How does a pressure chamber work?

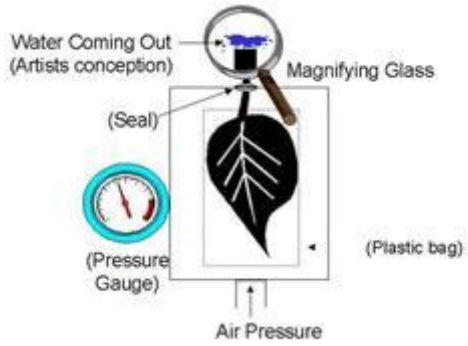
In simplest terms, the pressure chamber can be thought of as measuring the “blood pressure” of a plant, except for plants it is water rather than blood, and the water is not pumped by a heart using pressure, but rather pulled with a suction force as water evaporates from the leaves. Water within the plant mainly moves through very small inter-connected cells, collectively called xylem, which are essentially a network of pipes carrying water from the roots to the leaves. The water in the xylem is under tension. As the soil dries or humidity, wind or heat load increases, it becomes increasingly difficult for the roots to keep pace with evaporation from the leaves. This causes the tension to increase. Under these conditions you could say that the plant begins to experience “high blood pressure.”

Since tension is measured, negative values are typically reported. An easy way to remember this is to think of water stress as a “deficit”. The more the stress the more the plant is experiencing a deficit of water. The scientific name given to this deficit is the “water potential” of the plant. The actual physics of how the water moves from the leaf is more complex than just “squeezing” water out of a leaf, or just bringing water back to where it was when the leaf was cut. However, in practice, the only important factor is for the operator to recognize when water just begins to appear at the cut end of the petiole.

How a Pressure Chamber Works.

There are different types of pressure chambers, some using a tank of high pressure gas, some using a hand-pump, but all work on the same basic principle and in most cases the operation and use of the different types of pressure chambers is identical. This introduction gives examples using a hand-pump device that was developed here at UCD. Differing operational details will be noted in brackets [ ] for the pressurized tank style. All devices involve a potentially hazardous level of pressure however, and safety precautions related to the handling of the pressure chamber must be observed by the operator.

Principle of Operation



The Pressure Chamber

In simplest terms, the pressure chamber can be thought of as measuring the "blood pressure" of a plant, except for plants it is water rather than blood, and the water is not pumped by a heart using pressure, but rather pulled with a suction force as water evaporates from the leaves. Water within the plant mainly moves through very small interconnected cells, collectively called xylem, which are essentially a network of pipes carrying water from the roots to the leaves. The current model of how this works is that the water in the xylem is under tension, and as the soil dries, or for some other reason the roots become unable to keep pace with evaporation from the leaves, then the tension increases. Under these conditions you could say that the plant begins to experience "high blood pressure."

Simply put, the pressure chamber is just a device for applying air pressure to a leaf (or small shoot), where most of the leaf is inside the chamber but a small part of the leaf stem (the petiole) is exposed to the outside of the chamber through a seal. The amount of pressure that it takes to cause water to appear at the petiole tells you how much tension the leaf is experiencing on its water: a high value of pressure means a high value of tension and a high degree of water stress. The units of pressure most commonly used are the Bar (1 Bar = 14.5 pounds per square inch) and the Mega Pascal (1 MPa = 10 bars).

Because tension is measured, negative values are typically reported. An easy way to remember this is to think of water stress as a "deficit:" the more the stress, the more the plant is experiencing a deficit of water. The scientific name given to this deficit is the **"water potential"** of the plant. The actual physics of how the water moves from the leaf within the pressure chamber to the cut surface just outside the chamber is more complex than just "squeezing" water out of a leaf, or just bringing water back to where it was when the leaf was cut. In practice, however, the only important factor is for the operator to recognize when water just begins to appear at the cut end of the petiole.

What factors influence the measurement of water potential?

Using the Pressure Chamber in the Orchard

In addition to factors related to measurement technique there are two other factors which can influence tree water potential: l**eaf** and **plant.**

The most important **leaf** factor is the rate of water loss from the leaf at the moment of sampling. During the daytime, fully exposed, outer canopy leaves will lose water at a faster rate than shaded inner canopy leaves. A faster rate of water loss causes a more negative water potential. This factor can be eliminated, however, by covering the leaf for a minimum of about ten minutes prior to sampling, which is the recommended procedure. Covering stops the process of water loss. The water potential then equals the water potential in the stem where the leaf is attached. Water potential measured this way is called **stem water potential**.

