

Introduction to Botany: BIOL 154

Study guide for Exam 3

Alexey Shipunov

Lectures 18–26

Contents

| | | |
|----------|---|-----------|
| 1 | Questions and answers | 1 |
| 1.1 | Quiz | 1 |
| 2 | Tissues | 2 |
| 2.1 | Origin of tissues | 2 |
| 3 | Questions and answers | 2 |
| 3.1 | Quiz | 2 |
| 4 | Tissues | 2 |
| 4.1 | Origin of tissues | 2 |
| 4.2 | Tissues basics | 3 |
| 4.3 | First tissues: parenchyma and epidermis | 3 |
| 5 | Questions and answers | 8 |
| 5.1 | Quiz | 8 |
| 6 | Tissues | 8 |
| 6.1 | Step two: skeleton. Supportive tissues | 8 |
| 6.2 | Step three: construction sites. Meristems | 11 |
| 6.3 | Origin of tissues | 14 |
| 6.4 | Step four: pipes. Vascular tissues | 15 |
| 6.4.1 | Xylem | 15 |
| 7 | Questions and answers | 22 |
| 7.1 | Quiz | 22 |
| 8 | Leaf | 22 |
| 8.1 | Leaf in general | 22 |
| 8.2 | Leaf morphology | 23 |
| 8.3 | General characters | 28 |
| 8.4 | Repetitive characters | 29 |
| 9 | Questions and answers | 31 |
| 9.1 | Quiz | 31 |

| | |
|---|-----------|
| 10 Leaf | 31 |
| 10.1 Repetitive characters | 31 |
| 10.2 Terminal characters | 33 |
| 10.3 Leaves in nature | 35 |
| 10.4 Modifications of leaf | 41 |
| 11 Questions and answers | 50 |
| 11.1 Quiz | 50 |
| 12 Leaf | 50 |
| 12.1 Anatomy of leaf | 50 |
| 12.2 Ecological adaptations of leaves | 52 |
| 13 Questions and answers | 54 |
| 13.1 Quiz | 54 |
| 14 Leaf | 54 |
| 14.1 Ecological adaptations of leaves | 54 |
| 15 Stem and shoot | 64 |
| 15.1 Plant body | 64 |
| 16 Questions and answers | 67 |
| 16.1 Quiz | 67 |
| 17 Shoot | 68 |
| 17.1 Stem | 68 |
| 17.2 Development of stem tissues | 68 |
| 17.3 Anatomy of the primary stem | 71 |
| 17.4 Anatomy of the primary stem | 72 |
| 17.5 Components of shoot | 80 |
| 17.6 Phyllotaxis | 81 |

Outline

1 Questions and answers

1.1 Quiz

Results of Exam 2: questions (1)

22. Which of the terms is mismatched?

- A. Male — sperm
- B. **Gamete** — $2n$
- C. Sporophyte — $2n$

24. Syngamy is the:

- A. **Union of two opposite mating types**
- B. Fusion of cell walls
- C. Reductive division

Results of Exam 2: questions (2)

32. Nucleus:

- A. **Closed for viruses**
- B. Contains no RNA
- C. Both of above

33. Mitochondria:

- A. Were independent bacteria in the past
- B. Have no pores in envelope
- C. **Both of above**

Final question (2 points)

What is gametangium?

- Cell or organ (many cells) which keeps gametes and then releases them.

2 Tissues

2.1 Origin of tissues

Origin of tissues and organs of plants: first steps

Why did plants go to the land? Which problems did they meet and how did they resolve them? What was the plant way of acquiring tissues comparing with animals?

Final question (2 points)

What is a tissue?

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

3 Questions and answers

3.1 Quiz

Final question (2 points)

What is a tissue?

- (Shortest definition). Cell type. (However, complex tissues (below) are different.)

4 Tissues

4.1 Origin of tissues

Origin of tissues and organs of plants: first steps

Why did plants go to the land? Which problems did they meet and how did they resolve them? What was the plant way of acquiring tissues comparing with animals?

4.2 Tissues basics

Definition of tissues and organs

- **Tissue** is a union of cells which have common origin, function, and similar morphology
- **Organ** is a union of different tissues which have common function(s) and origin

Simple and complex tissues

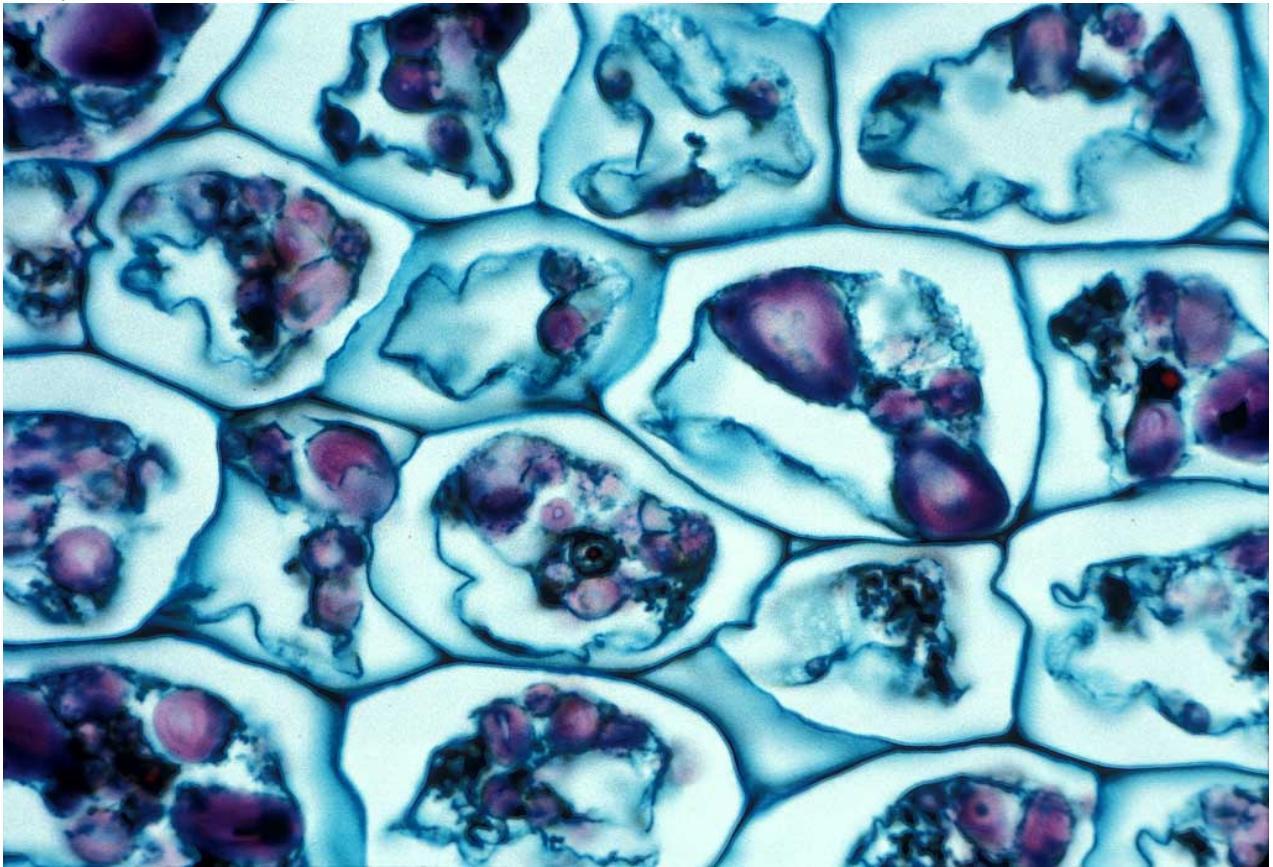
- **Simple tissues** have only one kind of cells
- **Complex tissues** have more than one cell type. This tissue type is unique for plants

4.3 First tissues: parenchyma and epidermis

Parenchyma (ground, main tissue)

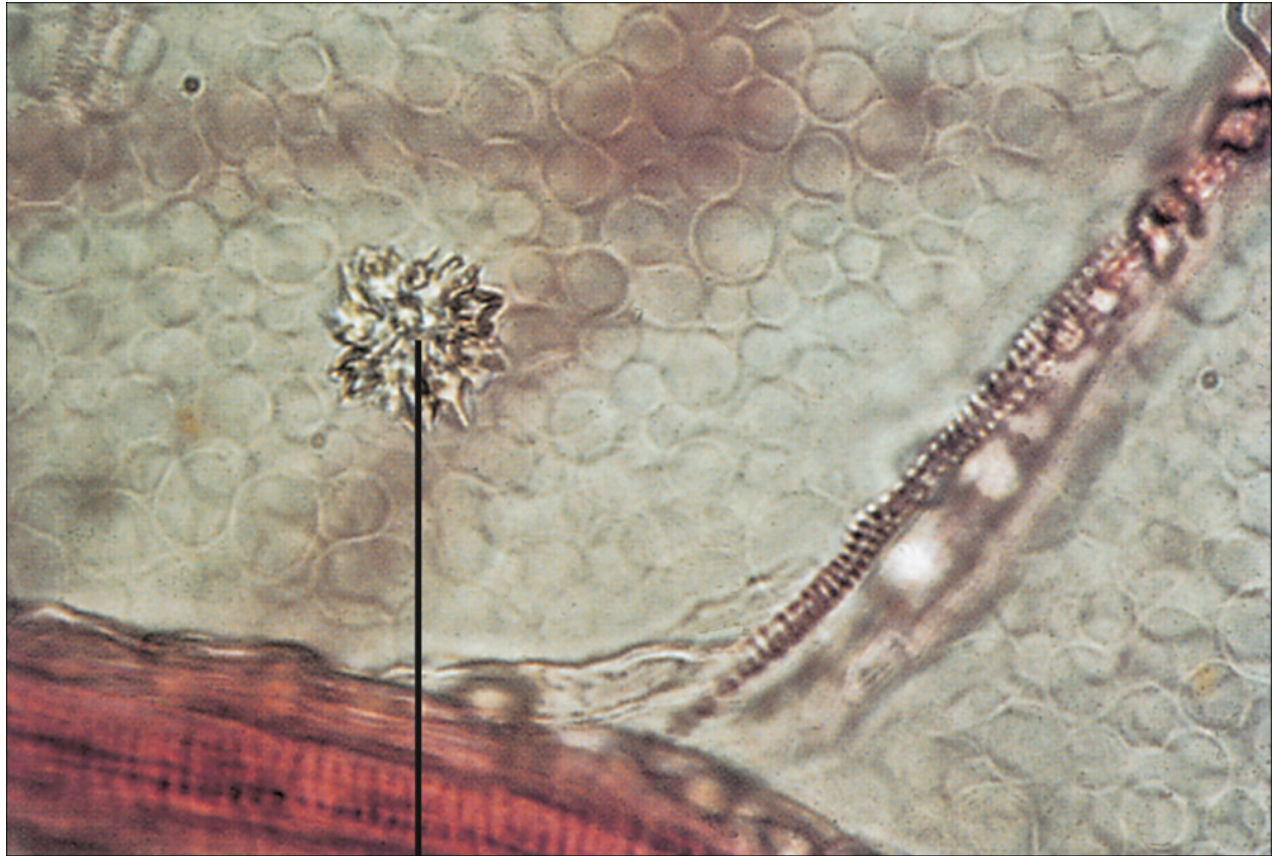
- Spherical or elongated cells
- Thin primary cell wall
- Sometimes, crystal inclusion bodies
- Main functions: photosynthesis and storage

Parenchyma cells of a potato



Parenchyma cells of a potato; the central cell shows obvious nucleus with starch stained purple (LM $\times 83$)

Parenchyma with crystals

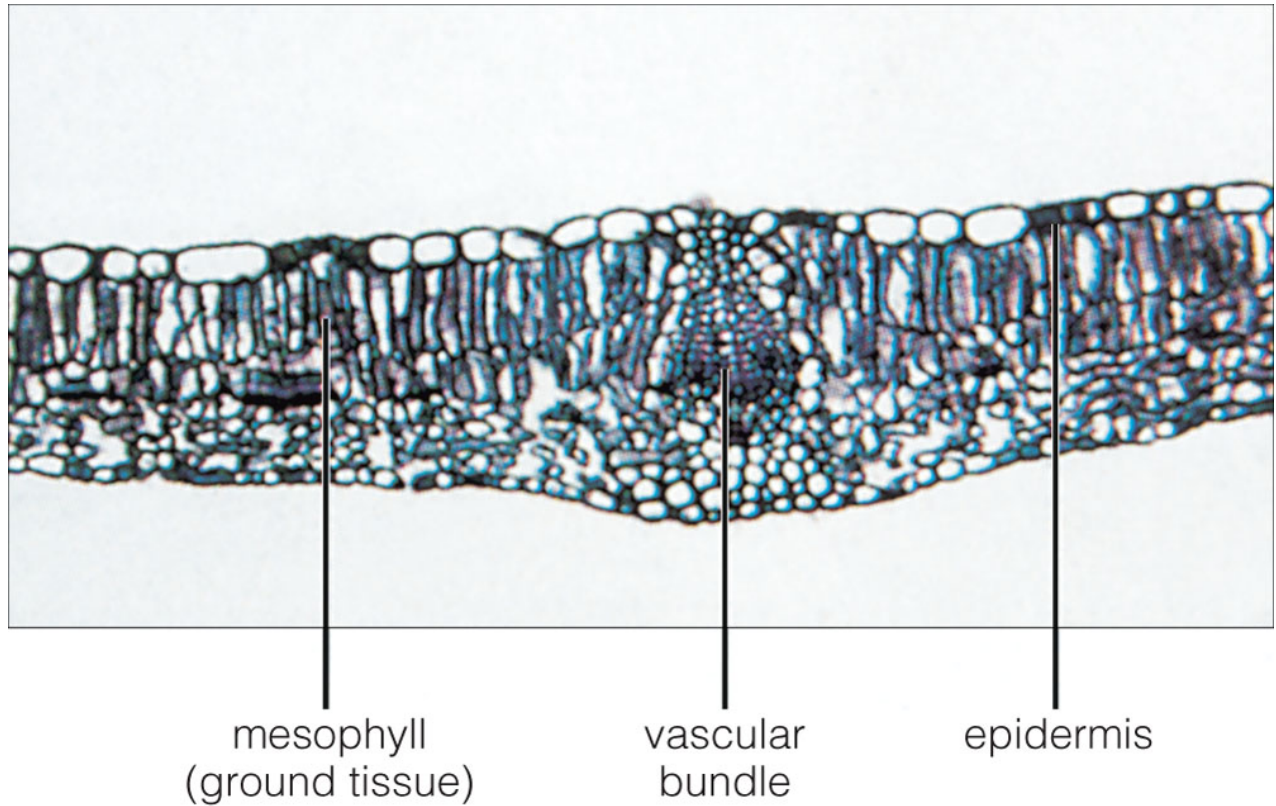


crystal

© 2006 Brooks/Cole - Thomson

Parenchyma cells often include crystals (e.g., of calcium oxalate)

