What Are Plants?

An Overview of Plant Science

VCE-Master Gardener Training Class
January 11, 2012

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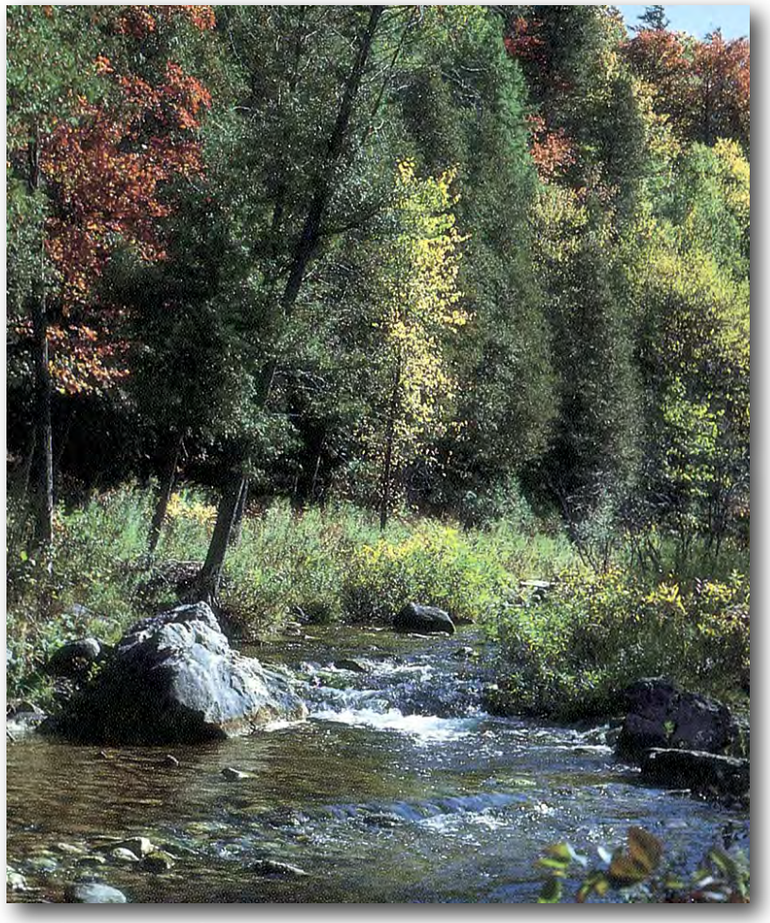
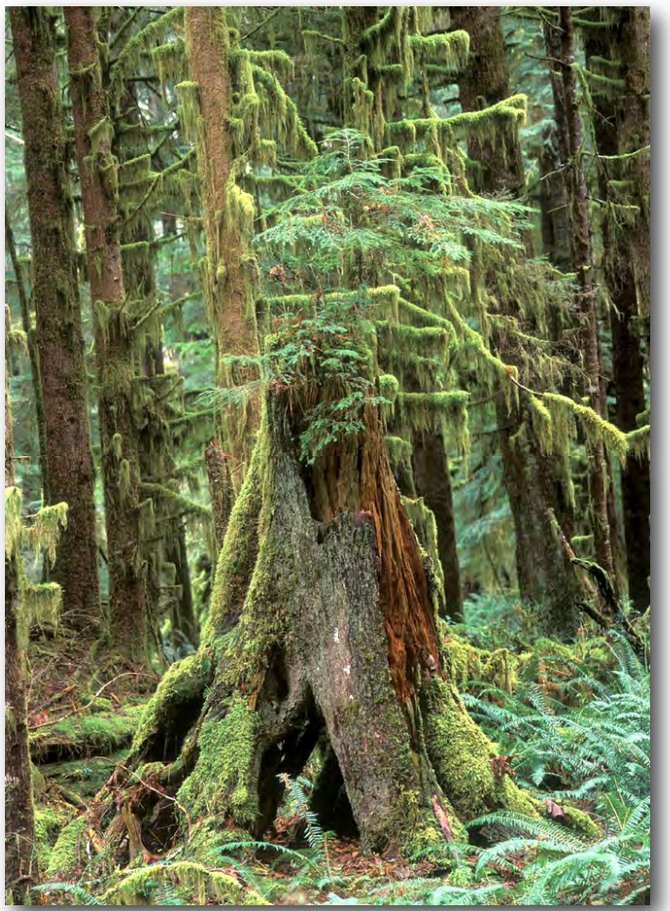
Plants Are So Ubiquitous We Often Ignore Them.



Plants dominating a temperate woodland ecosystem.



Plants dominating a Pacific Northwest rainforest.

Plants dominating a chaparral ecosystem.

Plants are Often Not the Passive Entities We Take Them For.

"A major difficulty in studying any plant behaviour is that time scales differ from those in animals. Whereas human beings operate in seconds, plants usually operate in weeks and months. Even though bamboos can grow a centimetre an hour, without some sort of recording device it would be extremely difficult for any human to observe this phenomenon. Plant behaviour in the wild is usually unrecorded and, as a consequence, much uncommon behaviour must simply be missed."

Tony Trewavas
from Aspects of Plant Intelligence

Plant Dominance

Plants dominate terrestrial environments to such an extent, that we frequently regard them as "background".

The seeming inactivity of plants reinforces a view of plants as passive environmental features.

Plant Behavior

Plants are in fact highly dynamic, continuously sensing, responding to, and shaping their environments.

The trick to appreciating plant behavior is to get on their time-scale. Plants live the slow life.

Contemporary Human Cultures Are The Product of a Relationship With Plants. Horticulture is an Extension of this Relationship.

The Great Pyramids at Giza--an example of what high population densities can achieve.

Agriculturalists Eat Plants. Seeds are Storable Nutritional Power Packages and the Foundation of Agricultural Societies.

Celery. High in water and fiber. Low in protein, starch, fat. The world's worst food.

Wheat. 100 grams contains 12.6 g of protein, 1.5 grams of fat, 71 grams of starch. Eat it and thrive. Or store it and thrive later.

The Domesticated Plant Species That Form the Foundation of Human Nutrition are Now Largely or Completely Dependent Upon Humans for Survival.

Teosinte, the wild ancestor of domesticated maize.

Maize, growing in the region where it may have been domesticated.

Human Civilization is the Result of our Relationship with Plants.

Hunter-gatherers

Agriculturalists

Industrialists

Human Population

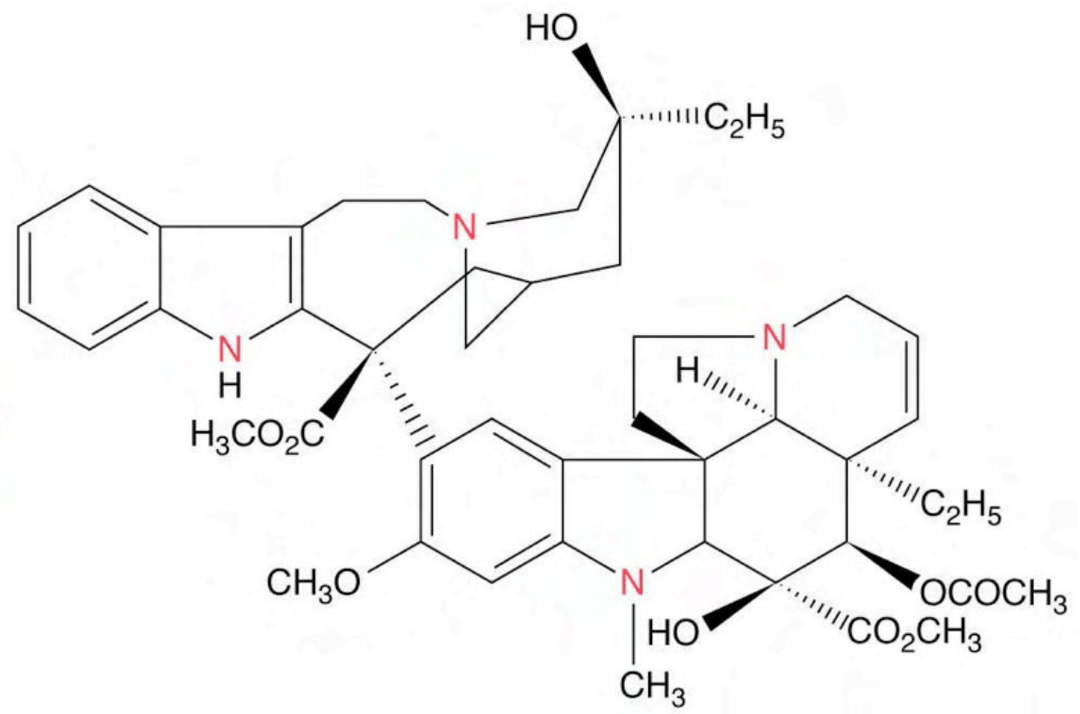
Human Environmental Impact

11,500 ybp
10 million people?

150 ybp
1 billion people

Plants Are the Source of Pharmaceuticals And Appreciated For Their Beauty.

Catharanthus roseus



Vinblastine

Catharanthus roseus **produces over 100 unique alkaloid structures.**

Vinblastine is used in treatment of Hodgkin's Lymphoma and other cancers.

More reasons to think deeply about plants

Most contemporary human societies are the result of the human-plant interaction that we call agriculture.

Large human populations and complex human societies are made possible by the unique properties of flowering plant seeds.

Plants are the source of many pharmaceuticals, which improve human health.

Plants are a major source of aesthetic pleasure, which improves human happiness.

Today's Topics...

Plant Behavior

Shaping Life on Land

Growing in Air

The Plant Cell Wall

Rooted to the Ground

Plant Development

- The Shoot Apical Meristem.
- Secondary Growth.

Photosynthesis

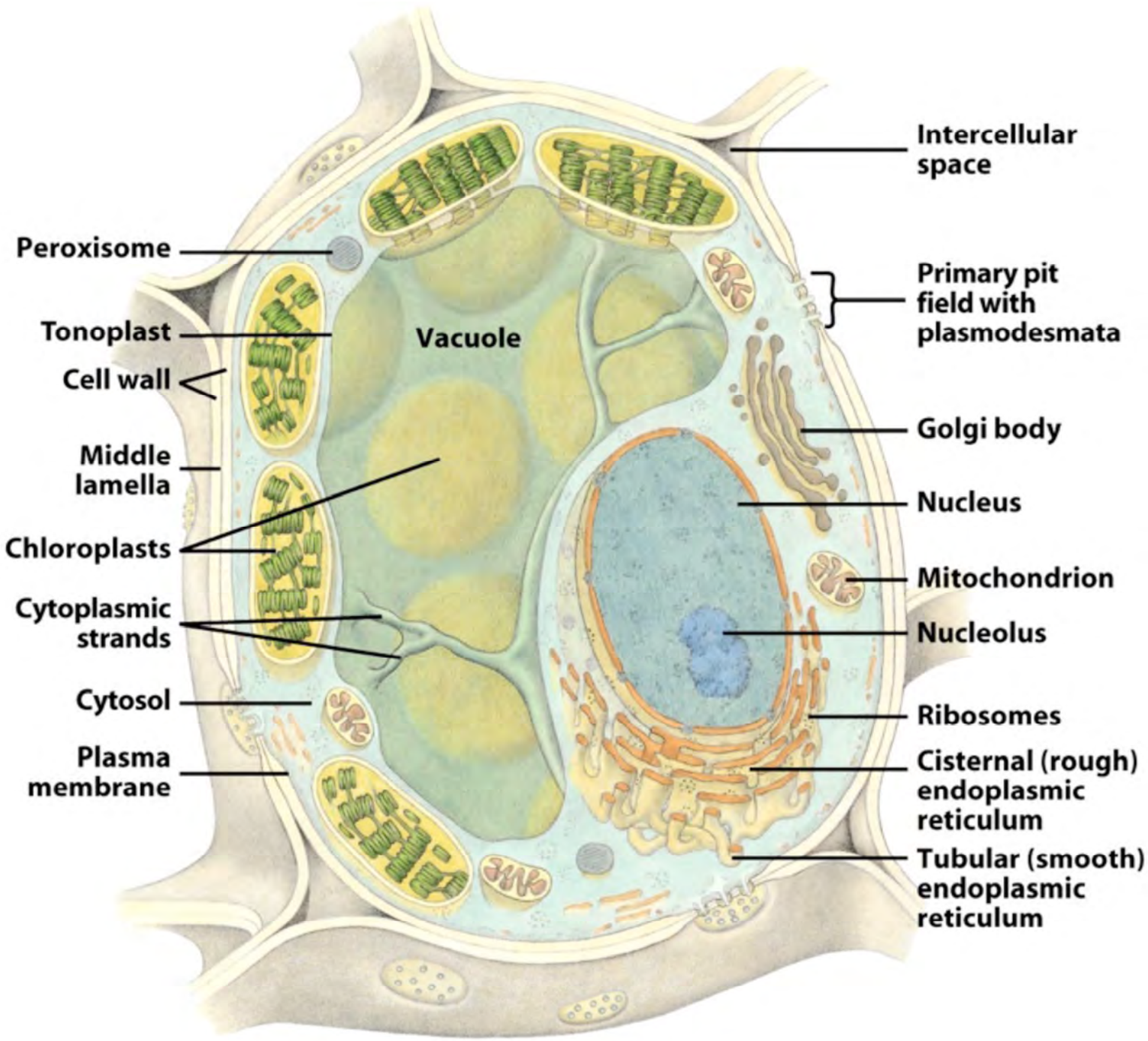
- Biochemistry
- Anatomy

Taxonomy and Plant Diversity

Plants are Estimated to Constitute 99% of Total Eukaryotic Biomass.

A bit of tropical rainforest in Costa Rica.

The Constituents of Living Things, Cells, Are Expensive to Produce and Maintain.



The Platonic plant cell.

Limiting Resources for Plants--

Water

Nitrogen

Phosphorous

Non-limiting Resources for Plants--

Energy

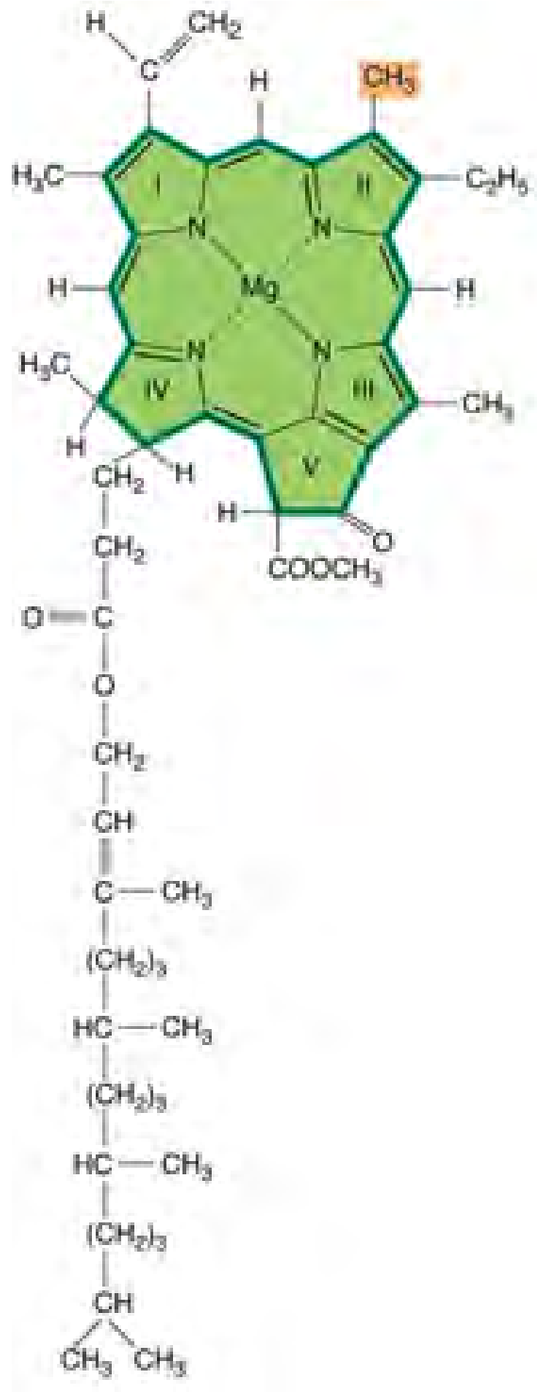
Our Planet is Awash in Solar Energy. Photosynthetic Organisms Tap Into An Effectively Unlimited Source of Energy.

"Earth receives approximately 4000 times more energy from the Sun each year than humans are projected to use in 2050."

Chris Somerville, 2006

Plants Are The Dominant Terrestrial Autotrophs, Courtesy of Photosynthesis.

The blue-green planet



Chlorophyll a

Autotroph: An organism that is able to synthesize the nutritive substances it requires from inorganic substances in its environment.

Raven, Evert, Eichhorn, Biology of Plants, 7th ed.

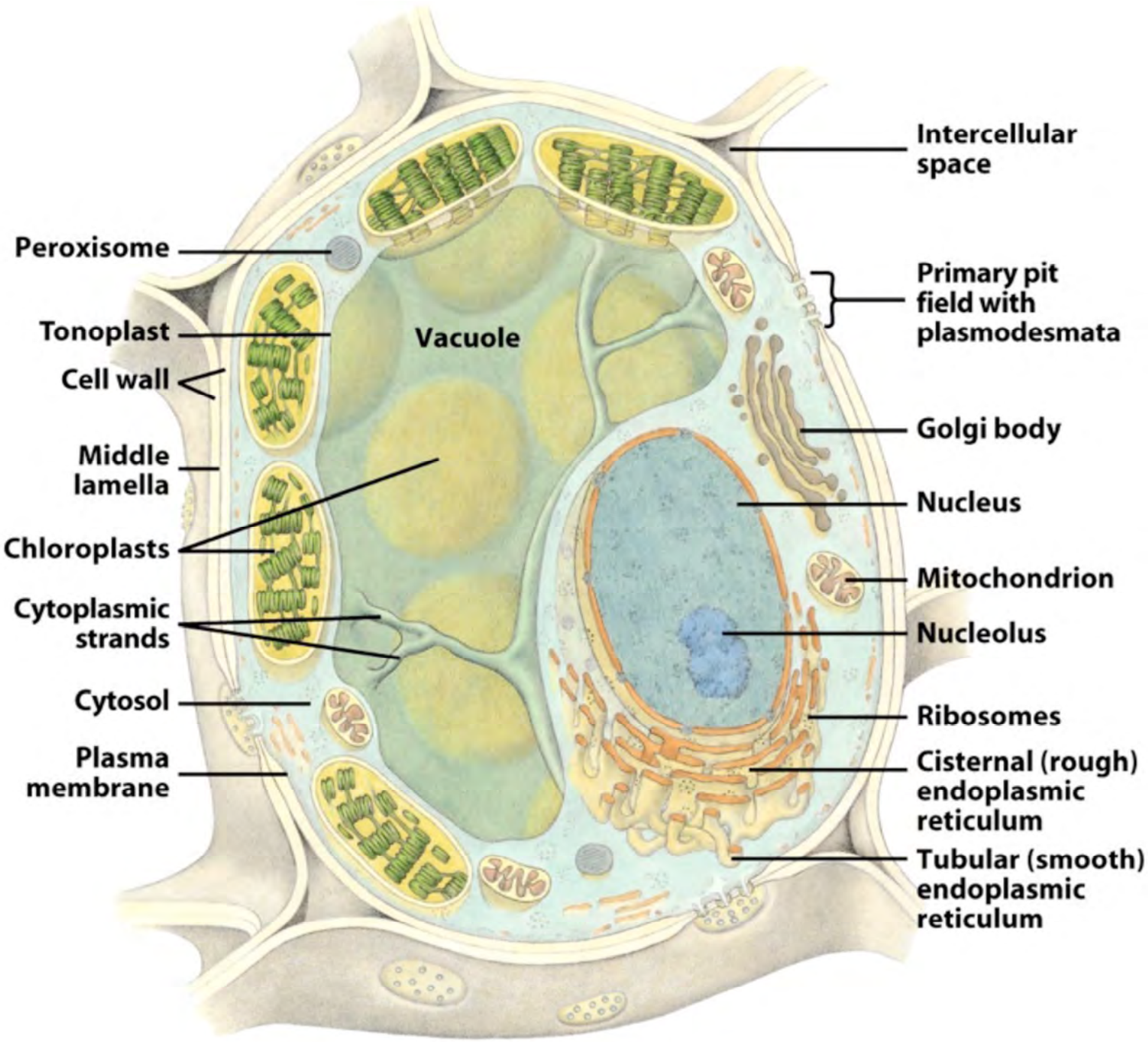
The Leaf Is the Organ of Photosynthesis.

Leaves--

1.) are disposable

2.) maximize surface area for light capture and gas exchange.

The Constituents of Living Things, Cells, Are Expensive to Produce and Maintain.



The Platonic plant cell.

Limiting Resources--

Water

Nitrogen

Phosphorous

Non-limiting Resources--

Energy

Carbon

The Cell Wall is made largely of carbohydrate.

Much of Plant's Contribution to Their 99% of Total Eukaryotic Biomass Is Dead.

Wood. Mostly Dead. Much of it quite dry.

Today's Topics...

Shaping Life on Land

Excluding bacteria, plants are most of what is alive on land by mass.

As a result of their physical dominance, plants create terrestrial ecosystems.

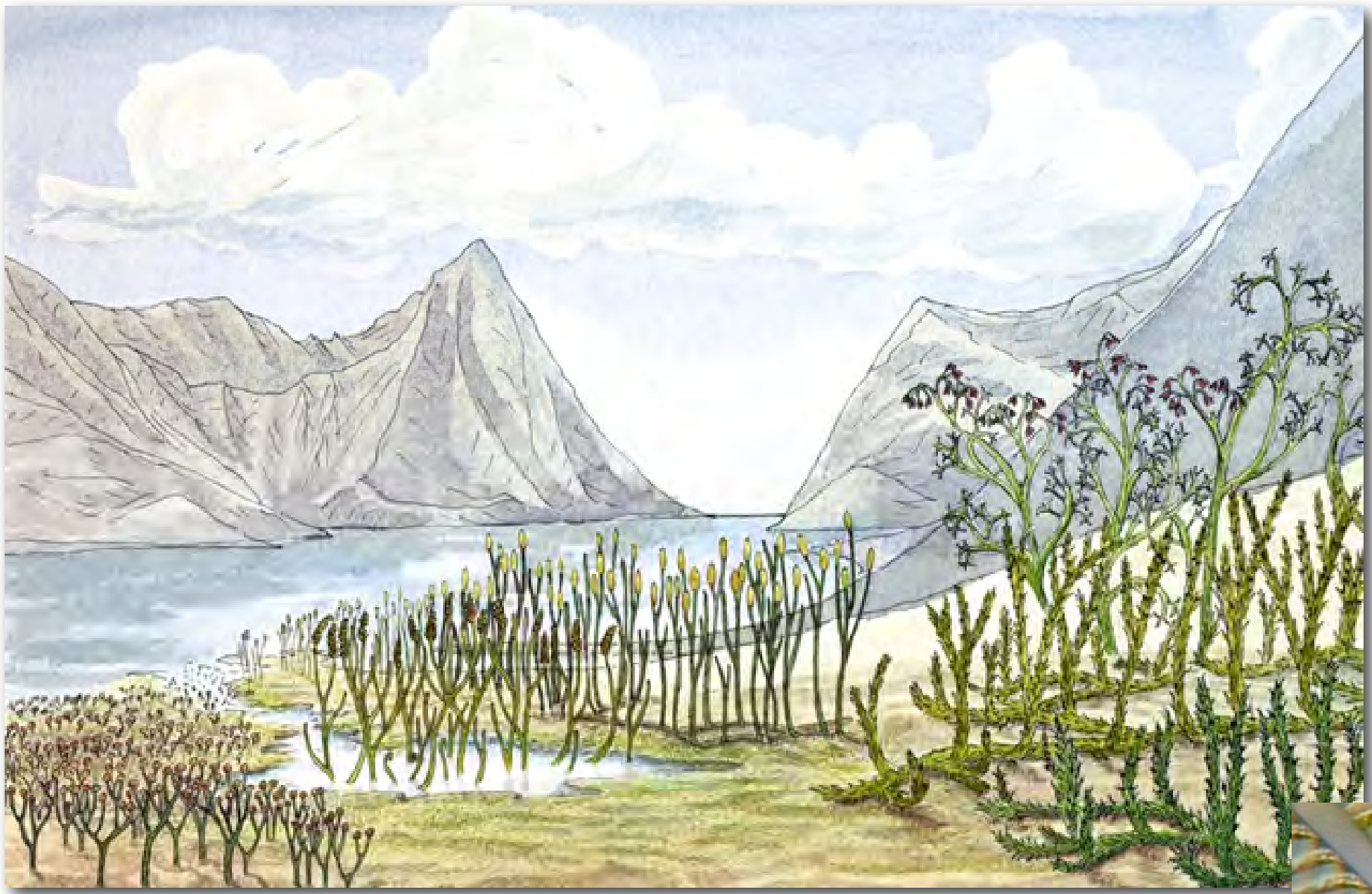
The great bulk of large, woody perennials are dead, a feature that allows plants to get big cheaply.

The enormous amount of stored energy in plant biomass is possible because plants are photosynthetic--they tap into an unlimited energy source.

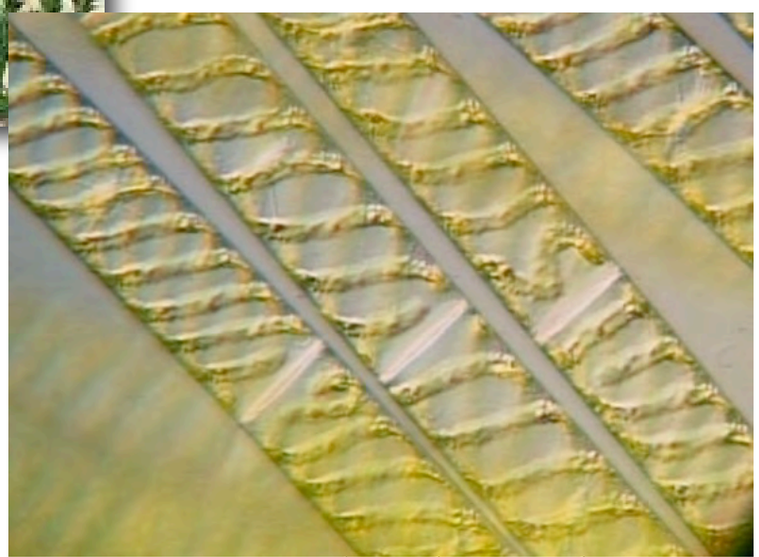
Leaf anatomy is understood as an adaptation for maximizing photosynthesis. Leaves are disposable solar panels.

Growing in Air

Plants Are Terrestrial Organisms.



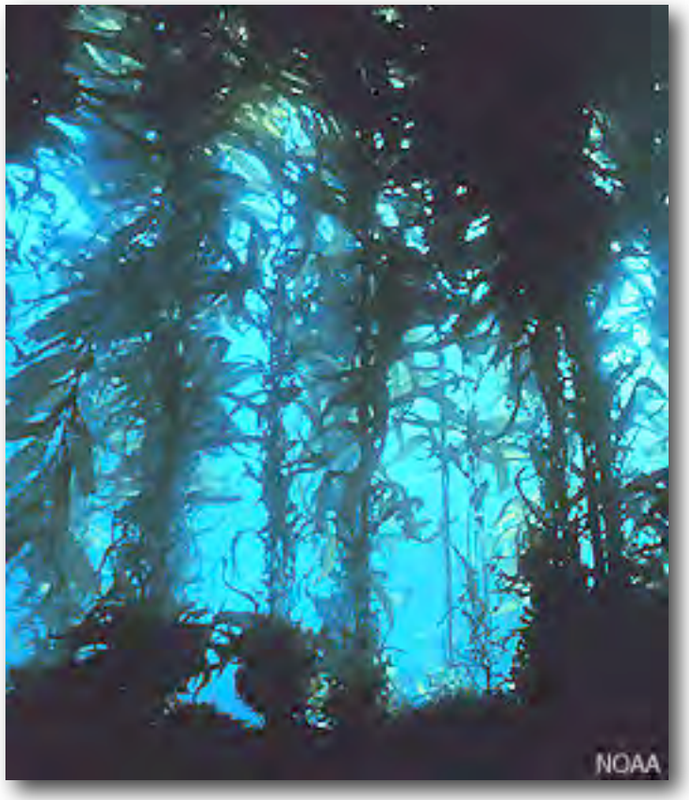
Reconstruction of an Early Devonian Landscape



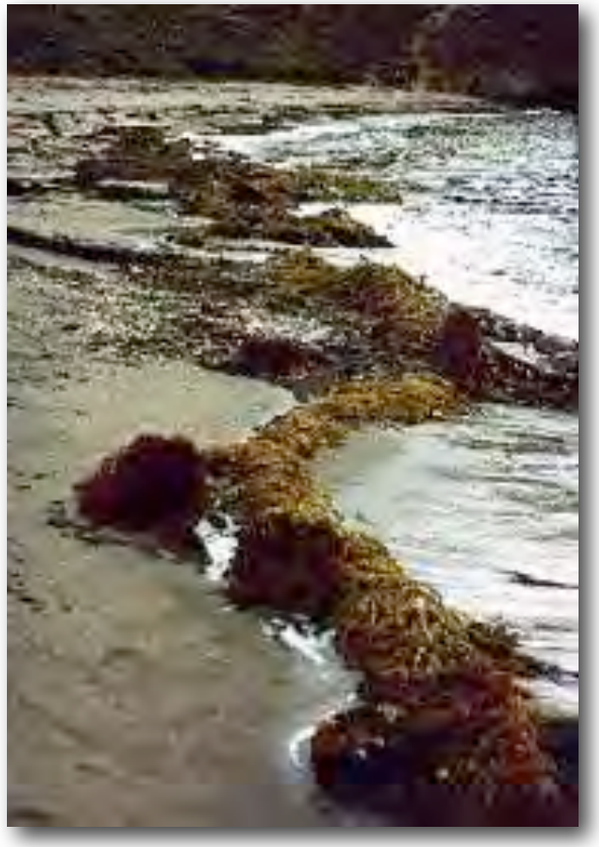
Spirogyra--the closest living relative of land plants?

Much of Plant Anatomy Is Understood As Coping With Life on Land.

Photosynthetic organisms need to get up to the light.



Water provides support.

