**Section 4: Physiology**

Internal Transport

- Diffusion
- Surface to Volume Ratio
- Internal Transport Strategies
- Cellular Transport
- Internal Transport in Plants

Respiration
Circulation
Digestion
Endocrinology
Nervous System
Muscles

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## Two problems with being big (multicellular)

1. Diffusion doesn't work well over a long distance
2. Surface to Volume Ratio decreases as organism gets larger

### Internal Transport

Movement of materials inside a multicellular organism

*for example:*

oxygen, water, glucose from external environment to cells;

carbon dioxide, waste products from cells out to environment

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## Diffusion is primary way that chemicals move from environment to exposed cells

**Diffusion works best under 100 μm**

Diffusion into a creature has to pass through its surface

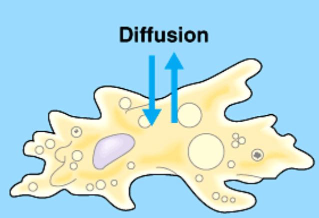
0.15 atmospheres of $O_2$ is required to diffuse into a 1 mm sphere

15 atmospheres of $O_2$ is required to diffuse into a 1 cm sphere

*Diffusion depends on Area/Distance, so 10x distance with 0.1 area requires 100x pressure*

(Earth has 0.21 atmosphere $O_2$)

**Diffusion works for a Single Cell (< 100 μm)**

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## Rate of diffusion = Pressure x Area / Distance

*Pressure is usually constant for a given chemical in the environment.*
*e.g. $P[O_2]$ is 0.21 atmospheres -> rapid diffusion into a 1 $mm^3$ cell.*
*So we can treat equation as*

***Rate of Diffusion = Area/Distance***

more surface area -> faster diffusion
less surface area -> slower diffusion
more distance to center (more volume) -> slower diffusion

To get fastest diffusion:
increase surface area and decrease distance

**Problem:**
as organism gets bigger, surface : volume ratio <u>decreases</u>

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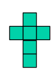
## Example: 1 cell

Volume: 1 $mm^3$

Surface Area: 6 $mm^2$



Ratio: 6 $mm^2$ of surface for every 1 $mm^3$ of volume

*$O_2$ enters cell from all sides:*
*at $P[O_2]$= 0.15 atmospheres, $O_2$ can easily diffuse thru out.*

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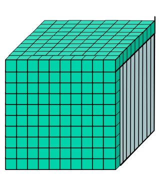
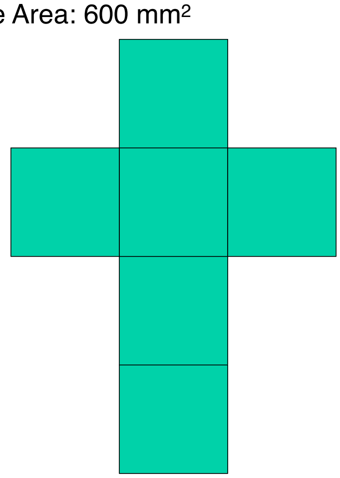
## Example: 1000 cell organism

Volume: 1000 $mm^3$



Surface Area: 600 $mm^2$



Ratio: 0.6 $mm^2$ of surface area for every 1 $mm^3$ of volume

*so have to push more supplies through smaller entrance area.*

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## Compare 2 Spherical Organisms

diffusion = area/distance
diffusion/cell = (area/distance)/volume

max distance to cells = r
surface area = 4 pi $r^2$
number of cells = volume = 4/3 pi $r^3$

| | small | large | *change* |
|---|---|---|---|
| **radius (mm)** | 1 | 10 | *10x* |
| **volume ($mm^3$)** | 4 | 4000 | *1000x* |
| **surface area ($mm^2$)** | 12 | 1200 | *100x* |
| **S/V ratio** | 3 | 0.3 | *0.1x* |
| | | | |
| **diffusion rate** | 12 | 120 | *10x* |
| **diffusion per 1 $mm^3$ "cell"** | 3 | 0.03 | *0.01x* |
| | | | |
| **$P[O_2]$ required to restore diffusion rate** | 0.15 | 15 | *100x* |

area goes up as square of distance
volume as cube of distance
S:V ratio goes down
diffusion rate goes way down

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## Surface Area/Volume Ratio is a General Problem
## not just for Oxygen and other gases

food and waste chemicals in and out

maximize exposure to light

need to get heat in or out
*little animals lose heat quickly,*
*big animals lose heat slowly...*

etc.