Photosynthetic parenchyma



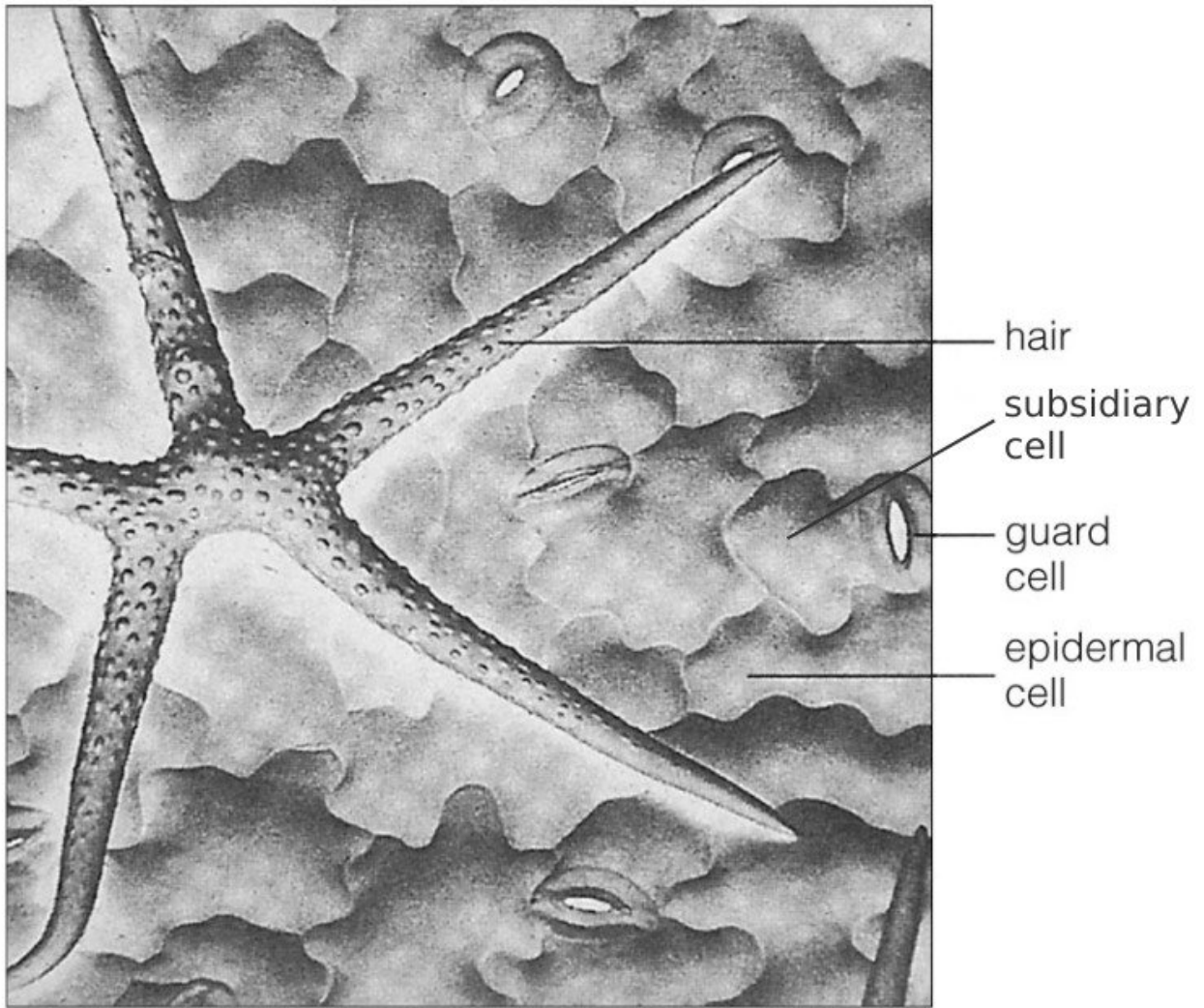
© 2006 Brooks/Cole - Thomson

Photosynthetic parenchyma (mesophyll) in lilac (*Syringa vulgaris*) leaf

Epidermis: the complex tissue

- Complex tissue of different cell types:
 - A. Epidermal cells
 - B. Stomata cells:
 - Guard cells
 - Subsidiary cells
 - C. Trichomes
- Shapes and chemical compounds vary
- Main functions: gas exchange, transpiration, defense

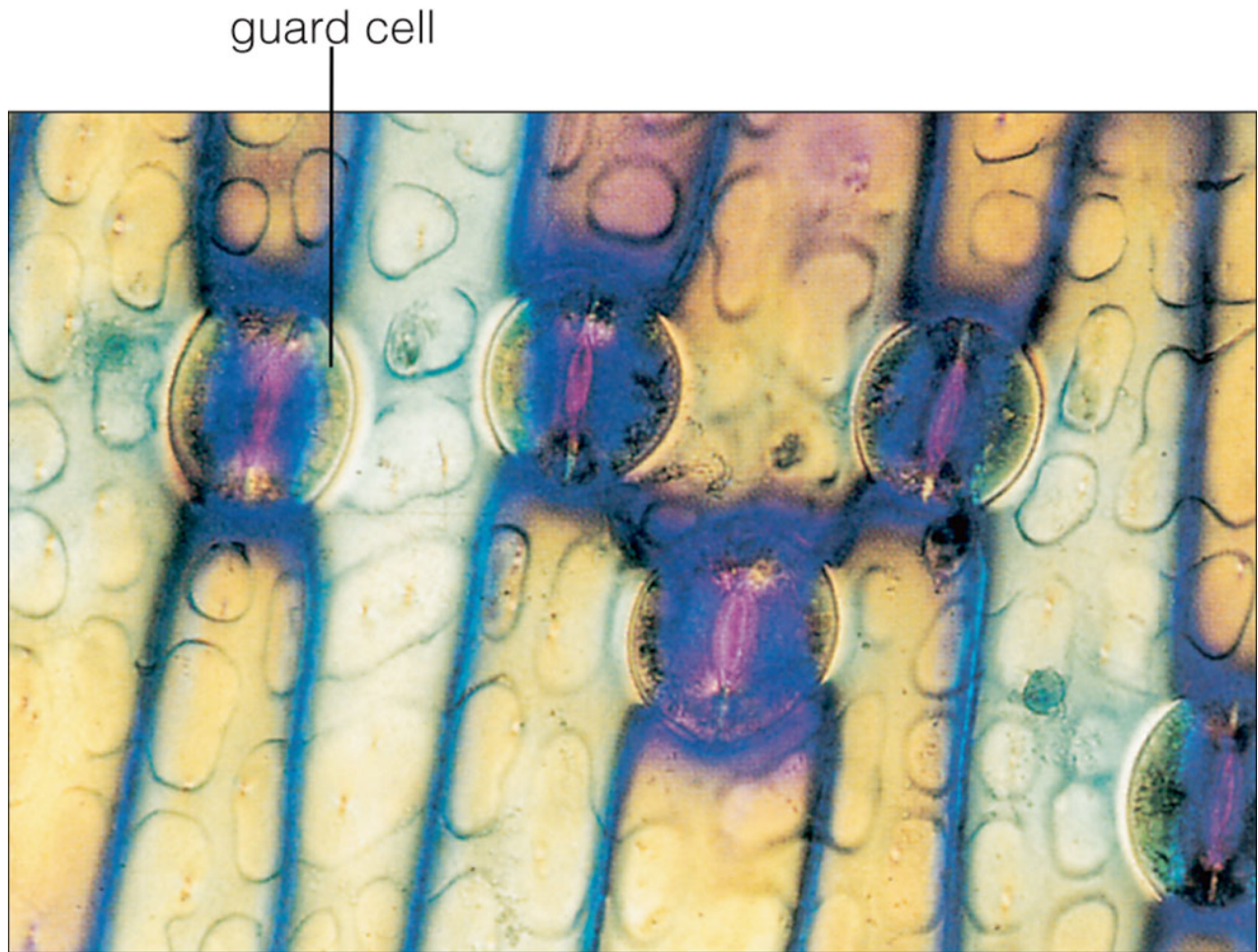
Epidermal cells



© 2006 Brooks/Cole - Thomson

Three kinds of Shepard's purse (*Capsella bursa-pastoris*) epidermal cells

Stomata



© 2006 Brooks/Cole - Thomson

Stomata with guard cells and pores (*Iris* sp.)

Summary

- The structure of plant body, its organs and tissues is a result of land colonization
- **Complex tissues** have different cell types, **secondary tissues** originate from lateral meristems (i.e., cambium)
- **Parenchyma**, or ground tissue, is a main component of young plant organs
- **Epidermis** is a complex tissue which includes stomata

Final question (2 points)

What is the complex tissue?

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

5 Questions and answers

5.1 Quiz

Final question (2 points)

What is the complex tissue?

- Tissue which has more than one cell type.

6 Tissues

More about plants₂ classification

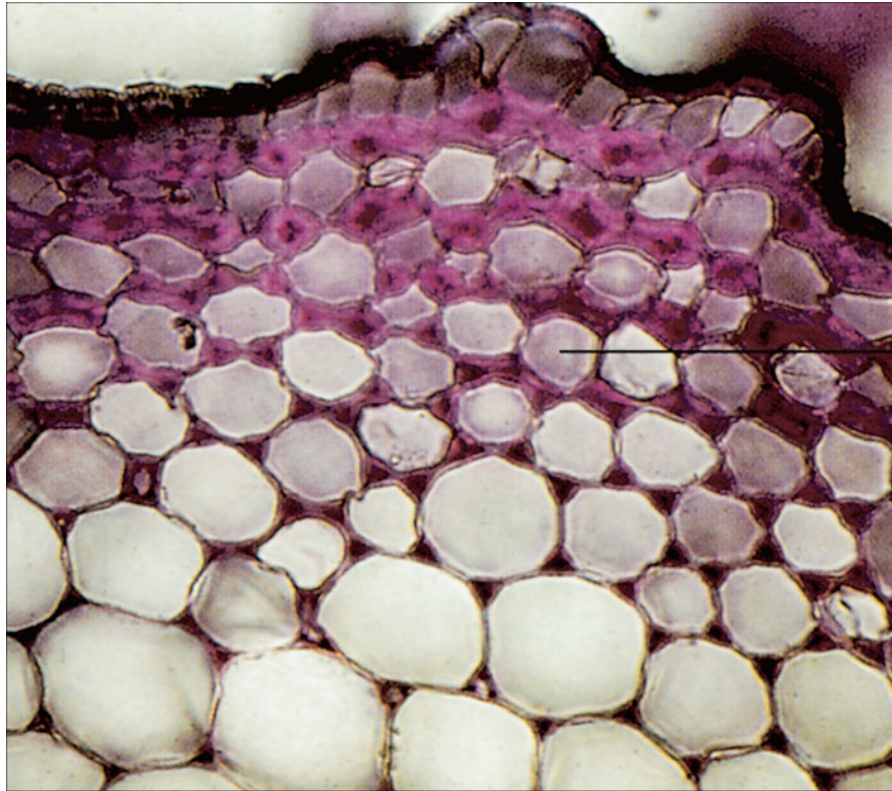
- Mosses (Bryophyta)
- Ferns and allies (Pteridophyta)
- Seed plants (Spermatophyta)
 - Conifers (Pinopsida)
 - Some other classes of seed plants
 - Angiosperms (Magnoliopsida)
 - * Monocots (Liliidae)
 - * Other subclasses of angiosperms (together: “dicots”)

6.1 Step two: skeleton. Supportive tissues

Collenchyma: living supportive tissue

- Elongated cells
- Thick primary cell wall (pectins + cellulose)
- Main functions: mechanical support of young stems and leaves

Angled collenchyma



collenchyma cell

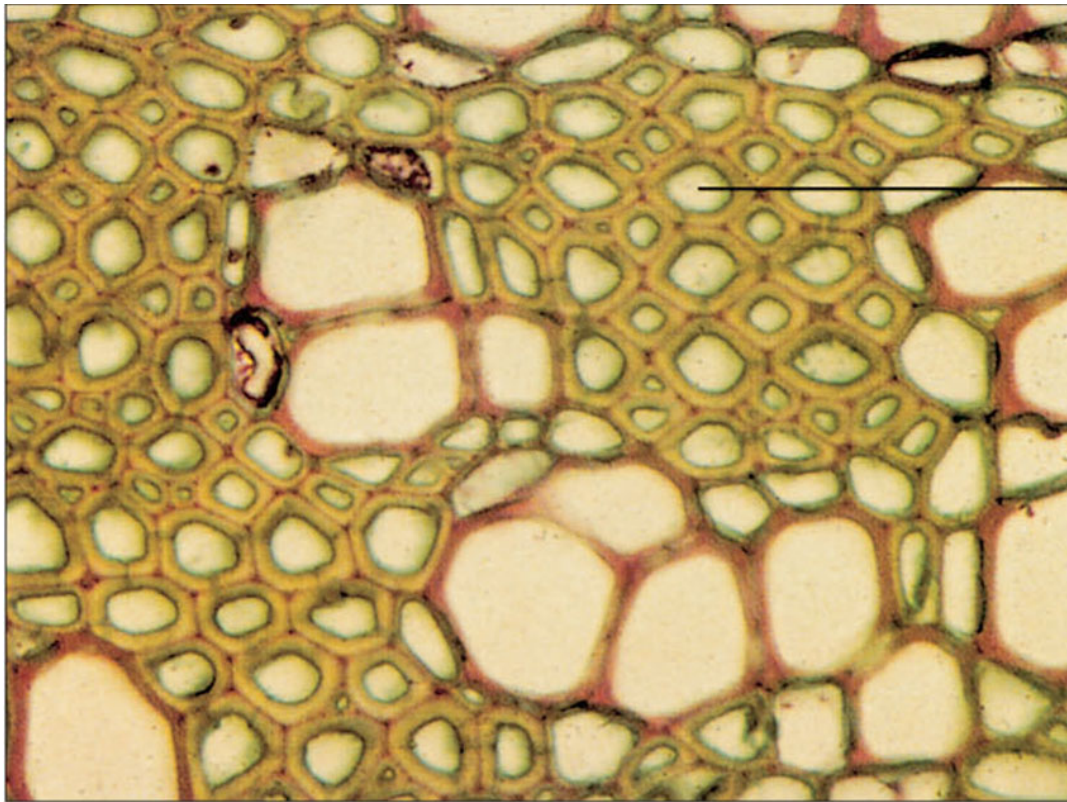
© 2006 Brooks/Cole - Thomson

Collenchyma cells of marigold (*Calendula officinalis*)

Sclerenchyma: dead supportive tissue

- Long cells (sclerenchyma fibers) or short crystal-like cells (sclereids)
- Dead cells with thick secondary cell wall, rich of lignin
- Supports weight of older plant organs, makes fruits non-edible before they become rip, makes stems firm

Sclerenchyma fibers

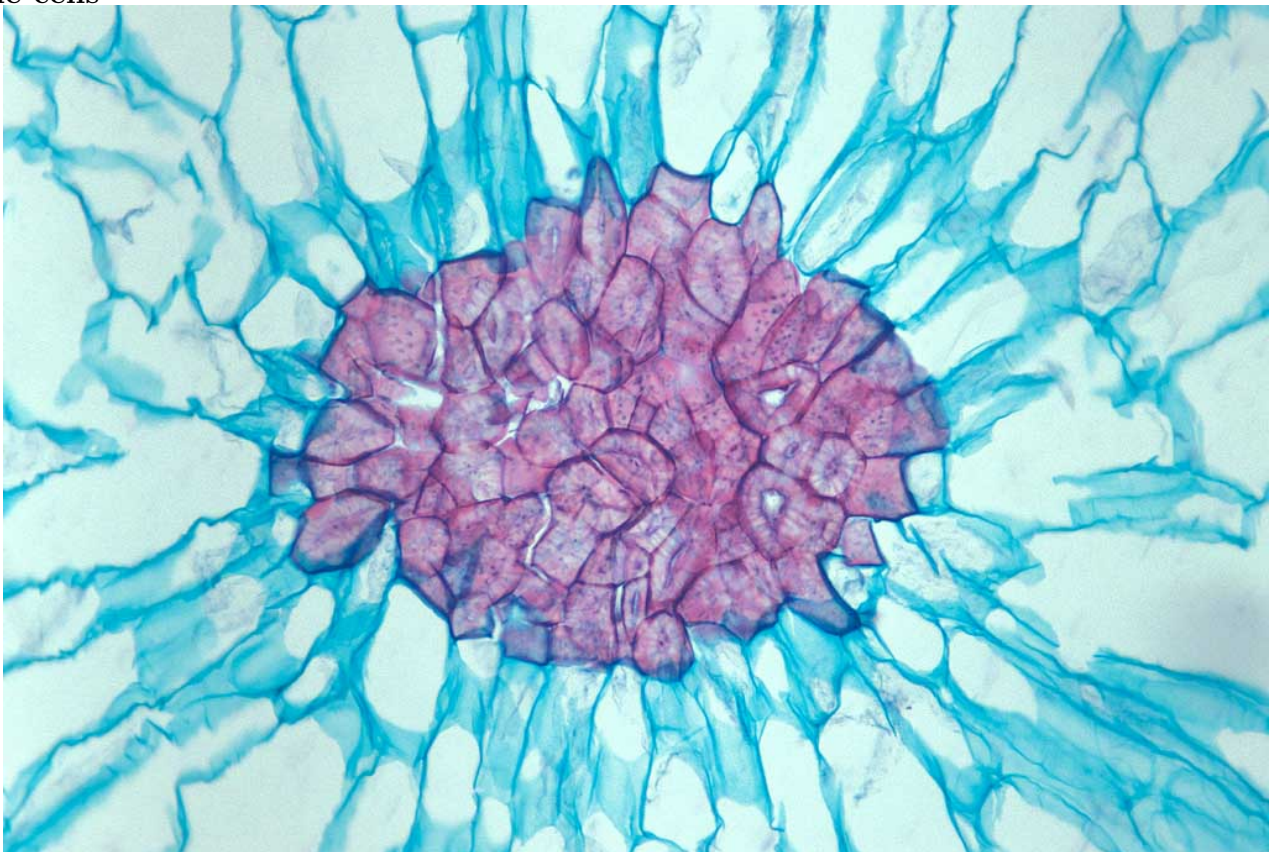


fiber

© 2006 Brooks/Cole - Thomson

Cross-section of sclerenchyma fibers in geranium (*Pelargonium* sp.)