The major advantage of stem water potential in trees is measurement uniformity: the type of leaf (spur leaf, shoot leaf), size or shape of leaf, and physiological condition of the leaf (nutritional status) has no influence on stem water potential. Leaf position within the canopy has a small effect, showing a slightly more negative stem water potential with increasing distance from the root system. For this reason the recommended leaf position in trees is from the lower canopy interior, close to the main trunk or scaffold branches.

The most important **plant** factors are: **weather conditions** at the time of sampling, **soil dryness**, and **root health**.

For a fully irrigated tree with a healthy root system, we have found that **weather conditions** can be taken into account using a table of expected, or *baseline values* corresponding to weather conditions of air temperature and relative humidity. Baseline tables have been established and confirmed for prunes and almonds (which have the same baseline values), and tables based on preliminary data are available for walnuts and pears. In all cases, hotter and dryer conditions cause a more negative stem water potential. For midsummer conditions in California the values of stem water potential measured on a fully irrigated prune or almond tree, for instance, will typically be between -6.0 bars and -10.0 bars.

The relationship of **soil dryness** to stem water potential is straightforward: as the soil becomes dryer, stem water potential will become more negative. The pressure chamber measures effective soil dryness throughout the root system as a whole. This is very different from soil-based monitoring methods, which only measure the soil in part of the root zone. Just after a full coverage irrigation (sprinkler or flood) stem water potential should correspond to the *baseline value*, and as the soil dries, stem water potential will become more negative than the *baseline*

value. For drip or micro-sprinkler systems that do not wet the entire soil, stem water potential may always be somewhat more negative than the baseline values, even after a full irrigation. This is probably due to the fact that some roots are in non-irrigated, dry areas of soil.

Root health will cause stem water potential to be more negative than the baseline, even under wet soil conditions. The process of root water uptake is not well understood, but any factor that influences root health, such as physical damage, damage by pests, infections by disease organisms, or poor soil aeration, will probably reduce the ability of roots to absorb water, and will cause stem water potential to be more negative than the baseline.

When is the best time of day to measure stem water potential?

Midday, from about 1:00 pm to 3:00 pm (daylight savings time) is the best time to measure stem water potential, because it corresponds to the time of maximum plant water stress (maximum water deficit). Midday is usually the time when weather conditions cause the maximum rate of water loss from the plant. This measurement is called **midday stem water potential**.

Definitions

We will assume that a leaf or leaflet is being used for the pressure chamber measurement, and that the leaf has been covered to prevent water loss, either for a long time while it is still attached to the plant, or just before removal from the plant. When a leaf is covered for a long time (we generally recommend about 2 hours) the measured water potential is called "stem water potential." In a variety of tree and vine crops it appears that stem water potential is the most sensitive of the two methods, so that method will be described here.

Leaf selection/covering

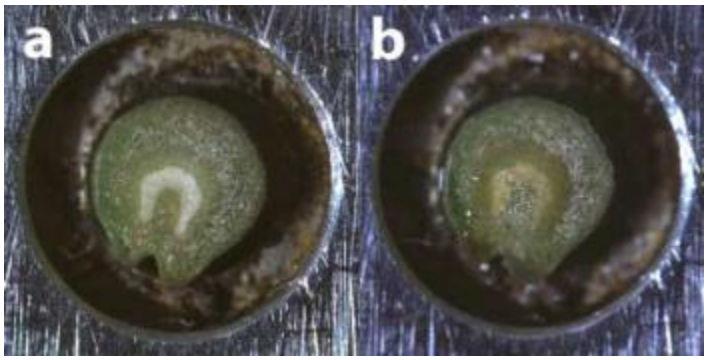
Sometime in the morning, a lower canopy leaf that is close to the trunk or a main scaffold is covered with a plastic/foil envelope (Fig.2 image gallery: Pressure Chamber). The recommended minimum time between covering and measuring in the pressure chamber is 10 minutes, but longer times (hours or days) are not a problem, as long as the leaf remains dry and undamaged. The leaf must be dry, in shade at the time of covering and should remain in shade until the time of sampling (Fig.3). Direct sunlight will cause the envelope to heat up, and can cause water condensation on the inside, which can artificially hydrate the leaf.