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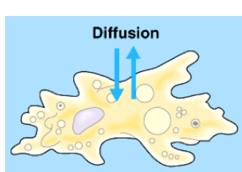
## Diffusion and Internal transport

**Issue**:
Moving chemicals from environment to cells (and vice versa)

**Problem:**
in multicellular organisms, diffusion may not be enough to get to cells inside the organism:

too far from surface (> 100 $\mu$m) for timely transport.

not enough surface area to allow sufficient diffusion into the volume of an organism

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## Solutions to limits on diffusion:

**1. Make sure all cells are <1 mm from environment**

*e.g. hydra is a hollow sphere (2-cells thick) that is open to the environment on both sides*

**2. Make sure environment is < 1 mm from all tissues**

*e.g. insects are perforated with tracheal tubes that bring atmosphere into the body*

**3. Specialized exchange surface: Increase surface area without increasing volume**

e.g. exchange surfaces in contact with environment are often broad& flate, wrinkly, or villiated (fingery)

**4. Use internal transport system to get chemicals from exchange surface <--> internal tissues .**

*e.g. xylem & phloem, respiratory/circulatory system, or gastrointestinal tract.*

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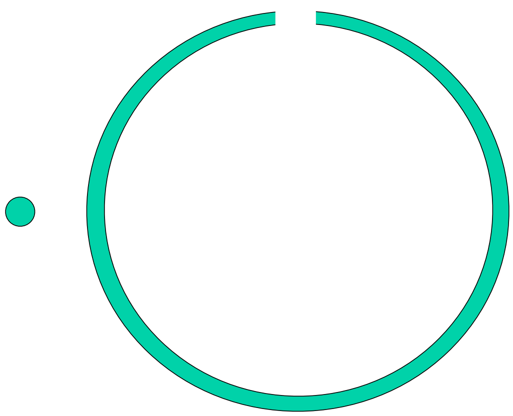
**Increase surface area, keep every cell within 100 $\mu$m of surface**



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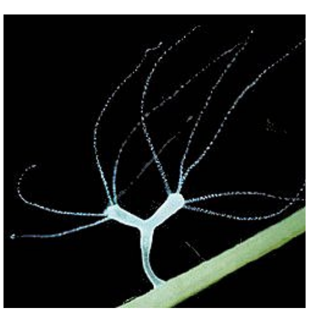
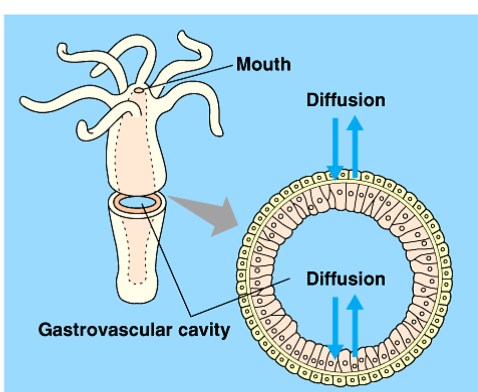
**Diffusion works with lots of surface area and a thin body**



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   ***e.g. insects are perforated with tracheal tubes that bring atmosphere into the body***

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   *e.g. xylem & phloem, respiratory/circulatory system, or gastrointestinal tract.*

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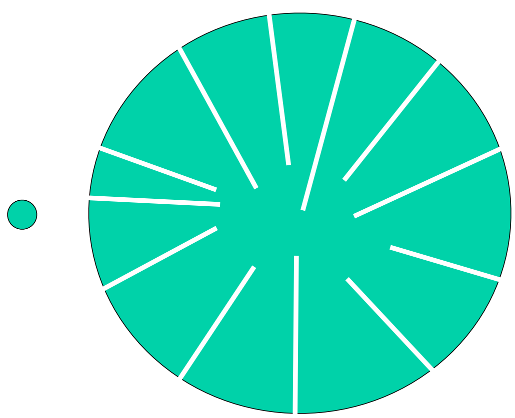
**Facilitate diffusion with tubes into volume (increase surface area internally)**



***e.g. insects***

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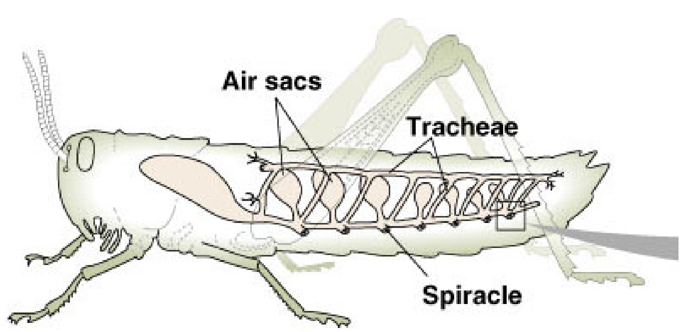


**(a)**

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## Solutions to limits on diffusion:

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   ***e.g. xylem & phloem, respiratory/circulatory system, or gastrointestinal tract.***