Stone cells



Stone cells (kind of sclereids) in pear fruit (*Pyrus communis*)

Sclereids from cherry pit



Sclereids from cherry (*Prunus* sp.) pit (LM $\times 400$)

6.2 Step three: construction sites. Meristems

Meristems: apical

- Centers of plant development
- Locate on the very ends of roots (RAM) and shoots (SAM)
- Produce intermediate primary meristems which form all primary tissues

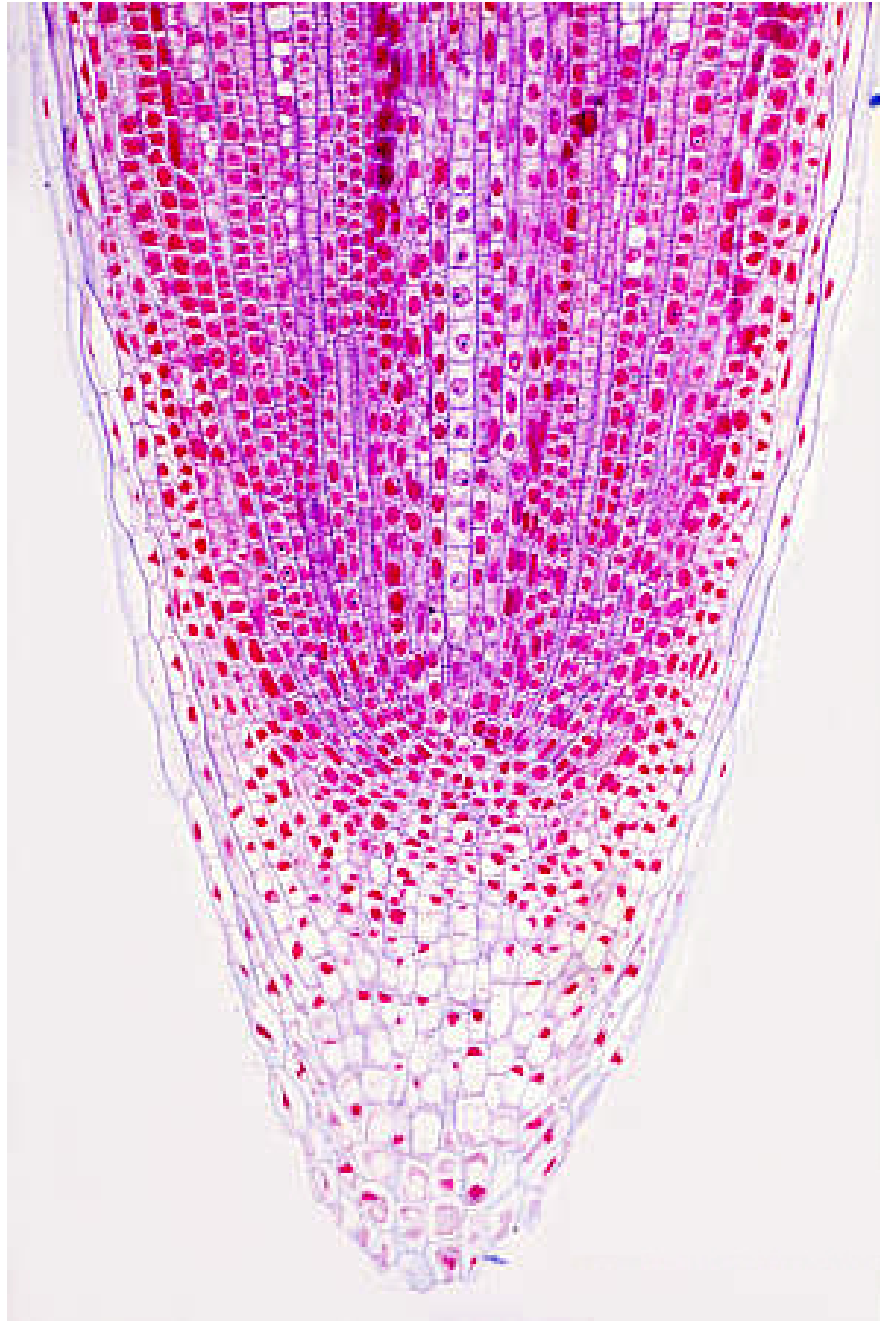
SAM



© 2006 Brooks/Cole - Thomson

Coleus sp. stem apical meristem (LM $\times 100$); primordia (embryonic leaves) are visible.

RAM



Corn (*Zea mays*) root apical meristem (© D. Webb)

Lateral meristem: cambium

- Originates from procambium which in turn originates from apical meristems
- Usually arises between two vascular tissues
- Main function: thickening. Produces secondary vascular tissues

Primary and secondary tissues

- Primary tissues originate from stem or root apex through primary meristems
- Secondary tissues originate from lateral meristems

Additional meristems

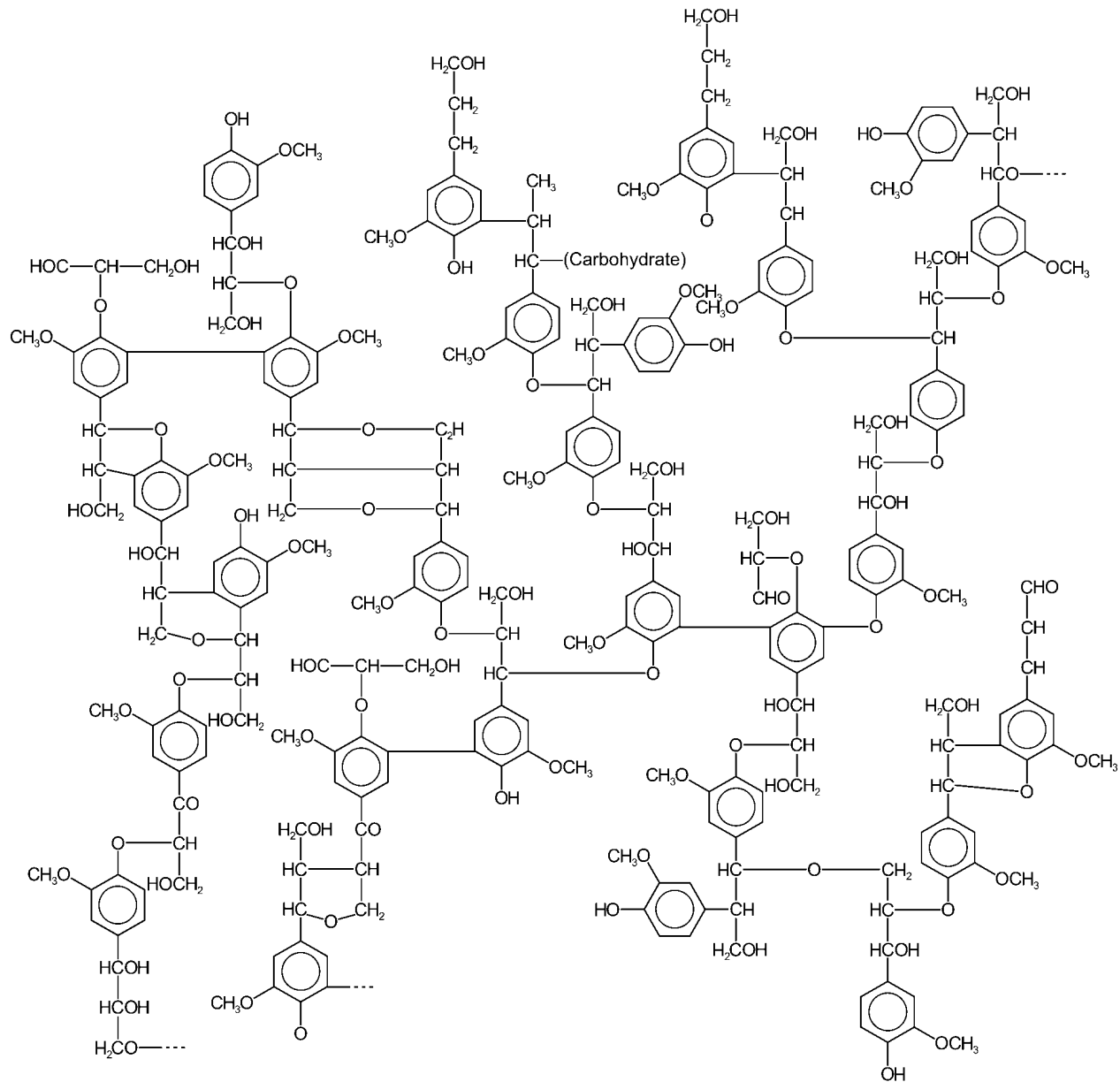
- **Intercalary** meristems: locate in stems, regulates stem elongation
- **Marginal** meristems are leaf-specific, they regulate leaf shape
- **Repair** meristems help to cure wounds, they form buds and roots in unusual places

6.3 Origin of tissues

Origin of tissues and organs of plants: first steps

- Plants were pushed on land for many reasons, including competition
- First challenge: drying. Response: **epidermis** and **parenchyma**.
- Second challenge: new level of competition. Response: growing up!
- Problem: big weight. Response: **collenchyma**.
- Competition grows, plants growing even higher. Weight grows. They also need to get rid of turgor dependency. Response: use lignin not only for epidermis surface (cuticle) but also for secondary cell walls—**sclerenchyma**.
- Competition grows again, plants need to grow faster. Solution: **meristems**.
- Size of plant is too big for plasmodesmata transportations. Solution: vascular tissues, **xylem** and **phloem**.

Lignin



Phenolic and other “plastic” compounds (e.g., lignin) were initially developed for spore distribution with a wind, then used in cuticle, then in the secondary cell walls.

6.4 Step four: pipes. Vascular tissues

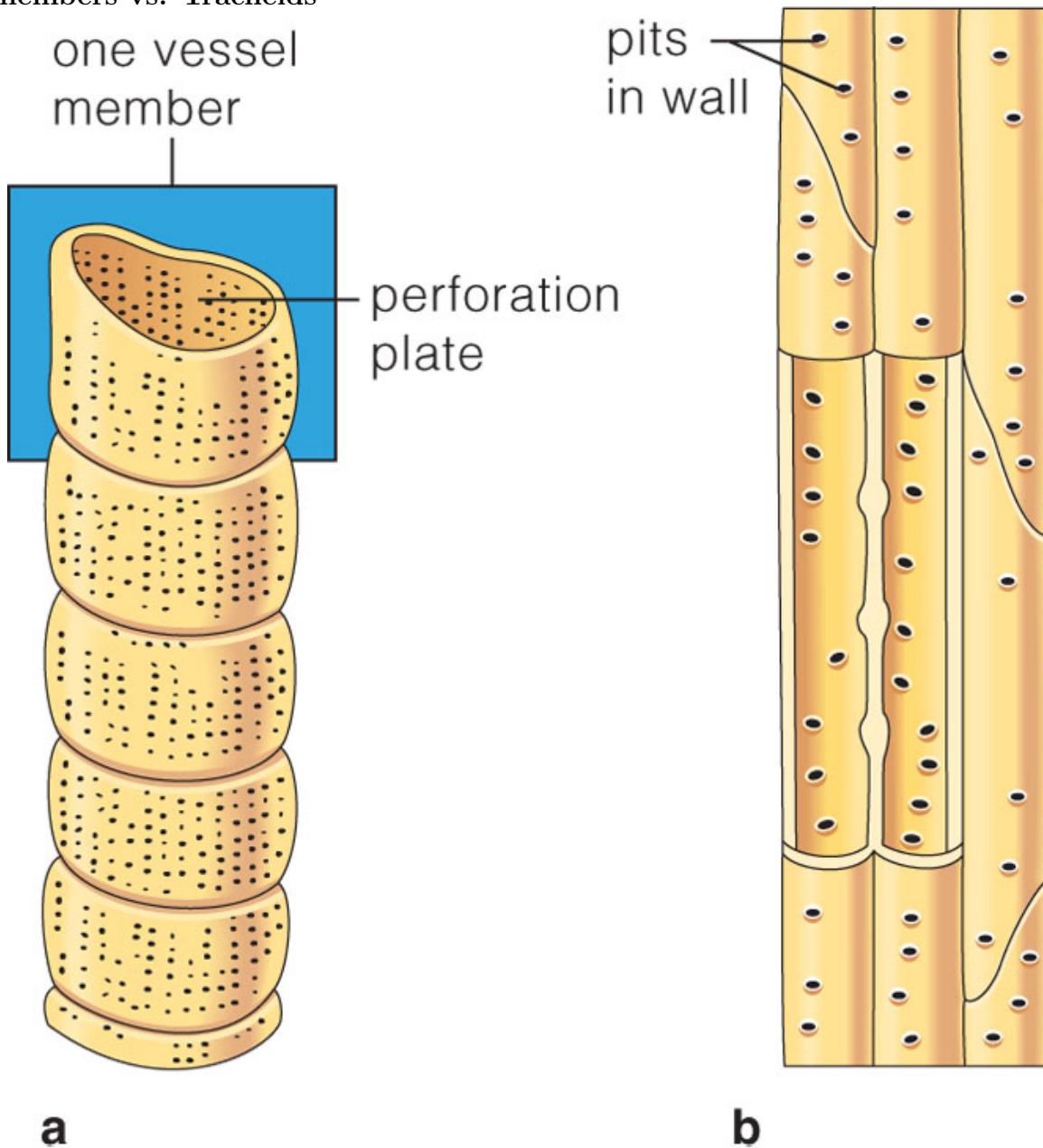
6.4.1 Xylem

Vascular tissues: Xylem

- Occurs in vascular bundles or vascular cylinder
- Types of cells: **tracheary elements** (tracheids and vessel members), **fibers**, and **parenchyma**
- Tracheids have pits; vessel members have perforations; all of them are dead cells
- Gymnosperms have only tracheids; flowering plants have tracheids + vessel elements together
- In flowering plants, primary xylem has mostly tracheids and vessels with scalariform perforations; secondary xylem has mostly vessels with open perforations