Sample Collection

It is most convenient to pick the leaf from the plant by gently snapping the leaf off at its connection to the spur or shoot, and then re-cut the leaf petiole with a sharp razor, at an angle, so that it easily slips through the seal. [For the pressure tank style it must be cut flat]. The leaf petiole is inserted through the sealing ring (Fig.4) of the chamber and then re-cut flush with the lid (Fig.5) after the seal is tightened. [For the pressure tank style, the leaf petiole is inserted through the seal so that after tightening there is at most 1 mm of petiole exposed outside of the chamber.]

Removal of the petiole by re-cutting has no influence on the pressure chamber measurement, nor does the degree of seal tightening, as long as the petiole remains intact and the endpoint can be clearly observed in both directions (see below). It is best that the minimum of petiole is left outside of the seal, however, because the more the petiole outside of the seal, the higher the pressure required to see the endpoint. If this is a small effect for your particular conditions then it will not be important, but may make it difficult for you to compare your values to published reference values or values obtained by others, and can generate unnecessary variation in your measurements. The leaf is then placed in the chamber (Fig.6) and lid sealed to the chamber. The details of how the lid is locked in place will depend on the chamber design.

Measurement



The petiole endpoint: a) when the xylem is dry, and b) when water comes out.

With the leaf inside the chamber, the measurement is made by simply increasing the pressure in the chamber by (Fig.7) until water begins to come out of the xylem that is exposed at the petiole cut surface. [For pressure tank style, the pressure is increased using a valve.] This is called the "endpoint." Usually, the pressure at which water appears is very definite, so that waiting a little too long for a lot of water, or stopping a little short if there is evidence that water is just beginning to come to the surface, does not correspond to much pressure difference. Using a hand lens, the water coming out of the petiole cut surface looks like an up-welling of water from a porous surface (Fig.8). The best endpoint is one where a small increase in pressure (say, 0.2 bar) causes a noticeable increase in the flow of water at the cut end, and where a decrease in pressure (sometimes this needs to be more like 1 bar) causes the water to disappear quickly back into the petiole.

The rate of pressure increase itself does not influence the measurement, unless it is so fast that the time taken to stop the pressurization or read the gauge causes overshoot. You should get nearly the same value if you re-measure the same leaf, especially when measuring stem water potential. This is essentially what you are doing when you reduce the pressure to see that water disappears into the petiole, and increase the pressure again until you see the endpoint. You should also get nearly the same value (typically within 0.3 bar) when you measure adjacent leaves on the same spur or shoot, so this is a good way to check your reproducibility or compare the effects of different operators or techniques.

Problems

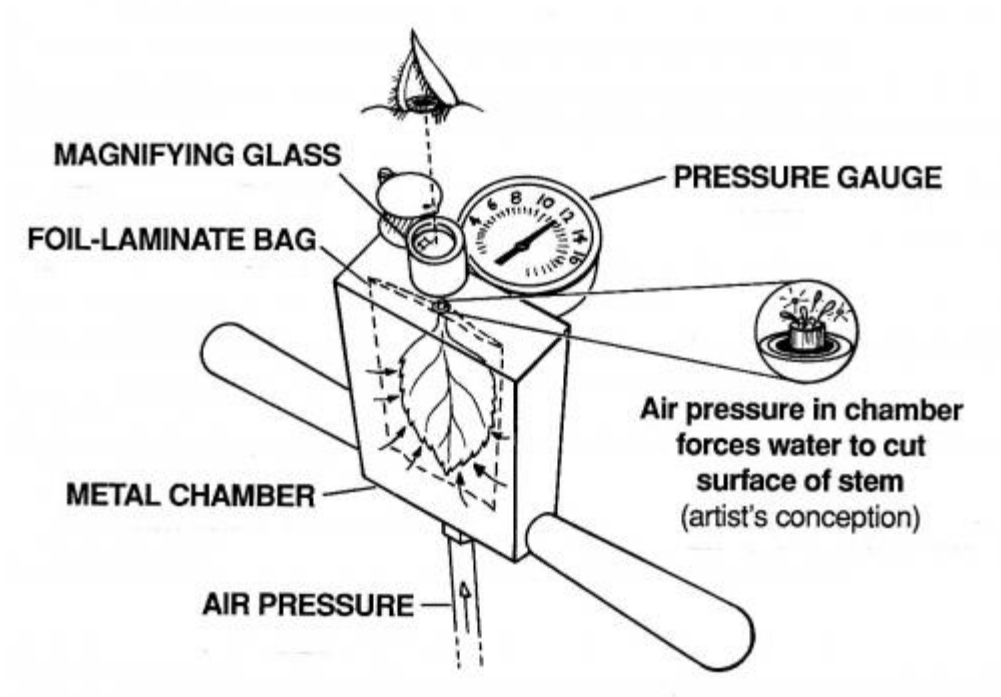
There are two common problems that can make the endpoint difficult to detect: bubbling and the appearance of non-xylem water. If there are breaks in the leaf inside the chamber, then air can be forced through the xylem and come out of the cut end. If this air pushes some water out, or if there is a little fluid from the cells at the cut surface, then the air coming out can bubble through the water, and it can look like there is water coming out when in fact it is just the same water being bubbled around. If this happens you can temporarily stop pressurization and dry the cut surface with a cloth or cotton swab. This should stop the bubbling, and allow you to continue the pressure increase. If the cut surface re-wets and starts bubbling immediately after being dried, then you are at (or may have past) the endpoint.