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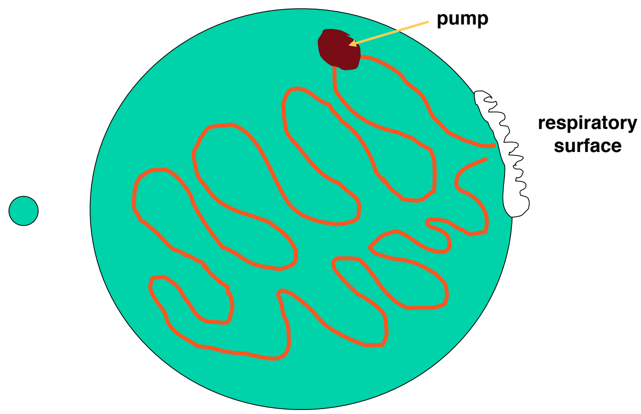
## Active Pumping
**to transport gases from respiratory surface to tissues**

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## Three Solutions for internal transport

**Diffusion**
keep all cells close enough to source of O2 & sink of CO2 that cells can directly access gases( flat & thin layer of cells)

**Facilitated Diffusion through Tubes**
If volume is too big, increase surface area by exposed to outside with series of tubes for passive diffusion of gases

**Active Pumping**
To increase ventilation of dedicated repiratory surface and transport gases to distant cells

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## Analysis of Internal Transport in an Organism:

1. What are the exchange surfaces?
2. How do the chemicals enter/exit the cells of the exchange surface?
3. What is the internal transport system that carries the chemicals from the exchange surface to target tissues?
4. What provides & controls the force to move chemicals through the system?
5. How are the chemicals unloaded by the transport system and taken up by the target cells?



## Internal Transport Strategies:

dedicated cells & tissues to provide for other tissues

increase surface area to increase surface to volume ratio *leafs, elephant ears*

dedicate tubes to transport stuff deep into tissues *digestive tract, blood vessels, breathing*

passages provide “active” transport down the tubes *heart, lungs, peristalsis*

chemical carriers designed to grab at source and release at destination *hemoglobin*

information transmission through the body and into cells *nerves, hormones*



## Uptake of Solutes by Individual Cells using Transport Proteins

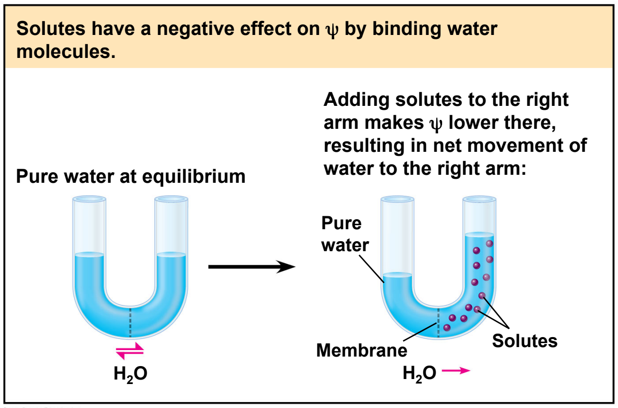
**1. Active Transport:**
requires energy to transport against electrochemical gradient

**2. Facilitated Diffusion:**
Selective channels to facilitate diffusion of a chemical along its concentration gradient (gated channels)

**3. Co-Transport of Solutes:**
One solute goes down concentration gradient, and brings another solute with it

## Osmosis: water moves to more concentrated solution

Figure 36.8a






particles suck

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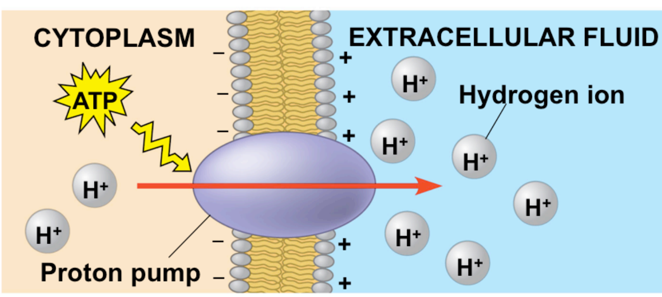
## Active Transport across the Membrane

**requires energy**, to move solute against its gradient (chemical or electrical)




(a) $H^+$ and membrane potential

(looks like ATP synthase in reverse)

**membrane potential**
caused by difference in charge across cell membrane.

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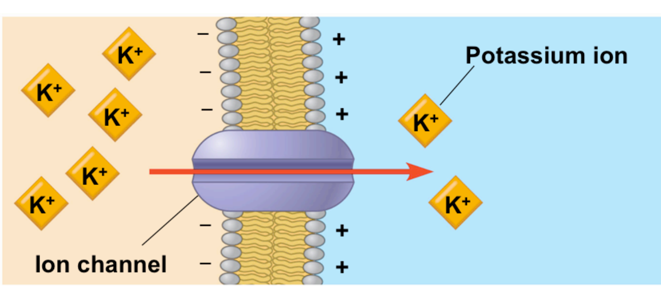
## Facilitated Diffusion across the Membrane

does not require energy, must be down a **gradient** (chemical or electrical)