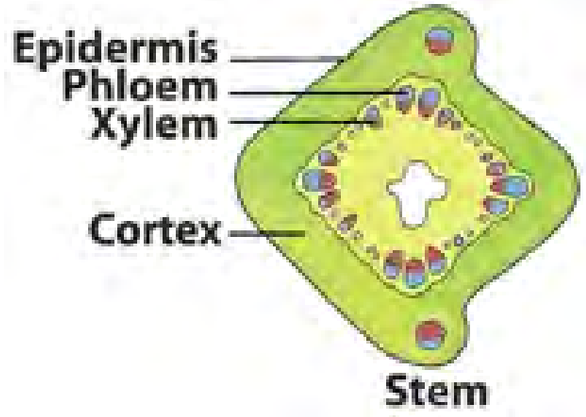


Air not so much.

Some Problems with Living on Land and How Plants Adapt To Them:

1. Water provides support. Air not so much.

Solution--Stem tissue provides support and elevation.



Solution--Root tissue provides anchoring.

All made possible by the cell wall.

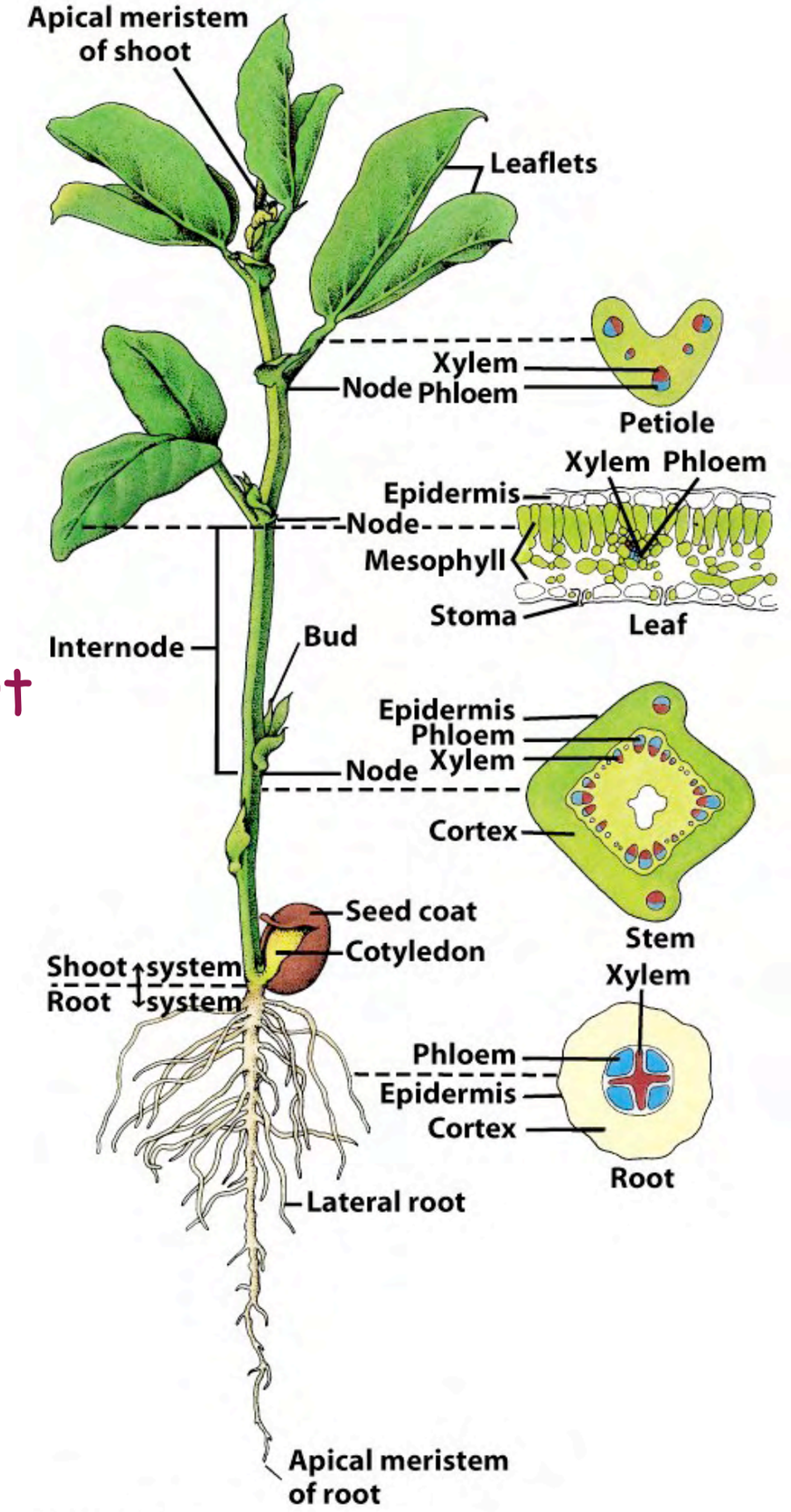
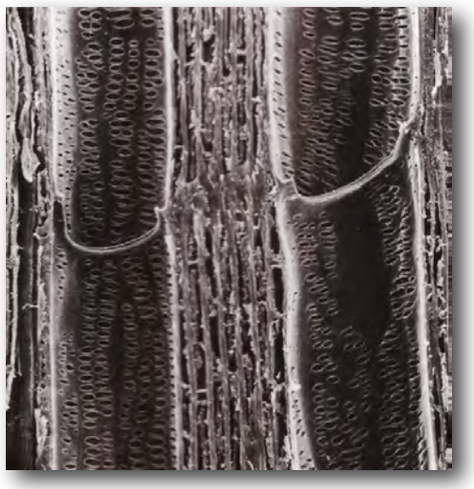


Figure 1-9
Biology of Plants, Seventh Edition

Some Problems with Living on Land and How Plants Adapt To Them:

2a. Air is a poor source of water. Going up toward the light necessitates a water transport system....

Solution--Xylem.



This adaptation also made possible by the cell wall.

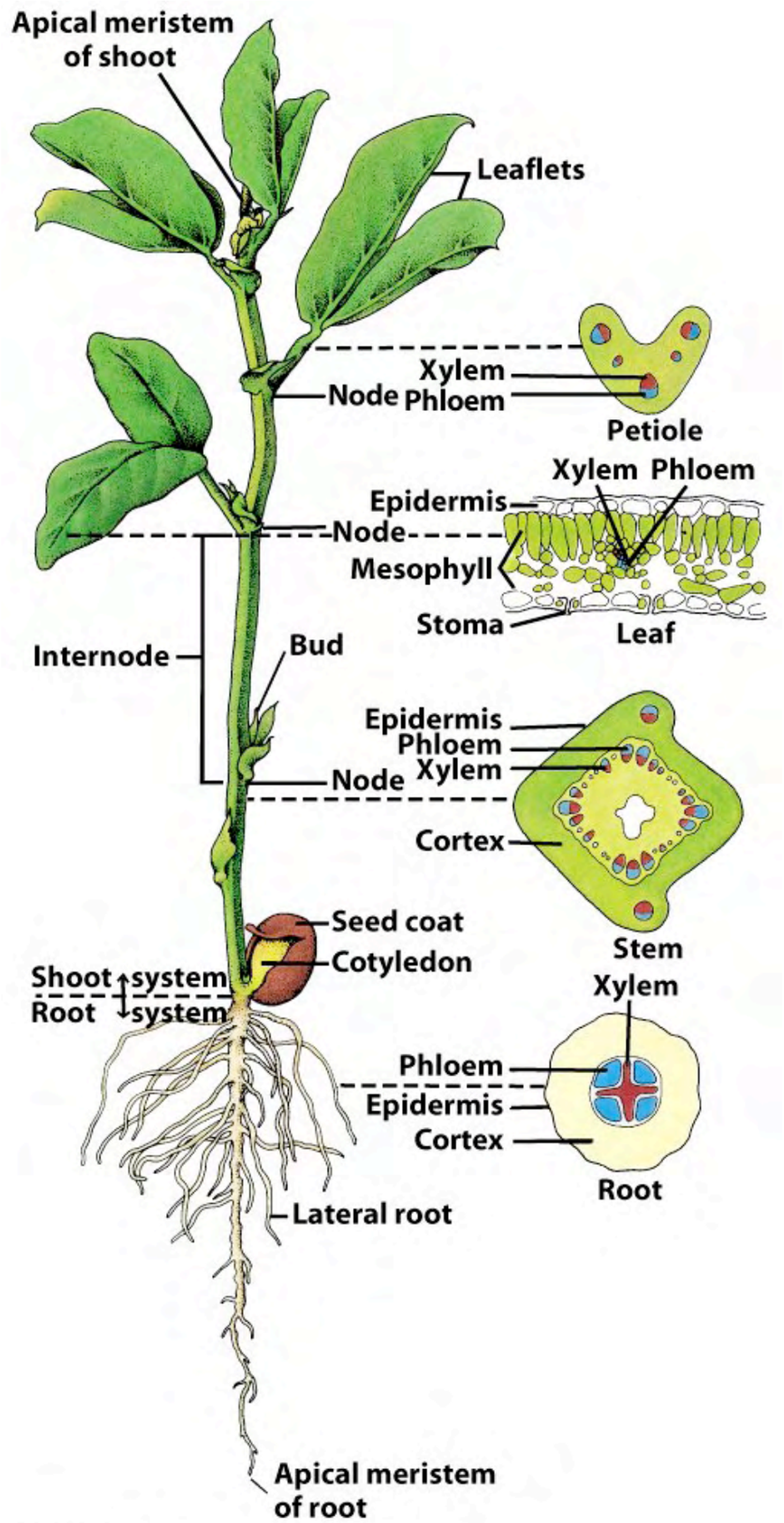


Figure 1-9
Biology of Plants, Seventh Edition

Some Problems with Living on Land and How Plants Adapt To Them:

2b. Air is a poor source of water. Going up toward the light necessitates a water source...

Solution. The root system.

Roots are another solution to the need for increasing surface area.

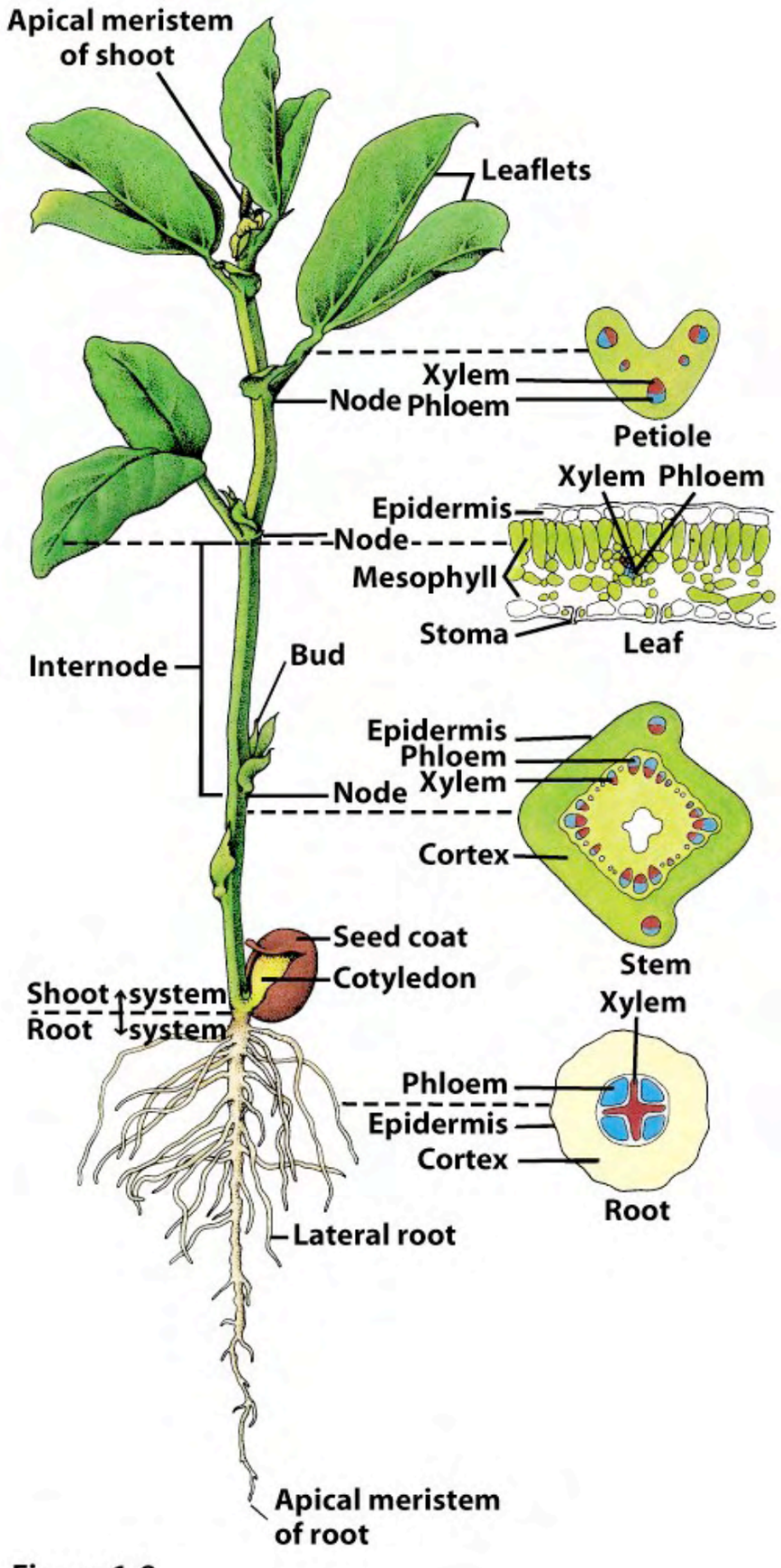
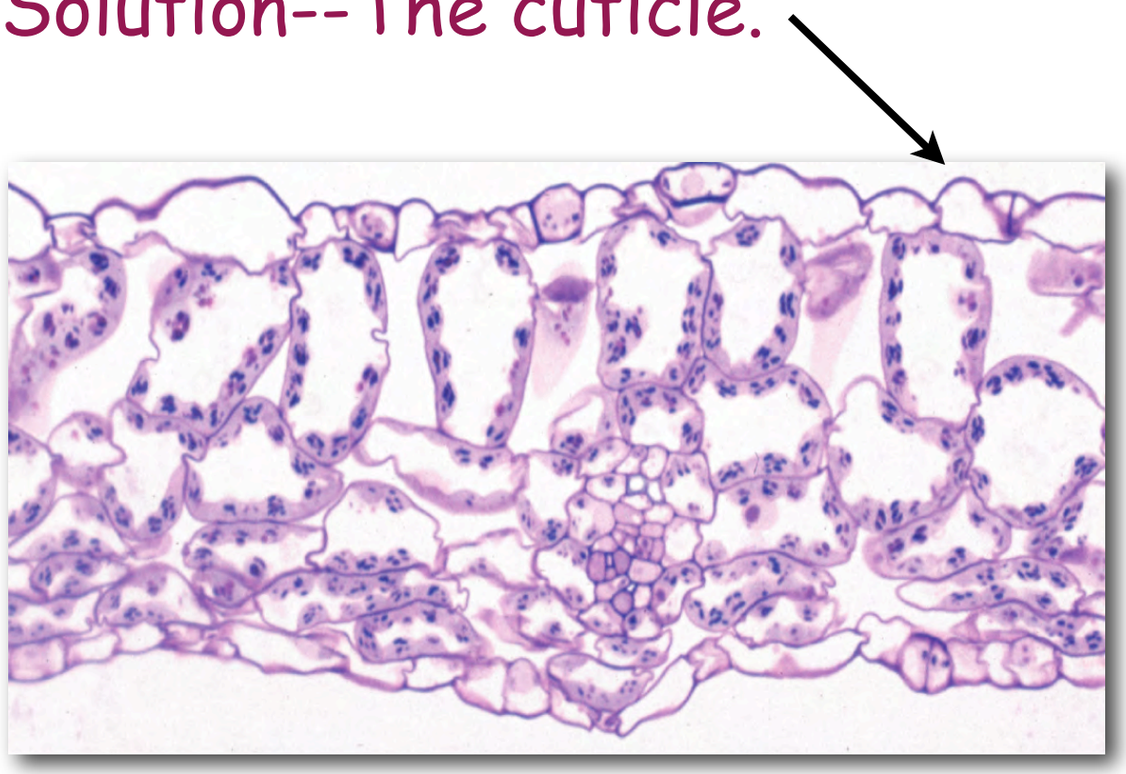


Figure 1-9
Biology of Plants, Seventh Edition

Some Problems with Living on Land and How Plants Adapt To Them:

2c. Air is a poor source of water. Having gotten water to the top of a plant, how not to lose it?

Solution--The cuticle.



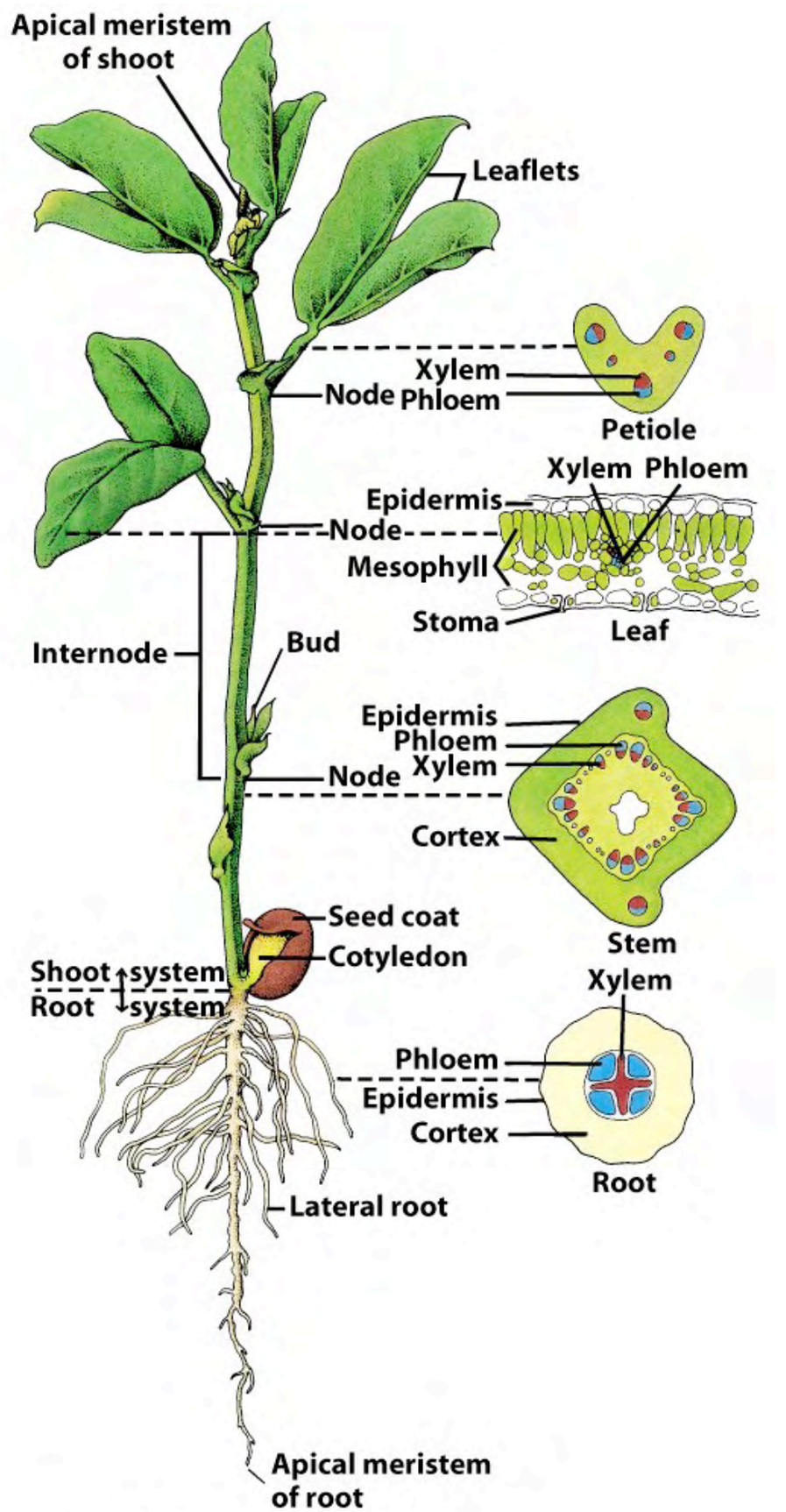


Figure 1-9
Biology of Plants, Seventh Edition

Today's Topics...

Growing in Air

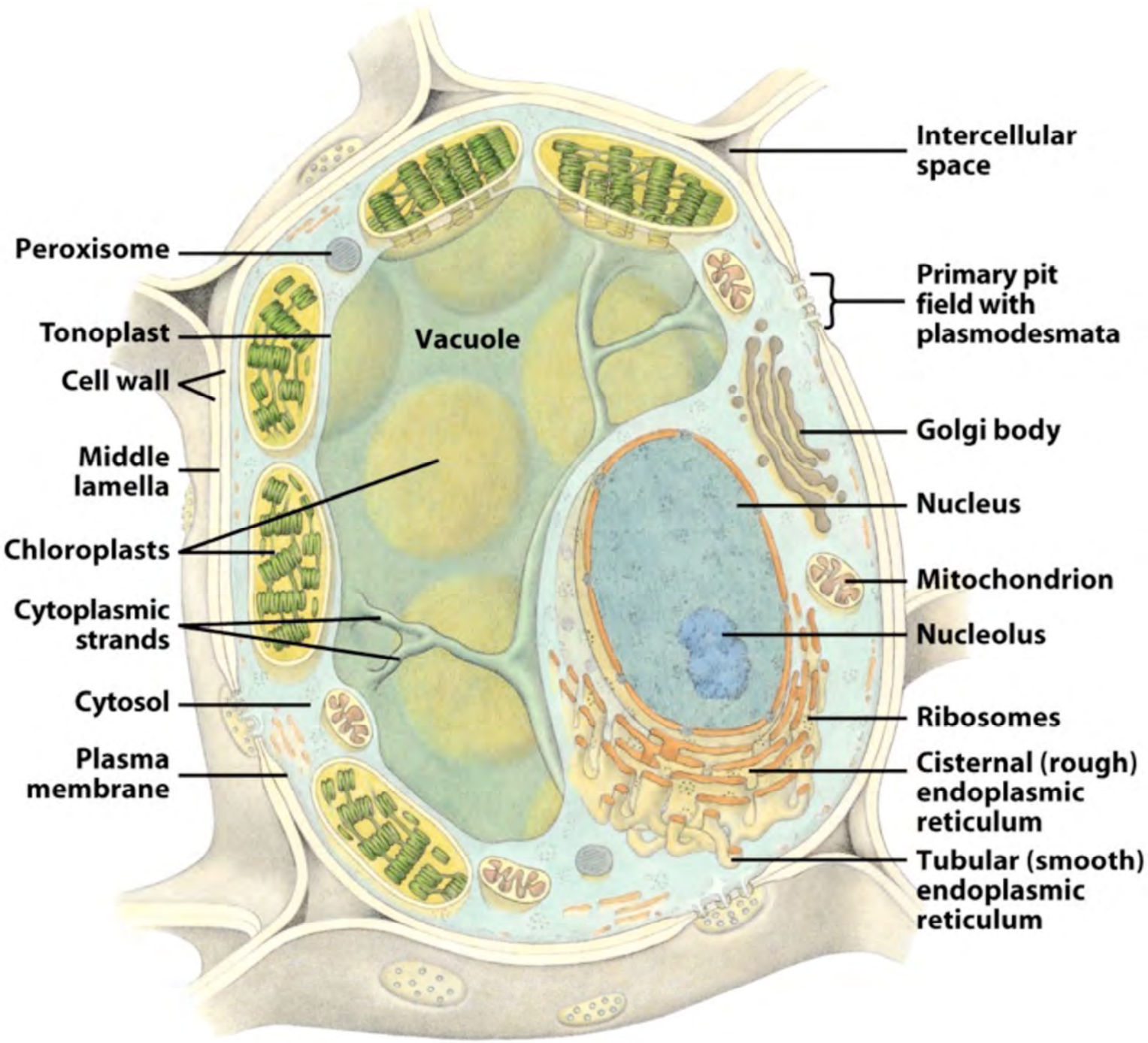
Plants need to get up to the light. Air does not provide much help with this.

Stems provide support for plants to grow up in air (or out when need be). The stem is the fundamental plant organ.

Much of plant anatomy can be understood as an adaptation for living on land.

The Plant Cell Wall

Plants Are Able to Support Themselves on Land and Build Bodies From Dead Tissue Thanks to Having Cell Walls.



The Platonic plant cell.

The Plant Cell Wall Is A Tremendous Repository of Stored Energy.

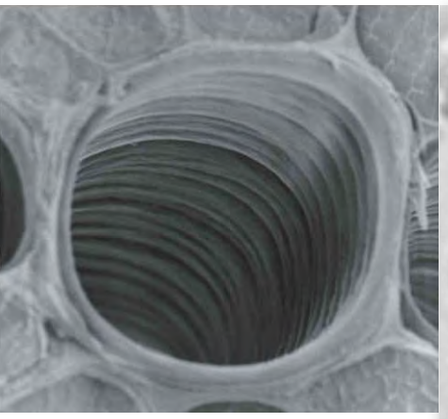
$$CO_2 + 2H_2O \xrightarrow{h\nu} (CH_2O) + O_2 + H_2O \text{ (Oxygenic photosynthesis)}$$

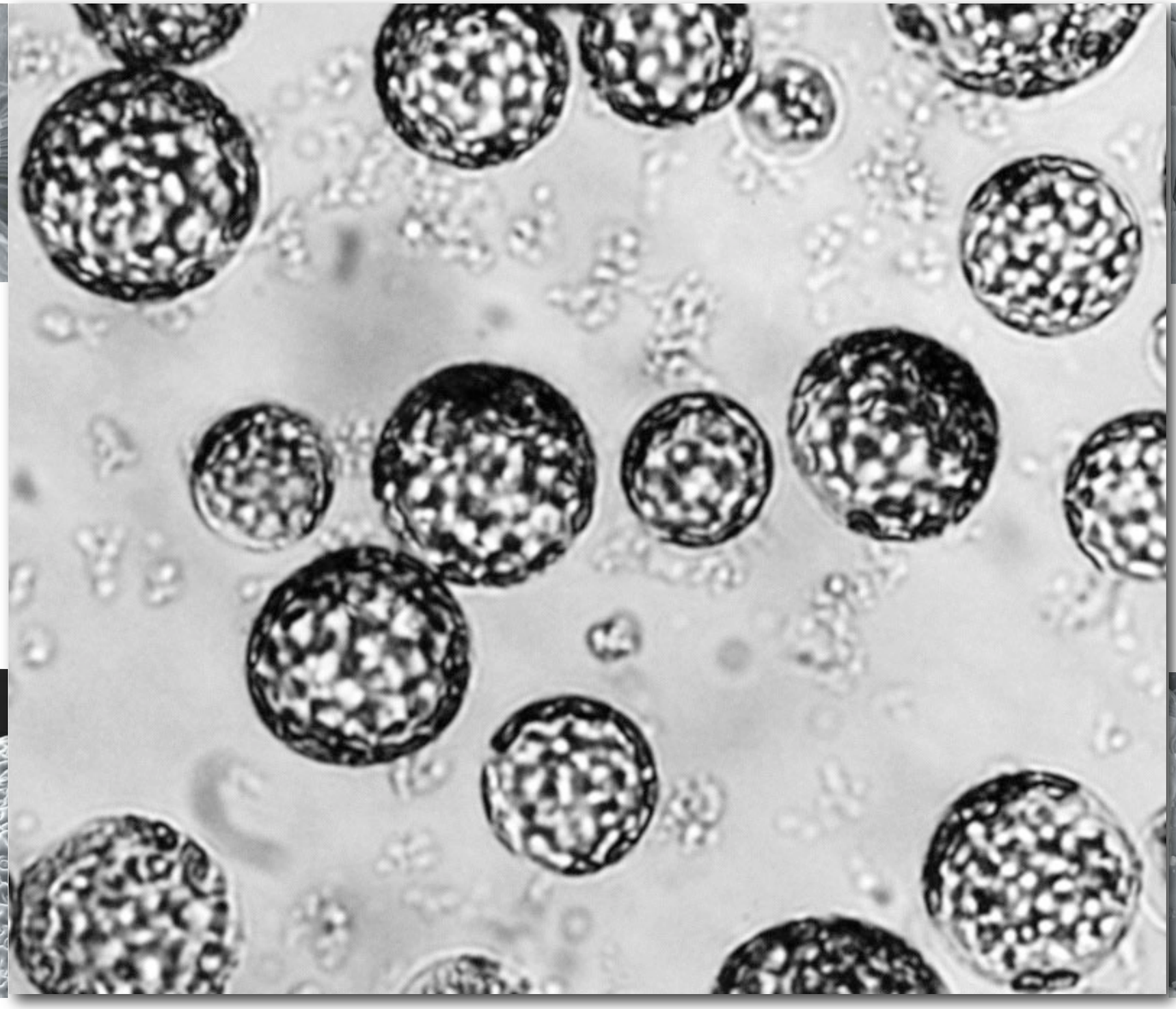
Fast-Release. A ground level fire in a pine forest. Low intensity fires such as this are an essential component of most Western ecosystems.

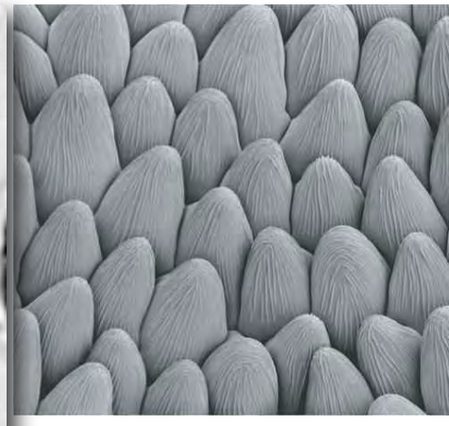
Photo: Mark Thiessen / National Geographic

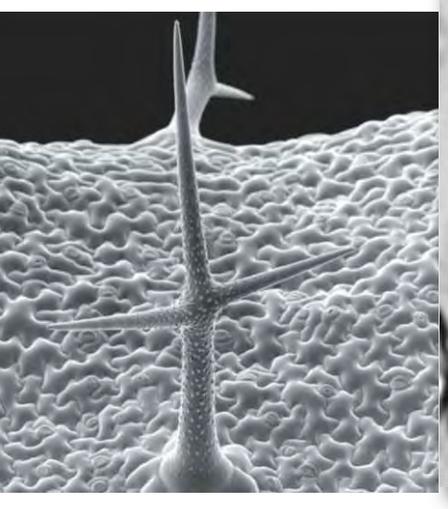
Slow-Release. White-rot fungi taking apart a log. Fungi are among the only organisms known to be capable of digesting wood and the only organisms known to degrade lignin.

