Topic: Mechanism of Stomatal Movement
B.Sc. Botany (Sub.) II
Group: C
Dr. Sanjeev Kumar Vidyarthi
Department of Botany
Dr. L.K.V.D. College, Tajpur

Mechanism of Stomatal Movement

The stomata are very minute apertures, usually found on the epidermis of the leaves. Each stoma is surrounded by two kidney-shaped special epidermal cells, known as guard cells.

The stomata may be found in all the aerial parts of the plant. They are never found on its roots. The epidermal cells surrounding the guard cells of the stoma are known as accessory or subsidiary cells. Usually the term stoma stands for the stomatal opening and the guard cells.

The guard cells are always living and contain chloroplasts. These cells, however, contain much amount of protoplasm than the other ordinary cells. Usually the stomata are found scattered on the dicotyledonous leaves whereas they are arranged in parallel rows in the case of monocotyledonous leaves. The number of stomata may range from thousands to lacs per square centimeter on the surface of the leaf.

The stomata may be found on both the surfaces of the leaf, but their number is always greater on the lower surface. However, the upper surface of the leaves of banyan and rubber trees lack stomata. The upper surface of the leaves of several xerophytes also lacks the stomata.

The free floating leaves of the water plants bear stomata only on their upper surface. In normal condition the stomata remain closed in the absence of light. They are always open in the day time or in the presence of light.

Stomatal Opening and Closing

Each stoma is surrounded by two guard cells. The kidney-shaped guard cells contain chloroplasts. A respiratory cavity or chamber is found under each stoma. The mechanism of the

closing and opening of the stomata depends upon the presence of sugar and starch in the guard cells. During day time or in the presence of light, the guard cells of the stomata contain sugar synthesized by their chloroplasts.

The sugar is soluble and increases the concentration of the sap of guard cells. Due to higher concentration of the cytoplasm of guard cells, the water comes to them from the neighbouring cells by osmosis and they become turgid. With the result the stomata remain open.

In the night or in the absence of light the sugar present in guard cells converts into the starch. The starch is insoluble, and this way the cell sap of the guard cells remains of much lower concentration than those of neighbouring cells, and the neighbouring cells take out the water from the guard cells by osmosis making them flaccid and the stomata closed.

The conversion of sugar into starch during night and vice-versa in day time depends upon the acidity (pH) and alkalinity of the cell sap of guard cells. During night there is no photosynthesis and the carbon dioxide accumulates in the guard cells, converting the cell sap into weak acidic starch.

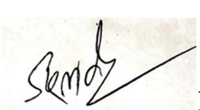
During day time the carbon dioxide is used in the process of photosynthesis, the cell sap becomes alkaline and the starch converts into sugar.

Concentration of CO_2 hypothesis by Bonner and Galston

Bonner and Galston have proposed the following mechanism of opening and closing of stomata. This depends upon the concentration of the carbon dioxide (CO_2) found in the stomatal chamber and not upon the presence or absence of light.

Normally .03% of carbon dioxide is found in the atmosphere, and when the density of the CO_2 in the sub-stomatal chamber also remains .03%, then the guard cells become flaccid and the stomata closed.

As the density of CO_2 retards gradually, the stoma begins to open and it opens gradually lengthwise until the density of CO_2 becomes .01%. Now the stomata are perfectly open and they are not open further beyond this density.



The photosynthesis takes place in day time and much of the carbon dioxide is being used in the process, the density becomes lesser than .03% and the stomata remain open during day time. During night or in the darkness, there is no photosynthesis, the density of carbon dioxide remains .03%, the guard cells remain flaccid and the stomata closed.

Active Potassium (K+) Theory

Role of potassium K+ in stomatal opening is now universally accepted. This was observed for the first time by Fujino (1967) that opening of stomata occurs due to the influx of K^+ ions into the guard cells.

The sources of K^+ ions are nearby subsidiary and epidermal cells, thereby increasing the concentration from 50 mM to 300 mM in guard cells. The increase in K^+ ions concentration increases the osmotic concentration of guard cells thus leading to stomatal opening. The uptake of potassium K^+ controls the gradient in the water potential.

This in turn triggers osmotic flow of water into the guard cells raising the turgor pressure. ATP helps in entry of K^+ ions into the guard cells. Levitt (1974) observed that proton (H^+) uptake by guard cell's chloroplasts takes place with the help of ATP. This leads to increase in value of pH in guard cells. Rise in pH converts starch into organic acid, such as malic acid.

$$\text{Starch} \rightarrow \text{phosphoglyceric acid} \xrightarrow{\text{carboxylase}} \text{Phosphophenol pyruvic acid} + CO_2$$

$$\downarrow$$

$$\text{Oxaloacetic acid}$$

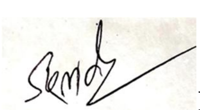
$$\downarrow$$

$$\text{Malic acid}$$

Malic acid further dissociates to form H^+ and malate anion. The uptake of potassium K+ ions is balanced by one of the following-

- Uptake of Cl^-
- Transport of H^+ ions from organic acids, such as malic acid
- By negative charges of organic acids when they lose H^+ ions.