(d) Ion channels

- Some channels are **gated** (i.e. channel opens or closes depending on intracellular events)
- Aquaporins -- channels for water molecules

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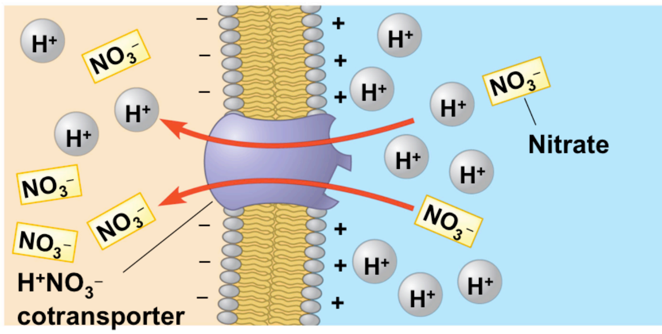
Figure 36.7c

## Co-Transport across the Membrane

**Uses potential energy of one solute (H+) as it follows gradient to transport a second solute with it, e.g. against the second solute's electrical gradient:**




(c) $H^+$ and cotransport of ions

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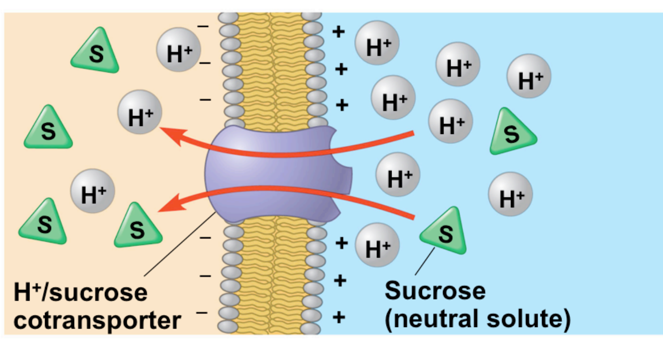
## Co-Transport across the Membrane

**Uses potential energy of one solute (H+) as it follows gradient to transport a second solute with it, e.g. against the second solute's chemical gradient:**




(b) $H^+$ and cotransport of neutral solutes

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## Analysis of Internal Transport in Plants:

## Where does the stuff of Plants come from?

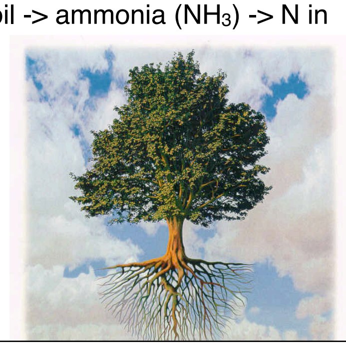
Major elements of life: C, H, O, N, P, minerals (Na, Ca, etc.)

Atmosphere -> $CO_2$ -> C, O in sugar, amino acids, fats

Atmosphere -> $H_20$ in soil -> H in sugar, amino acids, fats

Atmosphere -> $N_2$ -> bacteria in soil -> ammonia ($NH_3$) -> N in amino acids

Soil -> minerals -> P, Na, Ca, etc.



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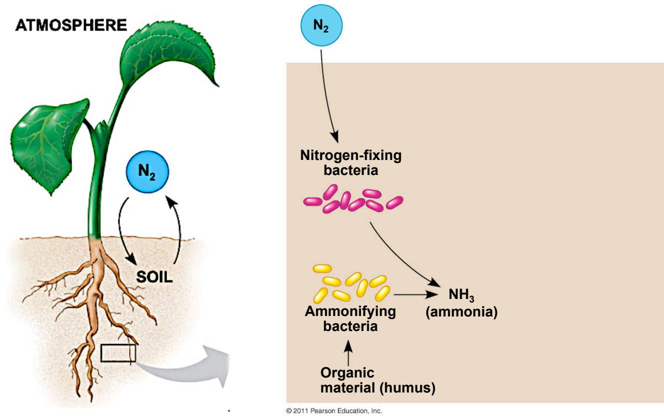


