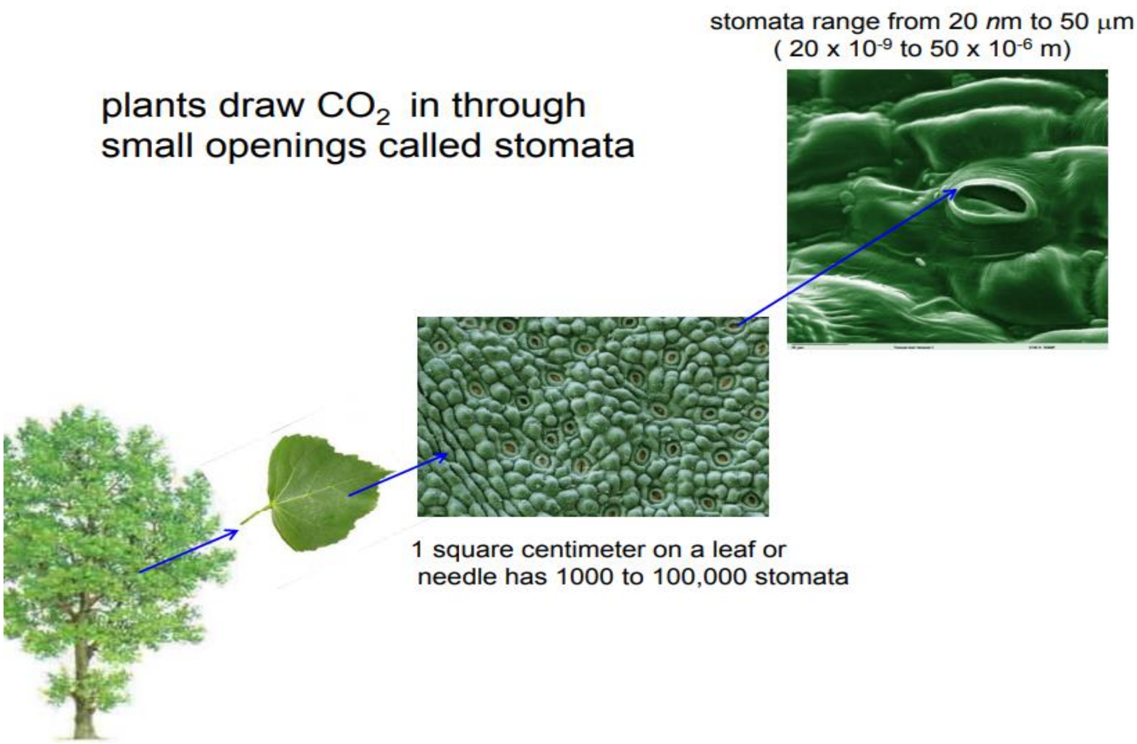
TRANSPIRATION

Transpiration is the process by which water is drawn from the soil through the plant as a result of evaporation from the leaves. Surfaces exposed to the air are generally covered with a layer which resists water loss. **Stomata** in the leaf surface permit water loss by evaporation from the leaf. Most transpiration (90–95%) occurs through these pores. The rate of transpiration increases with temperature and with wind speed. Changing the stomatal aperture varies the rate of water loss in changing environmental conditions.



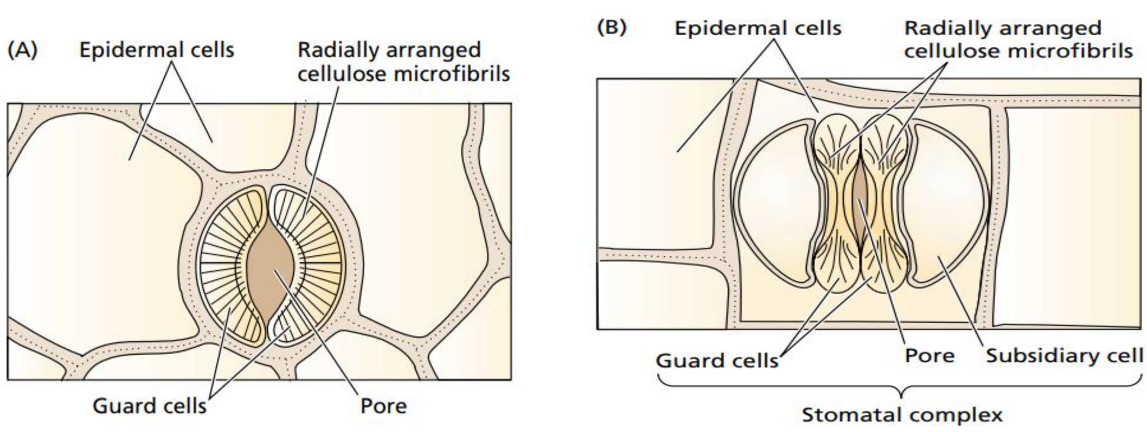
Leaves also absorb visible and invisible radiations of the Sun and get **heated** up. The water vaporizers and is given out in the atmosphere. This results in cooling down of the temperature of the leaves. As water vapor evaporates from the stomata it is replaced by water being pulled from the xylem. The water in the xylem is coming from the tree's roots. In other words, water is being pulled up through the tree by transpiration, Transpiration uses about **90%** of the water that enters the tree. The other **10%** is an ingredient in photosynthesis and cell growth and it is called the tree's sap.