The accumulation of large amounts of K^+ ions in guard cells is electrically balanced by the uptake of negatively charged ions, i.e., chloride and malate. The high amount of malate in guard cells of open stomata accumulates by hydrolysis of starch.



The stomatal closure is considered to be brought about by a passive or highly catalysed excretion of K^+ and CI^- from the guard cells to the epidermal tissue in general and subsidiary cells in particular. It is thought that subsidiary cells have an active reabsorption mechanism of K^+.

Factors Affecting Stomatal Movement

Most prominent factors that affect stomatal movement (opening and closing of stomata) include-

i. Light,

ii. Temperature,

iii. Water availability to plants, and

iv. Carbon dioxide (CO_2) concentration.

i. Light

Light has strong controlling influence on stomatal movements. Stomata generally open in light and close in darkness. The amount of light required to achieve optimum stomatal opening varies from species to species.

For example, some plants, such as tobacco require low light intensities, while others may require full sunlight. However, light intensity required to open the stomata is very low, as compared to the intensity required for photosynthesis.

The stomata of plants showing CAM (Crassulacean Acid Metabolism) are exceptional, as they open at night and close during the day. Even moonlight is sufficient to keep the stomata open in some CAM plant species.

This unique behaviour of stomata is a kind of adaptation to conserve moisture in CAM plants, such as pineapple, agave, aloe, etc. The period during which stomata remain open in daylight and close at night varies from species to species of plants. The effect of different wavelengths of light on stomatal movement also varies.

ii. Temperature

Usually an increase in temperature leads to increase stomatal opening provided water does not become a limiting factor. In some plant species, stomata remain closed even under continuous light at 0°C.

For example, in Camellia (tea plant), stomata do not open at very low temperature (below 0°C) even in strong light. However, if the temperature is increased, stomatal opening in such species increases. At temperatures higher than 30°C, there is decline in stomatal opening in some species.

iii. Water Availability

When availability of water is less, and rate of transpiration is high, plants undergo water stress. Water stress is also called water deficit or moisture deficit. Such plants begin to show signs of wilting and are known as water-stressed plants.

Most of the mesophytes under such conditions close their stomata quite tightly and completely in order to protect them from the damage which may result due to extreme water shortage. The stomata reopen only when water potential of these plants is restored. This type of control of stomatal movement by water is called hydro-passive control.

Accumulation of phytohormone abscisic acid (ABA) in the guard cells of several water stressed plants is now well established. The ABA causes stomata of such plants to close.

When water potential of water-stressed plant is restored, the stomata reopen and ABA gradually disappears from the guard cells. The type of control of stomata by water, mediated through ABA, is called hydro-active control. Externally applied ABA to leaves of normal plants also induces closure of stomata.

iv. Carbon Dioxide (CO_2) Concentration

CO_2 concentration has pronounced effect on stomatal movement. Reduced CO_2 concentration favours opening of stomata while an increase in CO_2 concentration causes stomatal closing. This happens even under the light. In certain species of plants, stomata also close merely by breathing near leaves.

The stomata which are forced to close by increased CO_2 concentration, do not reopen rapidly simply by flushing the leaf with CO_2 free air, and in dark. However, during subsequent light exposure, such stomata open soon.

This happens because CO_2 trapped inside the leaf is consumed in photosynthesis during light exposure. This shows, it is the internal leaf CO_2 concentration rather than the atmospheric carbon dioxide that is responsible for stomatal opening.

However, the cuticle present over the guard cells and epidermal cells is quite impermeable to CO_2 and ensures response of stomata to CO_2 present in the leaf rather than that of outer atmosphere.

Number of Stomata on Upper and Lower Surfaces of Leaves

Plants	Number of Stomata/mm²	
	Upper surface	Lower surface
Monocot		
Wheat	50	40
Barley	70	85
Onion	175	175
Dicot		
Sunflower	120	175
Alfalfa	169	188
Geranium	29	179

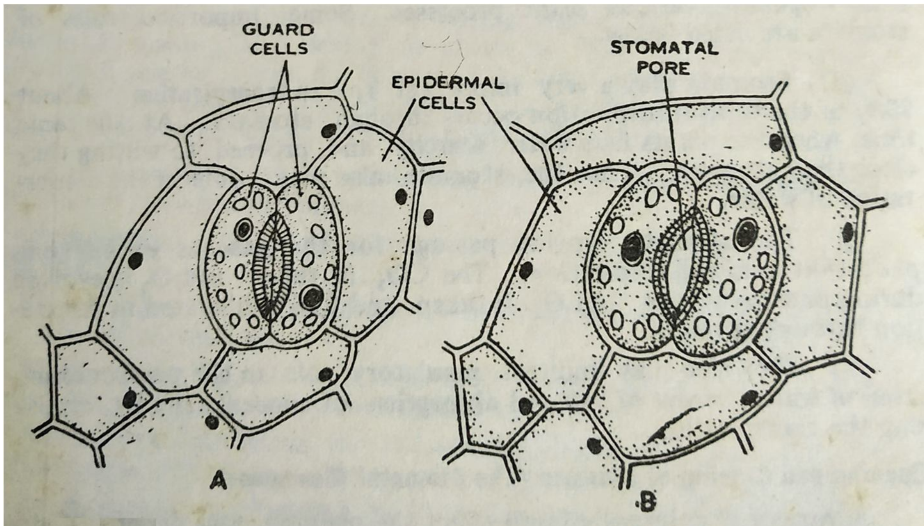


Fig. Stomatal apparatus ; A—closed stomata, B—open stomata.