The Cell Wall Is the Primary Determinant of Plant Cell Shape.





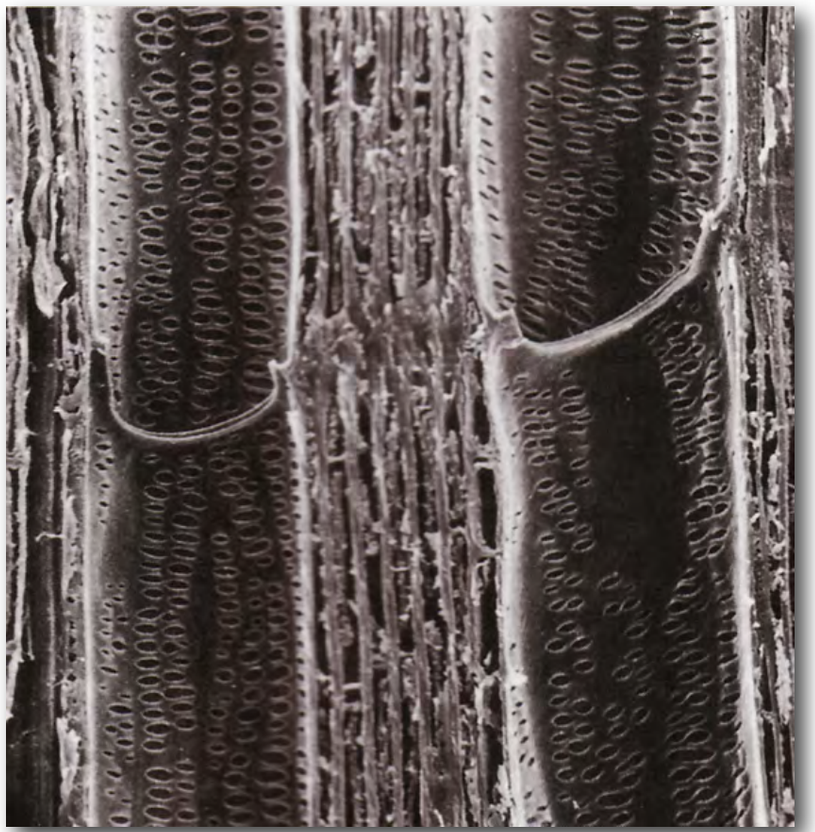




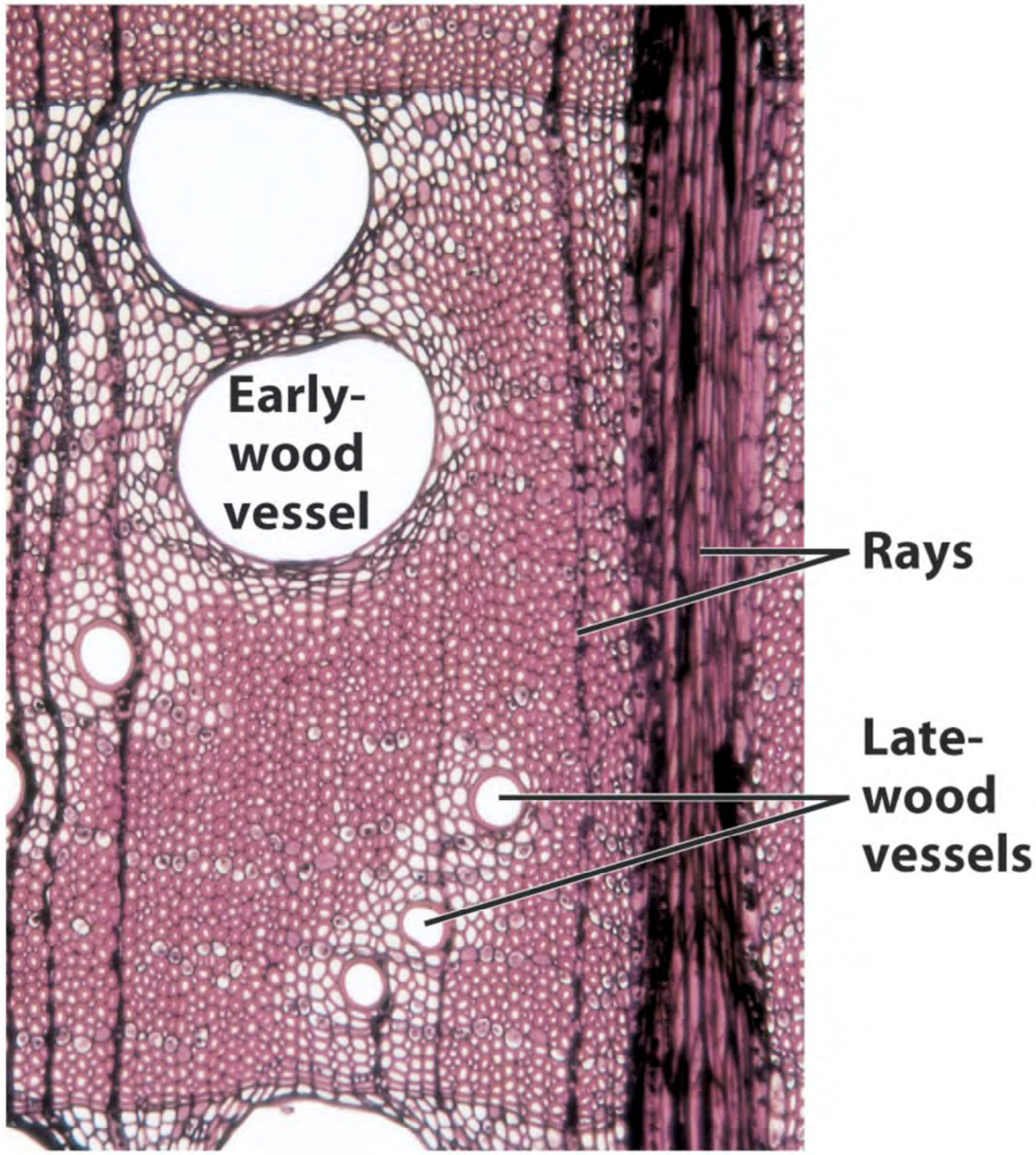
Plant protoplasts.

Cell function is often dependent upon cell shape.

Much of a Plant's Body May Be Comprised of Cell Walls Without Associated Cells.

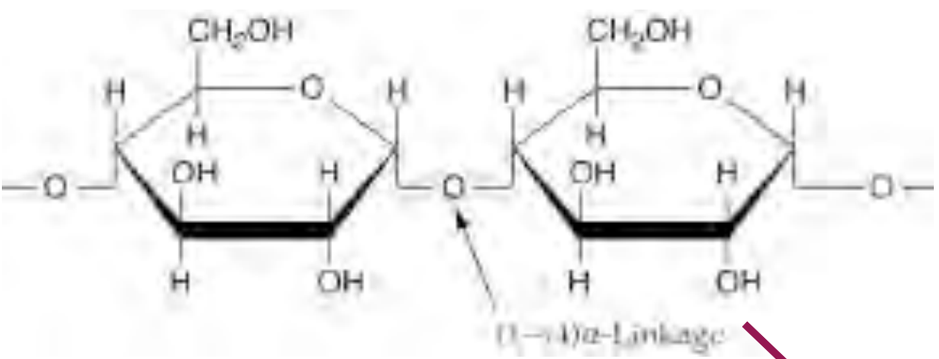


Tracheary elements of the xylem. Tracheary elements undergo programmed cell death upon maturation, resulting in empty cell walls.

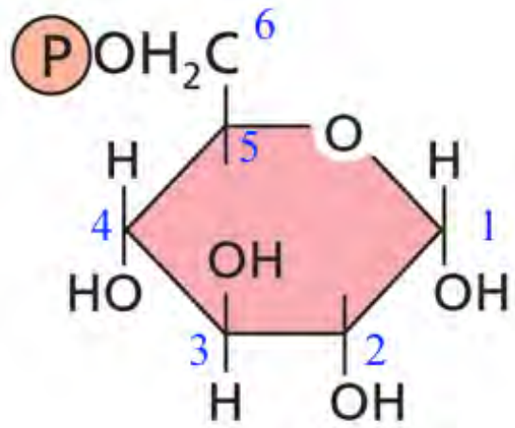


Transverse section of red oak. Apart from the ray cells, most of what you see are cell walls without any associated protoplast.

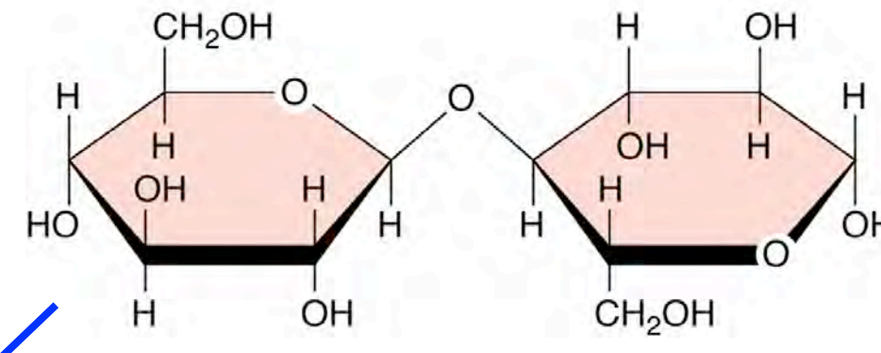
Cell Walls Are Immensely Strong, Yet Made of Linked Sugar, Chemically Different From Starch In Only a Single Aspect.



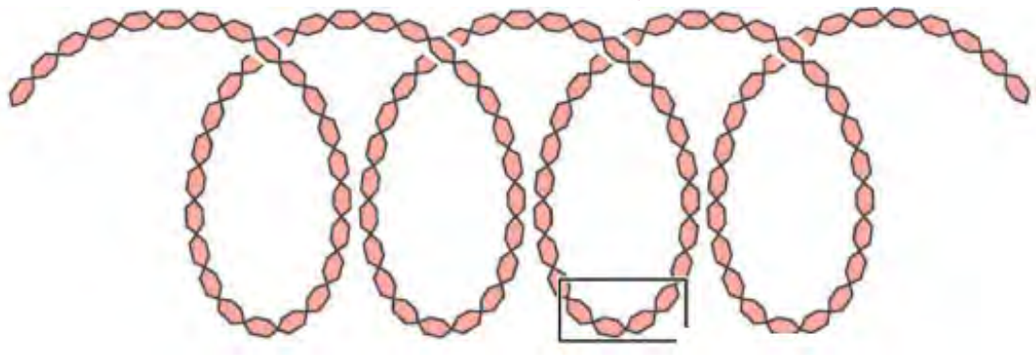
Amylose (α, 1→4)

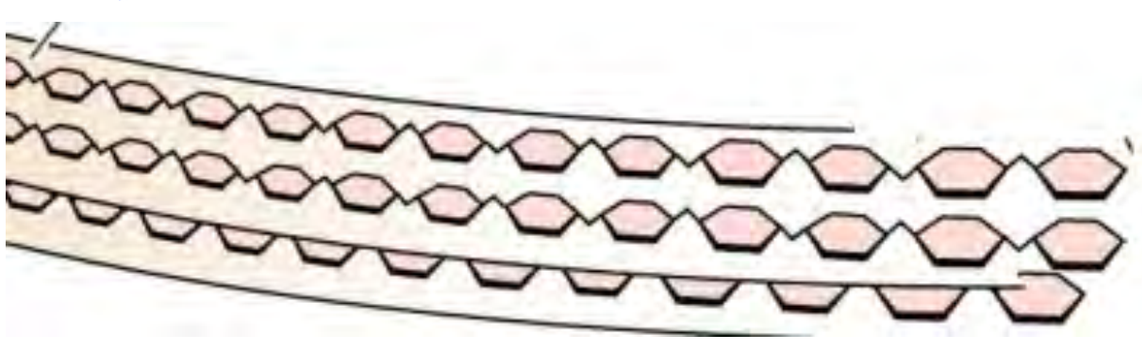


Glucose-6-phosphate

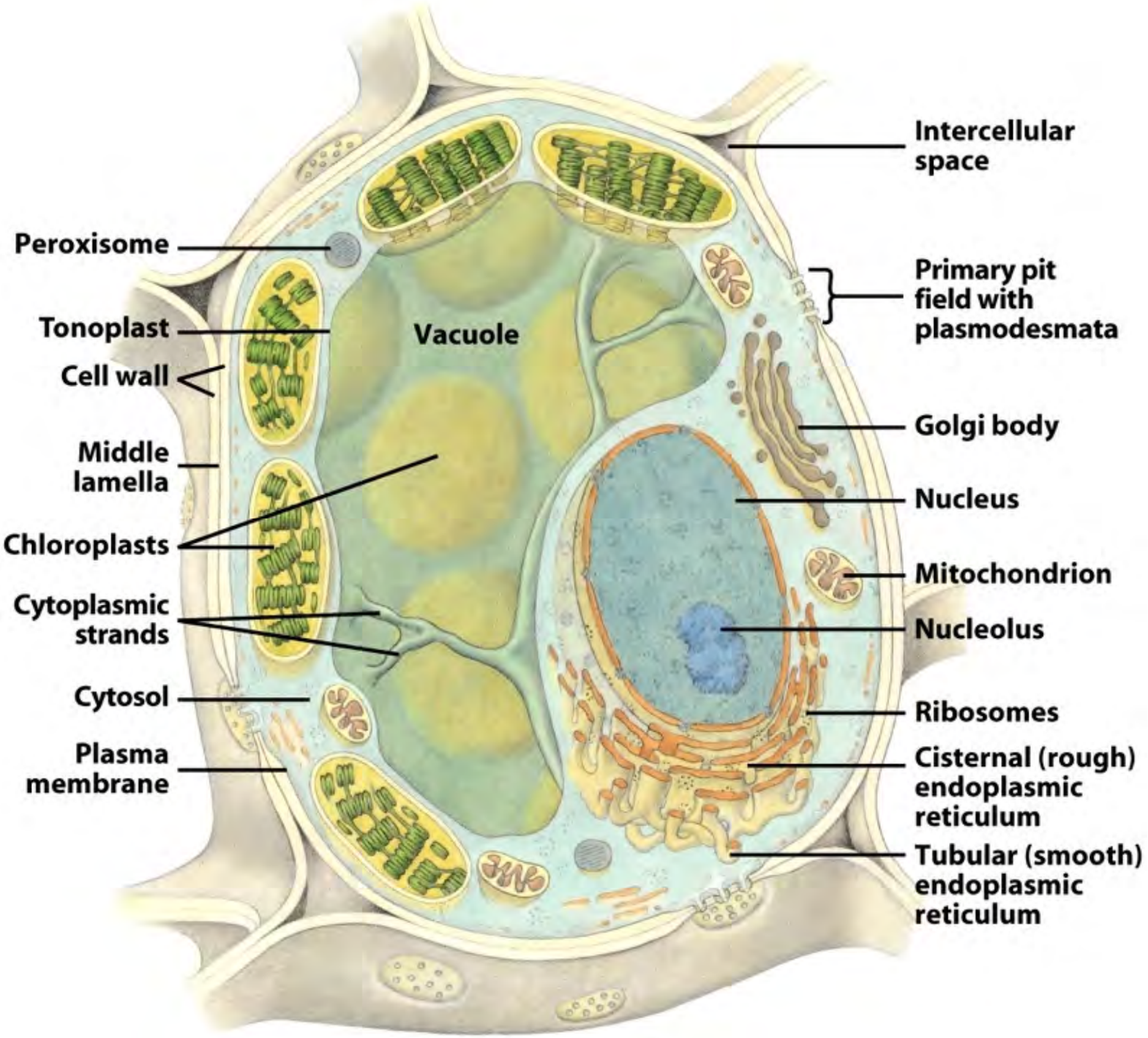


Cellulose (β, 1→4)





The Cell Wall Is a Key Regulator of Cell Growth.



The Wall Surrounds and Confines The Cell. For a Plant Cell To Grow...

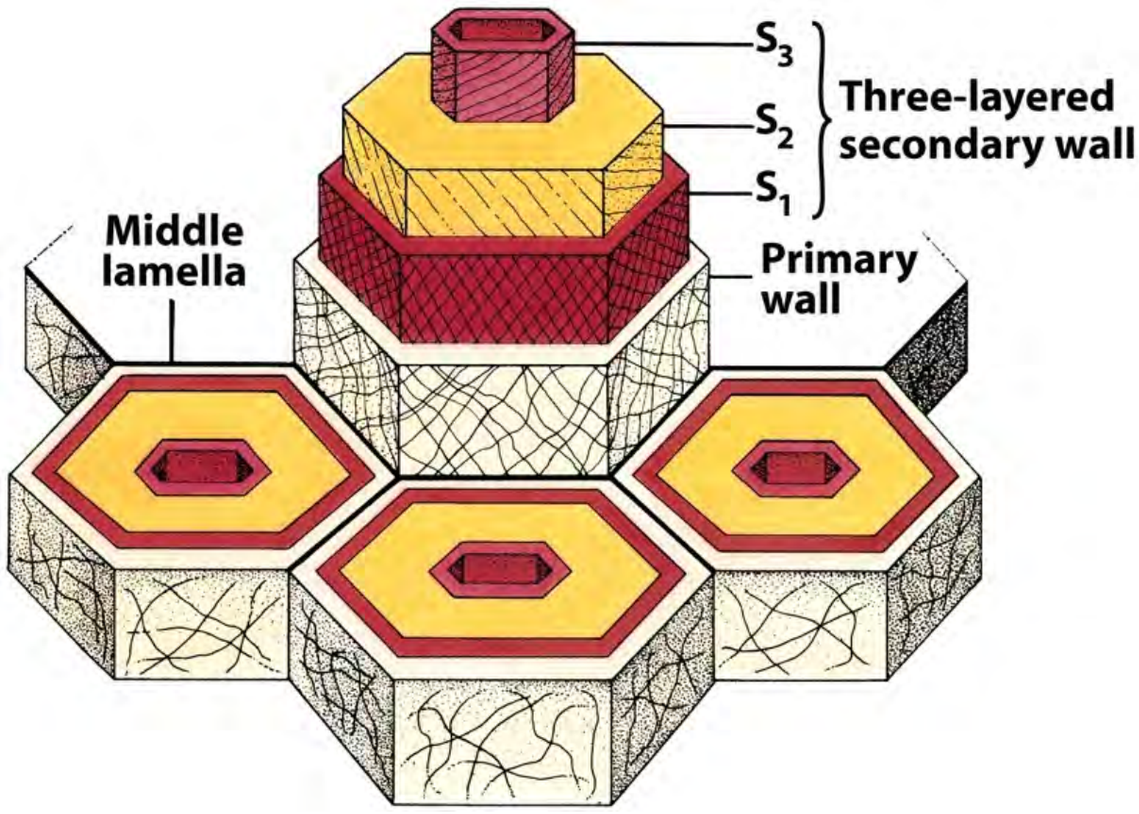
1.) Positive hydrostatic pressure must be exerted on the wall by the protoplast.

2.) The wall must loosen and expand.

Plants Require Water Saturation for Growth.

Pumpkin plants, at water saturation and otherwise.

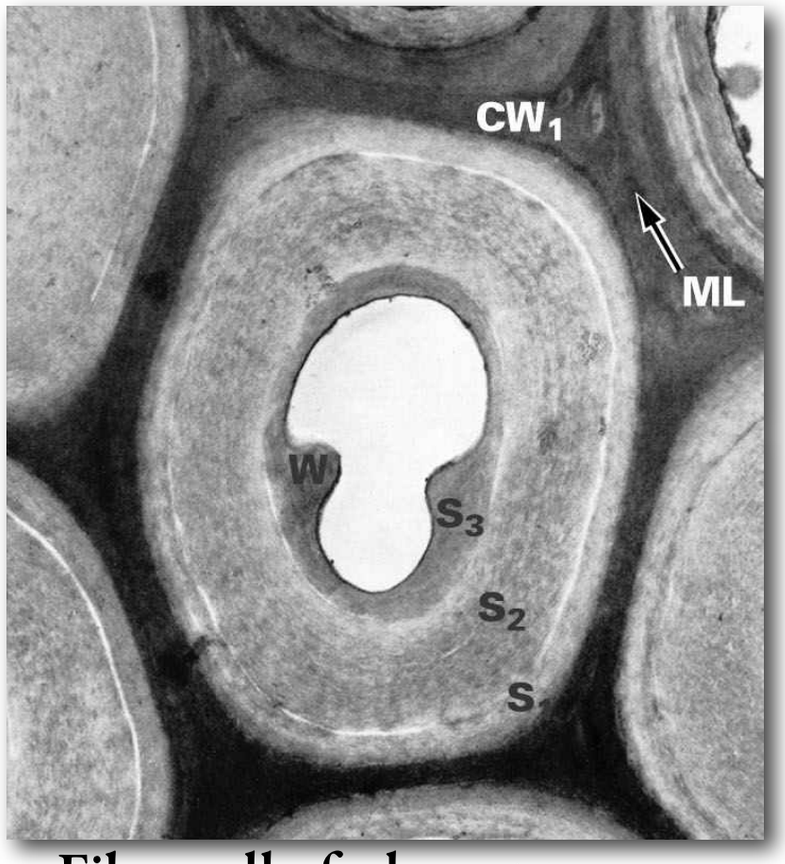
Secondary Walls Provide Additional Structural Rigidity in Specialized Cells.



Organization of secondary walls.

Secondary cell walls are formed interior to the primary cell wall.

Formation of secondary walls precludes cell growth and is followed by cell death.



Fiber cell of a locust tree, an example of prominent secondary cell walls.

Today's Topics...

The Plant Cell Wall

The plant cell wall stores energy captured via photosynthesis.

The plant cell wall determines the shape of cells, and by extension many aspects of plant function.

The plant cell wall, is made of cellulose. Cellulose has a tensile strength similar to steel. It is made of sugar.

For a plant to grow, the cell wall must expand. Cell wall expansion requires hydrostatic pressure. Plants can only grow when they have adequate water.

Wood is made from secondary cell walls. Plant cells that generate secondary walls subsequently die.

Rooted to the Ground

Plants Are Sessile.

Arctic Tern, busy going pole to pole.

Bristlecone Pine (*Pinus aristata)*, rooted in place for a very long time.

Plants Possess Three Basic Life History Strategies, Adaptations To Specific Climatic Conditions.

Annuals progress through one or more complete life cycles in a season.

Annuals undergo programmed senescence following seed production.

A member of the mustard family.

Plants Possess Three Basic Life History Strategies, Adaptations To Specific Climatic Conditions.

Biennials progress through one complete life cycles in two seasons.

Biennials undergo programmed senescence following seed production in the second season.

Queen Anne's Lace, a familiar binennial.

Plants Possess Three Basic Life History Strategies, Adaptations To Specific Climatic Conditions.

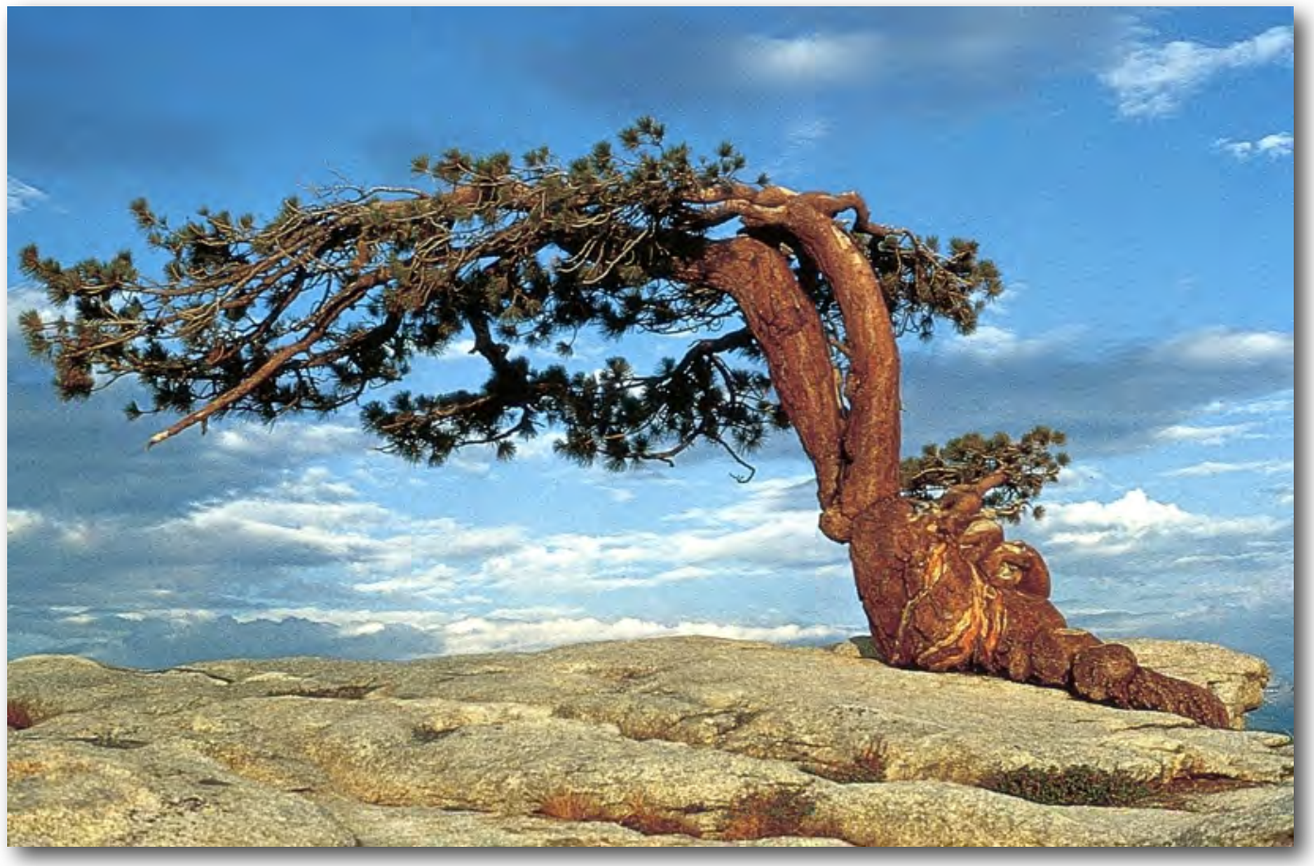
Perennials grow until they are killed by something.

Herbaceous perennials persist underground while the shoot dies off seasonally.

Woody perennials persist above ground indefinitely.

Lomatia tasmanica. The entire species is known from a single set of genetically identical individuals that is estimated to have been vegetatively reproducing itself for at minimum 43,600 years.

Plants Exhibit Developmental "Plasticity" as a Means of Adaptation to their Local Environments.



Jeffery Pines in Divergent Environments.

Phenotypic plasticity: The capacity of an organism to develop any of several phenotypic states, depending on the environment; usually this capacity is assumed to be adaptive.

From Evolution, Douglas J. Futuyama

Today's Topics...

Rooted to the Ground

Unlike animals, plant cannot relocate to escape changing environments.

Annuals and biennials are adapted to temperate latitudes by restricting their life-cycles to the optimal growing season.

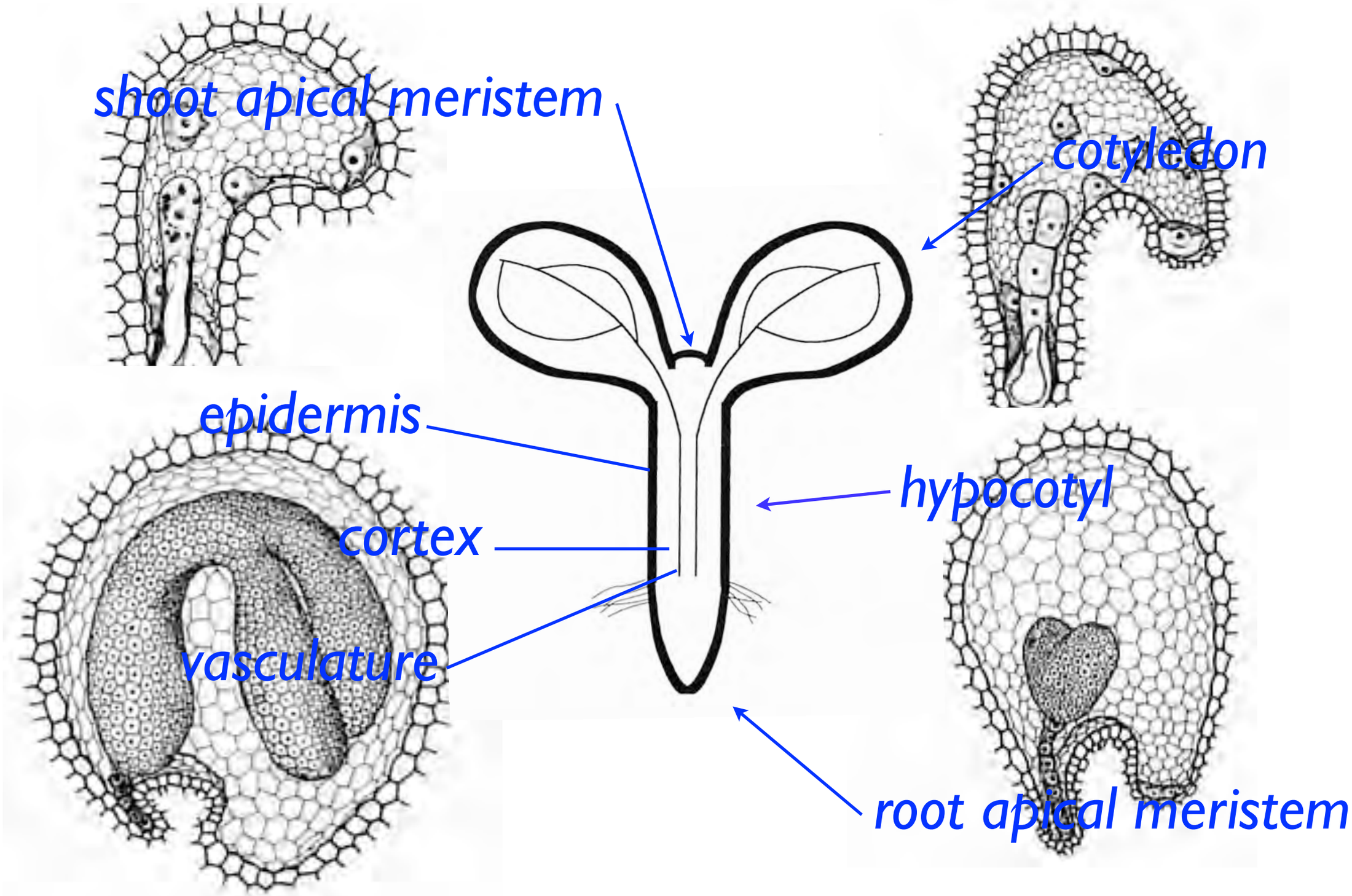
Perennial plants live until something kills them. In the interval their environments can change quite a bit.