The Cell Walls of Guard Cells Have Specialized Features

Guard cells show considerable morphological diversity, but we can distinguish two main types:

1. **Dumbbell shape**: One is typical of grasses and a few other monocots, such as palms; the other is found in all dicots, in many monocots, and in mosses, ferns, and gymnosperms. The pore proper is a long slit located between the two "handles" of the dumbbells. These guard cells are always flanked by a pair of differentiated epidermal cells called **subsidiary cells**, which help the guard cells control the stomatal pores. The guard cells, subsidiary cells, and pore are collectively called the **stomatal complex**.
2. **Kidney-shape**: In dicot plants and non- grass monocots, kidney-shaped guard cells have an elliptical contour with the pore at its center. Although subsidiary cells are not uncommon in species with kidney-shaped stomata, they are often absent, in which case the guard cells are surrounded by ordinary epidermal cells.

The alignment of **cellulose microfibrils**, which reinforce all plant cell walls and are an important determinant of cell
shape, plays an essential role in the opening and closing of the stomatal pore. In ordinary cells having a cylindrical shape, cellulose microfibrils are oriented transversely to the long axis of the cell. As a result, the cell expands in the direction of its long axis because the cellulose reinforcement offers the least resistance at right angles to its orientation. In guard cells the microfibril organization is different. Kidney-shaped guard cells have cellulose microfibrils fanning out radially from the pore. Thus, the cell girth is reinforced like a steel-belted radial tire, and the guard cells curve outward during stomatal opening. In grasses, the dumbbell-shaped guard cells function like beams with inflatable ends. As the bulbous ends of the cells increase in volume and swell, the beams are separated from each other and the slit between them widens.



The radial alignment of the cellulose microfibrils in guard cells and epidermal cells of (A) a kidney shaped stoma and (B) a grass like stoma. (From Meidner and Mansfield 1968.)

TYPES OF TRANSPIRATION

Transpiration can be of different types depending upon the specialized organ from where it is occurring.

1. **Stomatal** transpiration: It is the loss of water through specialized pores in the leaves. It accounts for around **80 to 90%** of the total water loss from the plants. Most of the transpiration takes place through stomata. Stomata are usually confined in more numbers on the lower sides of the leaves. In monocots. E.g. Grasses they are equally distributed on both sides. While in aquatic plants with floating leaves they are present on the upper surface.
2. **Cuticular** transpiration: Cuticle is an impermeable covering present on the leaves and stem. It causes only around **20%** transpiration in plants. It is further reduced due to a thicker cuticle in xerophytes.
3. **Lenticular** Transpiration: Lenticels are the tiny openings present on **the woody bark** through which transpiration occurs. Major part of water loss by deciduous trees during leafless stage.