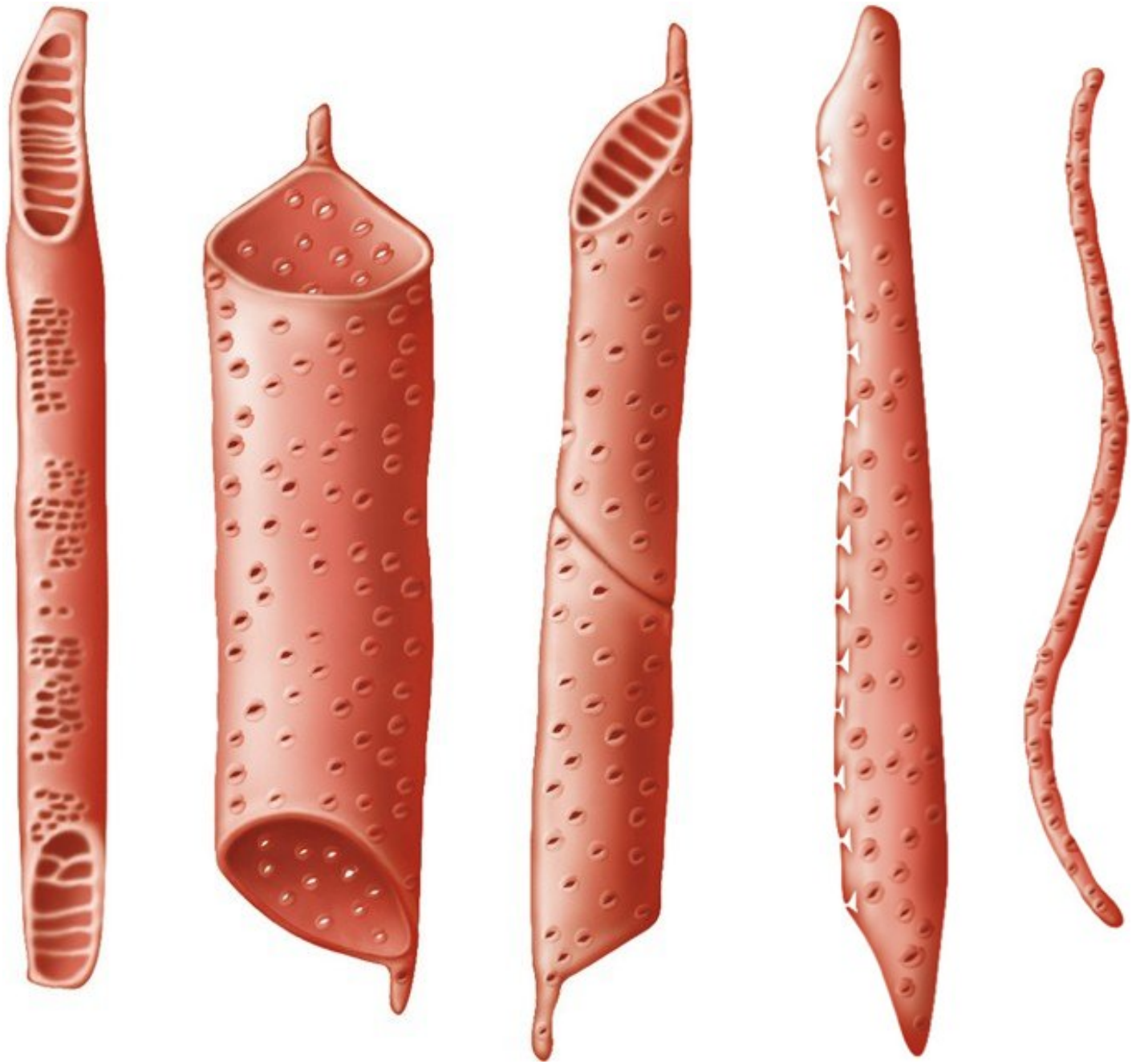
- Xylem elements (except parenchyma) are rich of lignin and are main components of wood
- Main functions: water transport and mechanical support