Perennial plants respond to dynamic environments by altering their growth. This is possible because plants grow continuously and produce new organs throughout their lives (indeterminacy).

Plant Development

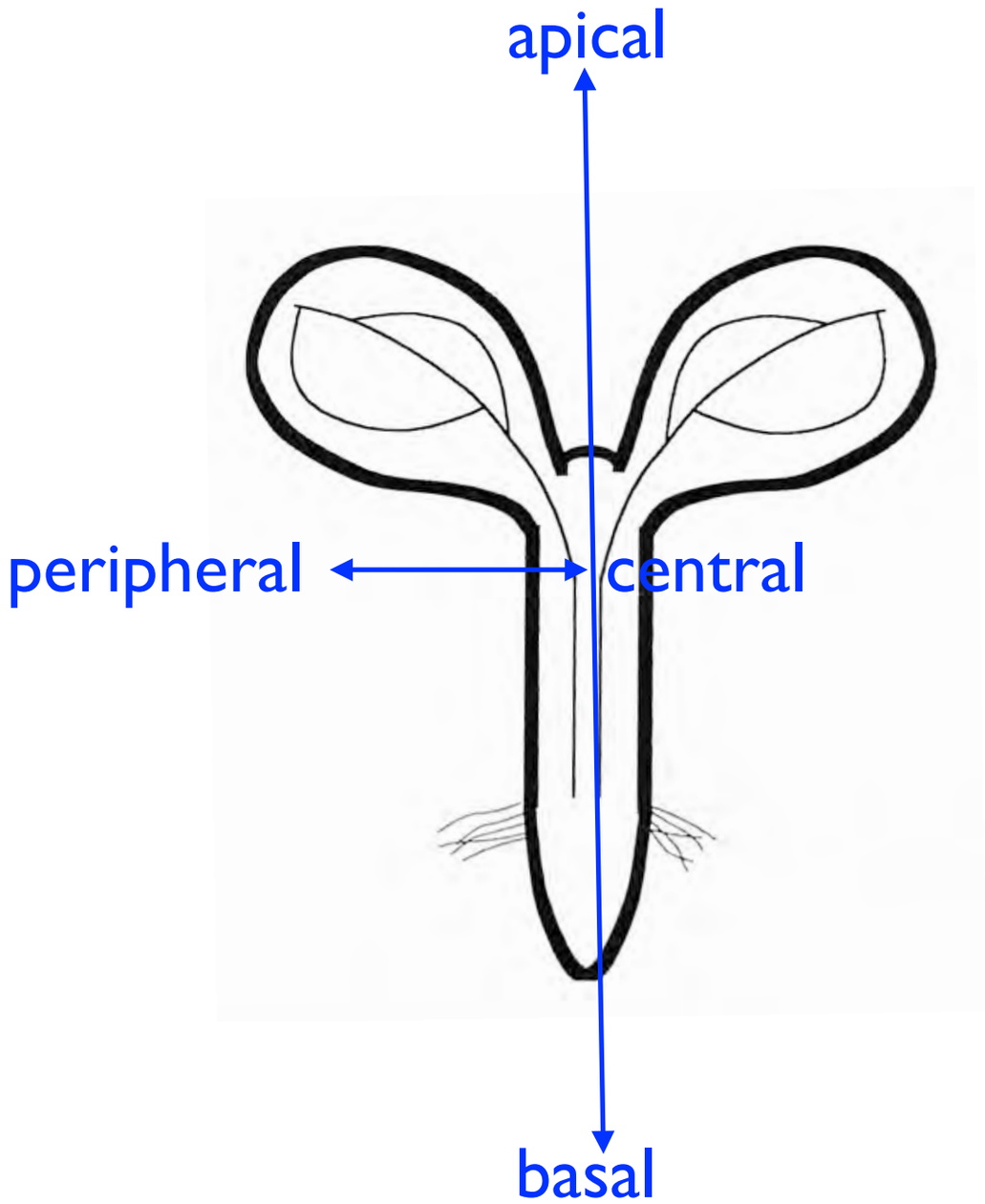
The Shoot Apical Meristem.

The Seedling is the Product of Embryogenesis.



Drawings by S. Erni from *Arabidopsis: An Atlas of Morphology and Developm*

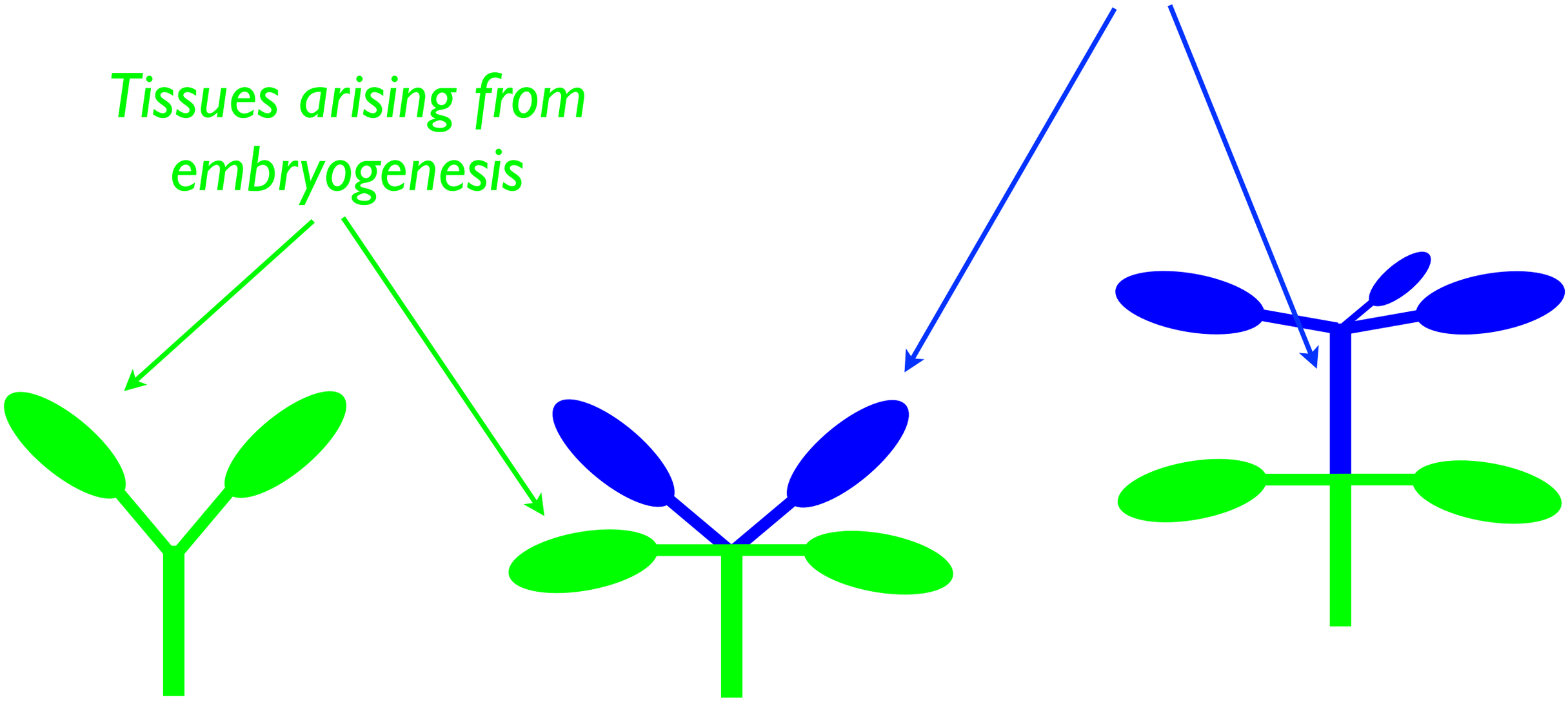
Embryogenesis Generates the Main Axes of the Plant and the Shoot and Root Meristems.



The Mature Plant is the Product of Post-embryonic Development.

Tissues arising post-embryonically from the shoot apical meristem

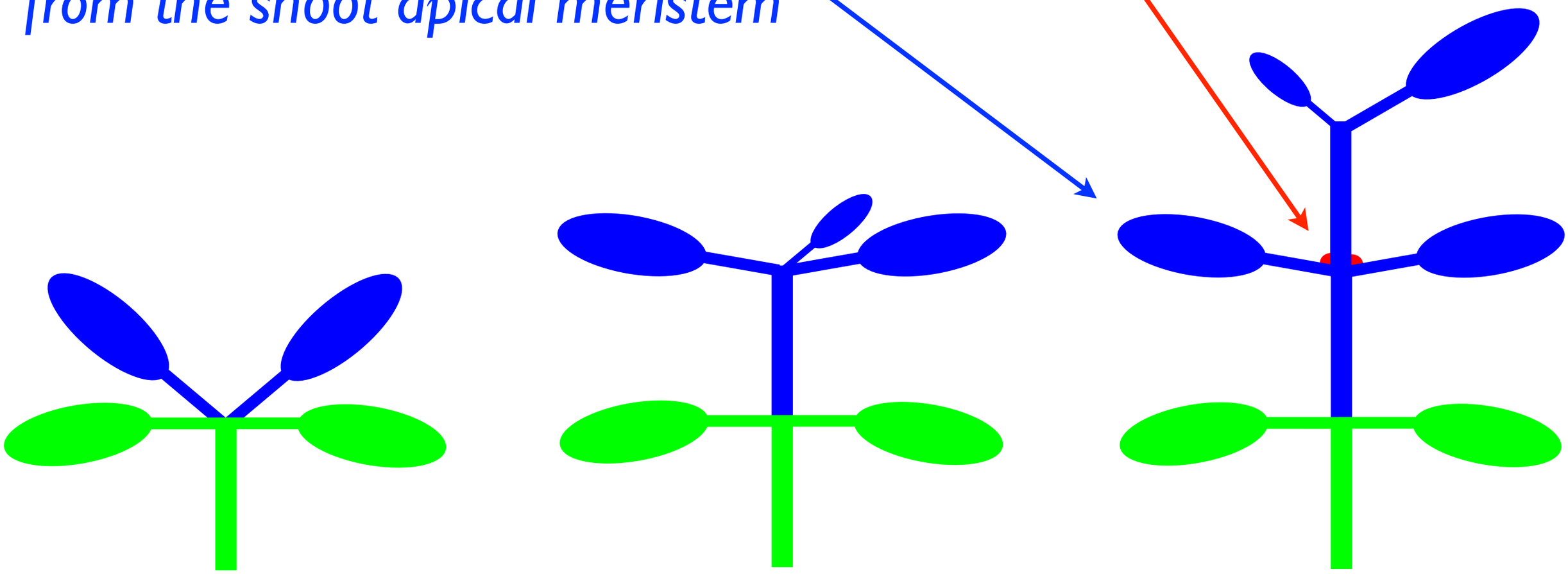
Tissues arising from embryogenesis



The Mature Plant is the Product of Post-embryonic Development.

Tissues arising post-embryonically from secondary meristems

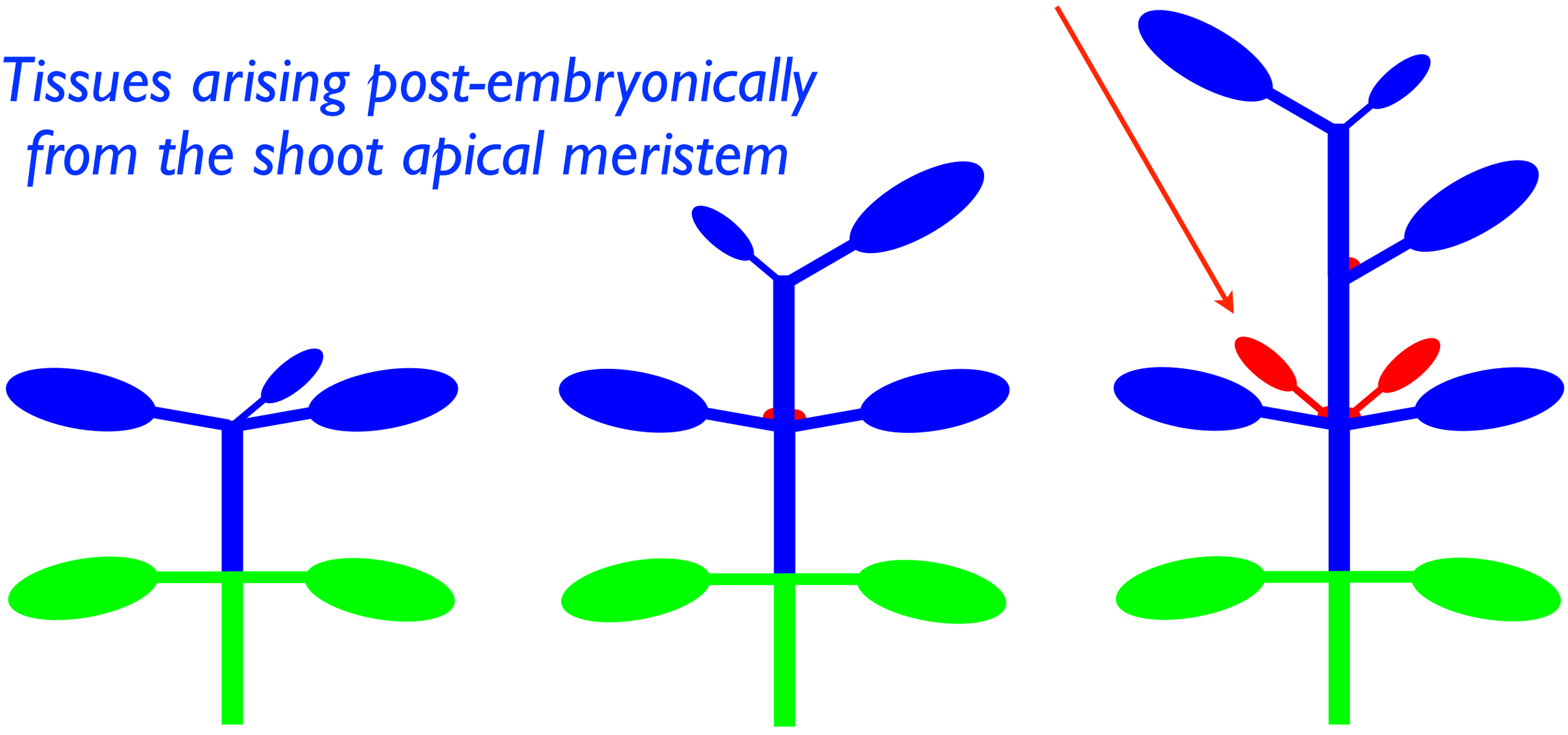
Tissues arising post-embryonically from the shoot apical meristem



The Mature Plant is the Product of Post-embryonic Development.

Tissues arising post-embryonically from secondary meristems

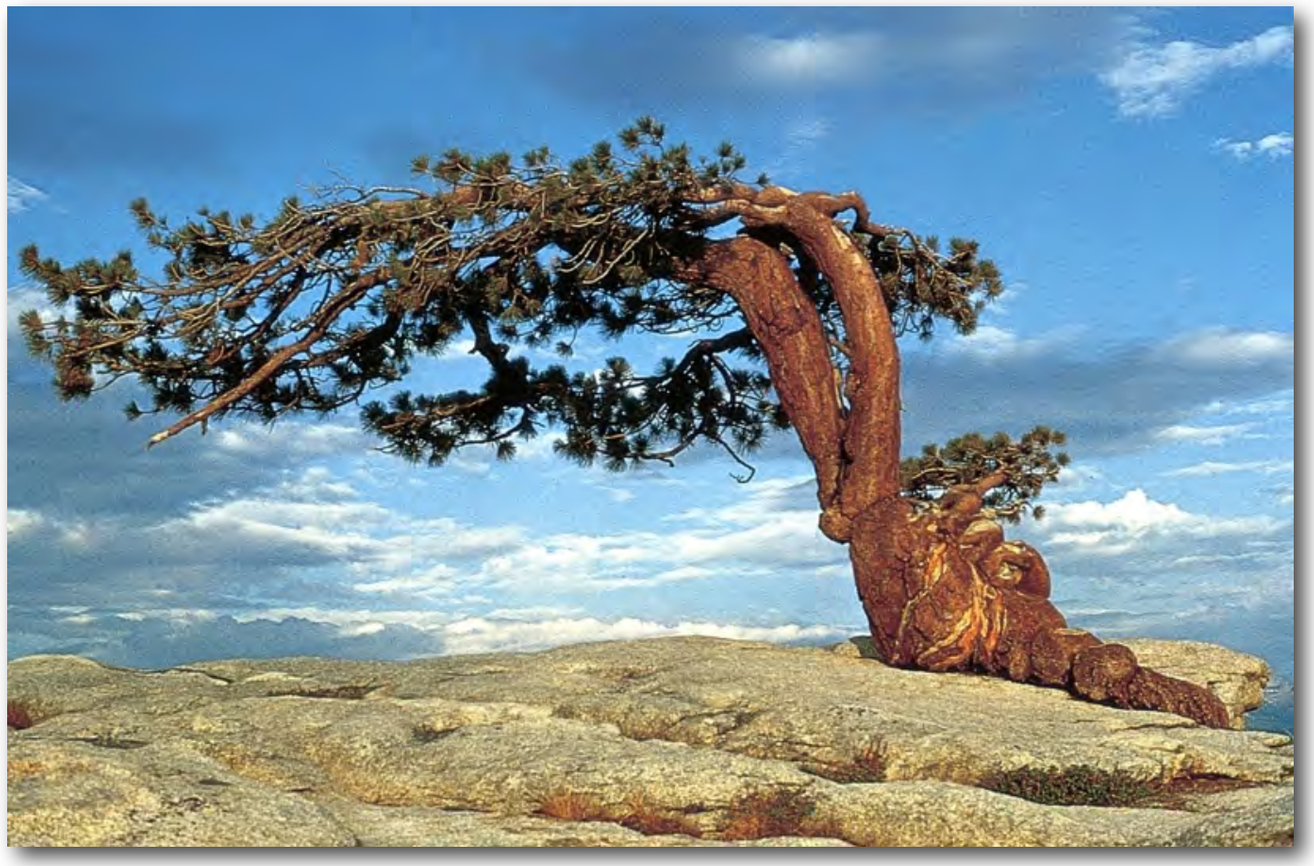
Tissues arising post-embryonically from the shoot apical meristem



A Shagbark Hickory--The Result of Post-Embryonic Development. Potentially No Embryonically Derived Tissues Remain.

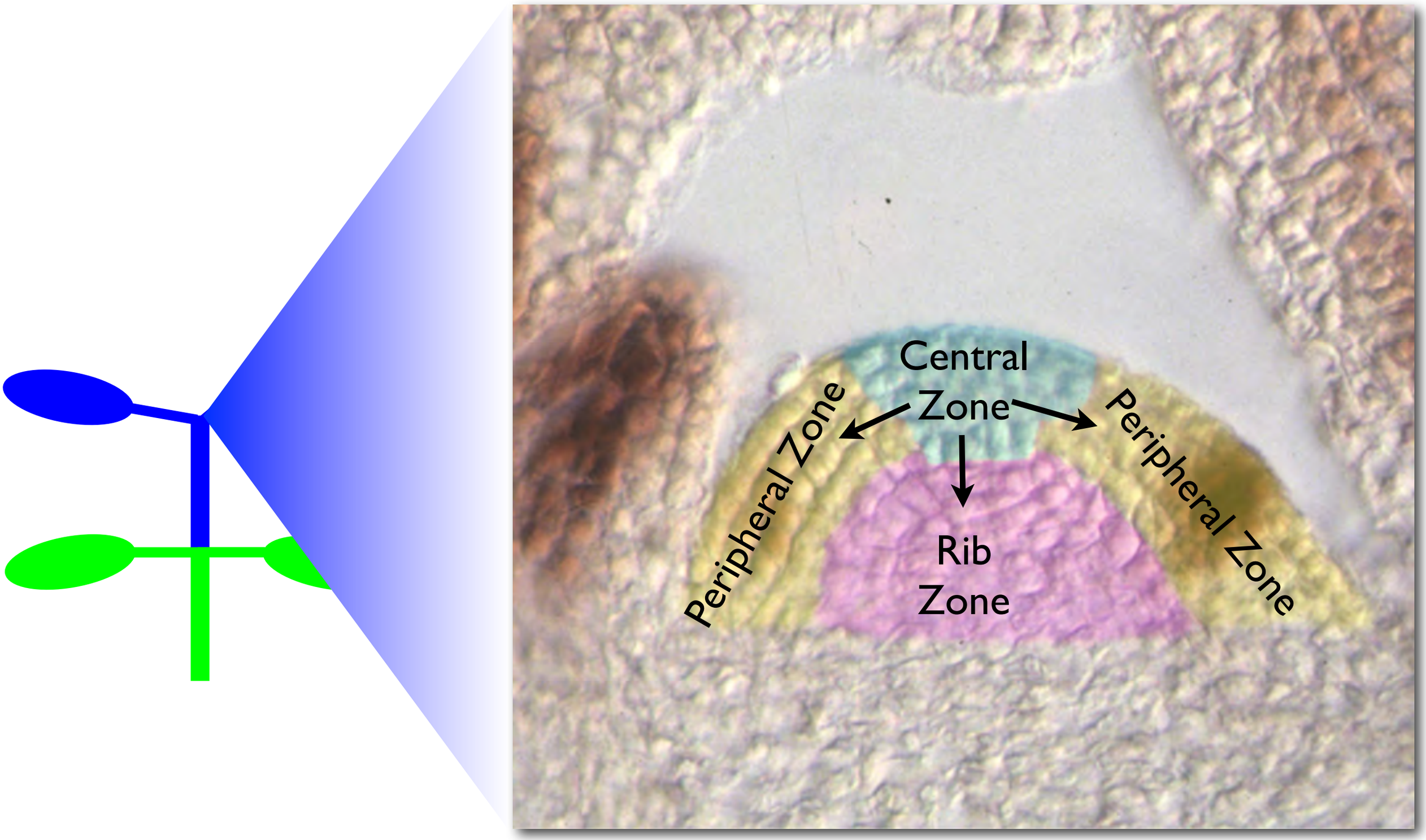
Figure 26-1
Biology of Plants, Seventh Edition

“Plasticity” and Longevity Are Consequences of Indeterminate Growth.

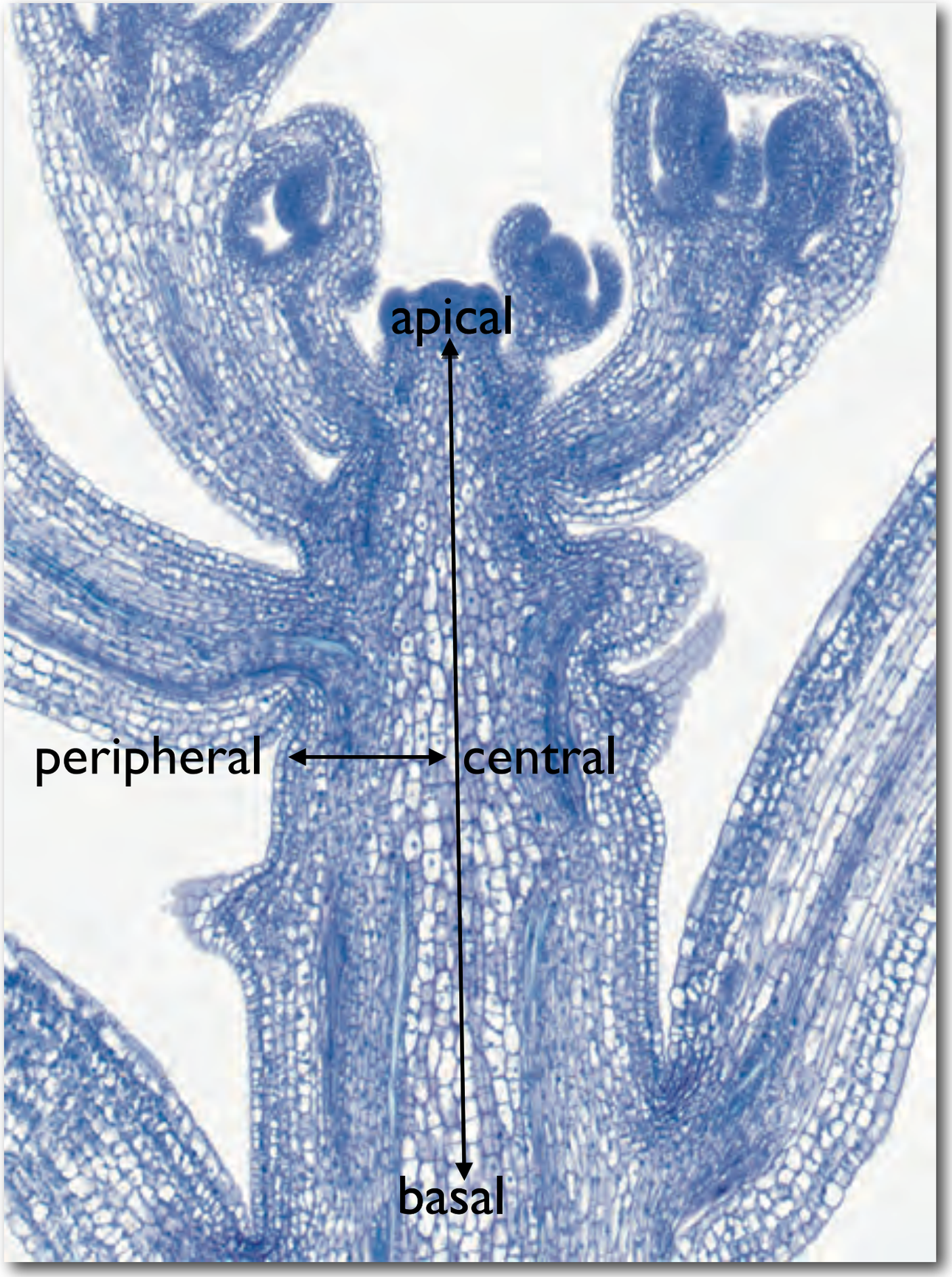


Jeffery Pines in Divergent Environments.

Indeterminate Growth Results From Plants Maintaining Populations of Undifferentiated and Totipotent Cells--Meristems.

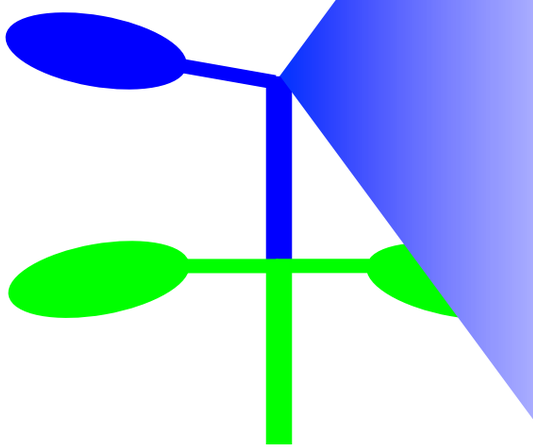


Shoots Are Organized Around Two Main Axes of Development.

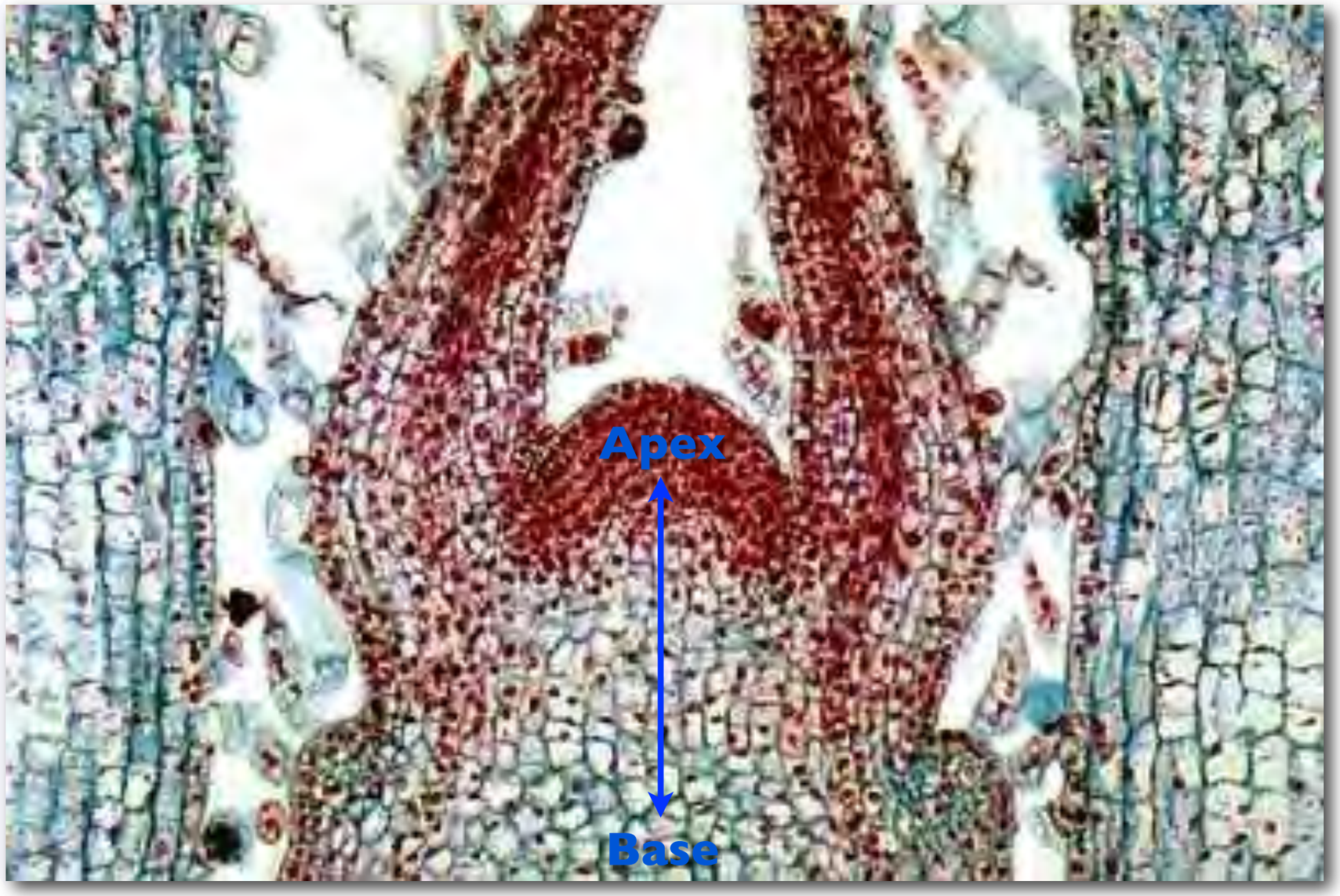


Longitudinal cross-section through an *Arabidopsis* shoot.