Figure 37.10a-1

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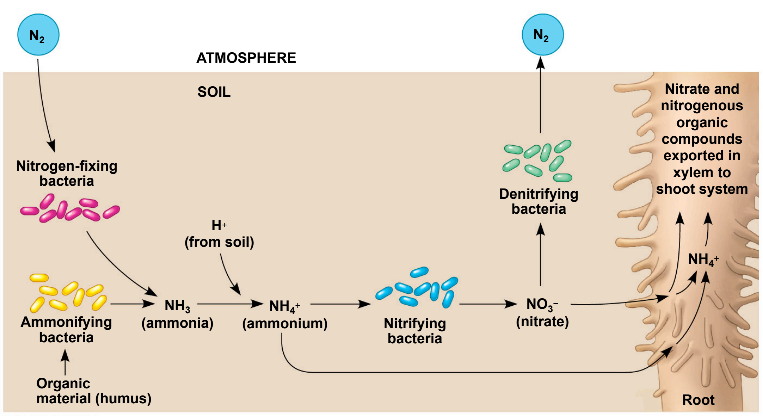
Figure 37.10a-2

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## Analysis of Internal Transport in Plants:

1. What are the exchange surfaces?:

   **roots for $H_20$, minerals; leaves for gases, light (sugar)**

2. How do the chemicals enter/exit the cells of the exchange surface?

   **diffusion (for gases), facilited diffusion, active transport, co-transport (sugar, nitrates)**

3. What is the internal transport system that carries the chemicals from the exchange surface to target tissues?

   **xylem for water (up to leaves); phloem for sugar (down to roots)**

4. What provides & controls the force to move chemicals through the system?

   **transpiration & stomata for xylem; translocation & osmotic pressure for phloem**

5. How are the chemicals unloaded by the transport system and taken up by the target cells?

   **diffusion (for gases & H20), facilited diffusion, active transport (protons), co-transport (sugar, nitrates)**

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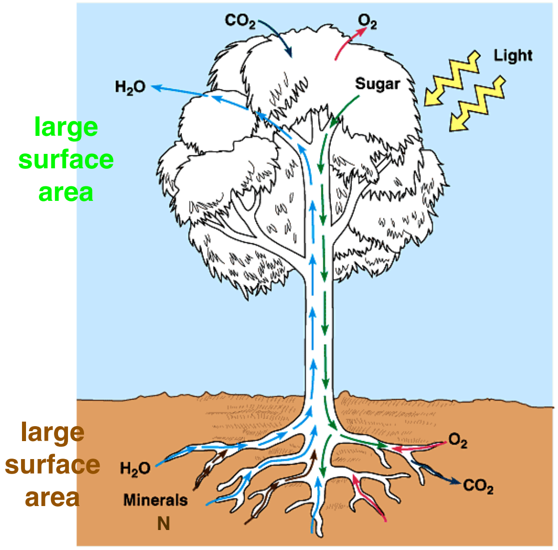
Figure 36.1 An overview of transport in whole plants (Layer 4)



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## Internal transport in Plants

1. uptake and loss of water & solutes by one cell
2. short distance transport between adjacent cells
3. long distance transport (roots <-> leaves) within specialized tubes (xylem and phloem)

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## Two Routes of Short-Distance Transport through cells

(Lateral transport in roots)

**Symplastic**
through the shared cytoplasm of adjacent cells (only solutes transported into cells can travel this way.)

**Apoplastic**
between the cell walls & extracellular spaces

**Transmembrane**
across both

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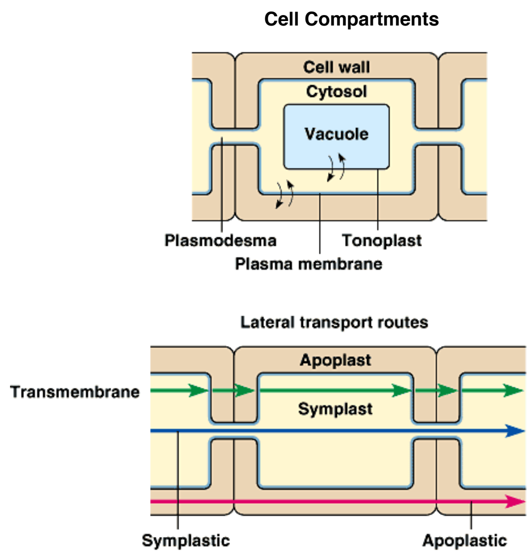