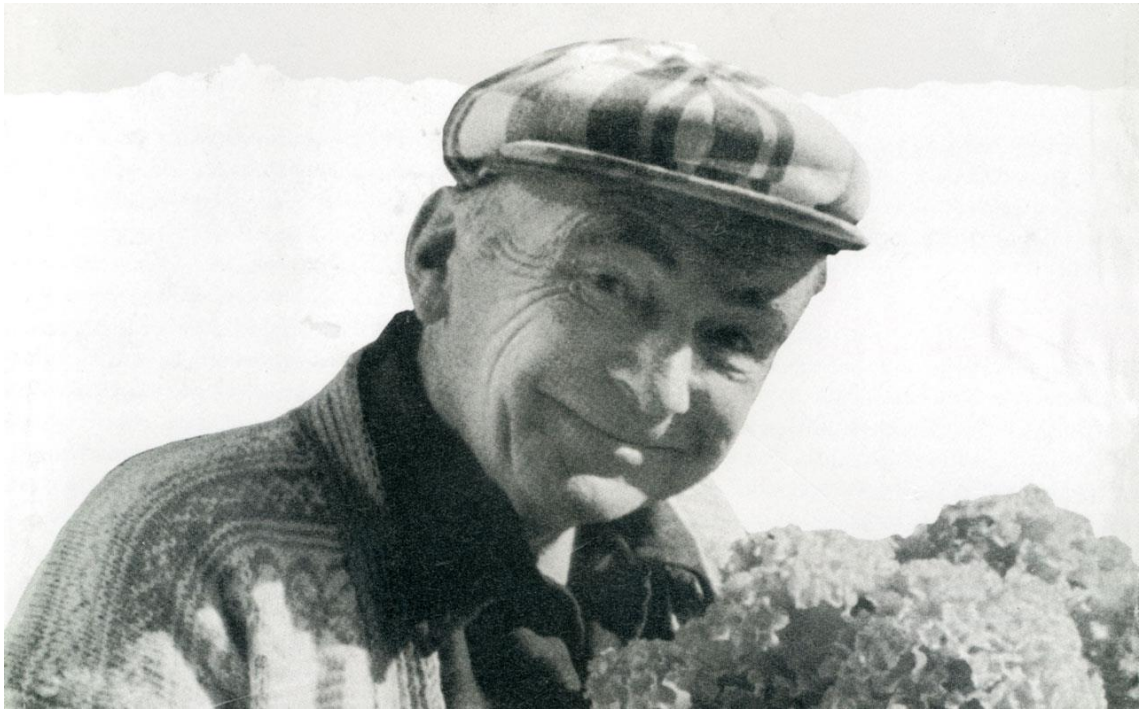
Non-xylem water can occur when you squeeze the petiole in the seal and water is physically squeezed out the cut end. [For the pressure tank style, sometimes this can happen if you re-tighten the seal during a measurement.] If you think it is the endpoint, note the pressure, then dry