What is the Shoot Apical Meristem?



Schematic representation of a generic plant.

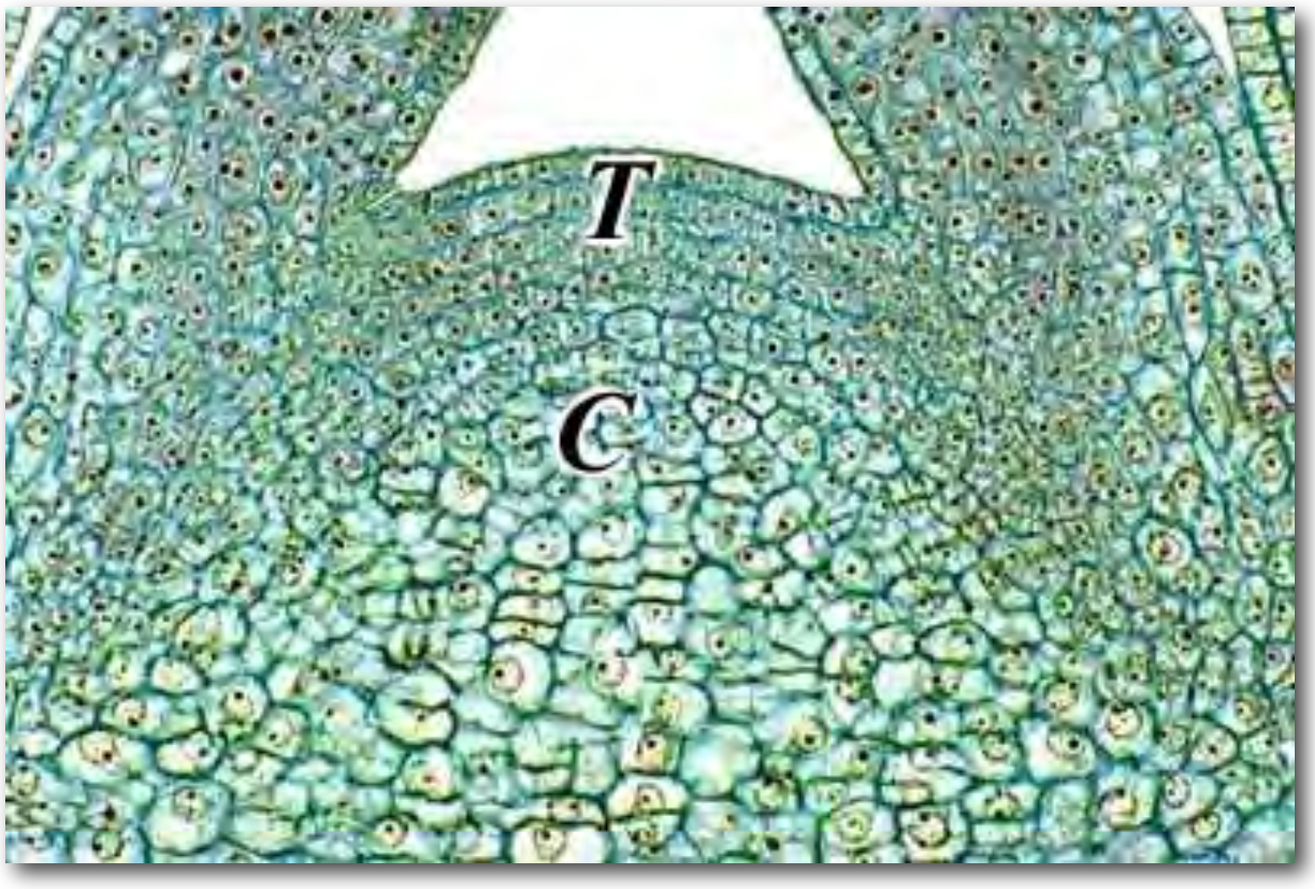


1. The Shoot Apical Meristem is the apical most structure of the sporophyte.

2. The Shoot Apical Meristem is comprised of undifferentiated, pluripotent cells.

3. The Shoot Apical Meristem is the source of both lateral organs (leaves and floral organs) and new stem tissue..

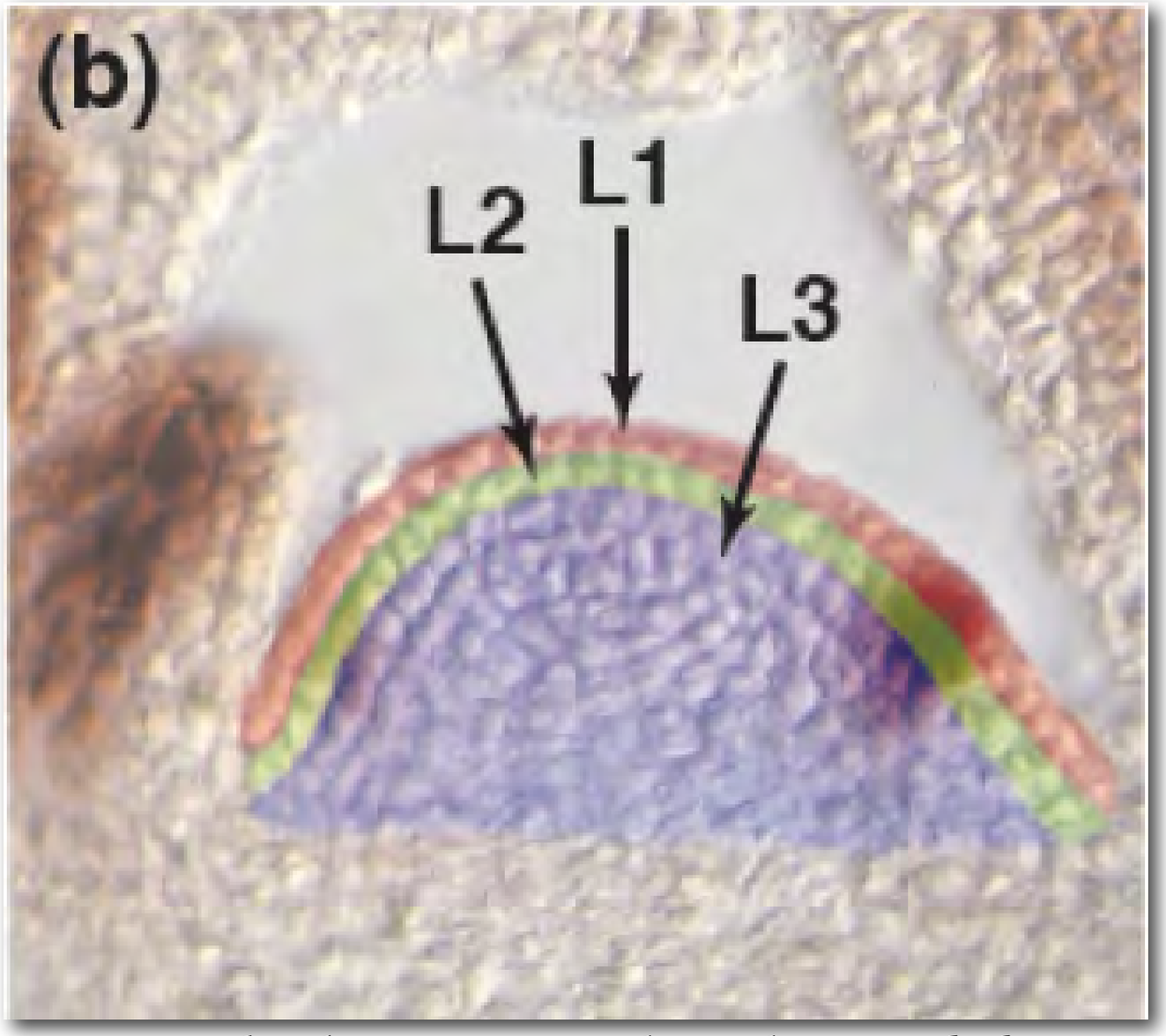
Shoot Apical Meristems Are Organized Into Tunica and Corpus Layers. The Organization is Apparent in the Orientation of Cell Divisions.



Longitudinal cross-section through a Lilac shoot apex.

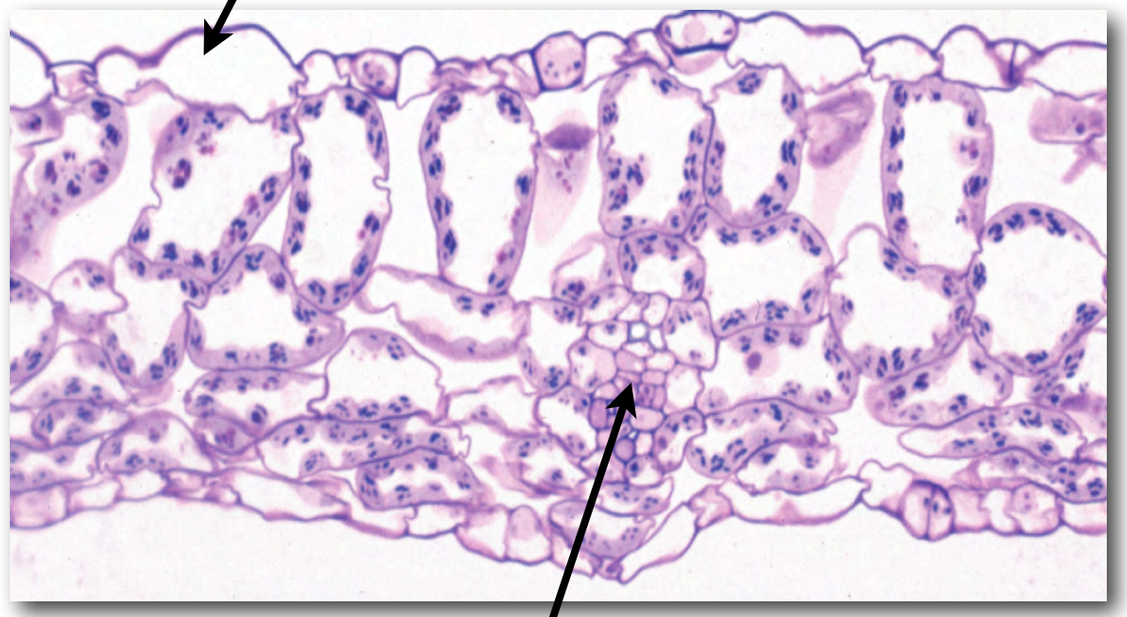
Schmidt, A. (1924) Histologische Studien an Phanerogamen Vegetationspunkten. Botany Archives. 8: pp 345-404.

The Shoot Meristem is Comprised of Three Clonally Distinct Cell Layers, Which Give Rise to Distinct Organ Tissues.



Longitudinal cross-section through an *Arabidopsis* shoot apex.

Epidermis--L1 derived.



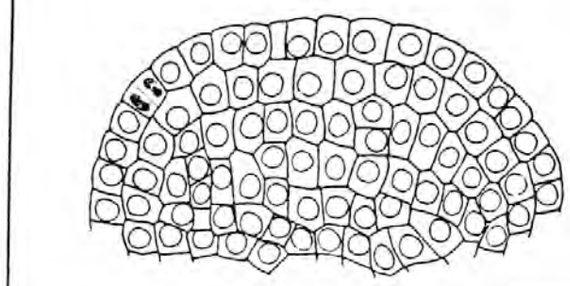
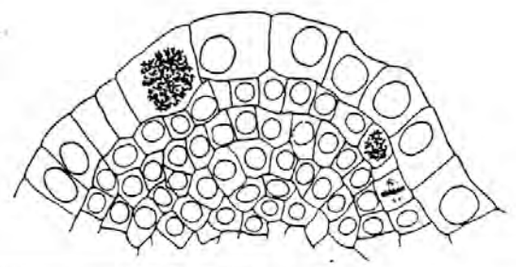
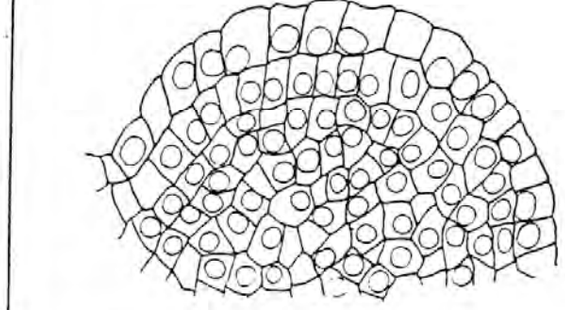
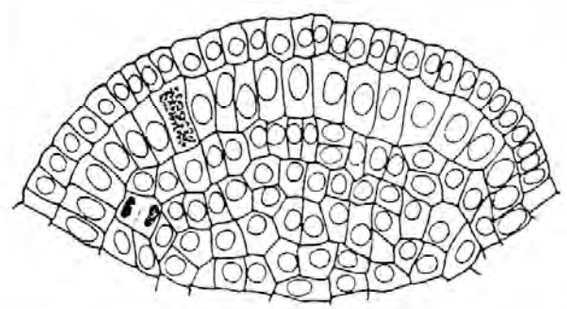
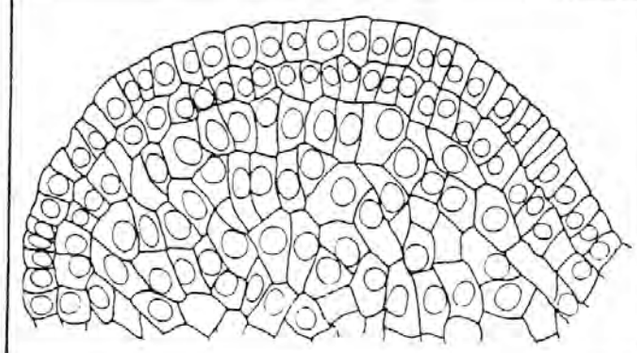
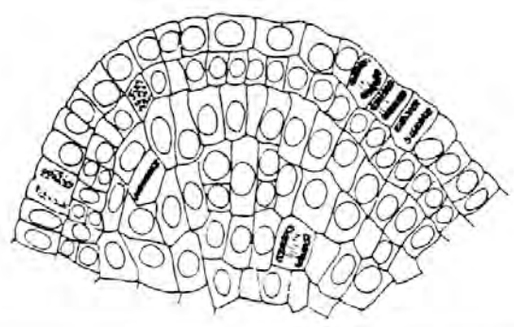
Longitudinal cross-section through an *Arabidopsis* leaf.

Vasculature--L3 derived.

Periclinal Chimeras Are a Consequence of the Clonal Distinctness of Meristem Layers.

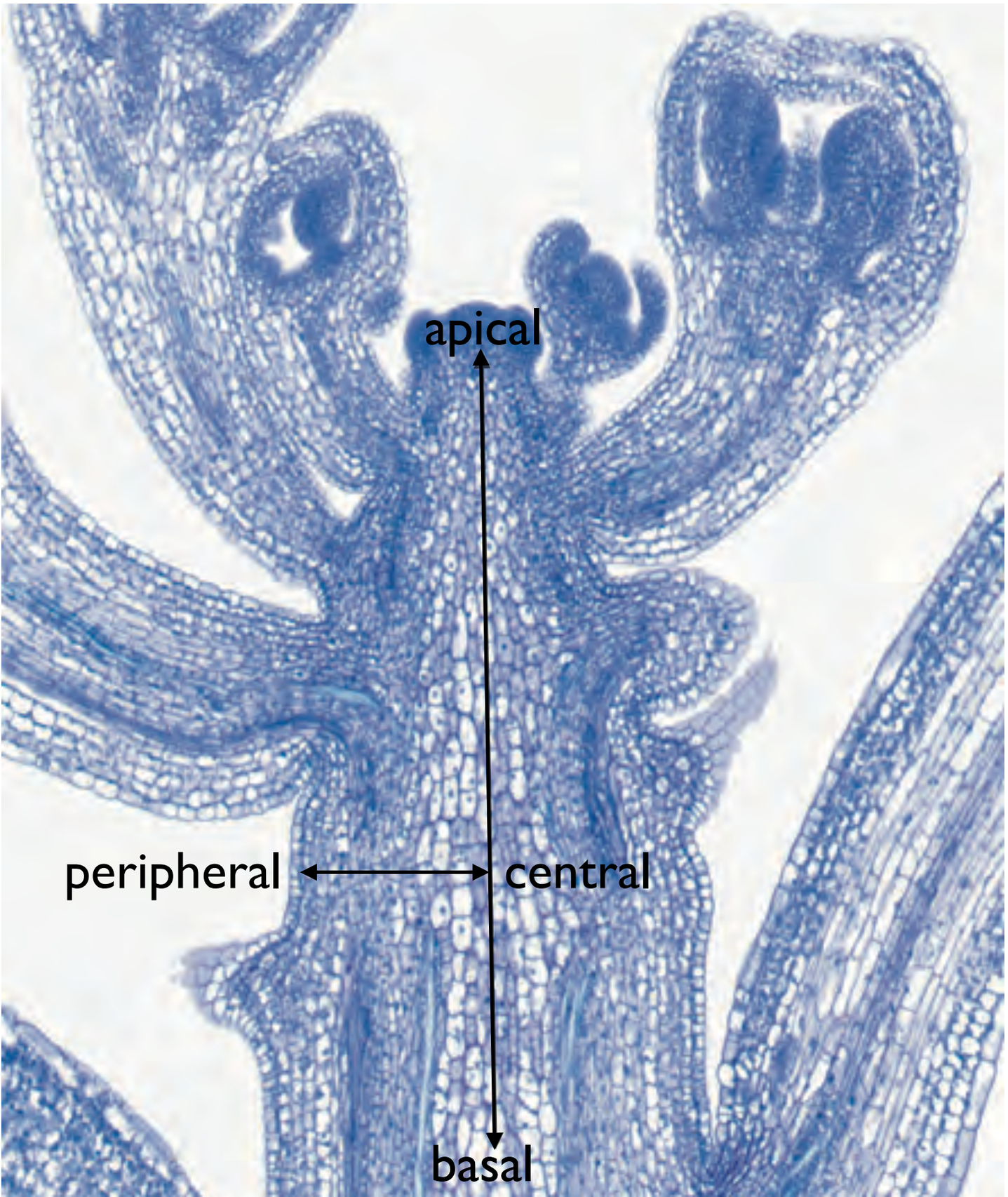
Variegated English Ivy-an example of a plastid chimera.

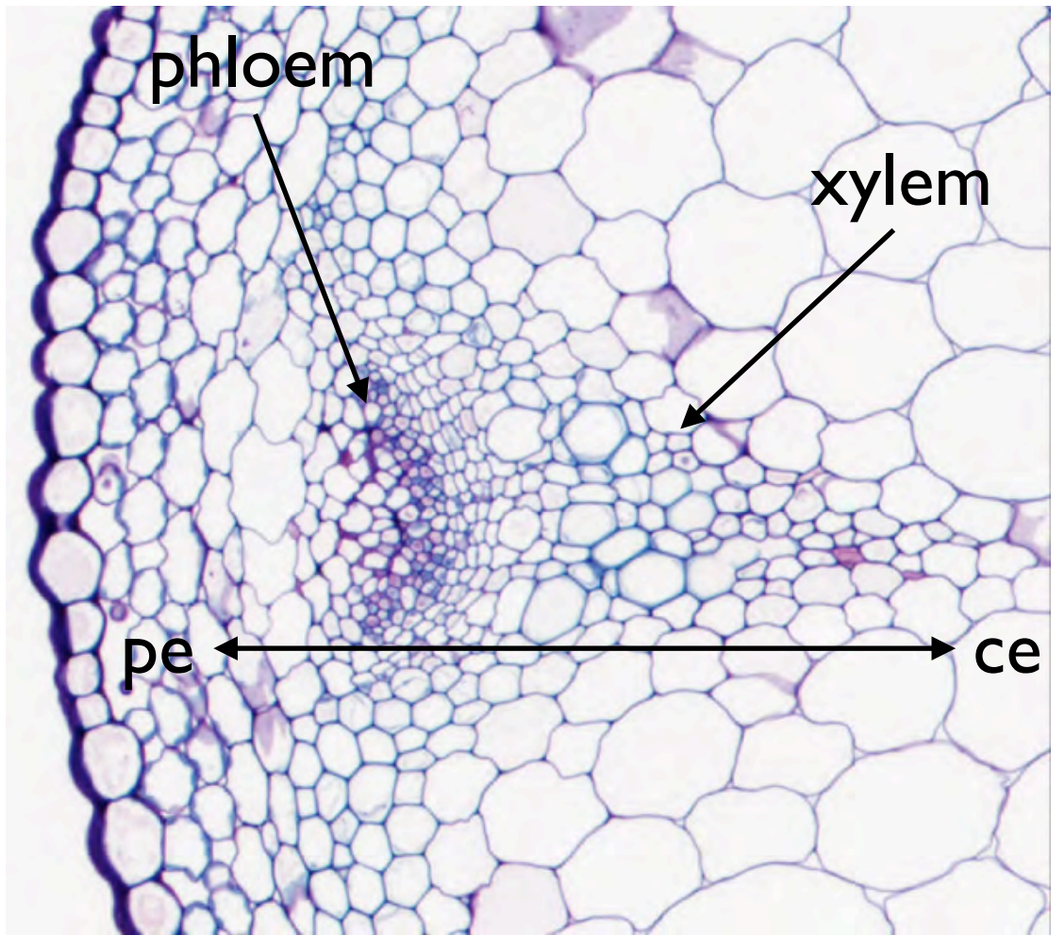
TABLE I TYPES OF PERICLINAL CHIMERAS IN 68 DATURAS

NO. OF CASES	TYPES	10μ	TYPES	NO. OF CASES
				6
	CONTROL 2n, 2n, 2n		8n, 2n, 2n	
30				4
	4n, 2n, 2n		2n, 4n, 2n	
10				4
	2n, 2n, 4n		4n, 2n, 4n	

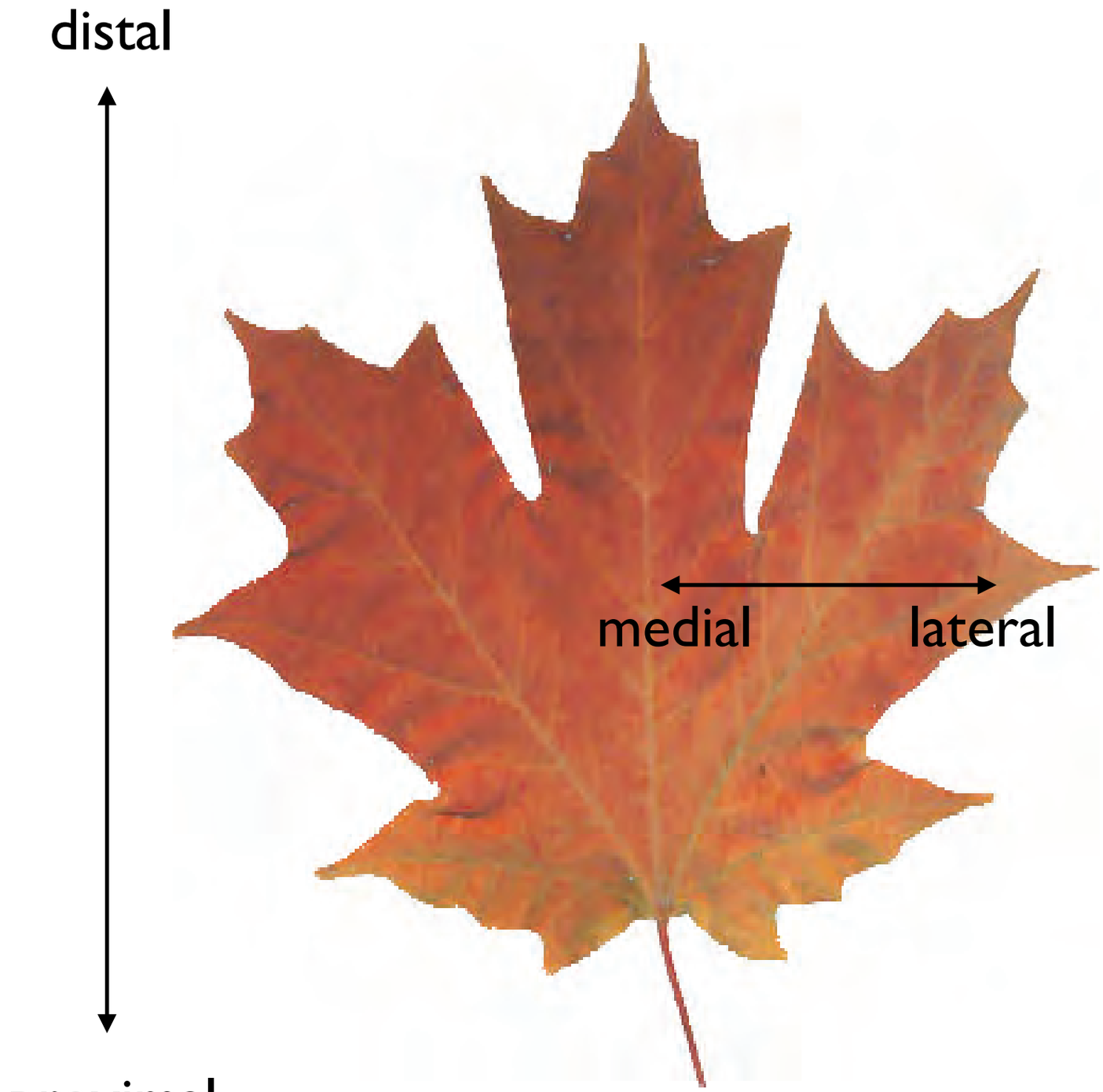
Satina et al. (1940) Demonstration of the three germ layers in the shoot apex of Datura by means of induced polyploidy in periclinal chimeras. American Journal of Botany 27: pp 895-905.

Stems Are Indeterminate Organs and Possess an Overall Radial Symmetry.





Lateral Organs Are Determinate Organs and Possess Three Axes of Symmetry.



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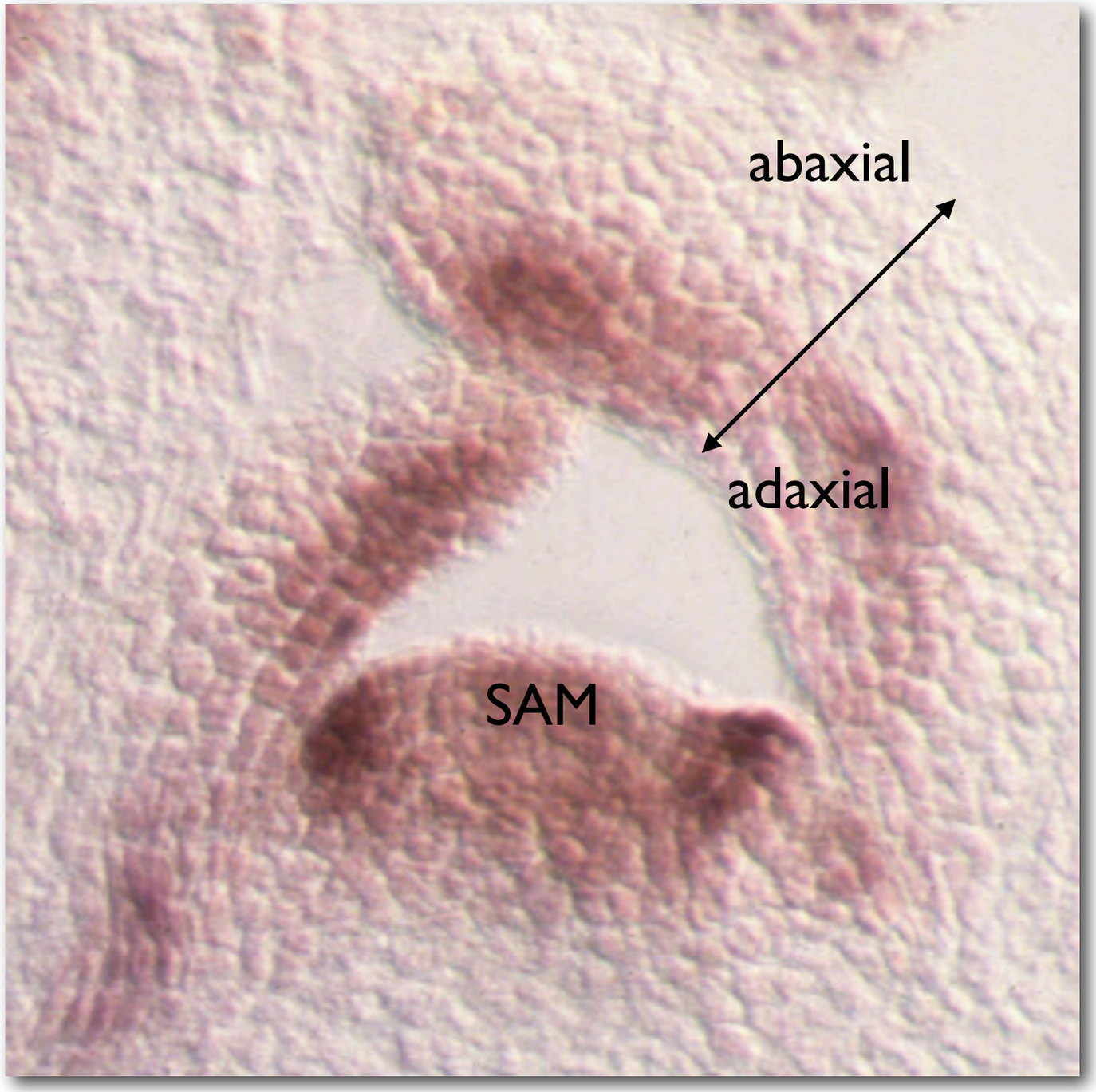
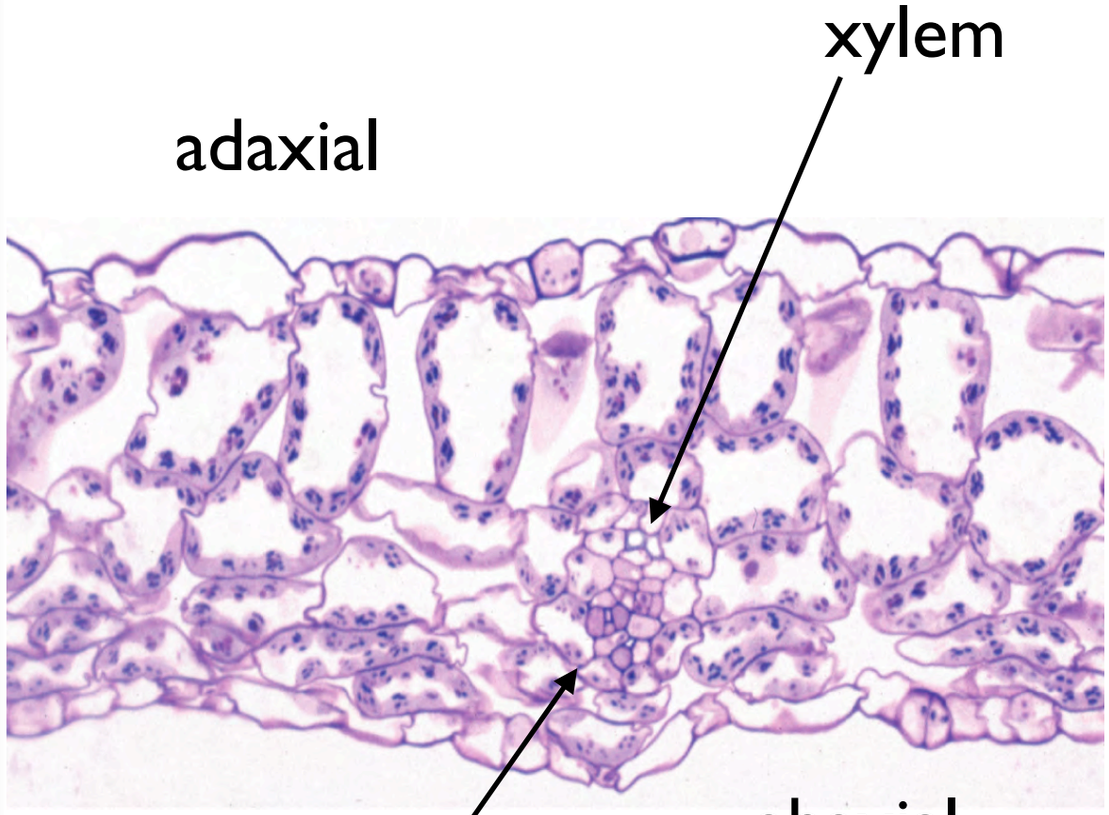




Today's Topics...

