sample 1, was placed in a hypertonic solution for 8 hours and then observed under the microscope. Another one, labelled as Sample 2, was placed in a hypotonic solution. Which of the following pictures represents Sample 1 and Sample 2? Write your answer in the blank space provided next to the sample name.

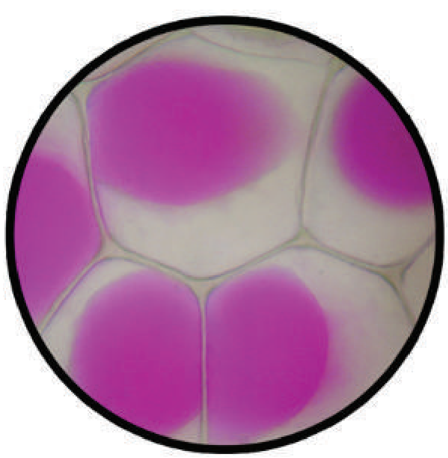


Fig. 2.16, **Picture A**, Epidermis of Rhoeo Discolour; Image by mnolf via Wikipedia

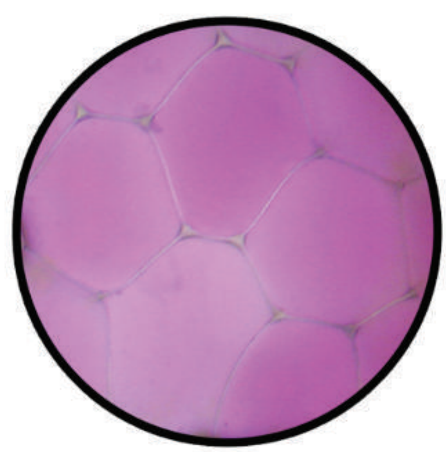
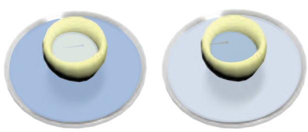


Fig. 2.17, **Picture B**, Epidermis of Rhoeo Discolour; Image by mnolf via Wikipedia

i. Sample 1 ---> Picture ________________________________

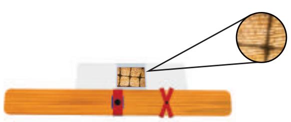
ii. Sample 2 ---> Picture ________________________________

Exploration Pathway



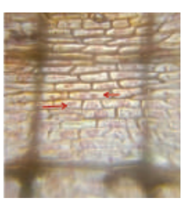
Explore Osmosis

Osmosis is the process by which solvent molecules move from a less concentrated to a more concentrated solution through a semi-permeable membrane. This process is vital in all kinds of biological scenarios (in our kidneys, in plants etc), as well as human applications (e.g. water filters). Here, we use a potato to demonstrate two different kinds of osmosis - endosmosis and exosmosis.



Microscope - Epidermal Cells

The onion peel is so fascinating because with your bare hands, you can easily peel off a unicellular layer from this very tasty stem vegetable. This peel can then be placed on a microscope slide and "stained", so that you may observe the wonderful brick-like structure of onion plant cells through your own DIY Microscope



Explore Plasmolysis

Plasmolysis is the process in which cells lose water in a hypertonic solution. In this TACtivity, we use an onion peel or epidermis of some leaves to observe the process of plasmolysis under a DIY Microscope.