Vessel members vs. Tracheids

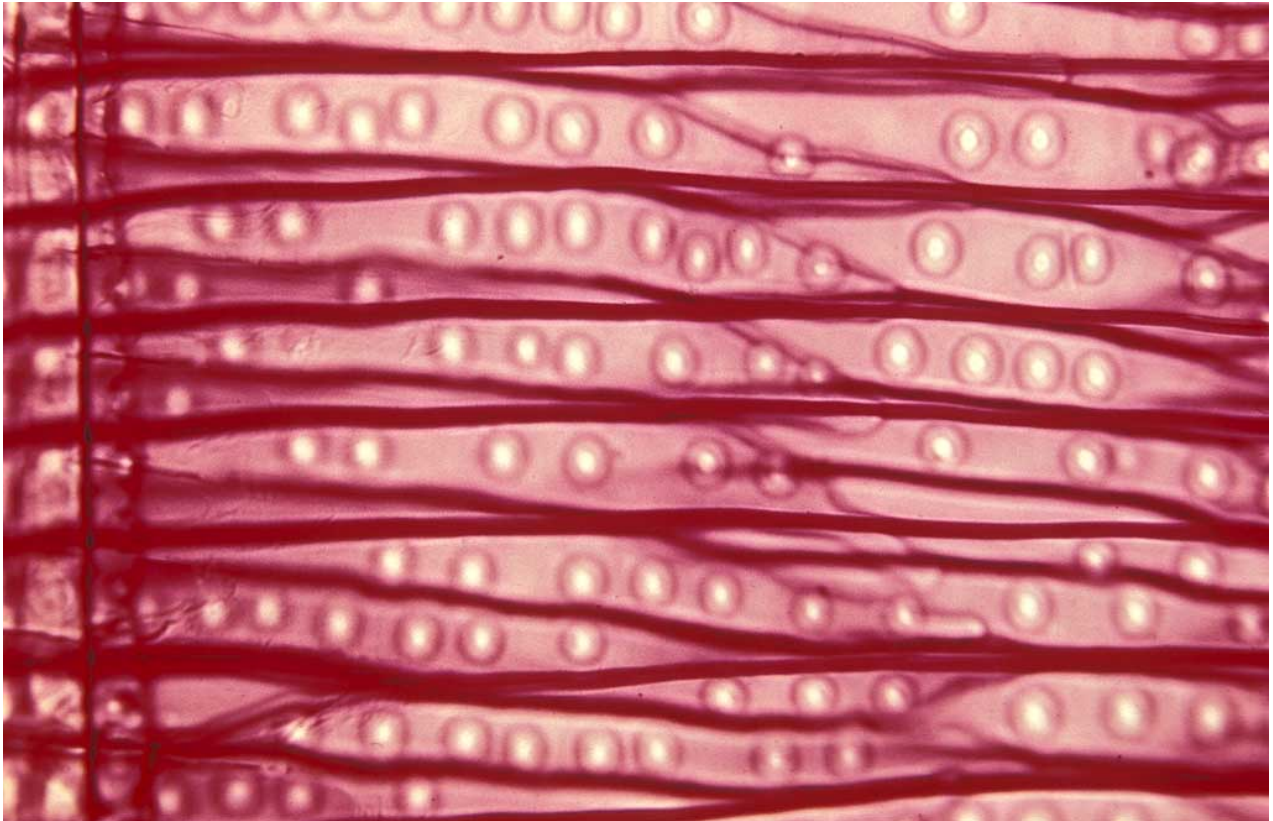


© 2006 Brooks/Cole - Thomson

Vessel members vs. Tracheids

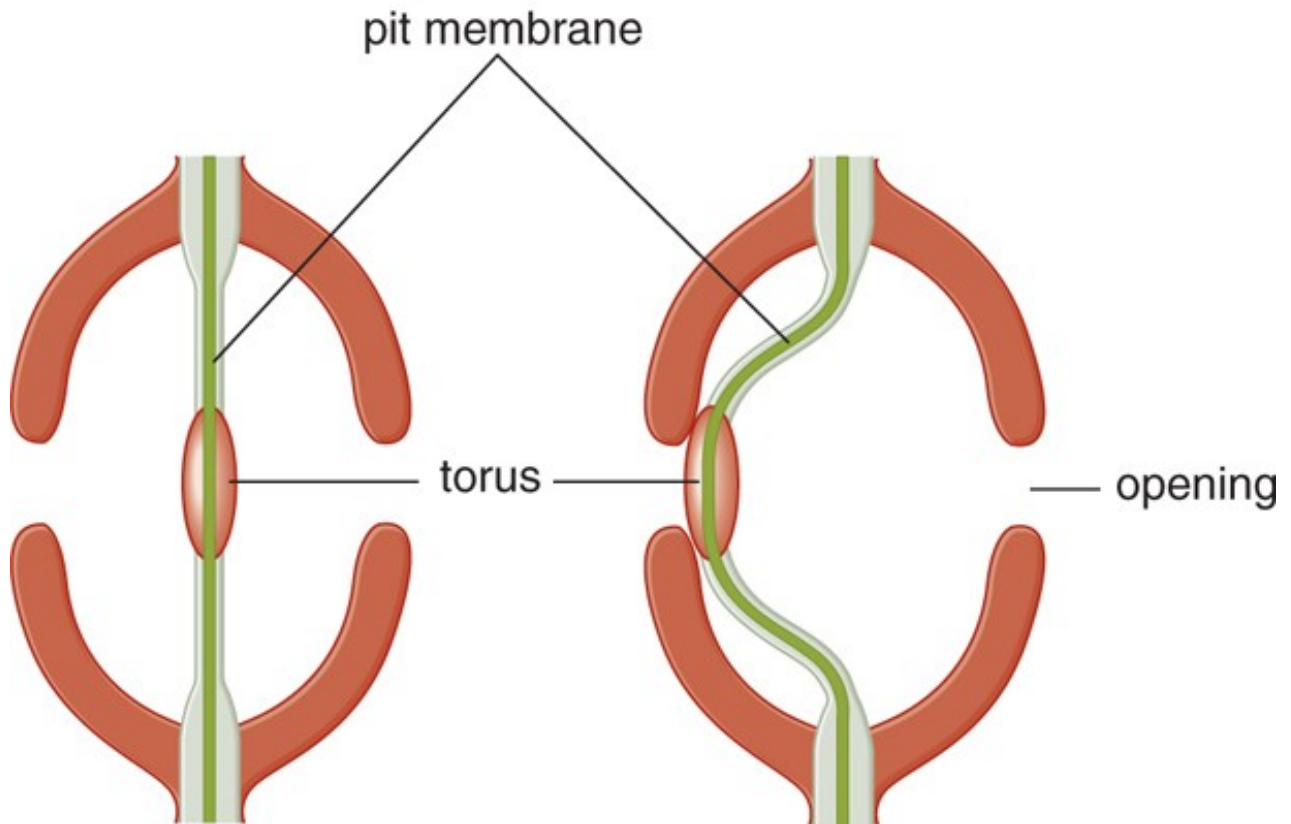


Tracheids



Pine (*Pinus* sp.) tracheids with pits

Pit is NOT a direct connection

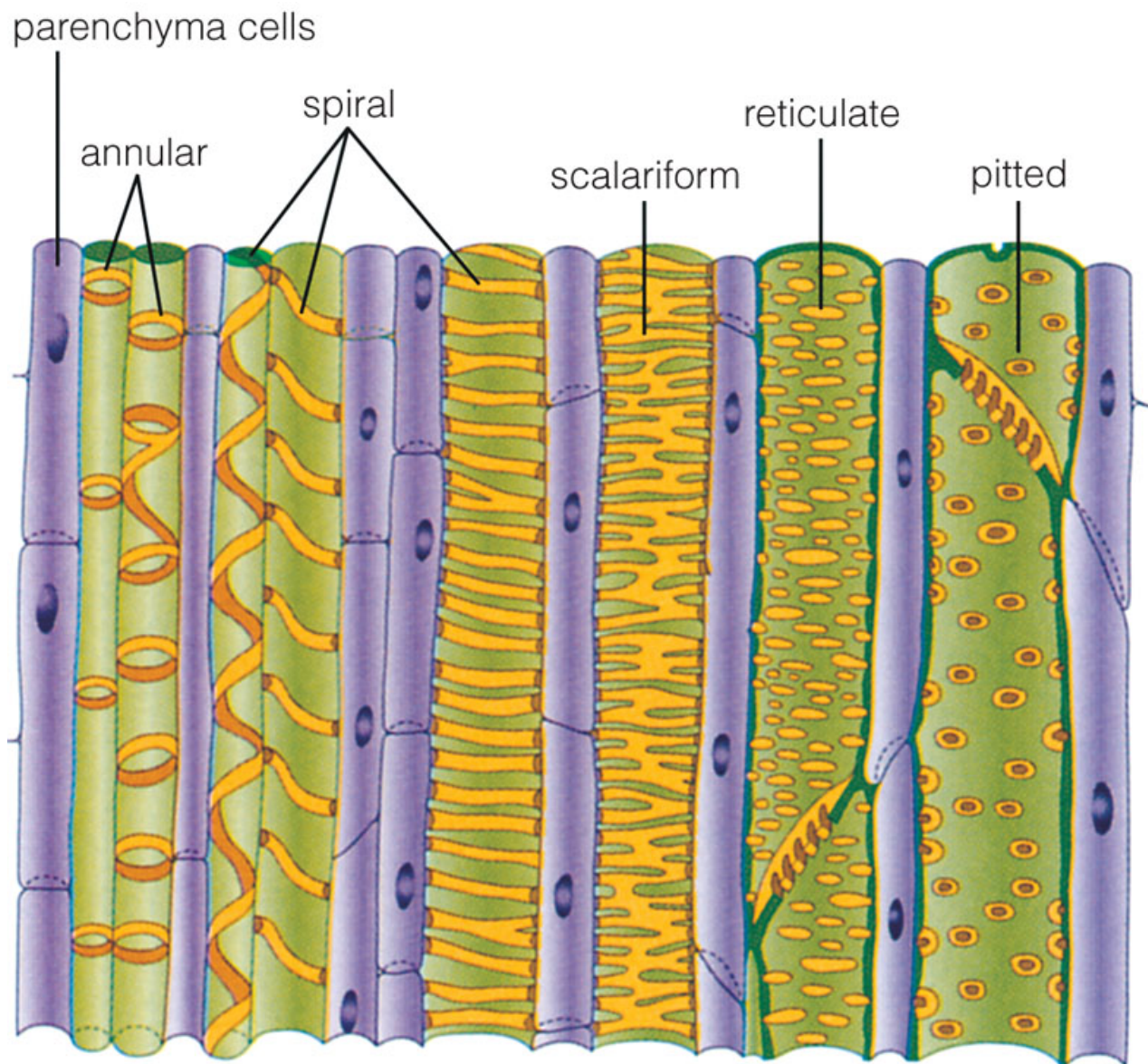


Vessels



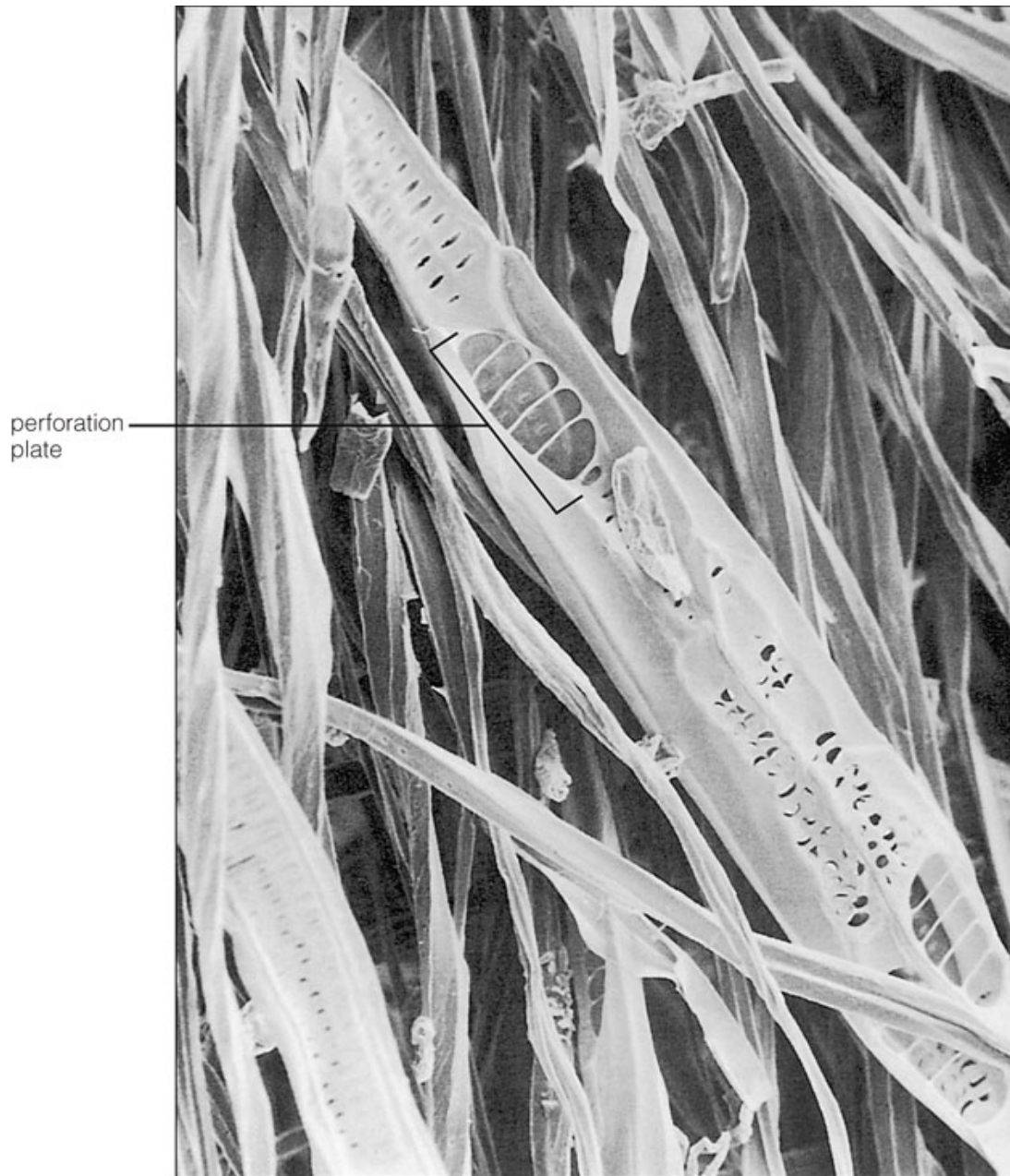
Ash (*Fraxinus americana*) secondary xylem with vessels (LM $\times 26$)

Perforations



© 2006 Brooks/Cole - Thomson

Scalariform perforations: direct connections



© 2006 Brooks/Cole - Thomson

Summary

- **Epidermis** is a complex tissue which includes stomata
- **Collenchyma** and **sclerenchyma** are simple supportive tissues
- **Secondary tissues** originate from lateral meristems (i.e., cambium)
- **Xylem vs. phloem:**
 - **State:** dead vs. living cells
 - **Transport:** water vs. sugar
 - **Direction:** up vs. down
 - **Biomass:** big vs. small

Final question (2 points)

What are secondary tissues?

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

7 Questions and answers

7.1 Quiz

Final question (3 points)

Name three differences between xylem and phloem.

- **State:** (mostly) dead vs. (mostly) living cells
- **Transport:** water vs. sugar
- **Direction:** up vs. (mostly) down
- **Biomass:** bigger vs. smaller

8 Leaf

8.1 Leaf in general

Definition, functions and features

- Lateral flattened organ of shoot with restricted growth
- Functions:
 - Photosynthesis
 - Respiration
 - Transpiration
 - Synthesis of secondary chemicals
- Features:
 - Have bud in the axil (remember compound leaves)
 - Do not grow by apex
 - Do not produce new leaves
 - Have hierarchical (fractal) morphology

8.2 Leaf morphology

Hierarchy

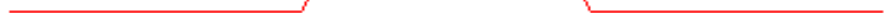


Fractals are hierarchical

$n = 0$



$n = 1$



$n = 2$



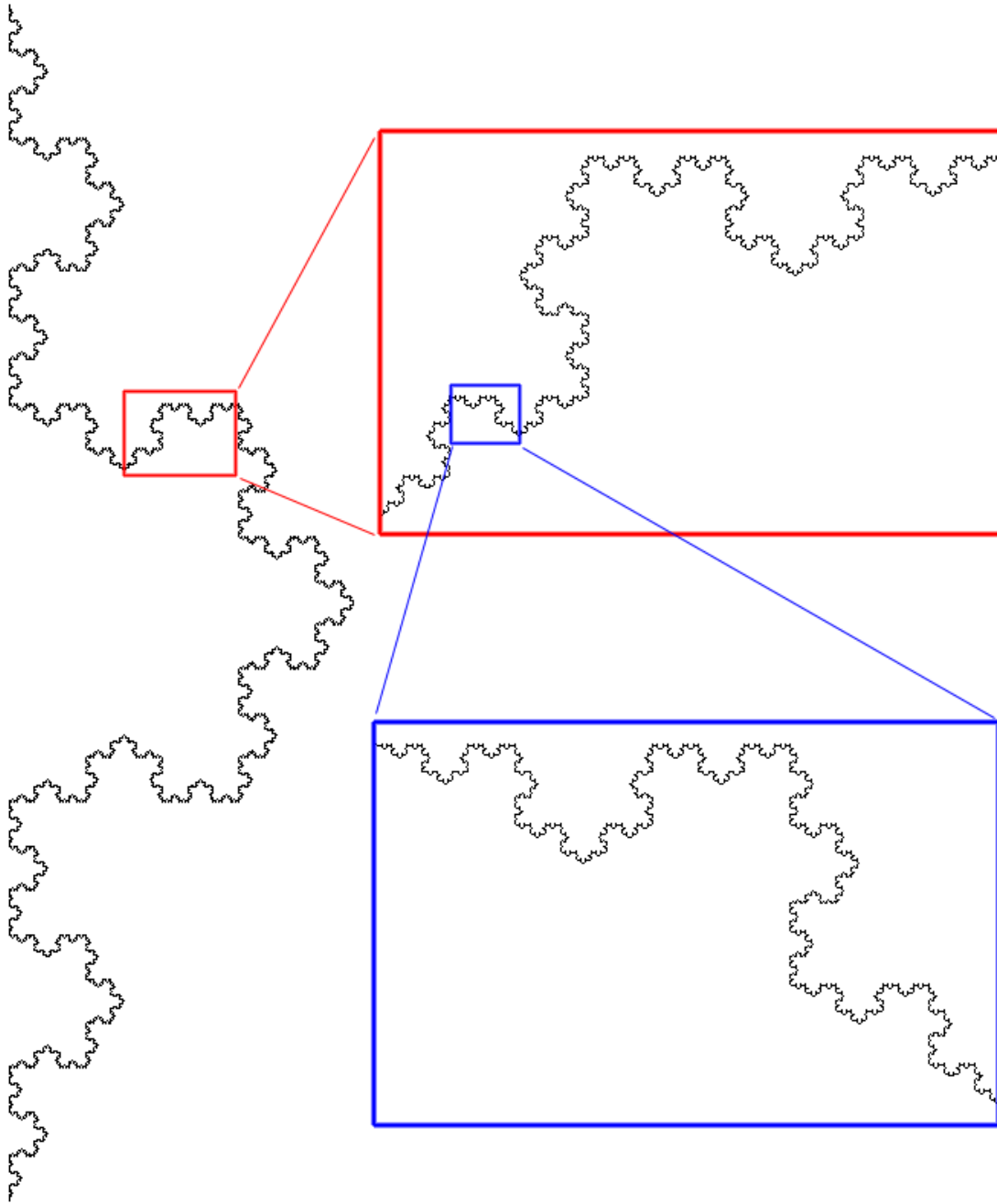
$n = 3$



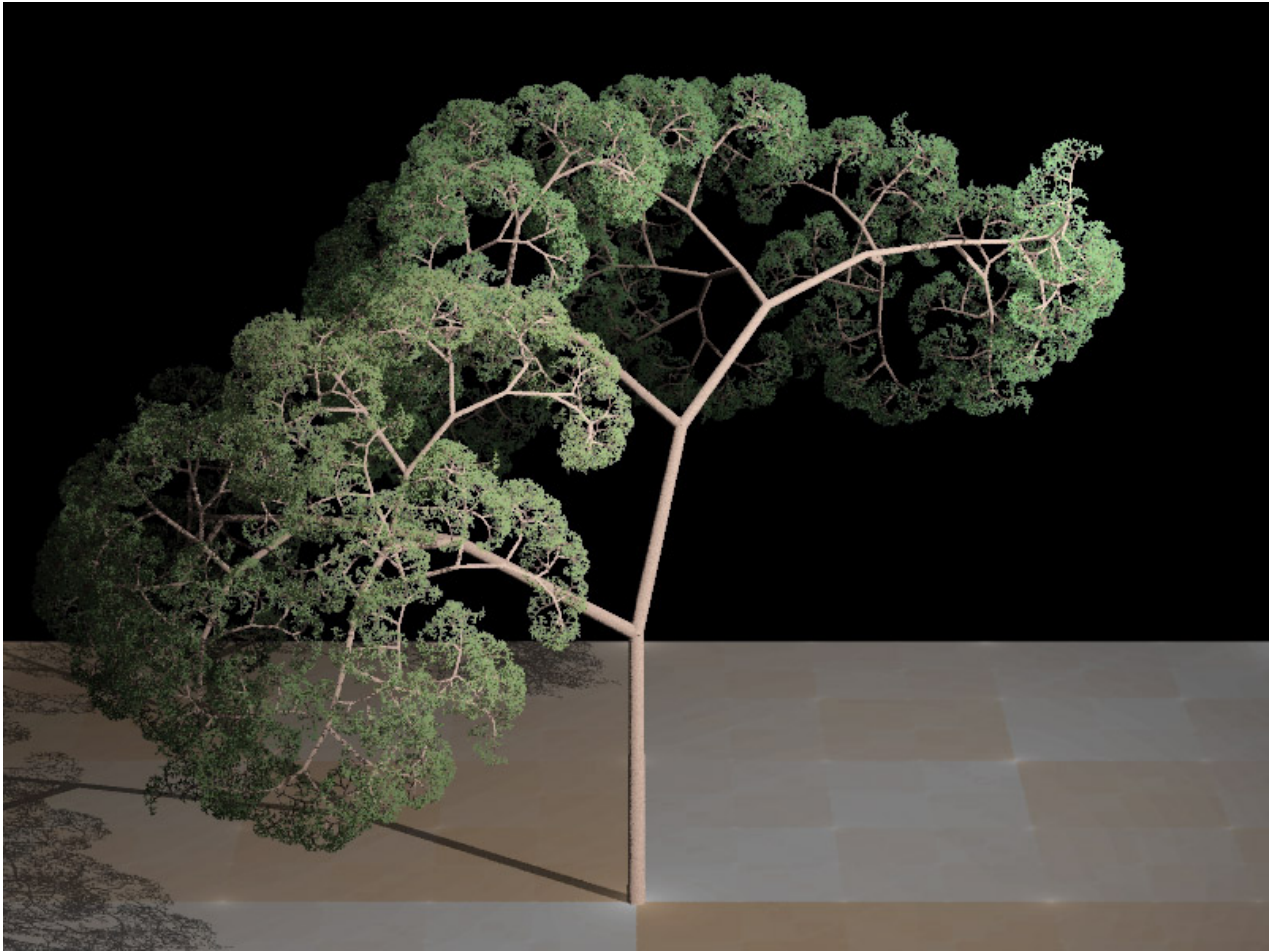
$n = 4$



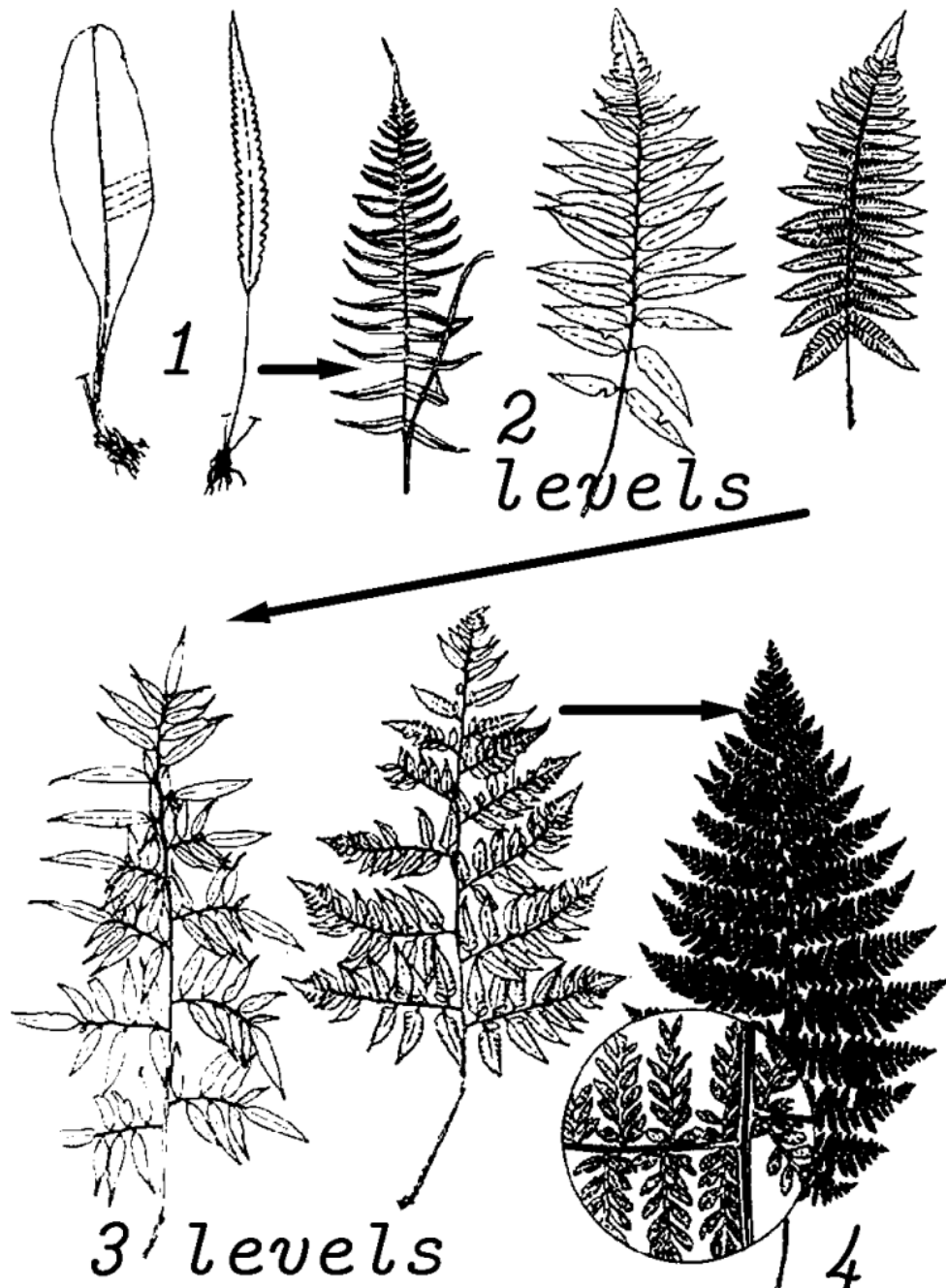
Fractals are self-similar



Fractals could be just like plants



And leaves could be just like fractals, with levels



Types of leaf characters

- General: applicable only to the whole leaf
- Terminal: applicable only to the terminals (e.g., terminal leaflets)
- Repetitive: repeating on each level of hierarchy