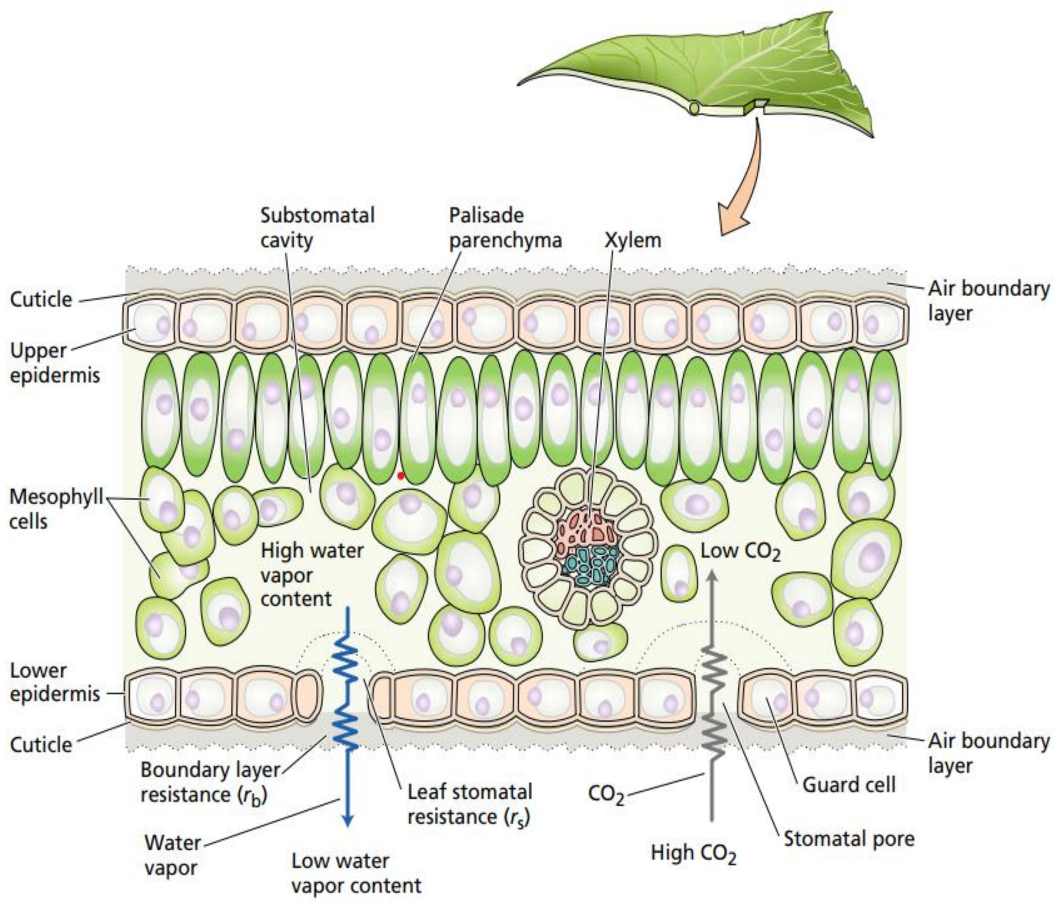
WATER MOVEMENT FROM THE LEAF TO THE ATMOSPHERE

The mechanism of stomatal transpiration which takes place during the day time can be studied in three steps

1. Osmotic diffusion of water in the leaf from xylem to intercellular space above the stomata through the mesophyll cells.
2. Opening and closing of stomata (stomatal movement)
3. Simple diffusion of water vapors from intercellular spaces to other atmosphere through stomata.

After water has evaporated from the cell surface into the intercellular air space, diffusion is the primary means of any further movement of the water out of the leaf. The waxy cuticle that covers the leaf surface is a very effective barrier to water movement. It has been estimated that only about 5% of the water lost from leaves escapes through the cuticle. Almost all of the water lost from typical leaves is lost by diffusion of water vapor through the tiny pores of the stomatal apparatus, which are usually most abundant on the lower surface of the leaf. On its way from the leaf to the atmosphere, water is pulled from the xylem into the cell walls of the mesophyll, where it evaporates into the air spaces of the leaf. The water vapor then exits the leaf through the stomatal pore. Water moves along this pathway predominantly by diffusion, so this water movement is controlled by the *concentration gradient* of water vapor. In **leaf mesophyll** there is an extensive system of **intercellular spaces** - present in cell walls - which correspond to the internal surface of water contact with the air. By this ***interface between the cell walls and the intercellular spaces*** is established a water **potential gradient**. Due to the water evaporation in the surface of the cell walls which are in contact with the air in the intercellular spaces.

The tensile strength is transmitted to the xylem that drives the upward flow of the water column from the root and is produced in the internal evaporation process in the leaves.



Plants have evolved over time to adapt to their local environment and reduce transpiration. Desert plant (xerophytes) and plants that grow on other plants (epiphytes) have limited access to water. Such plants usually have a much **thicker waxy cuticle** than those growing in more moderate, well-watered environments (mesophytes).

Water Loss Is Also Regulated by the Pathway Resistances

The important factor governing water loss from the leaf is the diffusional resistance of the transpiration pathway, which consists of two varying components:

1. **Leaf stomatal resistance (*r*s)**: resistance associated with diffusion through the stomatal pore.
2. **Boundary layer resistance (*r*b):** The resistance due to the layer of unstirred air next to the leaf surface through which water vapor must diffuse to reach the turbulent air of the atmosphere. The thickness of the boundary layer is determined primarily by wind speed. When the air surrounding the leaf is very still, the layer of unstirred air on the surface of the leaf may be so thick that it is the primary deterrent to water vapor loss from the leaf. Increases in stomatal apertures under such conditions have little effect on transpiration rate (although closing the stomata completely will still reduce transpiration). When wind velocity is high, the moving air reduces the thickness of the boundary layer at the leaf surface, reducing the resistance of this layer. Under such conditions, the stomatal resistance will largely control water loss from the leaf. Various anatomical and morphological aspects of the leaf can influence the thickness of the boundary layer. Hairs on the surface of leaves can serve as microscopic windbreaks. Some plants have sunken stomata that provide a sheltered region outside the stomatal pore. The size and shape of leaves also influence the way the wind sweeps across the leaf surface. Although these and other factors may influence the boundary layer, they are not characteristics that can be altered on an hour-to-hour or even day-to-day basis. For short-term regulation, control of stomatal apertures by the guard cells plays a crucial role in the regulation of leaf transpiration.