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Figure 36.10a

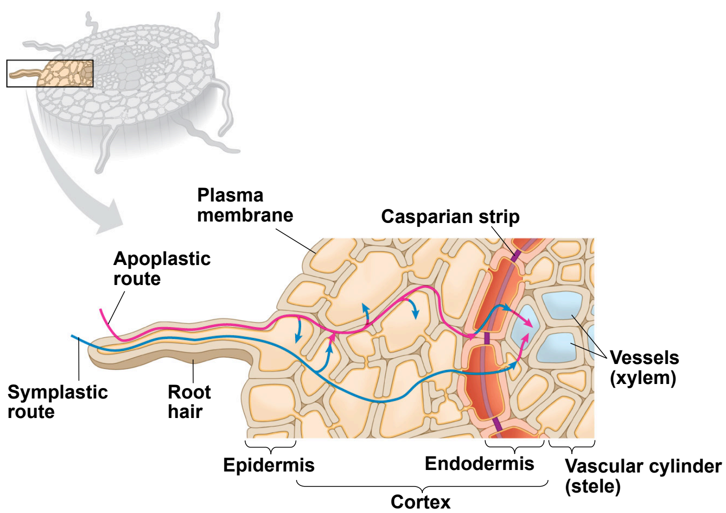




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Figure 36.10b

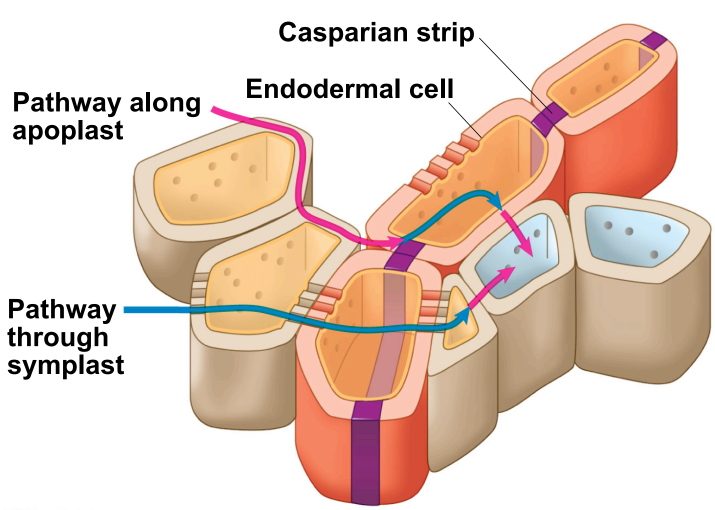




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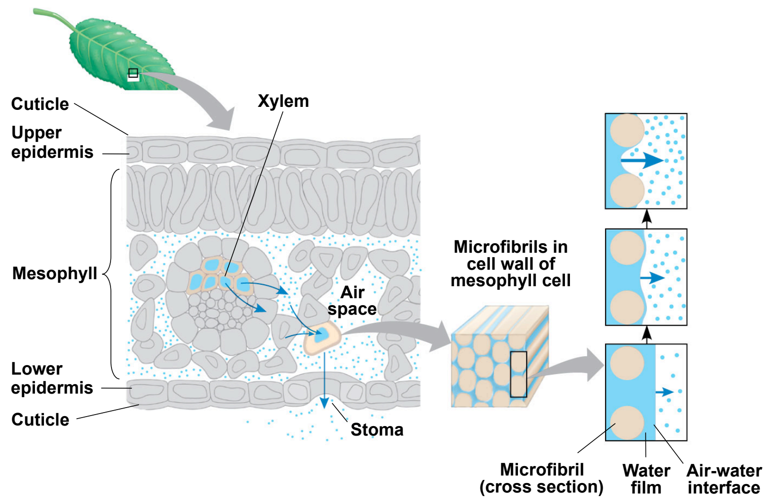
Figure 36.12



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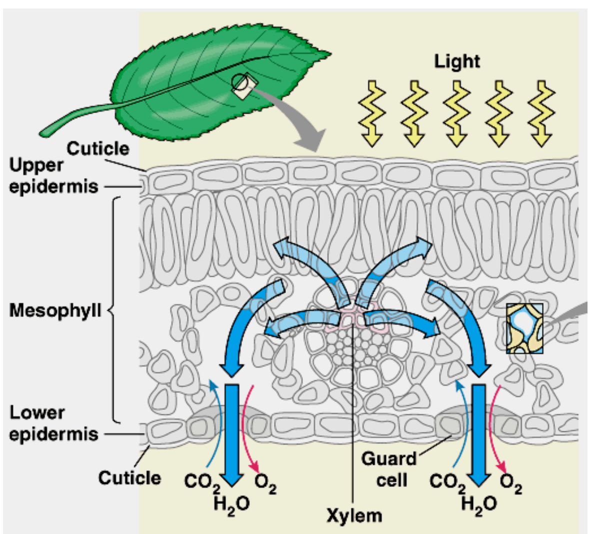


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## Water Potential (mega-pascals)

**= solute potential (roots) + pressure potential (transpiration)**

Roots concentrate minerals in apoplasm and xylem
-> osmotic pressure draws water from soil into xylem

Water evaporates from leaves through stomata
-> hydrostatic tension to draw water up xylem from roots

Plants control solute potential by opening channels for solutes or actively transporting small molecules into cell or transport tube; because of osmotic pressure, water will follow solutes into the cell/tube.