Hierarchy in leaf morphology

- **General** and **terminal** characters do not depend on hierarchy
- **Repetitive** characters may be different on each step of hierarchy

- Therefore, leaf description should state that “on first level of hierarchy, the shape is ..., on the second level, the shape is ...”
- It is possible that each level has different repetitive characters

8.3 General characters

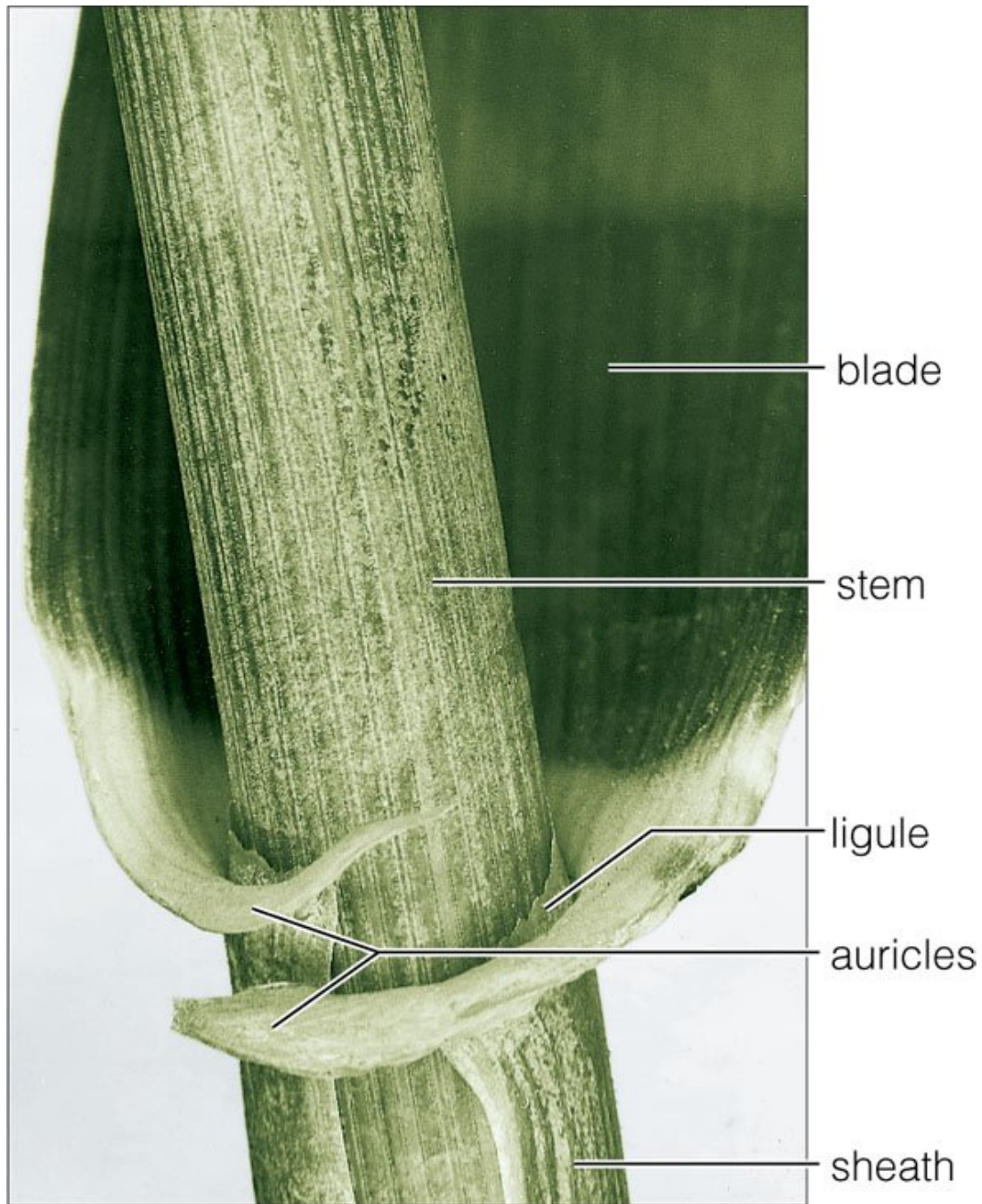
General characters

- General characters apply to the whole leaf
- Stipules (present or not, how many etc.)
- Other leaf base organs (sheath, ocrea, ligules etc.)

Stipules



Leaf base



8.4 Repetitive characters

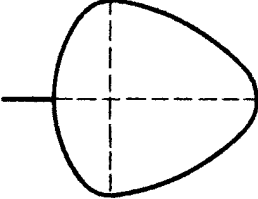
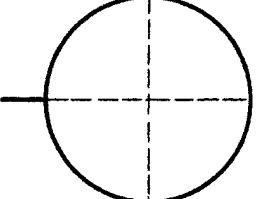
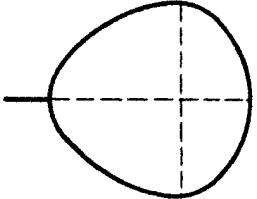
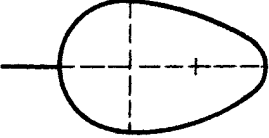
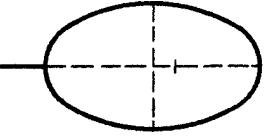
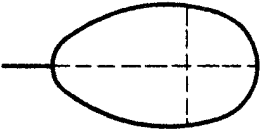

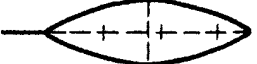
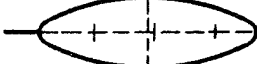
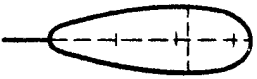
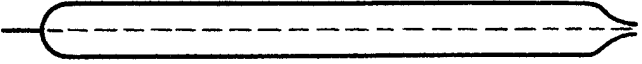
Repetitive characters

Repetitive characters are the same on each level of leaf hierarchy:

- Shape
- Dissection
- Petiole (stalked/non-stalked etc.)

Repetitive characters of same type may combine

Shape

| | Maximum width closer to leaf base | Maximum width in the middle | Maximum width closer to the apex |
|------------------------------------|---|---|---|
| Length = width or slightly more |  Deltate |  Circular |  Cuneate |
| Length > 1-1.5 x width |  Ovate |  Elliptic |  Obovate |
| Length > 3-4 x width |  Narrowly ovate |  Lanceolate  Oblong |  Narrowly obovate |
| Length > 5 x width |  Linear | | |

Summary

- Leaves have **general**, **repetitive** and **terminal** characters

Final question (2 points)

Please describe the leaf shape on the 2nd level of hierarchy.

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

9 Questions and answers

9.1 Quiz

Final question (2 points)

Please describe the leaf shape on the 2nd level of hierarchy.

- Narrowly obovate, basal leaflets almost obovate

10 Leaf

10.1 Repetitive characters

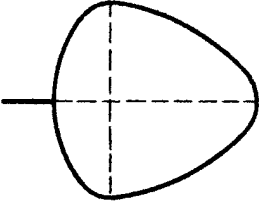
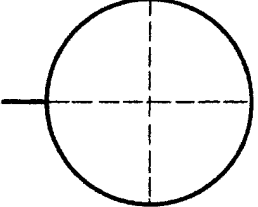
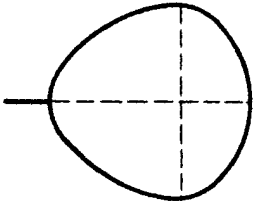
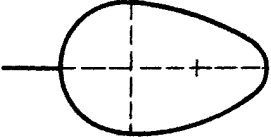
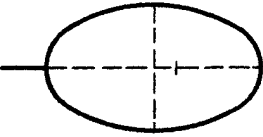
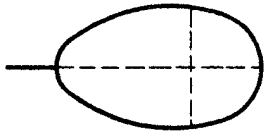
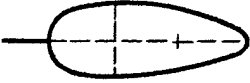

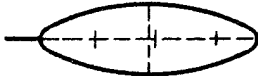
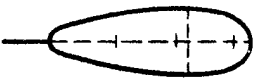

Repetitive characters

Repetitive characters are the same on each level of leaf hierarchy:

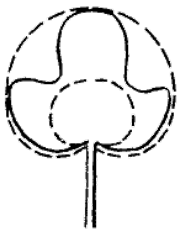
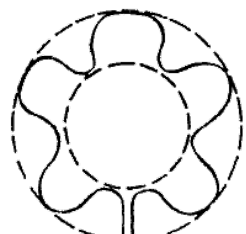
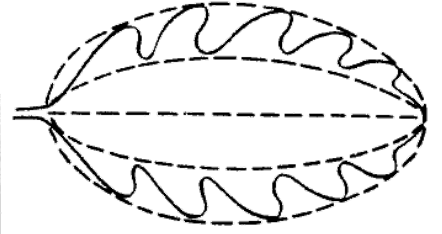

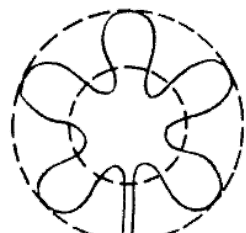
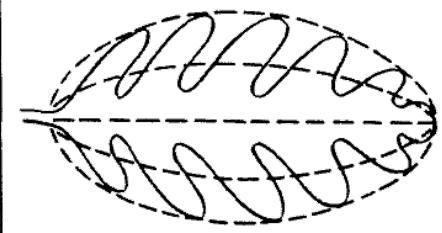
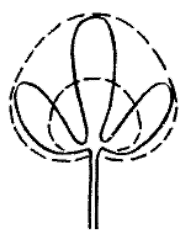
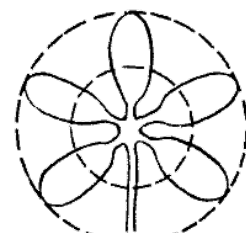
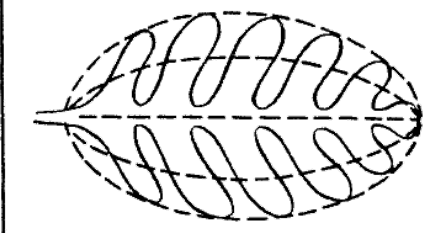
- Shape
- Dissection
- Petiole (stalked/non-stalked etc.)

Repetitive characters of same type may combine

Shape

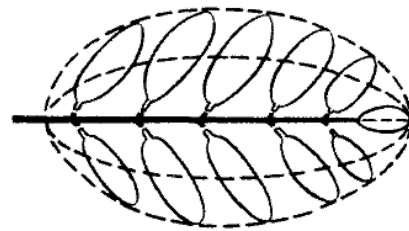
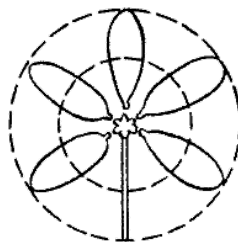
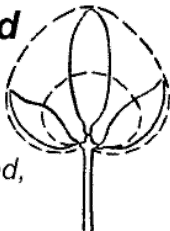
| | Maximum width closer to leaf base | Maximum width in the middle | Maximum width closer to the apex |
|------------------------------------|--|---|--|
| Length = width or slightly more |  Deltate |  Circular |  Cuneate |
| Length > 1-1.5 x width |  Ovate |  Elliptic |  Obovate |
| Length > 3-4 x width |  Narrowly ovate |  Lanceolate  Oblong |  Narrowly obovate |
| Length > 5 x width |  Linear | | |

Dissection

| | | Tri- | Palmately | Pinnately |
|----------------------|--|--|--|---|
| Simple leaves | Lobed (from 1/4 to 3/4) |  |  |  |
| | |  |  |  |
| | Dissected (from 3/4 to midrib) |  |  |  |

Compound leaves

(leaflets stalked, with joints)



10.2 Terminal characters

Terminal characters

Terminal (leaflet) characters are applicable only to terminal parts (normally, leaflets) of leaves:

- Form of base
- Form of tip
- Type of margin
- Surface
- Venation

Terminal characters: base of leaf blade

- Rounded
- Truncate (straight)
- Cuneate
- Cordate
- Sagittate

Terminal characters: leaf apex

- Rounded
- Mucronate
- Acute
- Obtuse
- Acuminate
- Retuse

Terminal characters: leaf margin

- Without teeth: smooth
- With teeth
 - Dentate
 - Serrate
 - Crenate
- Could be double-dentate, triple-serrate etc.