Plant Development

The Shoot Apical Meristem.

Most of plant growth and development occurs post-embryonically, quite unlike animals.

Indeterminacy, the capacity for growth and production of new organs throughout the plant's life, is made possible by meristems, populations of cells at shoot apices.

Meristem cells are undifferentiated, that is they have no specialized functions.

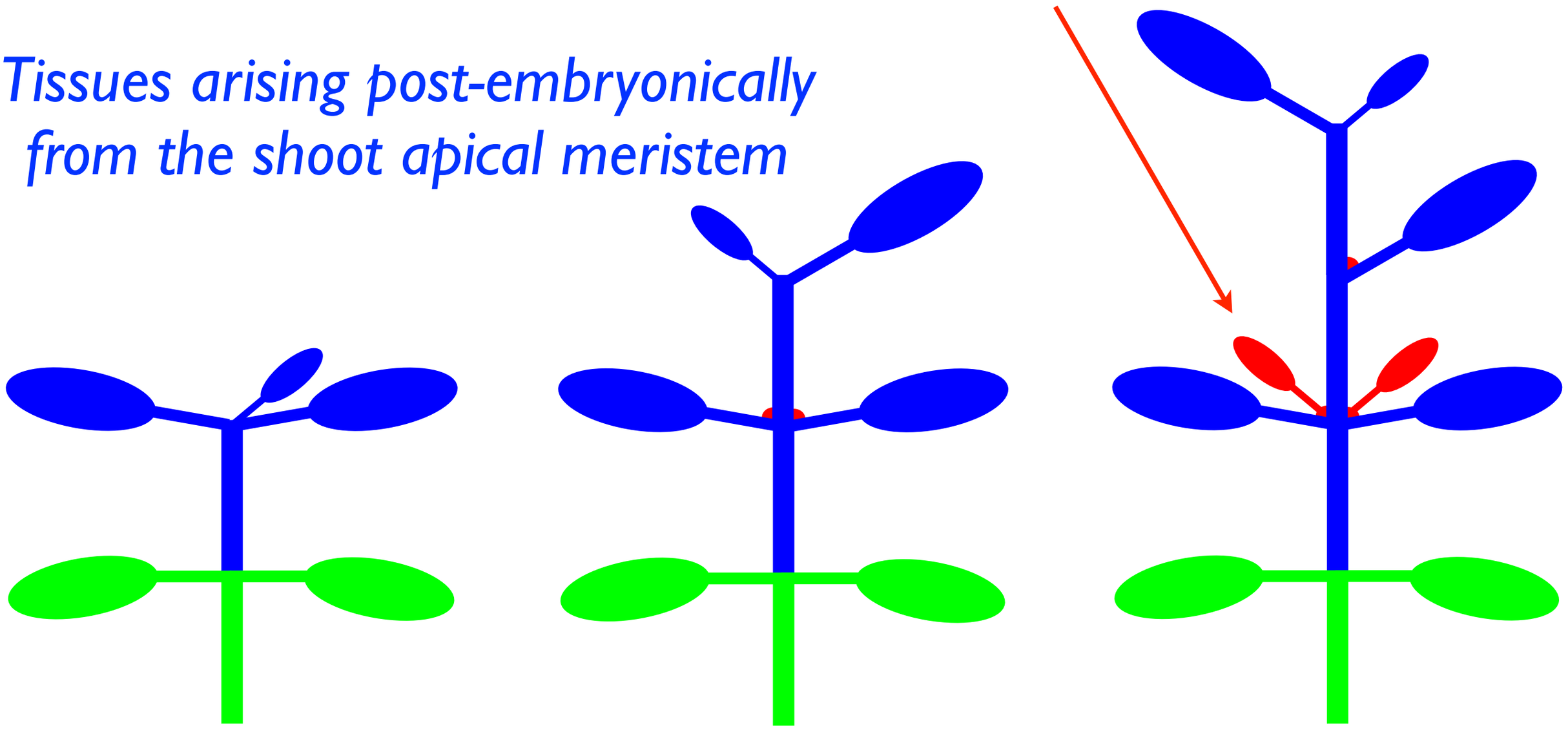
Meristem cells are totipotent, that is they can differentiate into any cell type in the plant.

Secondary Growth.

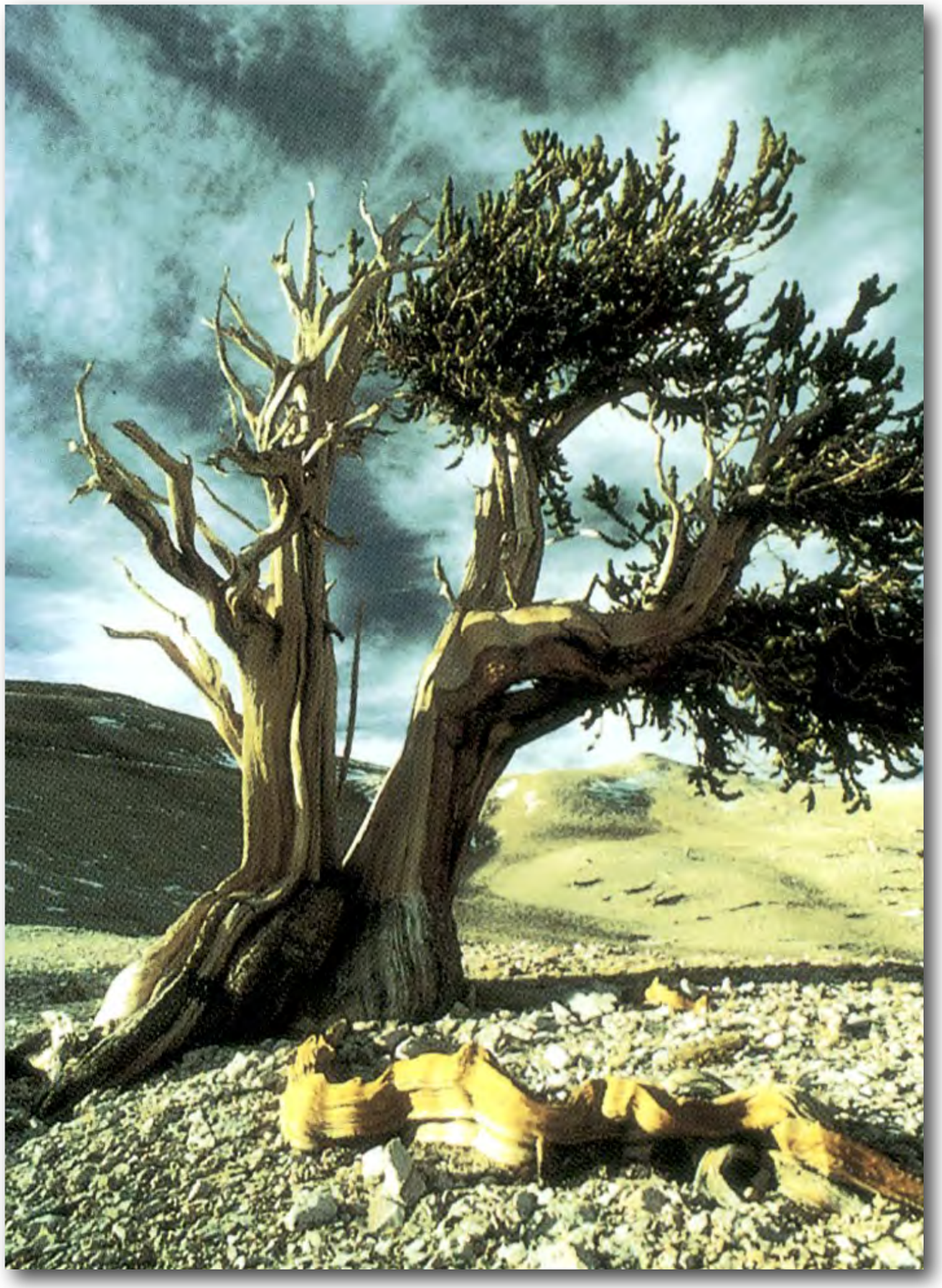
Primary Growth Cannot Continue Indefinitely Without a Corresponding Increase in Girth.

Tissues arising post-embryonically from secondary meristems

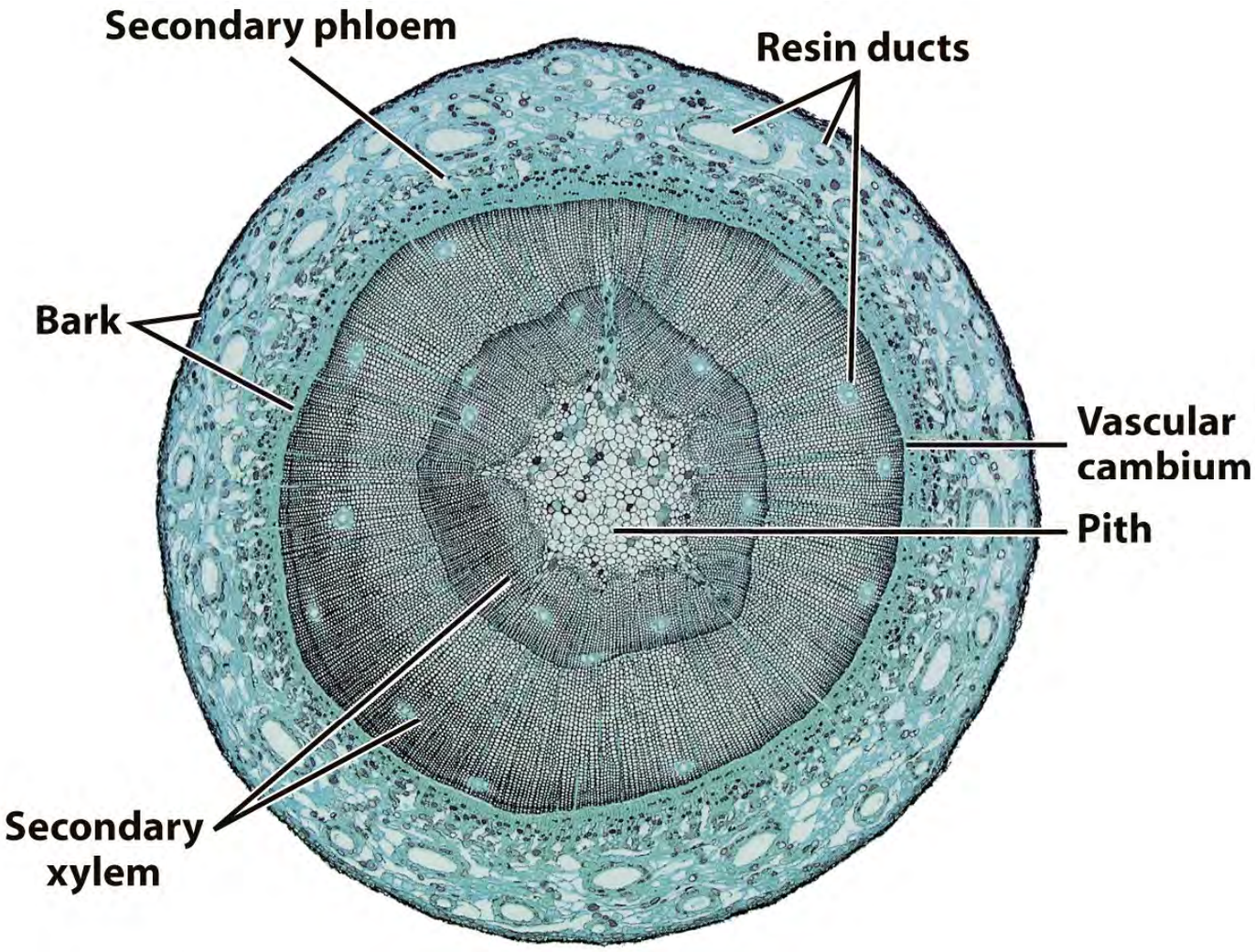
Tissues arising post-embryonically from the shoot apical meristem



Secondary Stem Growth is Principally Observed in Woody Perennials.

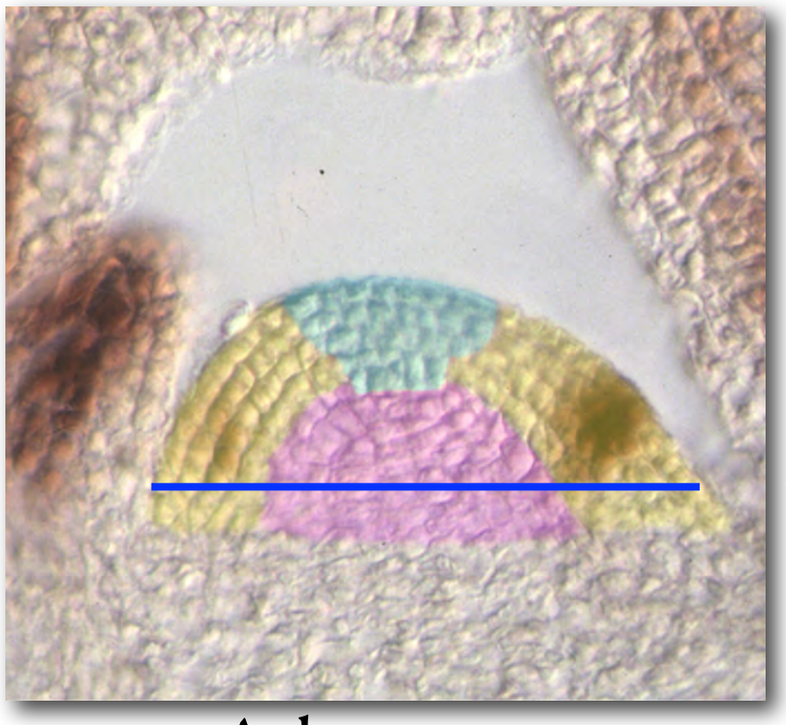


Bristlecone pine from the white mountains of California.

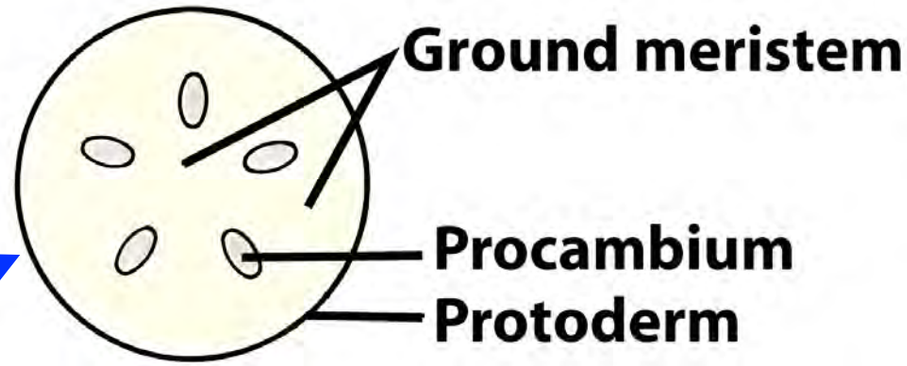


Transverse cross section through a pine stem.

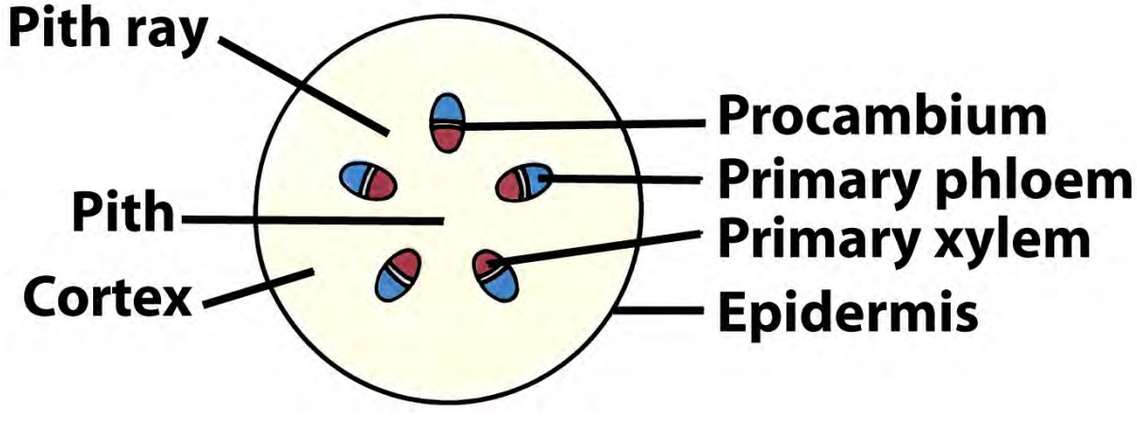
Secondary Stem Growth Occurs From the Vascular Cambium, an Internal Meristem That Promotes Lateral Expansion of the Stem.



A shoot apex.

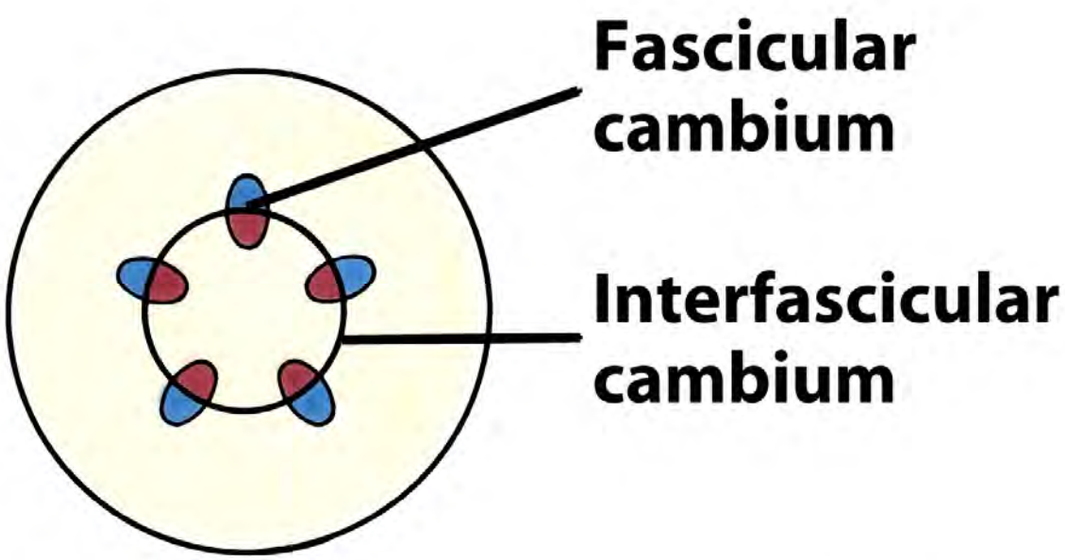


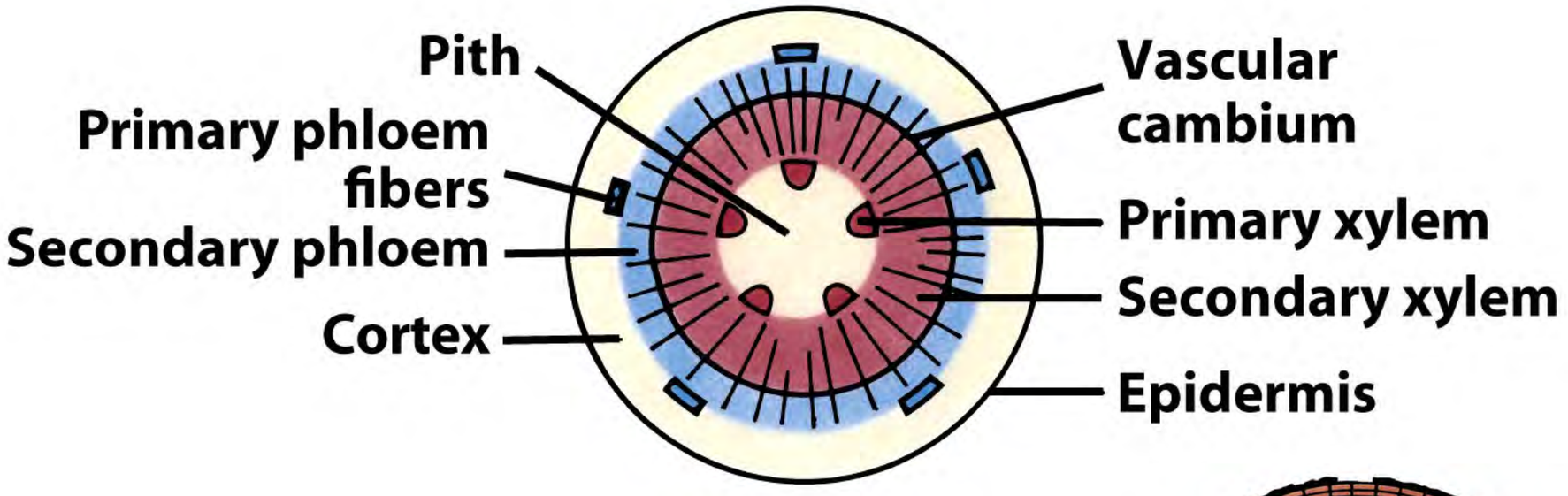
Transverse stem anatomy--within or just below the shoot meristem.

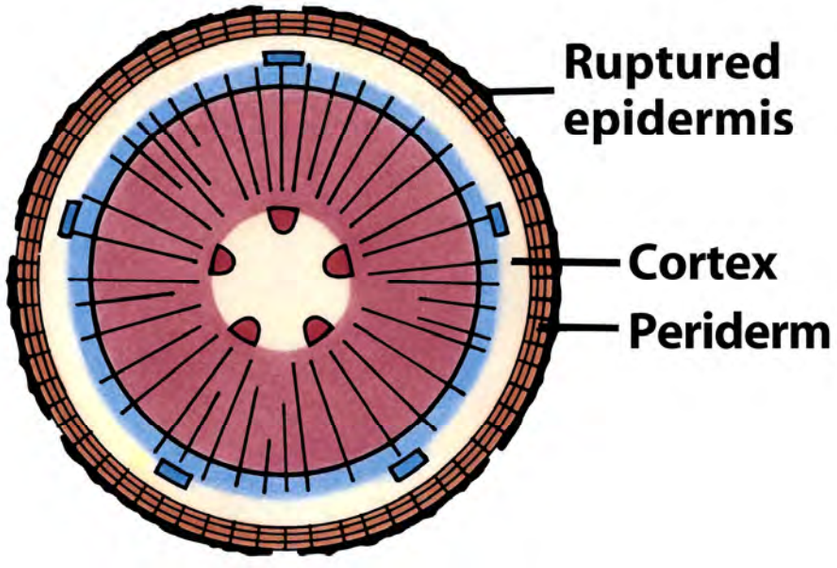


Transverse stem anatomy--further down the stem.

Secondary Stem Growth Occurs From the Vascular Cambium, an Internal Meristem That Promotes Lateral Expansion of the Stem.







Transverse stem anatomy--proceeding successively down the stem.

Today's Topics...

Plant Development

Secondary Growth.

Plants increase in girth by secondary growth.

Secondary growth is performed by the vascular cambium, an internal meristem.

Vascular cambium gives rise to xylem and phloem, the conducting tissue of the plant.

Photosynthesis

Biochemistry

Much of Plant's Contribution to Their 99% of Total Eukaryotic Biomass Is Dead.

Wood. Mostly Dead. Much of it quite dry.

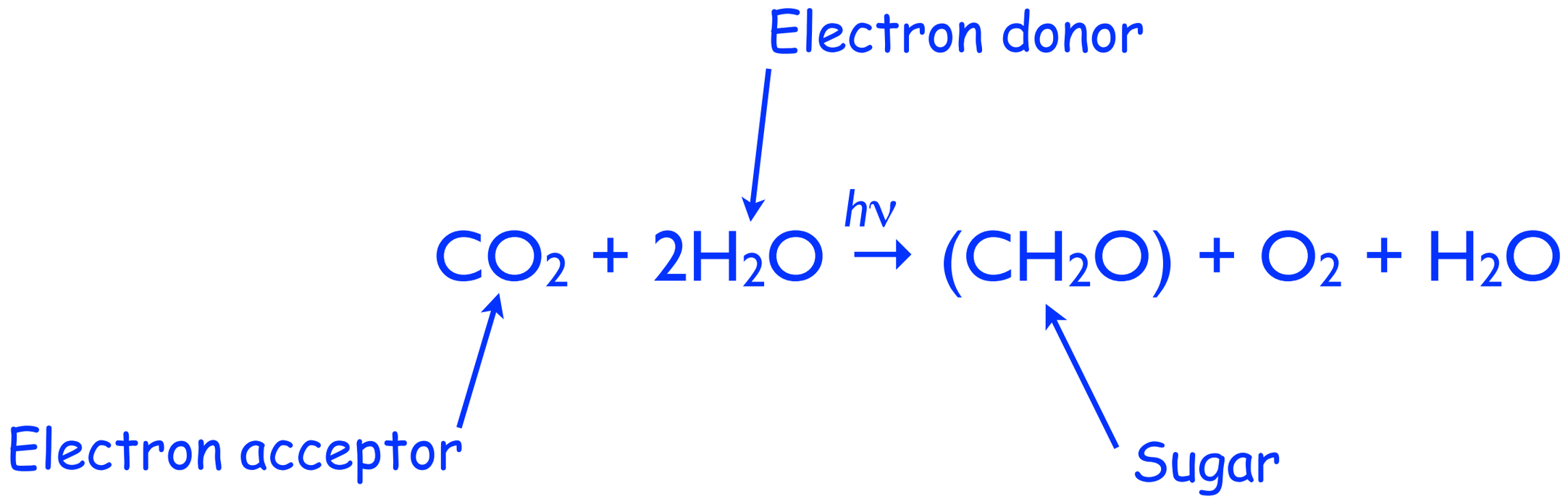
How do the plants obtain the energy and raw materials to generate all this biomass?

Our Planet is Awash in Solar Energy. Photosynthetic Organisms Tap Into An Effectively Unlimited Source of Energy.

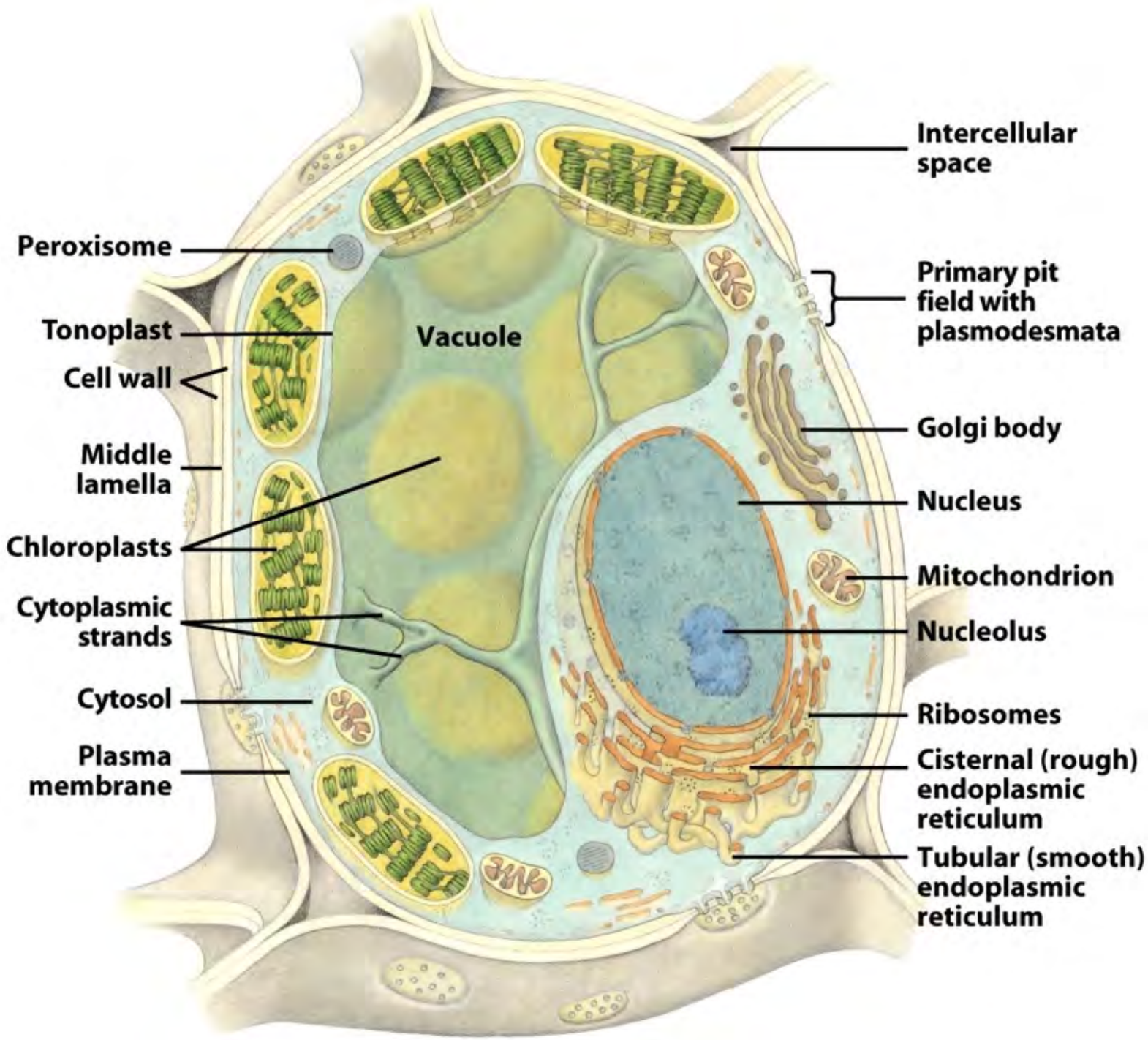
"Earth receives approximately 4000 times more energy from the Sun each year than humans are projected to use in 2050."