**1 Atmosphere: 0.1 MPa**
**Lungs: 0.1 MPa**
**Car Tire: 0.2 MPa**
**Inside plant cell: 1.0 MPa**

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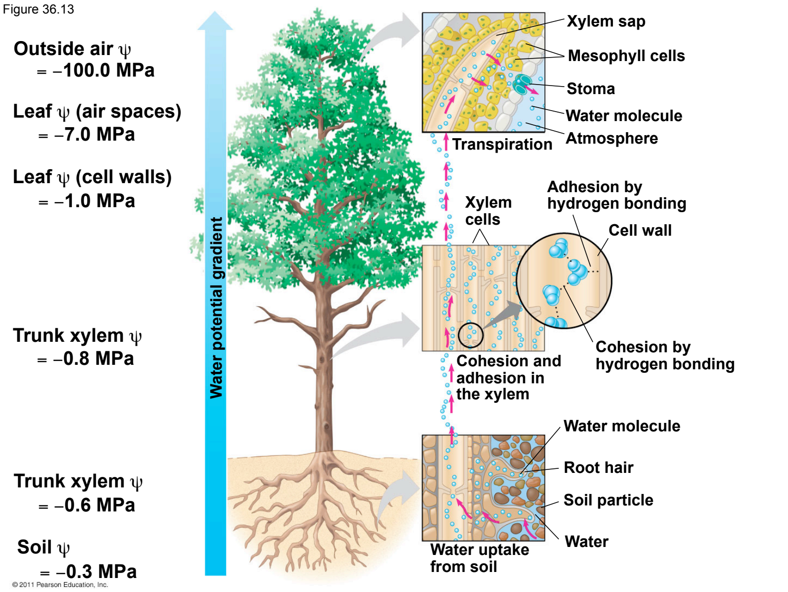
Figure 36.13



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## Notes on Transpiration:

**Cavitation:**
**a water vapor bubble in the xylem interrupts transpirational pull**

**Guttation:**
**at night, water pressure from roots forces liquid water out the xylem even though transpiration is low (root cells pump minerals into xylem, which draws water in)**

**Transpiration to photosynthesis ratio**
**amount of water lost per gram of $CO_2$ used in photosynthesis**
**C3 plants, 600g $H_20$ : 1g $CO_2$**
**C4 plants, 300g $H_20$ : 1g $CO_2$**

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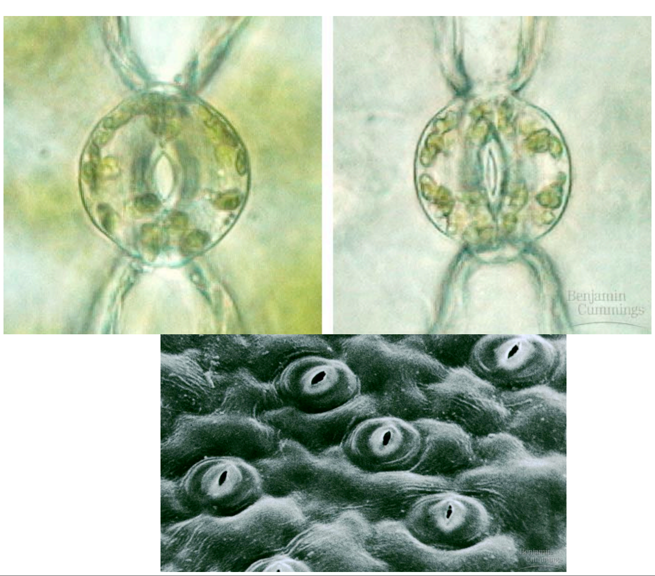
Figure 36.12 An open (left) and closed (right) stoma of a spider plant *(Chlorophytum colosum)* leaf

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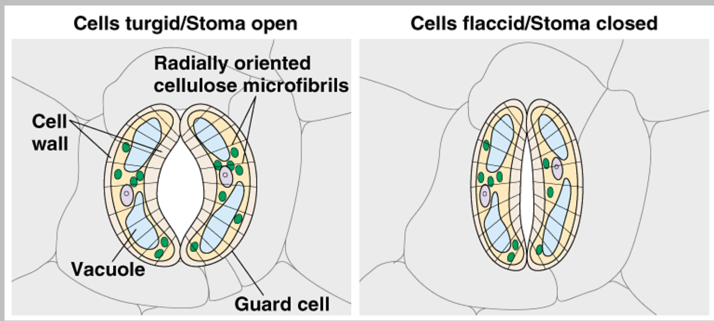
Open