Terminal characters: leaf venation

| Main vein \ Lateral veins | No | One | Several |
|---------------------------|------------|--------|---------|
| | Apodromous | Hypho- | Acro- |
| No | | | |
| Several | ... | Ptero- | Actino- |

Plan of leaf description

- A. General characters (leaf as a whole):
 - (a) stipules (present / absent, deciduous / not);
 - (b) base (sheath / no sheath, ligule / no ligule, auricles / no auricles)
- B. First level of hierarchy: repetitive characters:
 - (a) symmetry (symmetrical / asymmetrical);
 - (b) shape;
 - (c) dissection;
 - (d) petiole (length)
- C. Second level of hierarchy
- D. Third level of hierarchy and so on
- E. Terminal characters (leaflets):
 - (a) base [of leaf blade] (rounded, truncate, cuneate, cordate, sagittate);
 - (b) apex (rounded, mucronate, acute, obtuse, acuminate, retuse);
 - (c) margin (whole, dentate, serrate, crenate; degree of order);
 - (d) surface (color, hairs etc.);
 - (e) venation (apo-, hypho-, acro-, ptero-, actinodromous)

10.3 Leaves in nature

Heterophylly

- Juvenile and adult leaves
- Water and air leaves
- Sun leaves and shade leaves

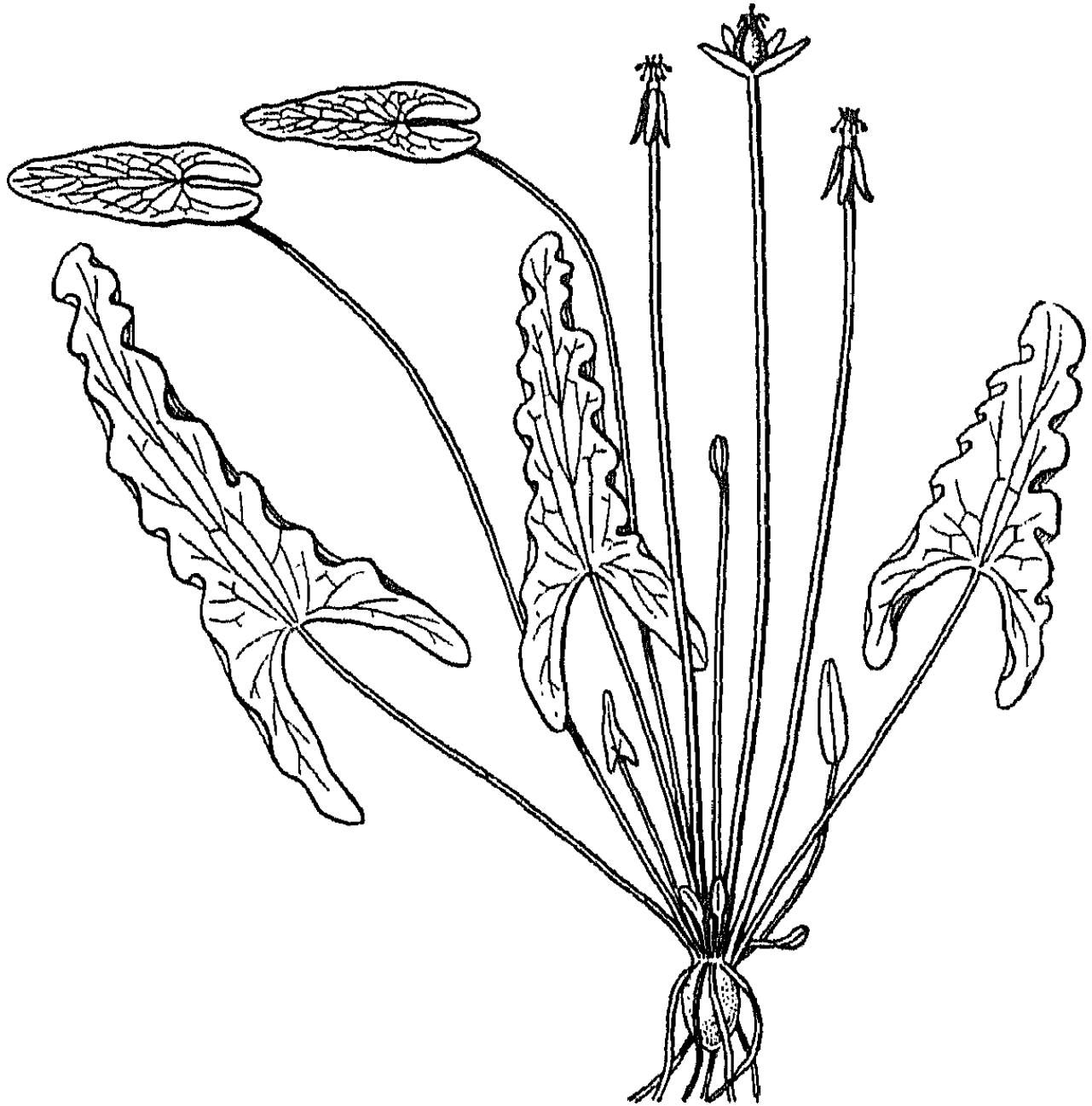
Juvenile leaves of *Juniperus* sp.



Juvenile leaves of *Eucalyptus* sp.



Submerged and floated leaves of *Ondinea*



Leaf mosaic

- Distribution of leaves of plants in a single plane, usually perpendicular to light rays
- Provides the least shading of leaves by one another

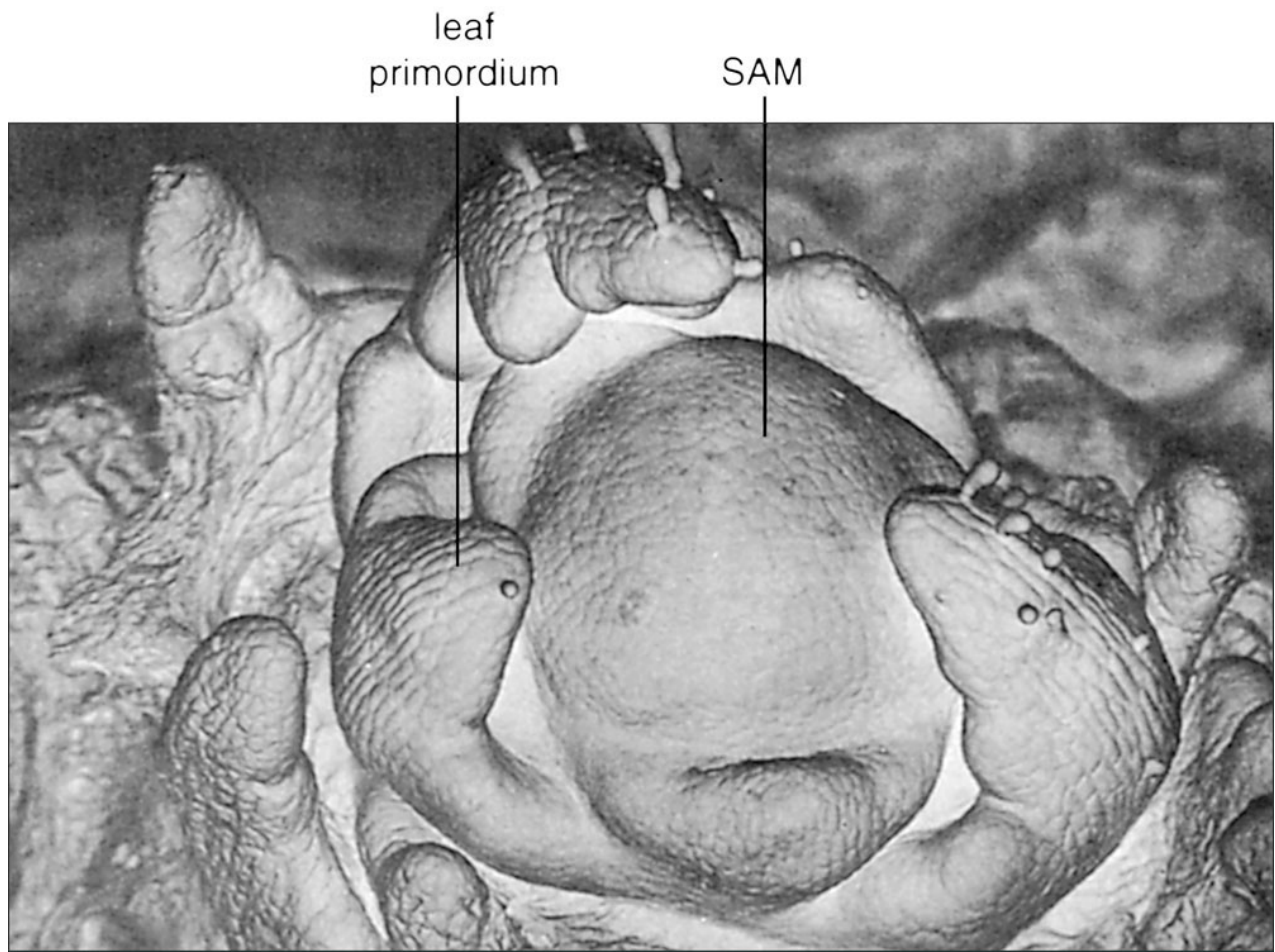
Leaf mosaic of red maple (*Acer rubrum*)



Seasonal life of leaves

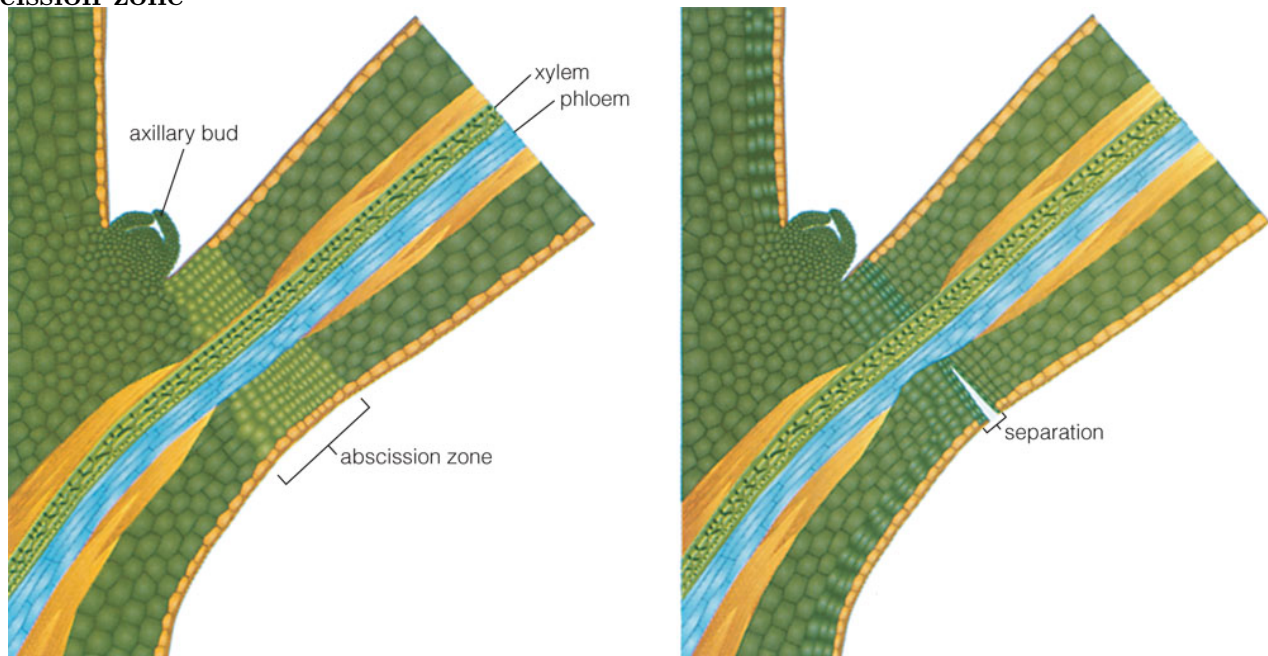
- Leaves arise from SAM through leaf primordia
- Old leaves separate from plant in a region called abscission zone

Leaf primordia



© 2006 Brooks/Cole - Thomson

Abscission zone



© 2006 Brooks/Cole - Thomson

10.4 Modifications of leaf

Goethe's theory of modification



Famous German poet and writer Johann Wolfgang Goethe is also a founder of plant morphology. He invented an idea of “primary plant” (“Urpflanze”) where all organs were modifications of one primordial organ.

Leaf modifications

- Spines
- Tendrils
- Succulent leaves
- Traps
- Plantlets

Tendrils of sweet pea (*Lathyrus odoratus*)



Plantlets on the leaf of *Kalanchoe pinnata*



Leaf of Venus flytrap (*Dionaea muscipula*)



Everything is possible when plant needs nitrogen!

Venus flytrap in work

Urn leaf of yellow pitcher plant (*Sarracenia flava*)



Sarracenia flava on Buttercup Fields, Mississippi



Prey in the urn



Urn leaf of purple pitcher plant (*Sarracenia purpurea*)



Hairs prevent insects from climbing out of leaf

“Cobra Lily” (*Darlingtonia californica*)



Sticky tape leaf of butterwort (*Pinguicula* sp.)



Leaf margins are slowly rolling

Sticky tape/trap leaf of sundew (*Drosera intermedia*)



Leaves are constantly open and close and finally digest the glued insects

Table of modifications

| <i>Function</i> | Stem / shoot | Leaf | Root |
|-----------------|--------------|-----------------------------|------|
| Expansion | | Plantlets | |
| Storage | | Succulent leaves | |
| Photosynthesis | | DEFAULT | |
| Defense | | Spines, scales | |
| Support | | Leaf tendrils | |
| Interactions | | Traps, “sticky tapes”, urns | |

Summary

- Leaves have **general**, **repetitive** and **terminal** characters
- **Heterophylly** is a co-existence of different types of leaves on the same plant
- **Abscission zone** helps the separation of leaf at the end of season

Final question (2 points)

Draw simple, whole ovate leaf with acute apex, serrate margin and cordate base.

For Further Reading**References**

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154

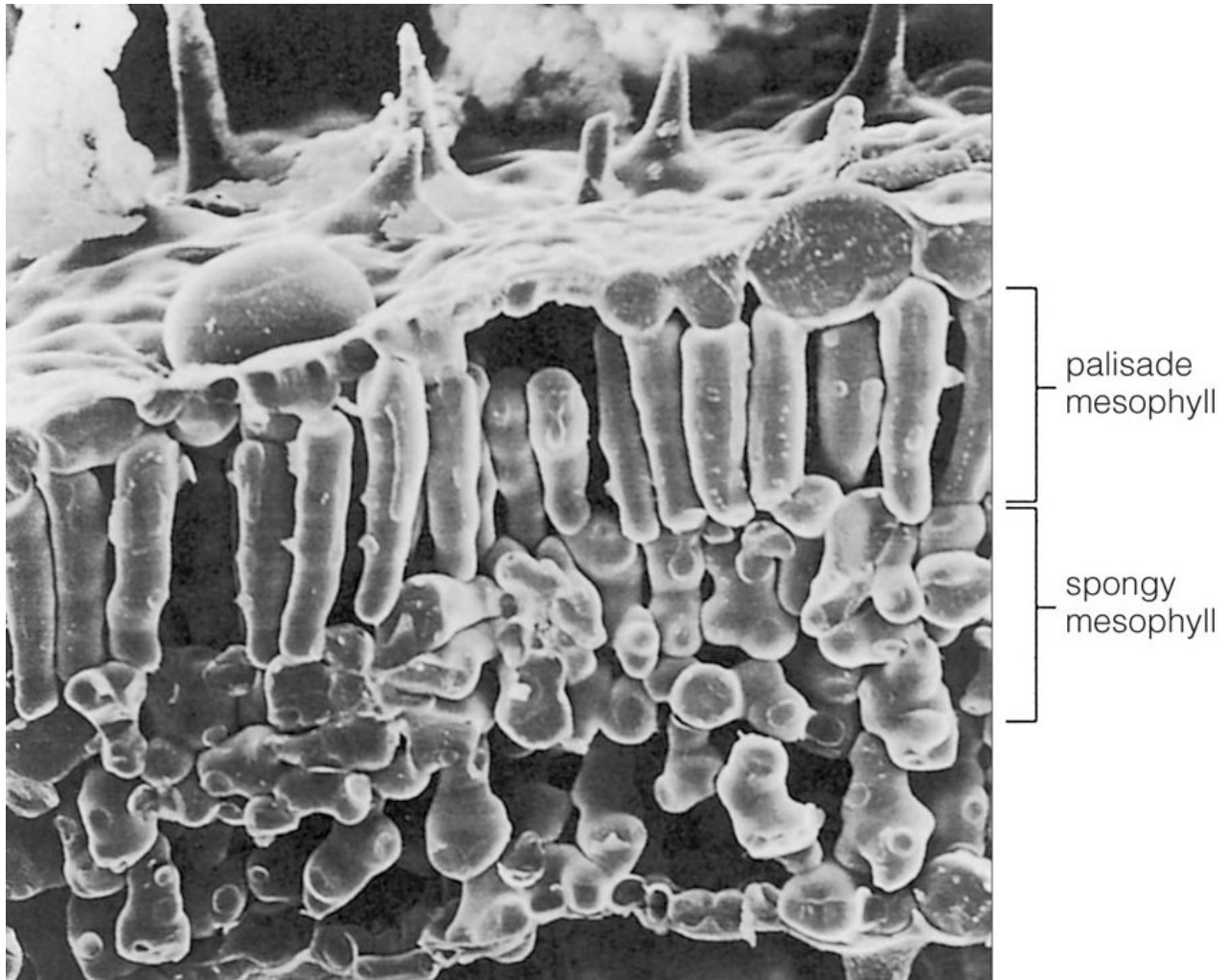
Outline**11 Questions and answers****11.1 Quiz****Final question (2 points)**

Draw simple, whole ovate leaf with acute apex, serrate margin and cordate base.