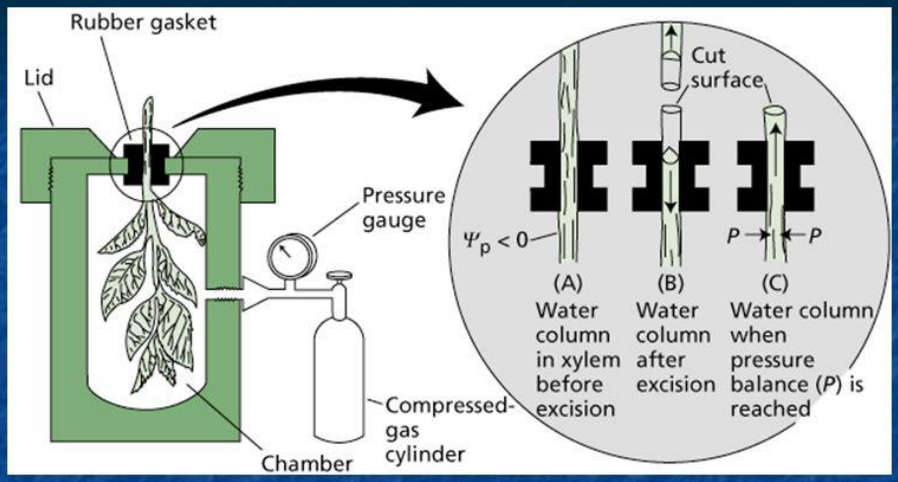
off the cut end and raise the pressure a bit. If more water comes out of the cut surface, then it probably was the endpoint, but if it remains dry, then it probably was non-xylem water. Some species of plants have resins or other materials that can come out of the petiole when the leaf is pressurized, but these typically come out of tissue other than the xylem, so a good knowledge of the leaf anatomy can help the operator to discern the difference between the correct endpoint (water from the xylem) and the appearance of these other fluids.

Reproducibility

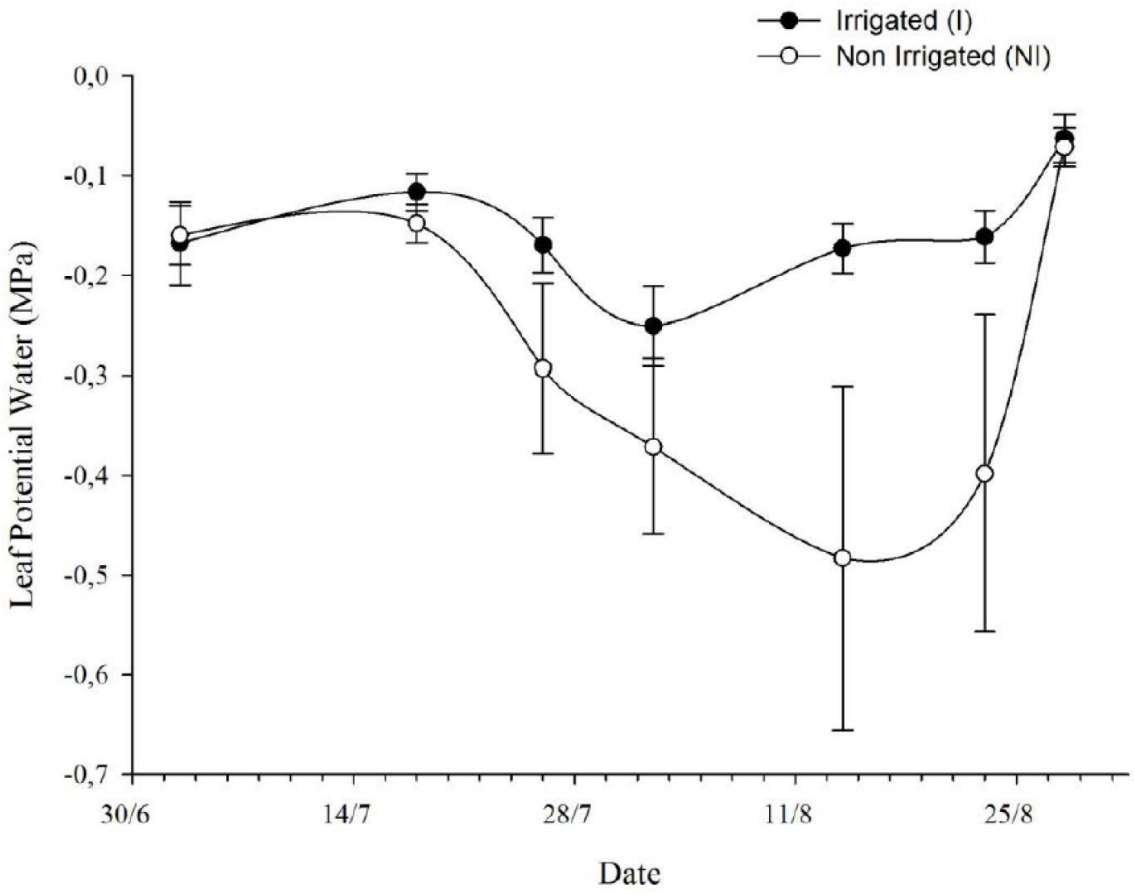
Two or more leaves on the same tree should give almost identical readings, i.e., within about 0.2 bar. It is good practice for beginners to sample more than one leaf per tree to check for reproducibility of measurement. With experience, only 1 leaf per tree is necessary. You should also get nearly the same value if you re- measure the same leaf. This is done once you see the first endpoint by reducing the pressure enough that water disappears into the petiole, and then increasing the pressure until you see the endpoint again. Different trees can give different readings, however, and these will reflect real differences in water potential, so it is important to keep track of each tree separately.