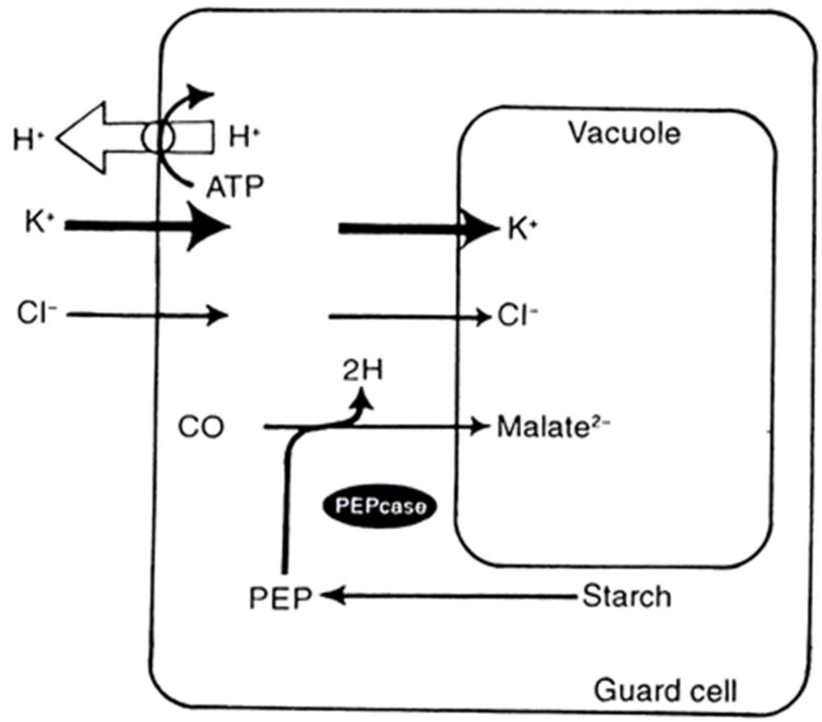


Fig. Role of potassium K^+ ions in stomatal opening.

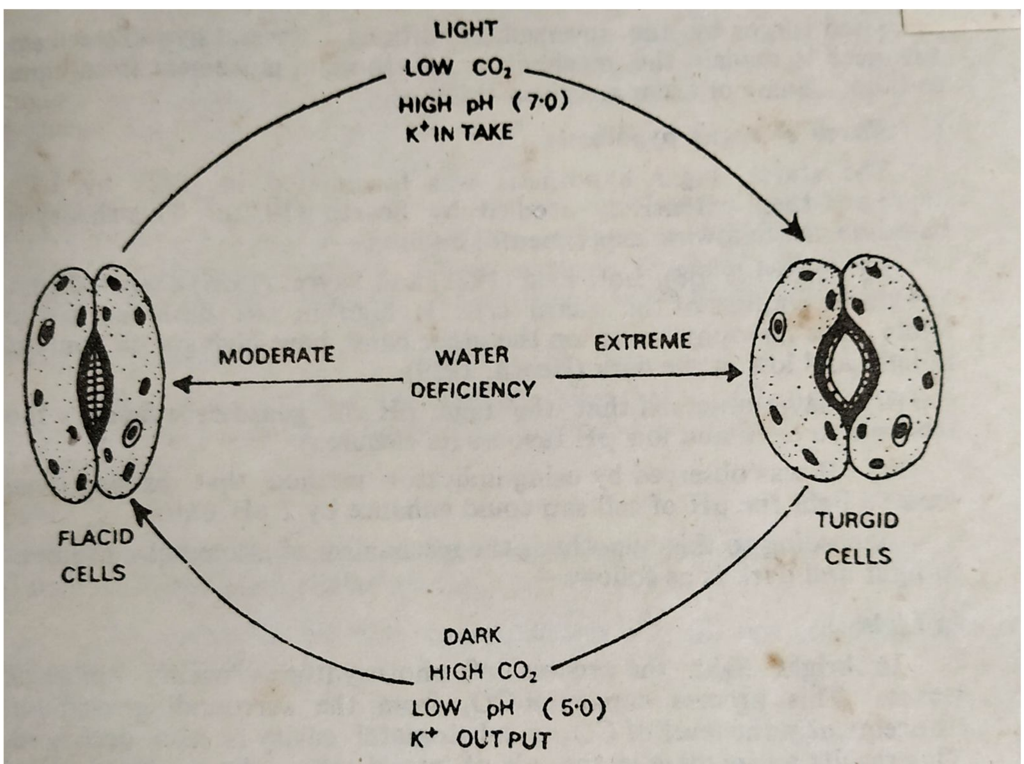


Fig. Diagram showing normal responses of stomata to light, CO_2, pH, K ion and water deficiency.