An Increase in Guard Cell Turgor Pressure Opens the Stomata

Guard cells function as multisensory hydraulic valves. Environmental factors such as light intensity and quality, temperature, relative humidity, and intracellular CO2 concentrations are sensed by guard cells, and these signals are integrated into well-defined stomatal responses.

If leaves kept in the dark are illuminated, the light stimulus is perceived by the guard cells as an opening signal, triggering a series of responses that result in opening of the stomatal pore. The early aspects of this process are ion uptake and other metabolic changes in the guard cells. Here we will note the effect of decreases in osmotic potential (Ψs) resulting from ion uptake and from biosynthesis of organic molecules in the guard cells. Water relations in guard cells follow the same rules as in other cells. As Ψs increases, the water potential decreases and water consequently moves into the guard cells. As water enters the cell, turgor pressure increases. Because of the elastic properties of their walls, guard cells can reversibly increase their volume by 40 to 100 %, depending on the species. Because of the differential thickening of guard cell walls, such changes in cell volume led to opening or closing of the stomatal pore.

Transpiration rate:

The effectiveness of plants in moderating water loss while allowing sufficient CO_2 uptake for photosynthesis can be assessed by a parameter called the **transpiration ratio**. This value is defined as *the amount of water transpired by the plant, divided by the amount of carbon dioxide assimilated by photosynthesis.*

For typical plants in which the first stable product of carbon fixation is a three-carbon compound (such plants are called C3 plants; about 500 molecules of water are lost for every molecule of CO_2 fixed by photosynthesis, giving a transpiration ratio of 500. (Sometimes the reciprocal of the transpiration ratio, called the *water use efficiency*, is cited. Plants with a transpiration ratio of 500 have a water use efficiency of 1/500, or 0.002.).

The large ratio of H_2O efflux to CO_2 influx results from three factors:

1. The concentration gradient driving water loss is about 50 times larger than that driving the influx of CO_2. In large part, this difference is due to the low concentration of CO_2 in air (about 0.03%) and the relatively high concentration of water vapor within the leaf.
2. CO_2 diffuses about 1.6 times more slowly through air than water does (the CO_2 molecule is larger than H_2O and has a smaller diffusion coefficient).
3. CO_2 uptake must cross the plasma membrane, the cytoplasm, and the chloroplast envelope before it is assimilated in the chloroplast. These membranes add to the resistance of the CO_2 diffusion pathway.

Some plants are adapted for life in particularly dry environments or seasons of the year. These plants, designated the C4 and CAM plants, utilize variations in the usual photosynthetic pathway for fixation of carbon dioxide. Plants with C4 photosynthesis (in which a four-carbon compound is the first stable product of photosynthesis) generally transpire less water per molecule of CO_2 fixed; a typical transpiration ratio for C4 plants is about 250.

Desert adapted plants with CAM (crassulacean acid metabolism) photosynthesis, in which CO2 is initially fixed into four-carbon organic acids at night, have even lower transpiration ratios; values of about 50 are not unusual.

Factor affecting rate of Transpiration

1. Atmospheric Humidity is inversely proportional to rate of transpiration.
2. Temperature is directly proportional to rate of transpiration.
3. Light intensity is directly proportional to rate of transpiration.
4. Wind velocity is directly proportional to rate of transpiration.
5. Carbon dioxide concentration is inversely proportional to rate of transpiration.
6. The factors like structure of leaf area of transpiring surface, number of stomata, orientation of leaf is included in the category.

Significance of transpiration:

- Aids in hydrological cycle.
- As transpiration helps in the movement of xylem sap, it increases the absorption of mineral nutrients by the roots from the soil.
- It causes cooling effect on leaf and plant surface. 80% of the cooling effect of a shade tree comes from the evaporative cooling effects of transpiration. This benefits both plants and humans.
- It produces suction pressure for absorption, ascent of sap, mineral translocation and distribution if minerals.
- It maintains turgidity: Water maintains the turgor pressure in cells much like air inflates a balloon, giving the non-woody plant parts form. Turgidity is important so the plant can remain stiff and upright and gain a competitive advantage when it comes to sunlight. Turgidity is also important for the functioning of the guard cells, which surround the stomata and regulate water loss and carbon dioxide uptake. Turgidity also is the force that pushes roots through the soil.