Chris Somerville, 2006

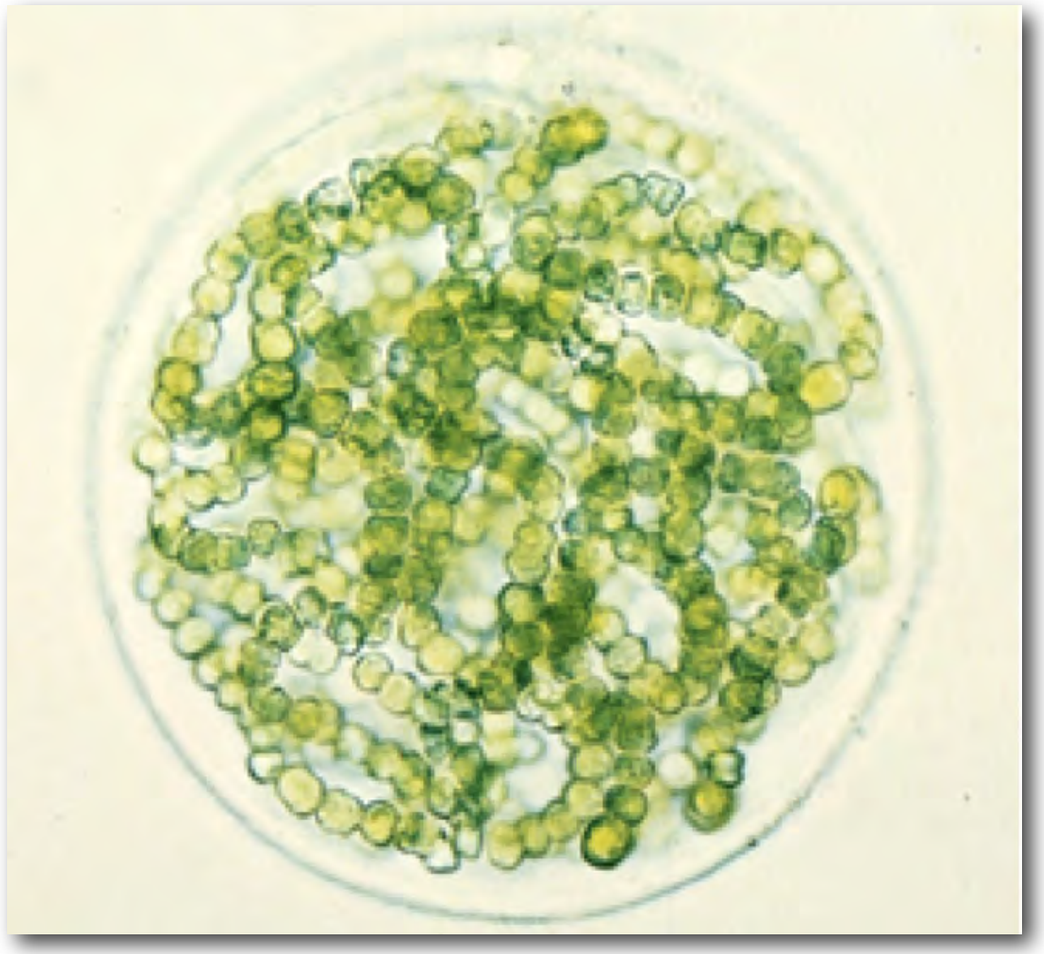
Photosynthesis is an Energy Conversion Reaction.



Photosynthesis Occurs Exclusively in the Chloroplast.

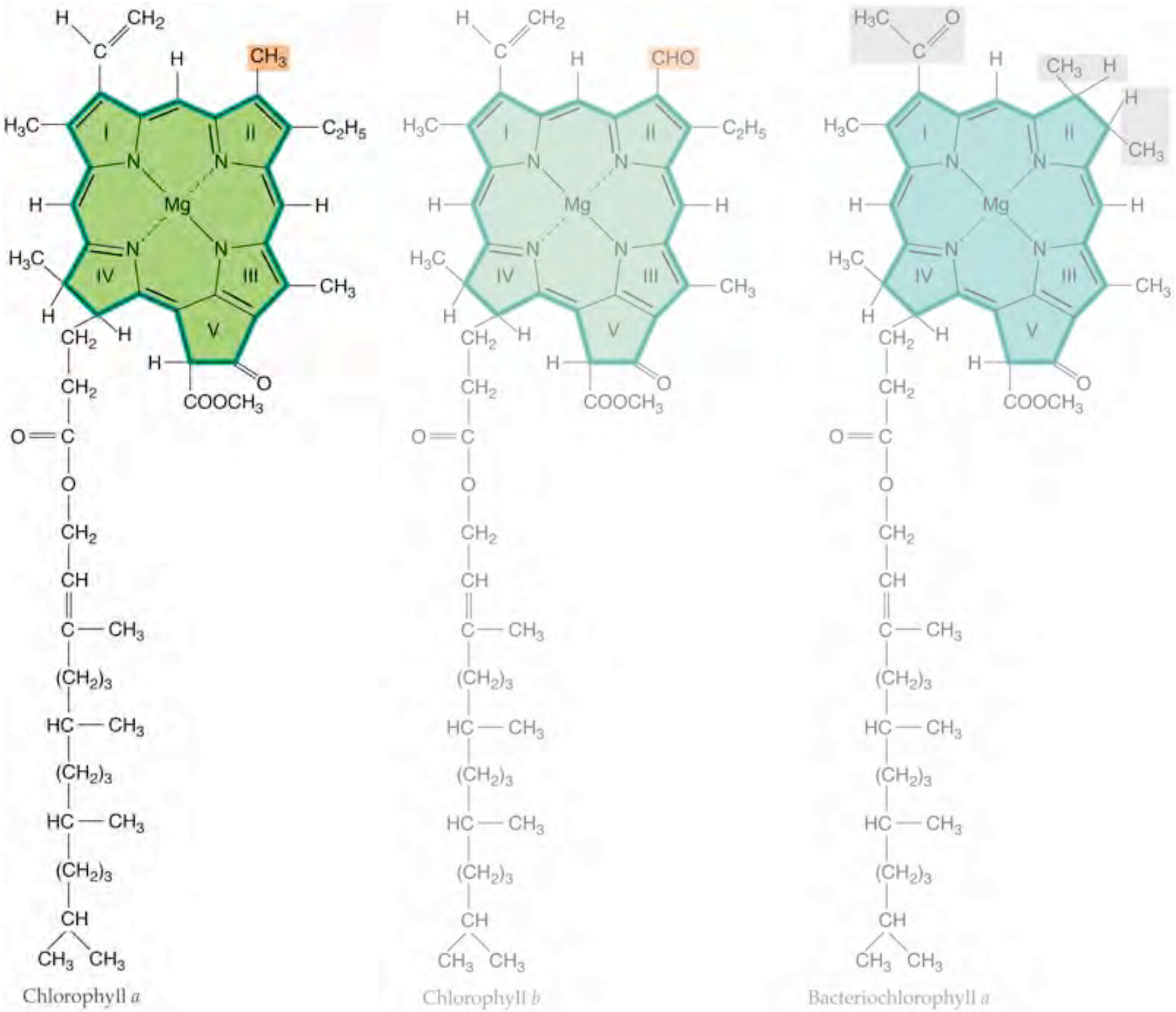


Extant Cyanobacteria Are the Closest Living Relatives to Chloroplasts.



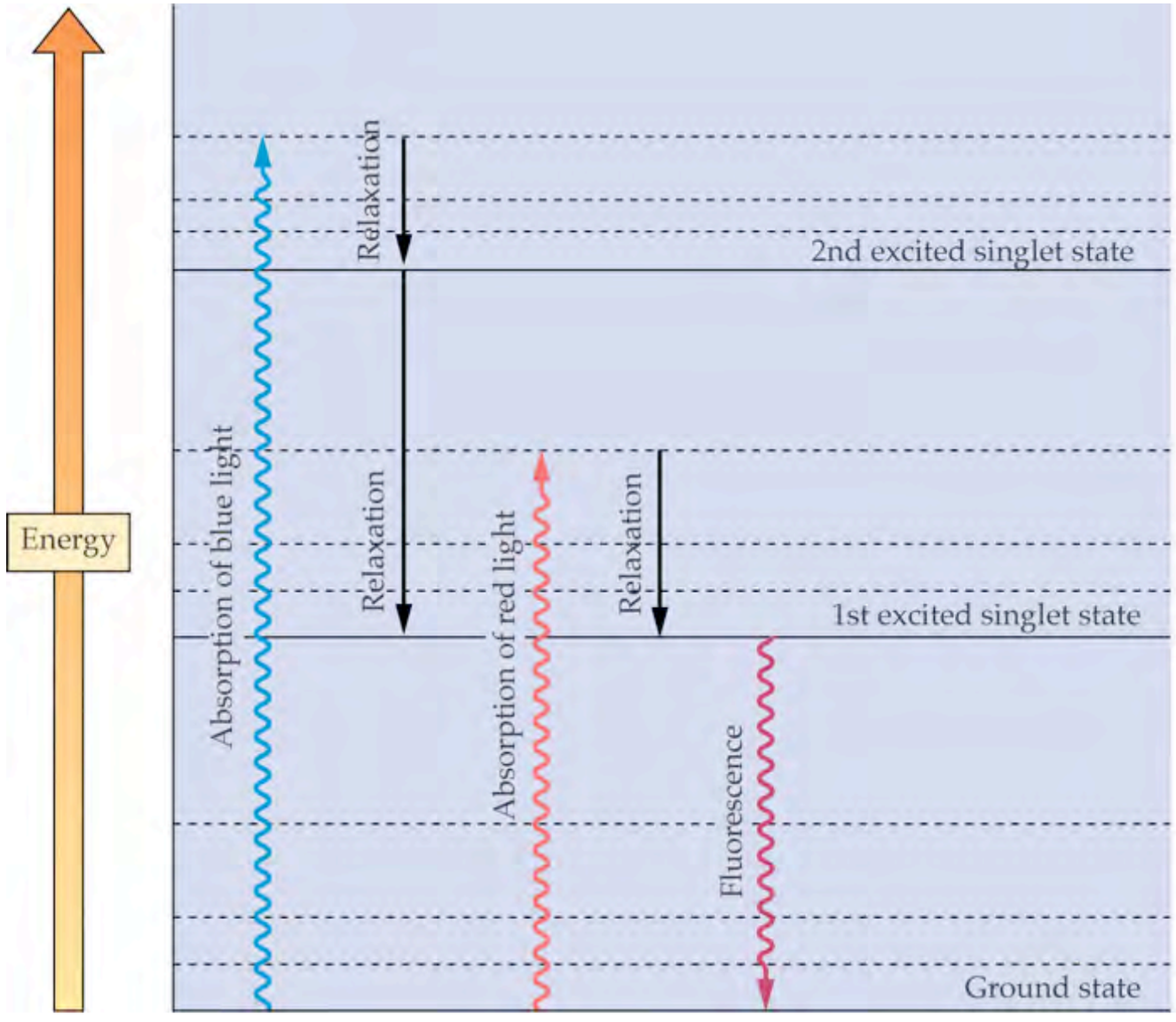
Nostoc

Chlorophyll is the Primary Light Harvesting Pigment in Plants.

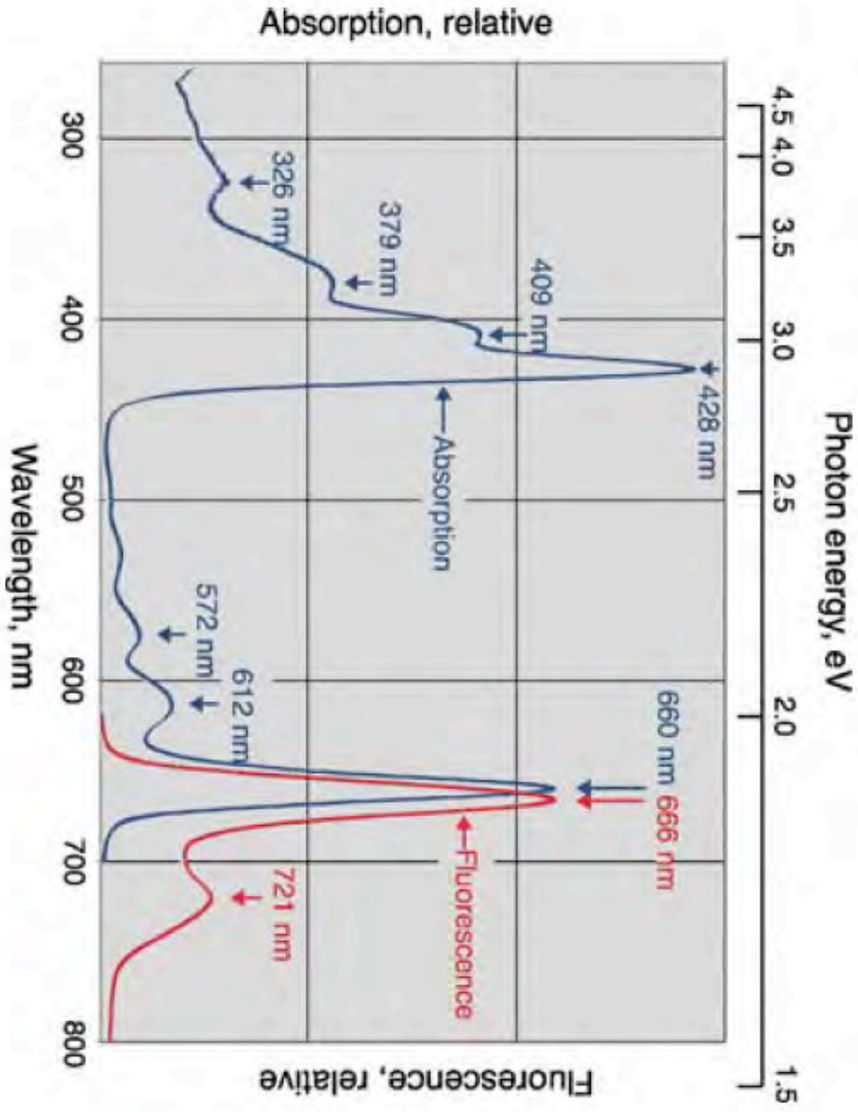


Chlorophyll a is found in all organisms that perform oxygenic photosynthesis.

Light is Absorbed by Chlorophyll Predominantly in One of Two Excited States.



Energy levels of chlorophyll a.

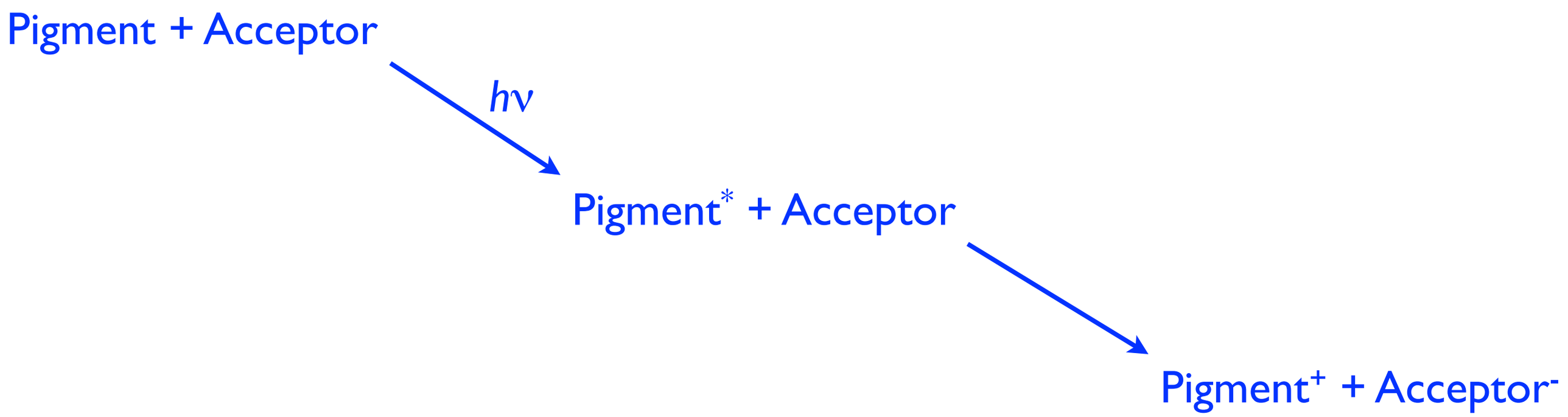


Absorption and fluorescence spectra of chlorophyll a.

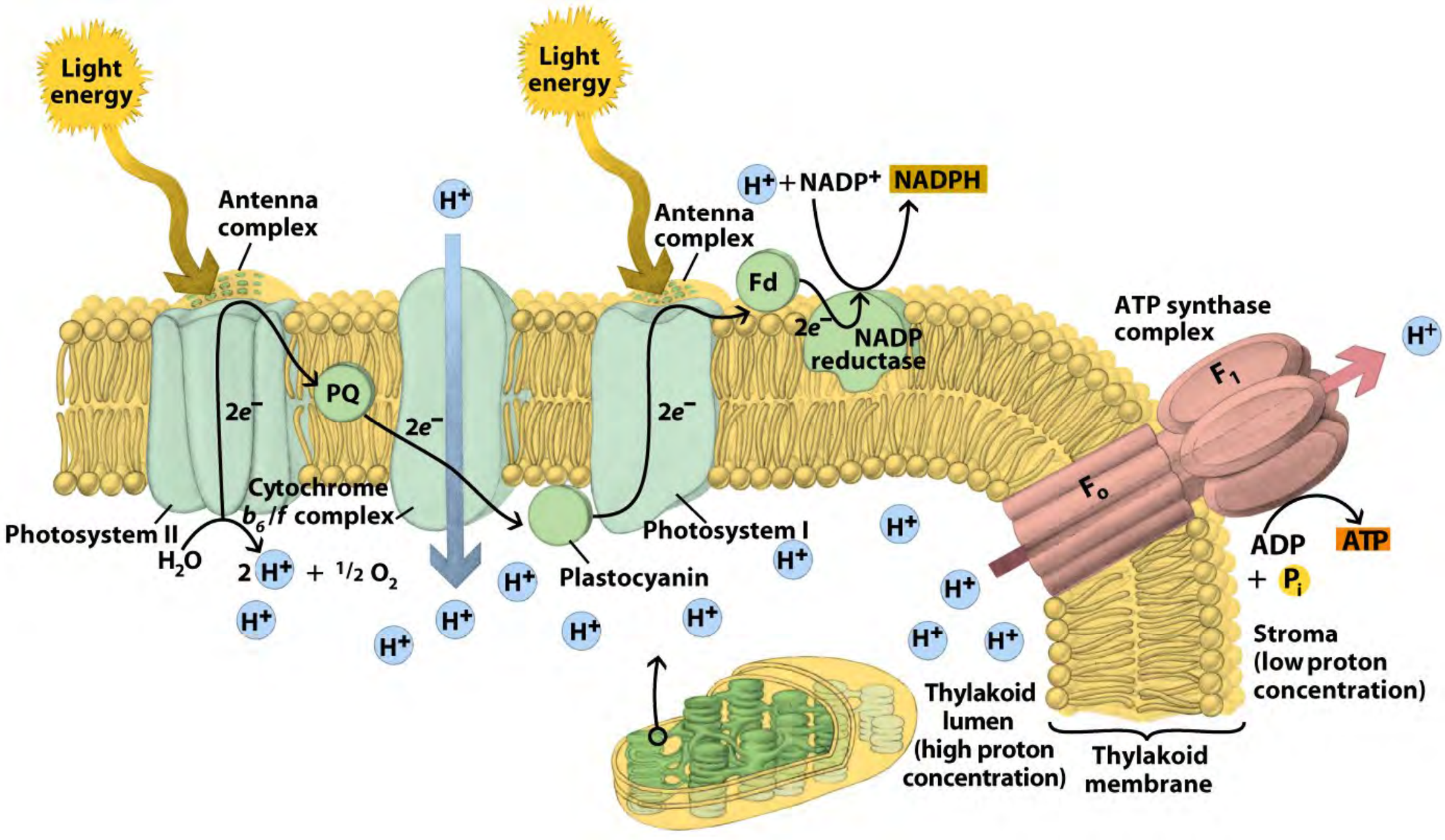
Excited states are unstable and will return to ground state.

Only the first excited singlet state is used for photosynthetic charge separation chemistry.

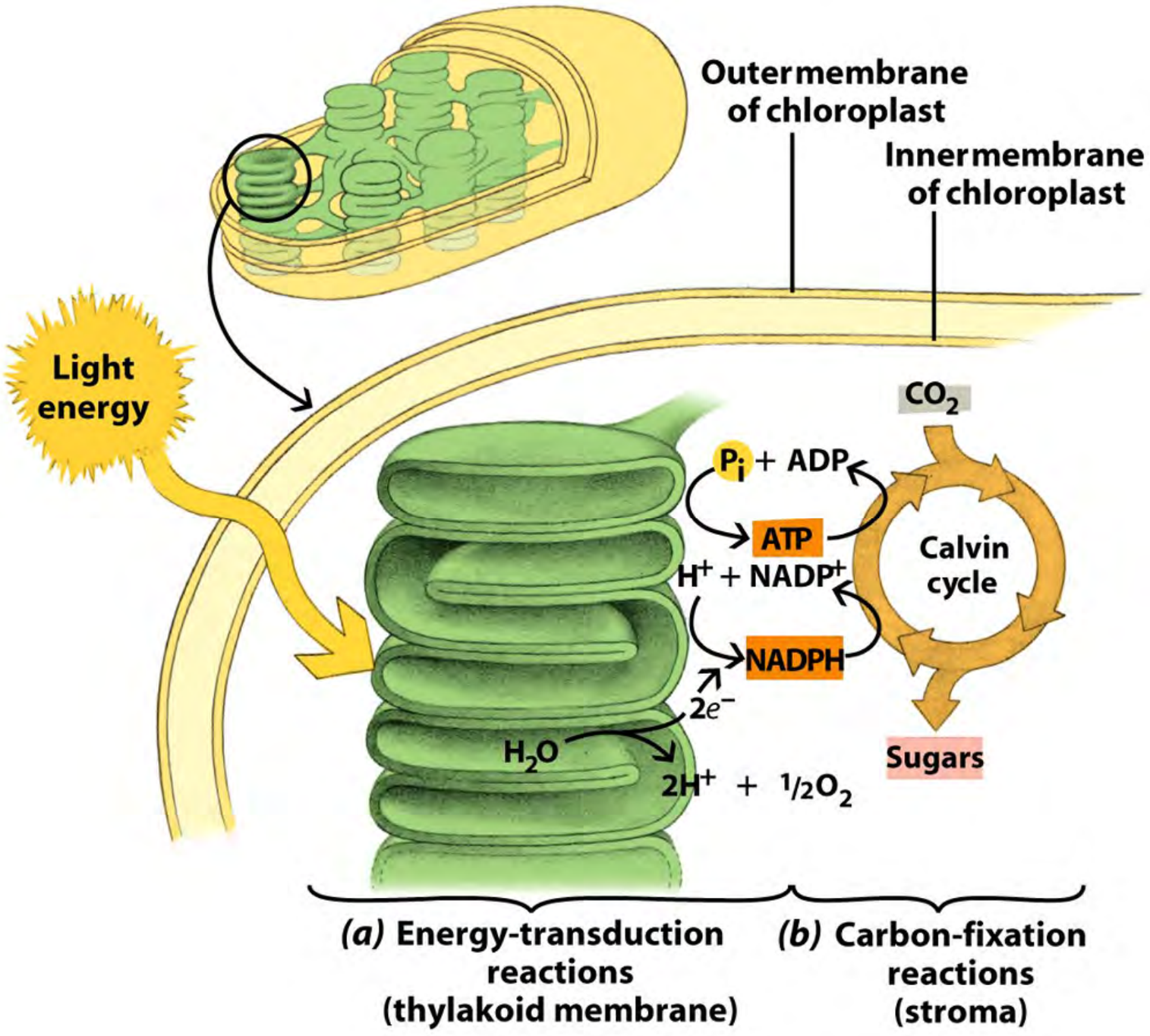
Charge Separation Provides the Mechanism for Conversion of Light Energy to Chemical Bond Energy.



Photosynthetic Light Harvesting Is A Most Elaborate Process of Moving Electrons.



Carbon-fixation Reactions Use Energy From Light Harvesting To Make Sugar.



Today's Topics...

Photosynthesis

Biochemistry

Photosynthesis is an energy conversion process, transforming light energy into chemical energy (sugar).

Electrons of specific atoms in chlorophyll absorb light and are transferred to from chlorophyll (the electron donor) to another molecule (the electron acceptor) eventually harnessing the absorbed energy in a stable chemical bond.

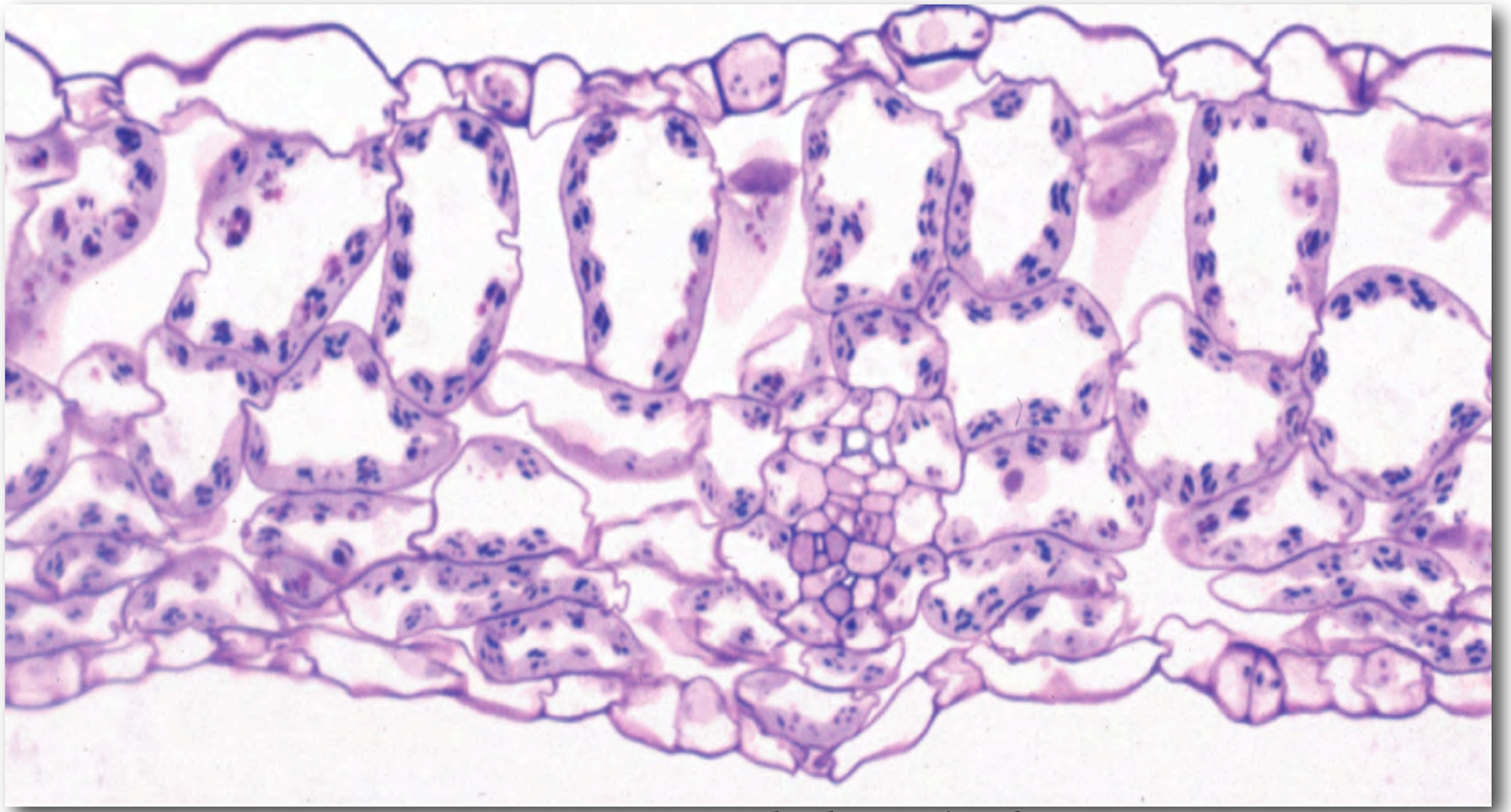
Water is the ultimate source of electrons in photosynthesis. Sugar is the ultimate electron acceptor.

Photosynthesis occurs exclusively in chloroplasts, descendants of photosynthetic bacteria.

Photosynthesis is separable into light-harvesting and carbon fixation phases.

Anatomy

Efficient Photosynthesis Requires A Continuous Supply of Abiotic Raw Materials.



An *Arabidopsis* leaf.