Closed




High water conditions

Low water conditions

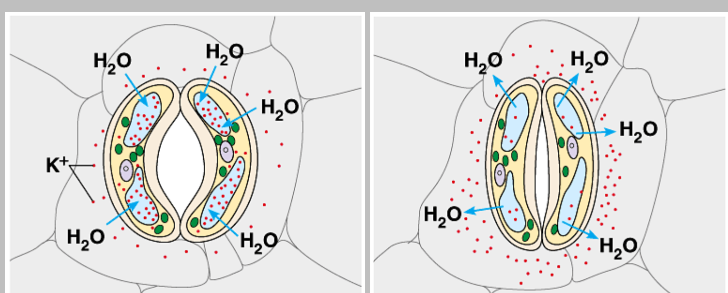


Open:

Guard Cells Turgid

Closed:

Guard Cells Flaccid




**Plants control transpiration by allowing K+ to move into guard cells: water follows K+, so cells swell, and stoma opens**



## Translocation

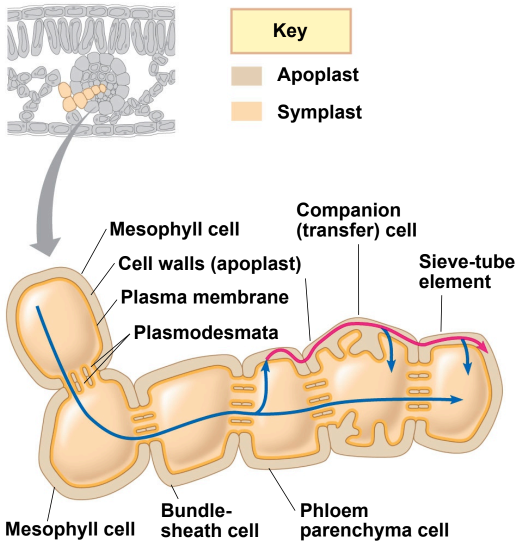
Transport of sucrose in the phloem from sugar source (leafs) to sugar sinks (fruit, roots, budding shoots, etc.)

Sucrose moves via apoplastic and symplastic routes from mesophyll cell to companion (transfer) cell and sieve-tube members of phloem vessels.

Sucrose is actively transported into sieve-tube members by H+ co-transporter

Phloem moves at rate of 1m / h due to water pressure:
water moves into phloem with high sugar concentration, and leaves phloem at low concentration end.

Figure 36.17a




(a)



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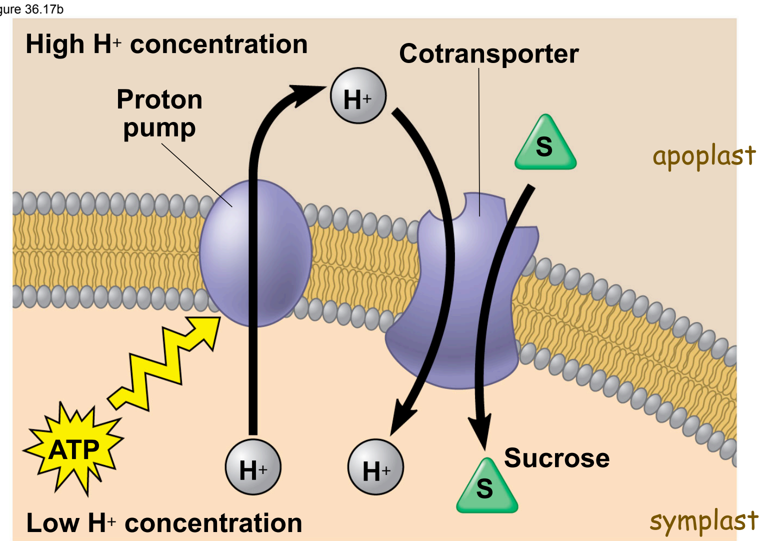
Figure 36.17b




(b)



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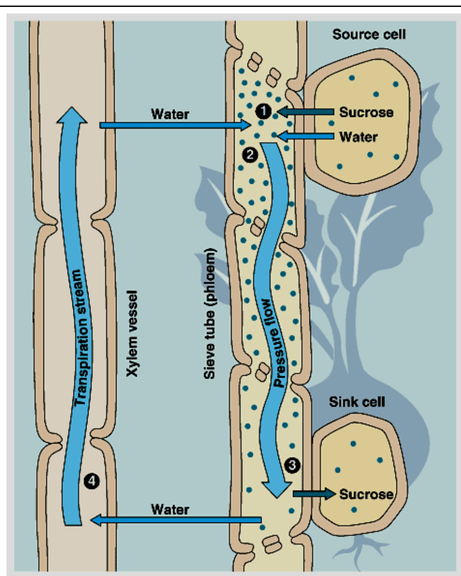




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