The pressure chamber method for measuring plant water potential. The diagram at left shows a shoot sealed into a chamber, which may be pressurized with compressed gas. The diagrams at right show the state of the water columns within the xylem at three points in time: (A) The xylem is uncut and under a negative pressure, or tension. (B) The shoot is cut, causing the water to pull back into the tissue, away from the cut surface, in response to the tension in the xylem. (C) The chamber is pressurized, bringing the xylem sap back to the cut surface.



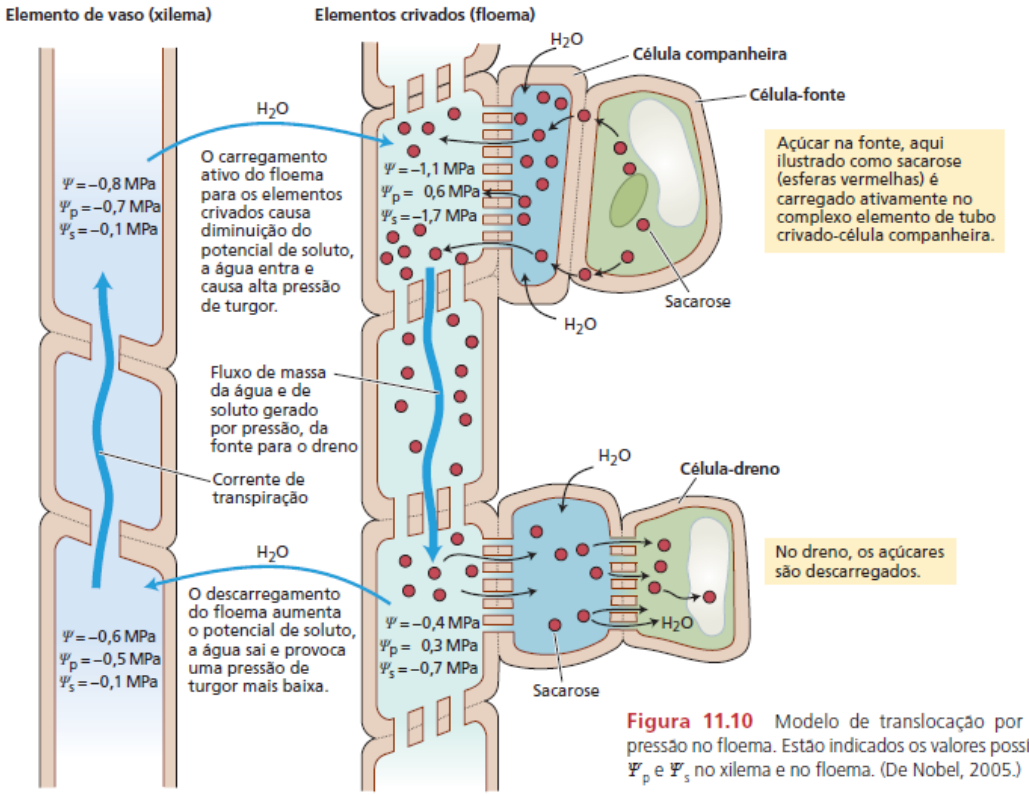


Figura 11.10 Modelo de translocação por fluxo de pressão no floema. Estão indicados os valores possíveis de Ψ, Ψ_p e Ψ_s no xilema e no floema. (De Nobel, 2005.)