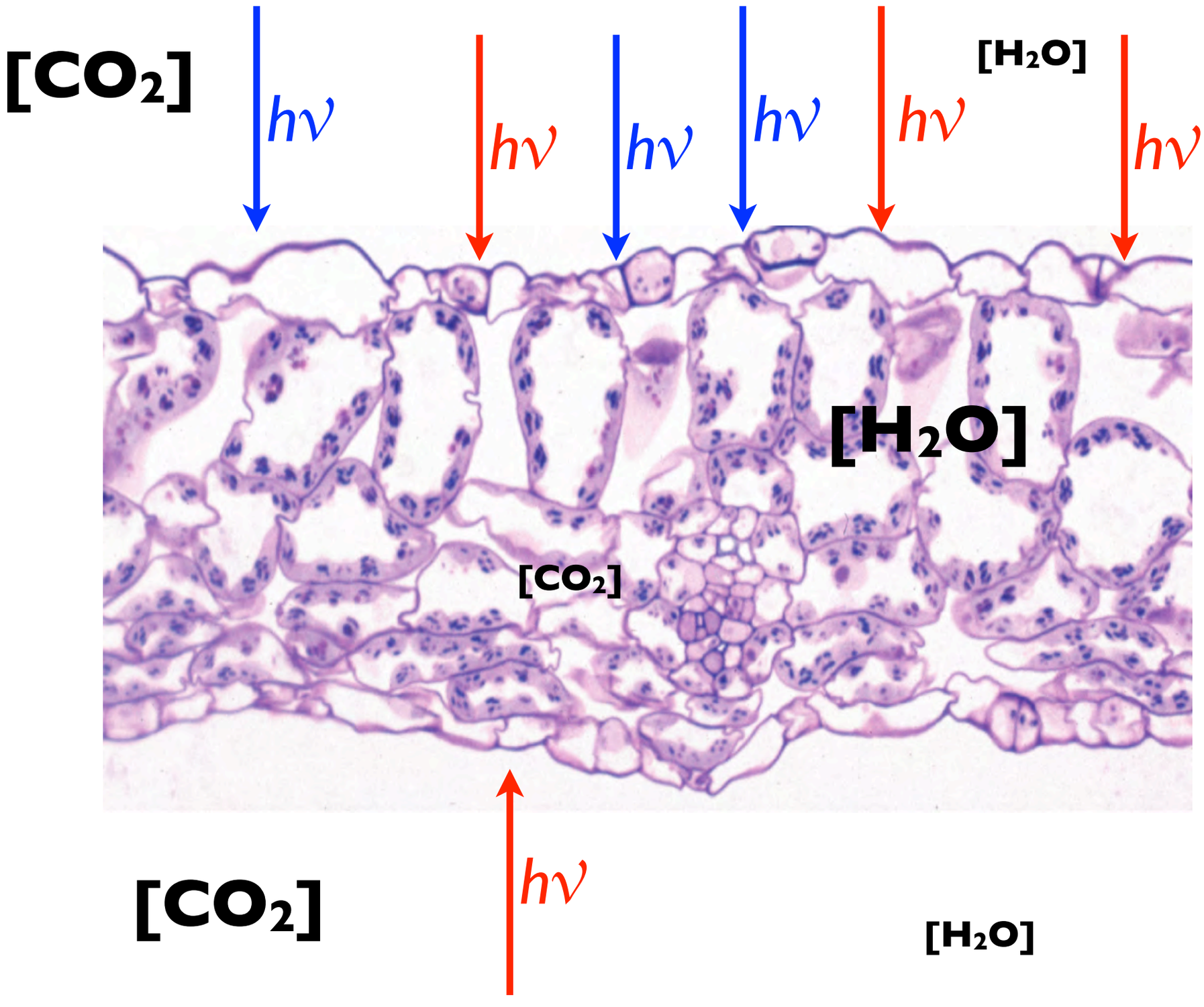
CO_2--atmospheric gas

H_2O--enters the leaf as a liquid, exits the leaf as a gas.

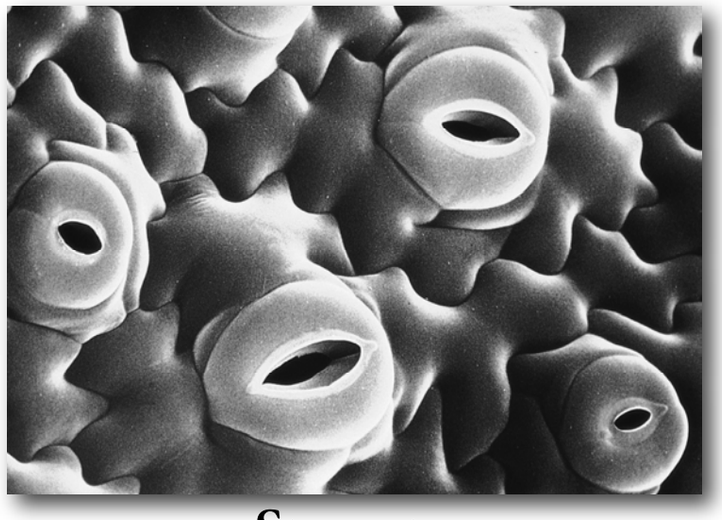
Light.

$$CO_2 + 2H_2O \xrightarrow{h\nu} (CH_2O) + O_2 + H_2O \text{ (Oxygenic photosynthesis)}$$

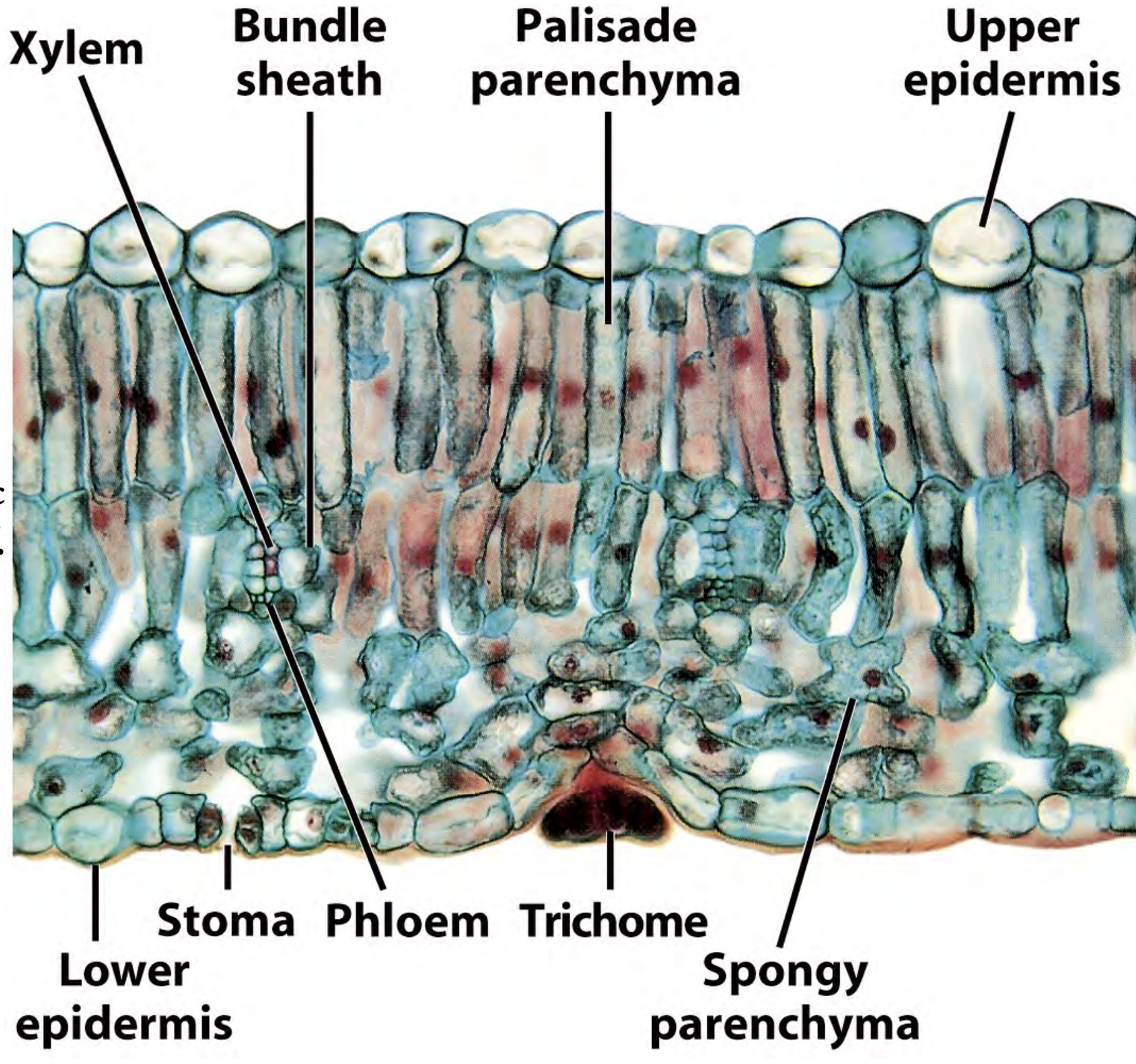
Sunlight is Maximally Incident on the Top Leaf Surface. Gas Exchange is Maximal on the Bottom Leaf Surface.



Stomata Regulate Gas Exchange Into and Out of the Leaf.

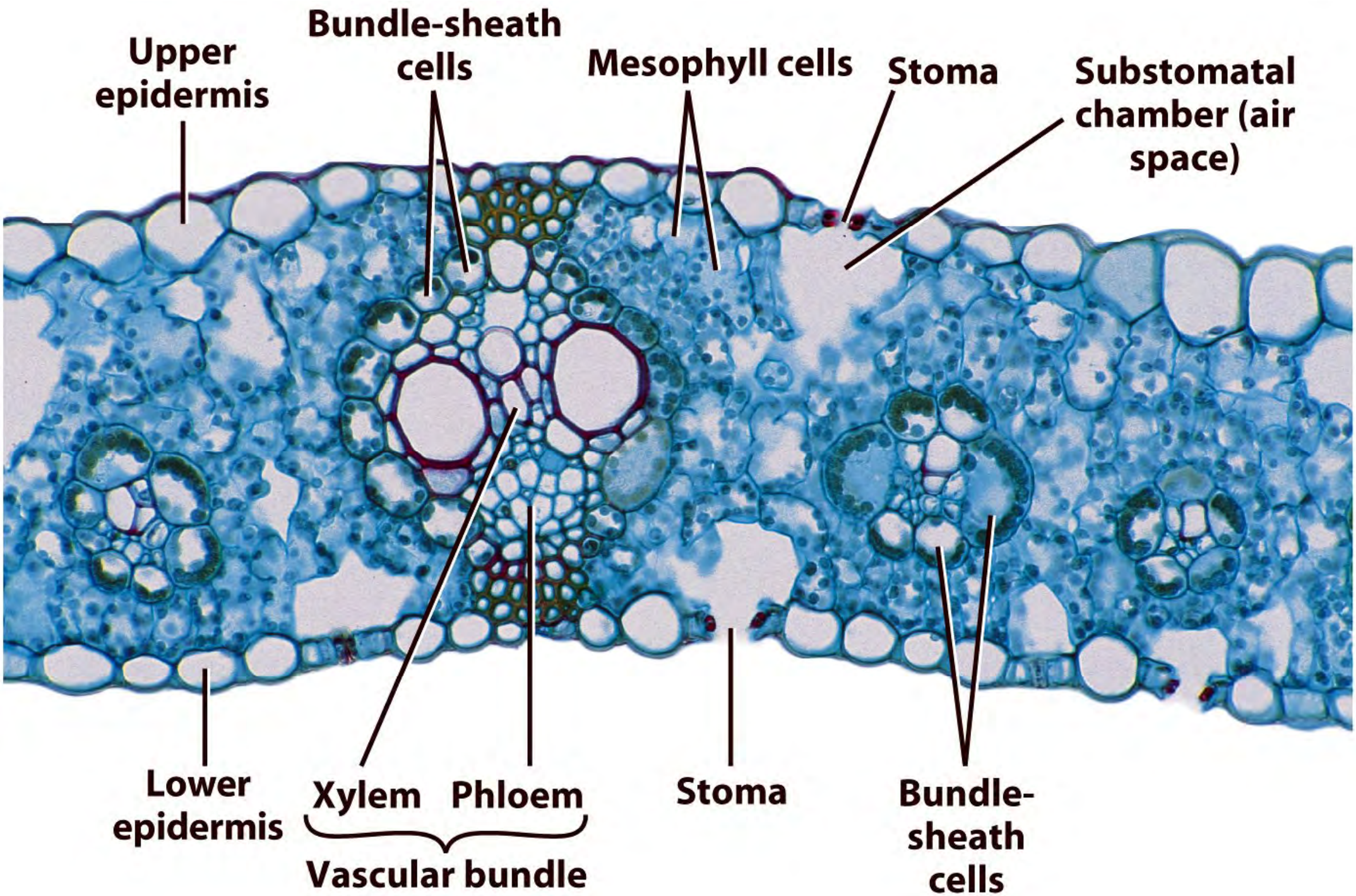


Stomata



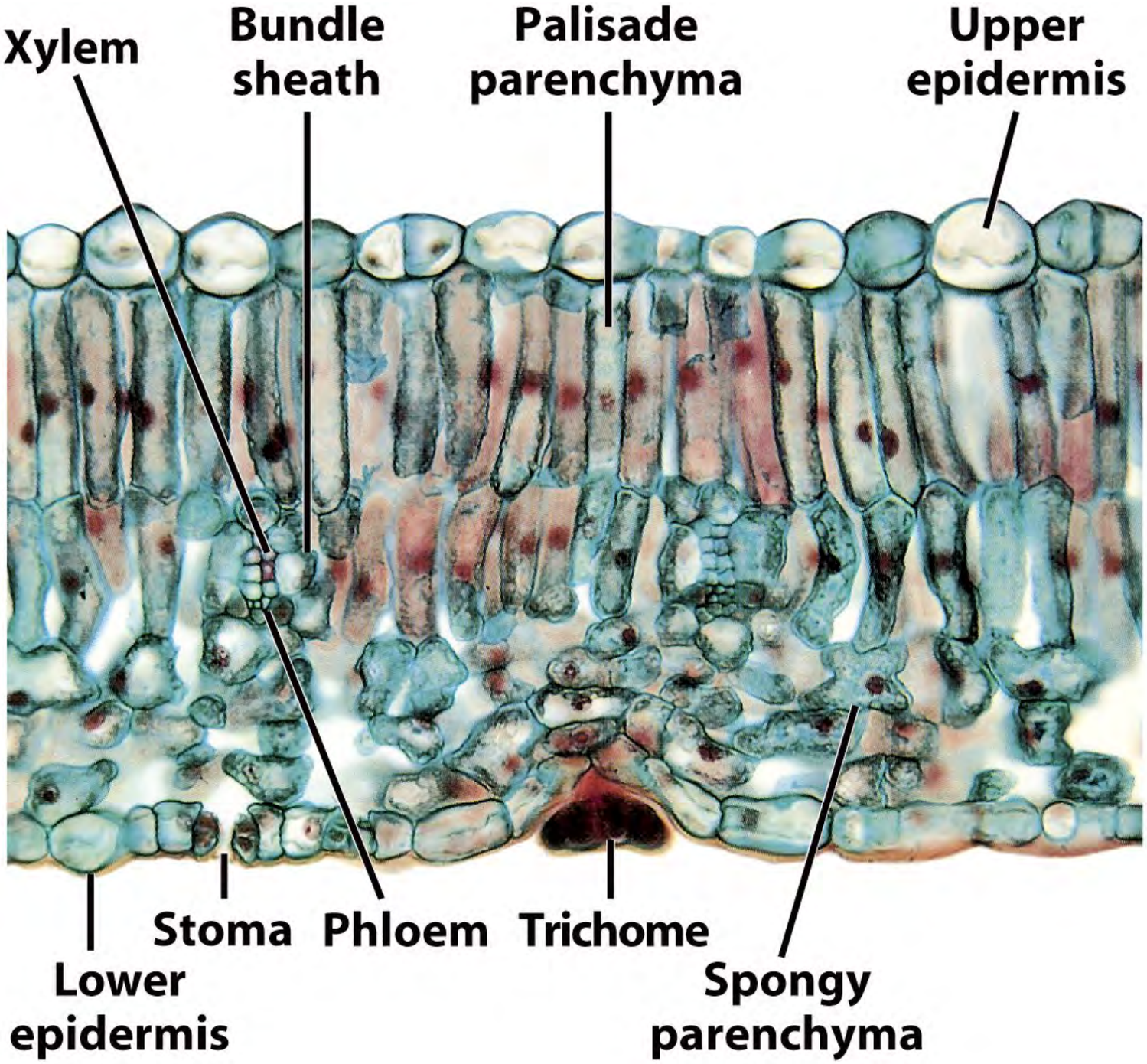
A sun-adapted lilac leaf.

C_4 Plants Employ a Unique Leaf Anatomy, and a Unique Carbon Fixation Process, That Together Result In Greatly Enhanced Photosynthetic Efficiency in Hot Weather.



Transverse cross-section through a maize (C_4) leaf

C_3 Anatomy--for Comparison.



Transverse cross-section through a lilac (C_3) leaf

Concentration of CO_2 by C_4 Metabolism Allows C_4 Plants to Reduce Stomatal Pore Size, Conserving Water.

The unstoppable crabgrass!

The hotter, the drier, the yuckier, the better….

Today's Topics...

Photosynthesis

Anatomy

Photosynthesis requires continuous supply of light, water as a liquid and CO_2 as a gas.

Gas exchange occurs through stomata, pores that can open and close to permit or limit gas exchange.

Regulation of stomata principally controls water loss, as there is no way to acquire CO_2 without simultaneously losing water.

Taxonomy and Plant Diversity

Taxon are Discreet Levels of Classification.

Kingdom

Phylum (or Division)--Coniferophyta

Class

Order

Family--Pinaceae

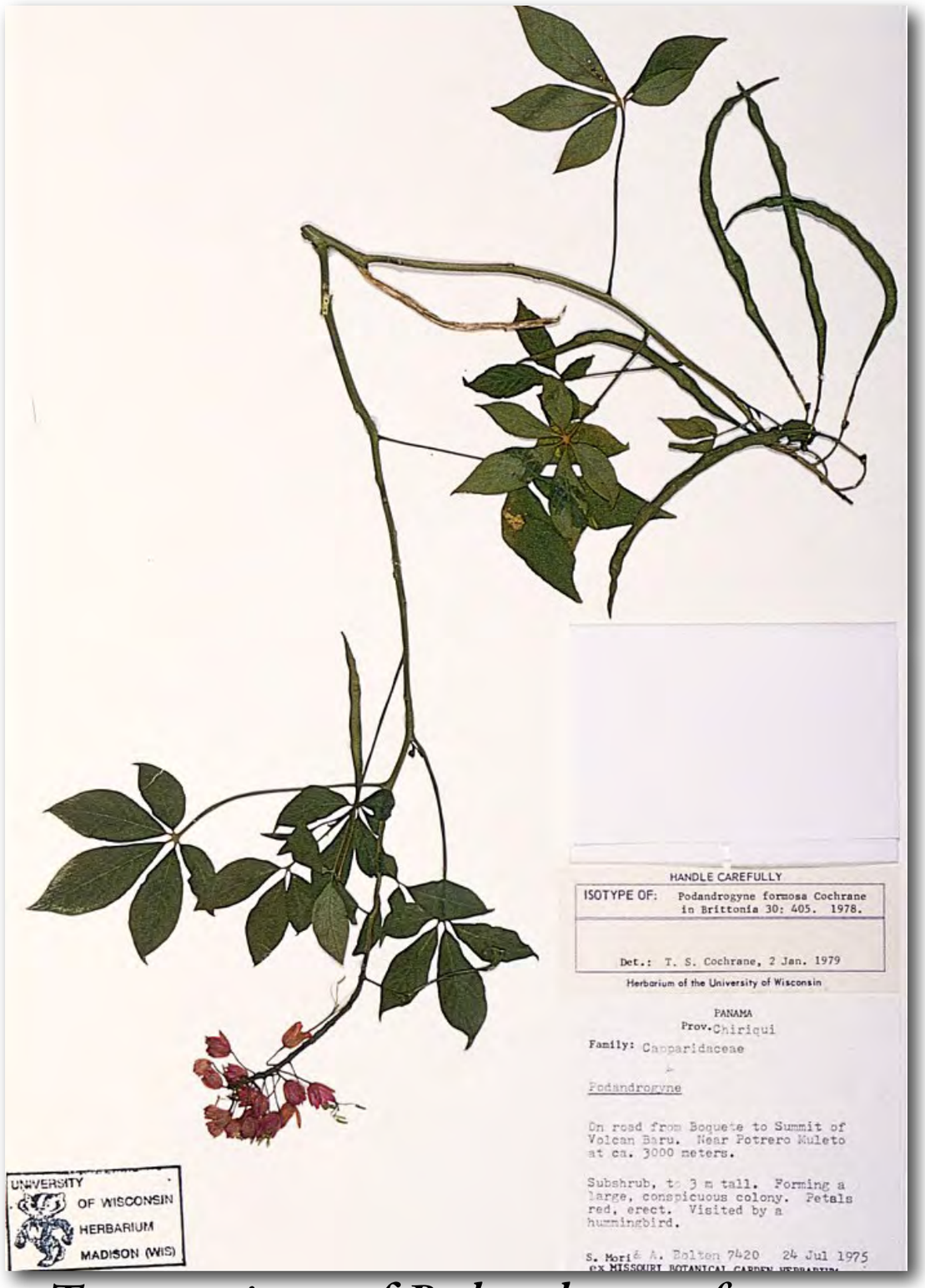
Genus--Pinus

Species--radiata

Monterey Pine

Plant biologists are especially fond of the family taxon (aceae).

Every Species Designation is Based Upon a Single Described Specimen, the Type Specimen.



Type specimen of *Podamdrogyne formosa*

The Binomial Classification System is the Contribution of Carl Linneaeus.

Carl Linnaeus, systematist and popularizer of the binomial system.

genus

Linnaea borealis

species

Linnaeus suspected that the genus was more stable or "fundamental" than the species.

Linnaeus was attempting to generate both a catalog of diversity, and to infer underlying design principles.

Today's Topics...

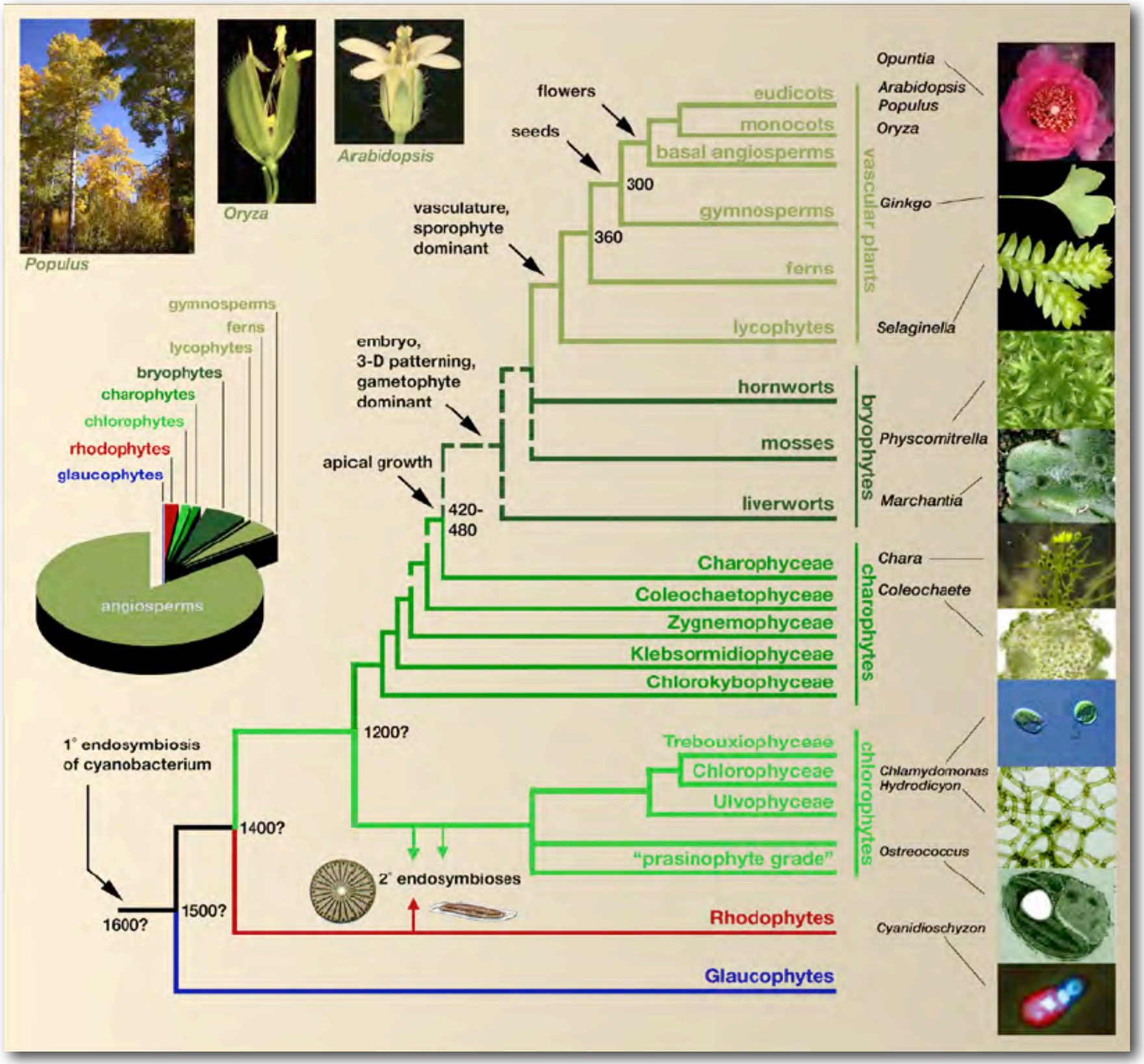
Taxonomy

Unique, taxonomic classifications are essential to have an intelligent conversation about plants.

Genus and species are sufficient to designate a specific plant species.

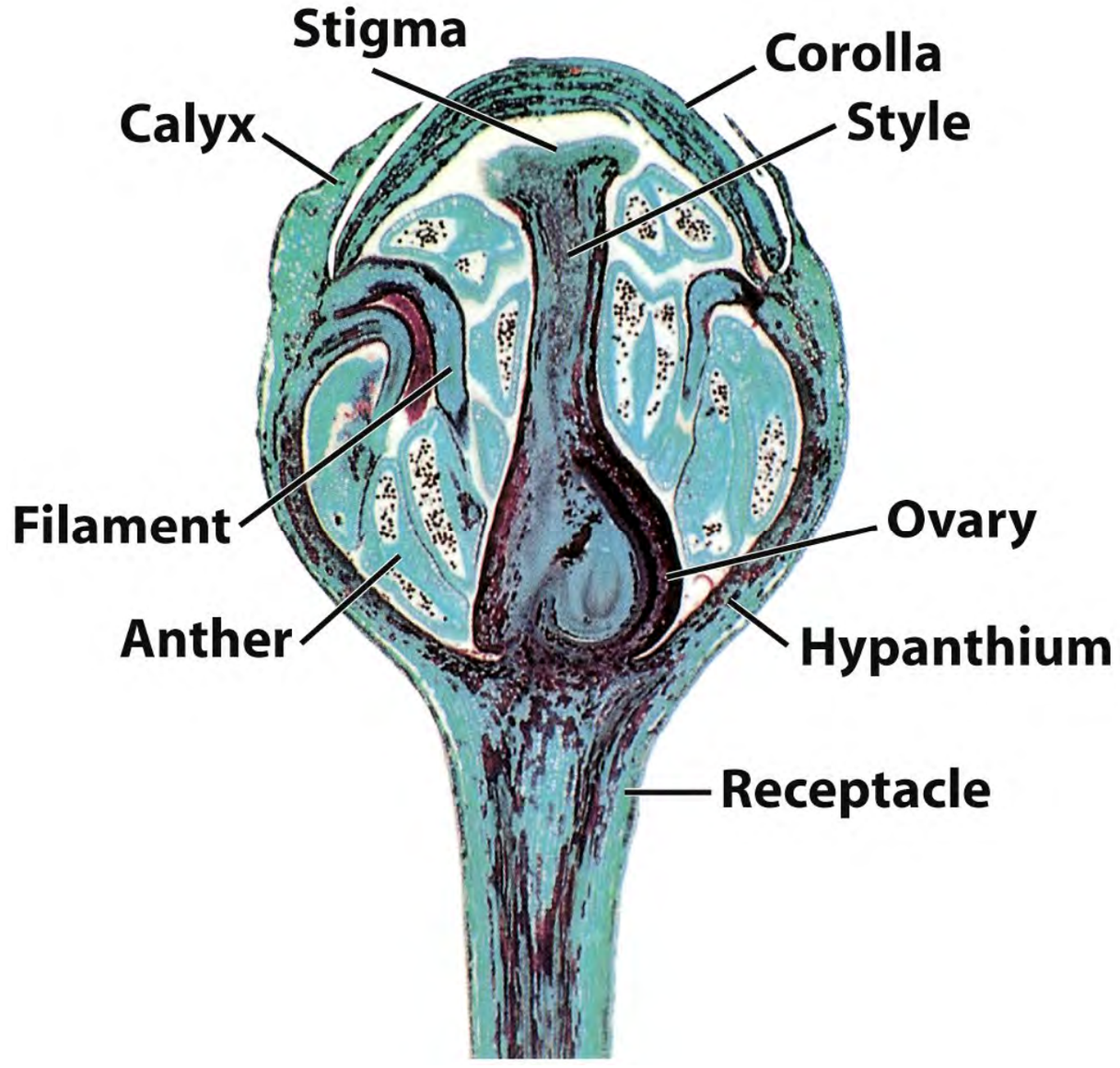
Higher levels of taxonomic classification, above the genus, attempt to reflect evolutionary relationships among plants. The higher we go, the more problematic it becomes to fit traditional taxonomic groups to biological reality.

The Great Bulk of Land Plant Diversity Today Is Comprised of Flowering Plants.



Angiosperms Are Characterized By Novel Reproductive Traits, Including Flowers.

Cherry flowers.



Longitudinal cross section through a cherry flower.

Stigma, style and ovary comprise the gynoecium, a structure unique to angiosperms.

The Co-Evolution of Angiosperm-Pollinator Relationships Is Believed to Have Catalyzed An Unprecedented Terrestrial Diversification in Both Angiosperms and Insects.

Most gymnosperms rely upon wind for dispersal of pollen.

Many angiosperms have evolved highly specific relationships with pollinators, primarily but not exclusively insects, to transport their pollen.

Dependence upon wind for pollination requires a minimum population density for effective reproduction.

Pollination by insects permits much lower population densities, in turn allowing greater degrees of niche specialization.

Thanks Folks!

VCE-Master Gardener Training Class
January 11, 2012

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