[See on board]

12 Leaf**12.1 Anatomy of leaf**

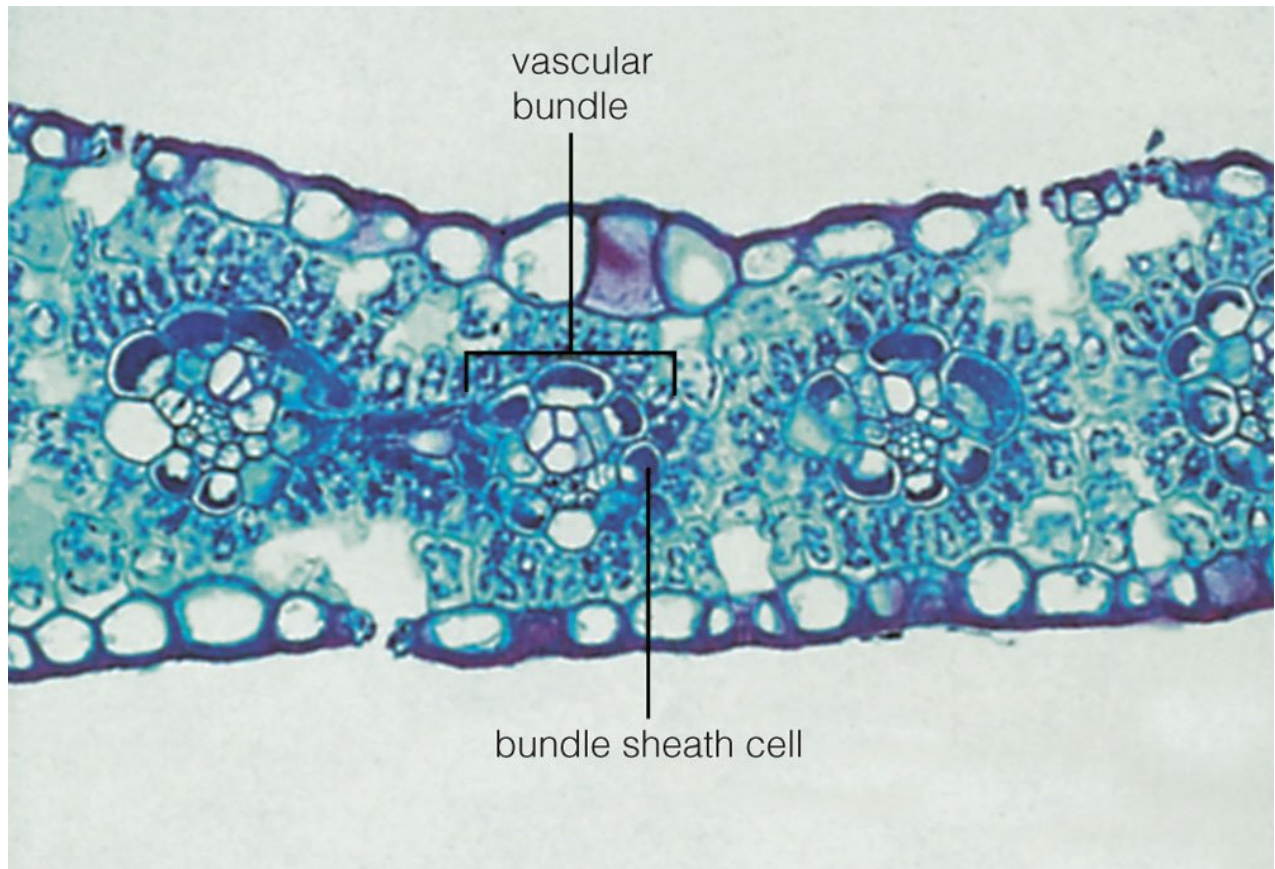
Palisade and spongy cells



Veins/vascular bundles and stomata

- Phloem typically faces downwards, xylem—upwards
- Bundles of C_4 -plants have additional bundle sheath cells
- Stomata work with the “bacon principle”

Bundle sheath cells

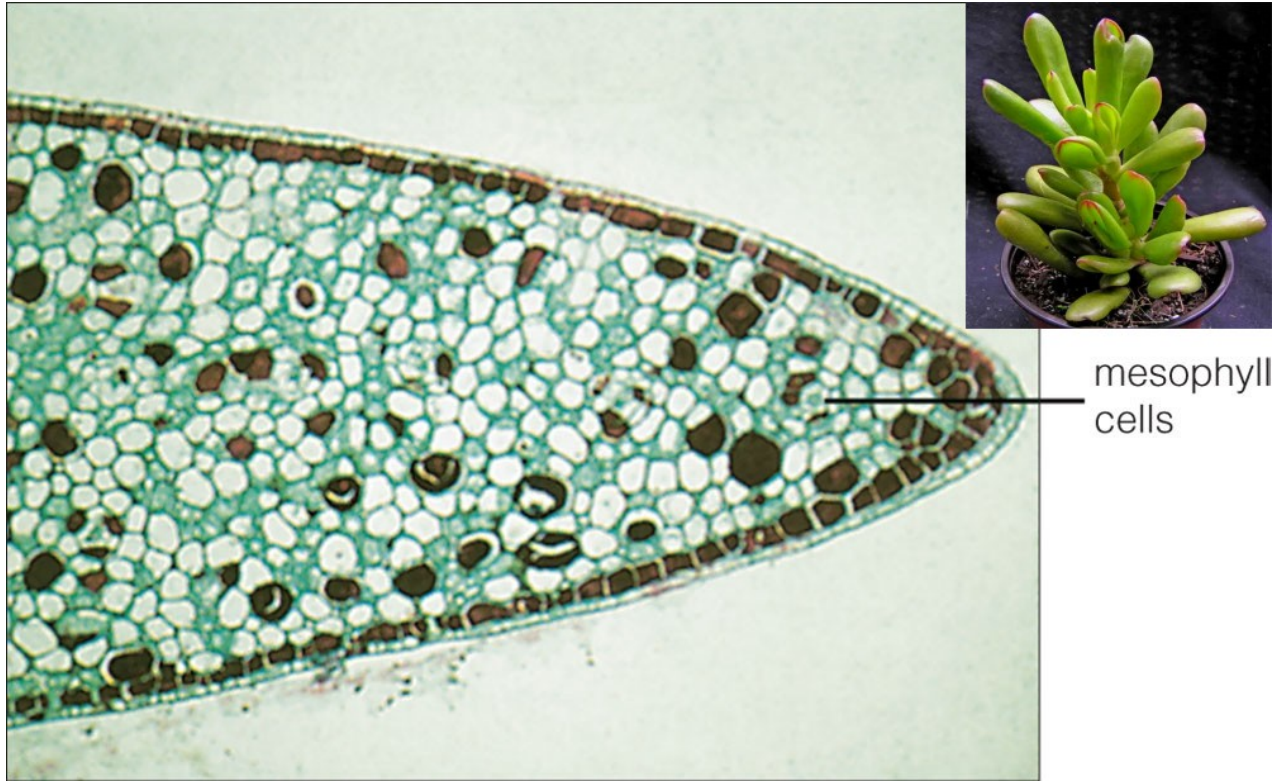


12.2 Ecological adaptations of leaves

Plants and water

- Xerophytes: sclerophytes and succulents (stem and leaf)
- Mesophytes
- Hygrophytes
- Hydrophytes

Leaf succulent (*Crassula argentea*)



Xerophyte leaf—needle of pine (*Pinus contorta*)



Final question (2 points)

Why are sclerophytes typically spiny?

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

13 Questions and answers

13.1 Quiz

Final question (2 points)

Why are sclerophytes typically spiny?

- They need more defence
- They need secondary cell walls
- They need less surface

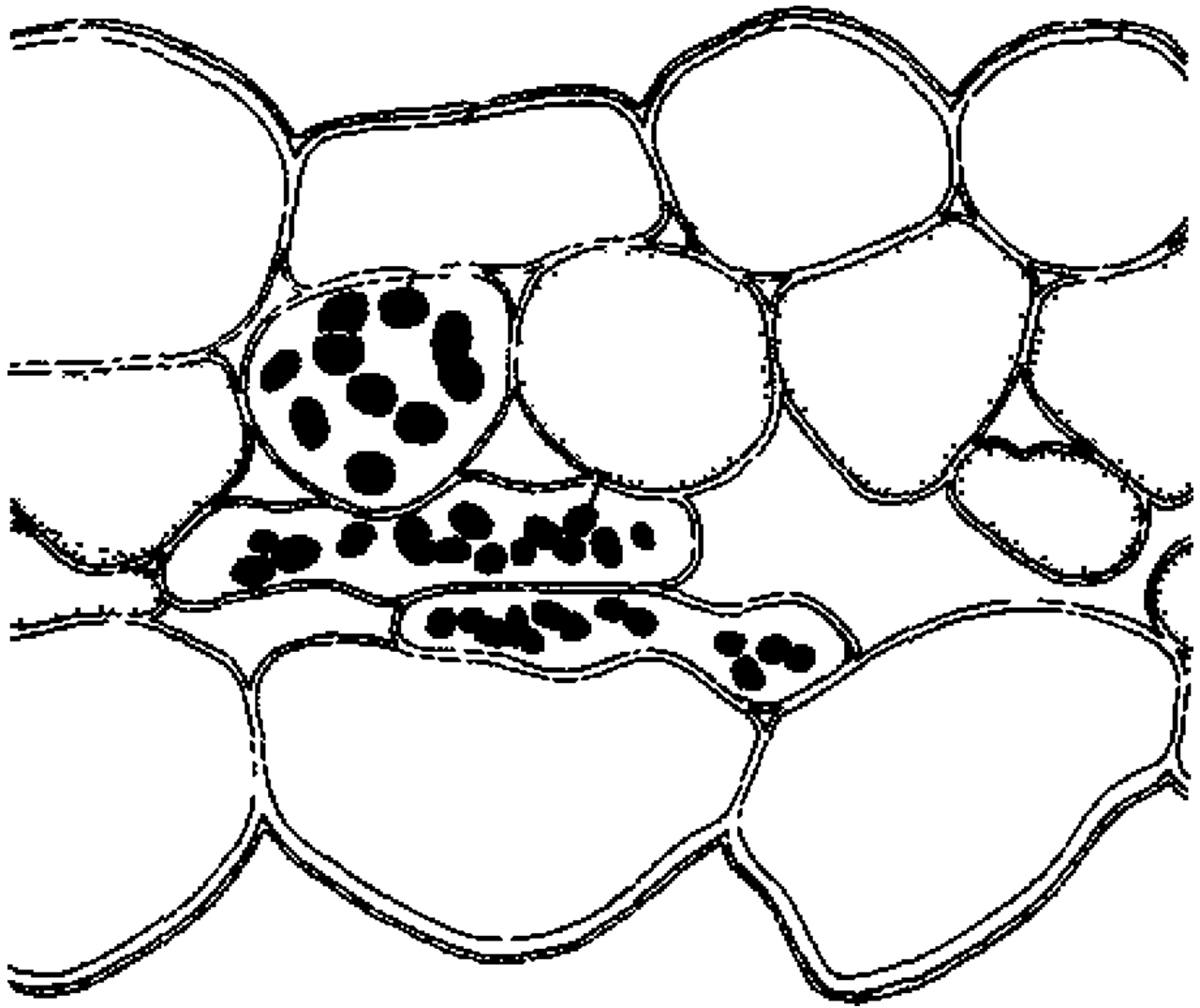
14 Leaf

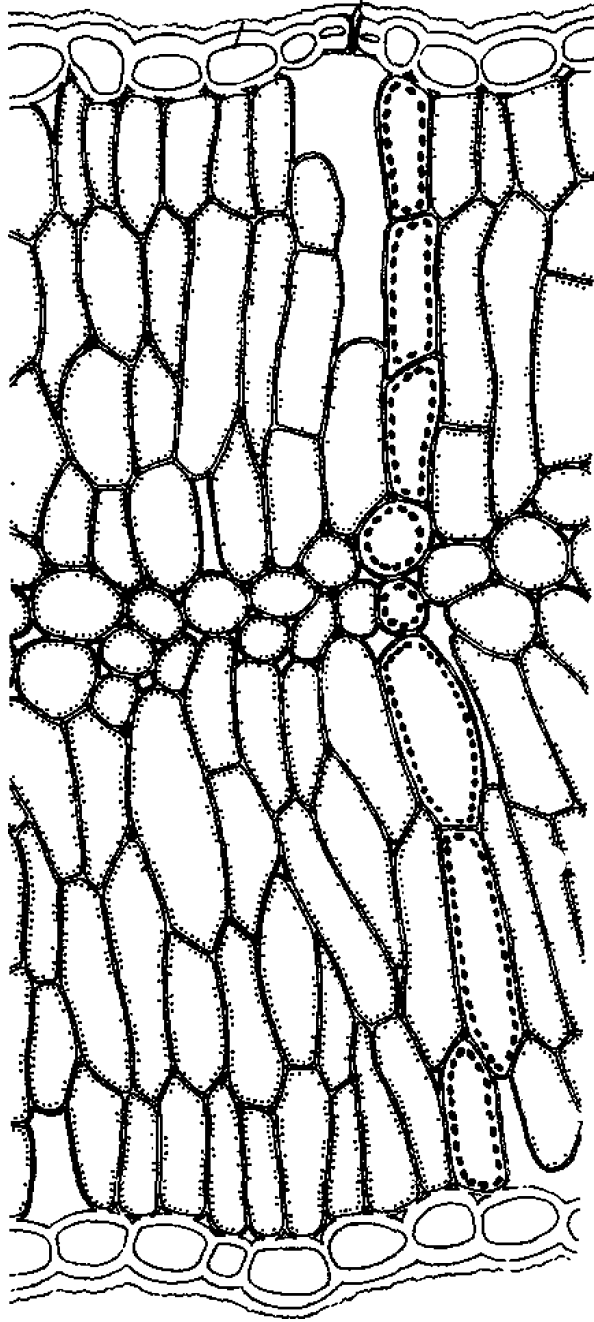
14.1 Ecological adaptations of leaves

Plants and light

- Sciophytes
- Heliophytes

Sciophyte and heliophyte



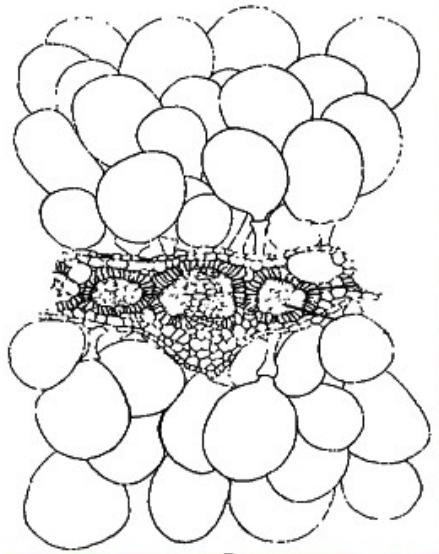


Oxalis acetosella and *Sylphium laciniatum*

Leaves and soil

- Halophytes (accumulate, excrete or avoid NaCl)
- Nitrate halophytes (grow on soils rich of NaNO_3)
- Oxylophytes (grow on acidic soils)
- Calciphytes (grow on chalk soils rich of CaCO_3)

Leaf of salt-accumulating halophyte



Atriplex prostrata

Leaves and substrate

- Psammophytes (grow on sand)
- Petrophytes (grow on rocks)
- Rheophytes (grow in fast springs)

Rheophyte



Macarenia clavigera from Venezuela

River with rheophytes



They are flowering, too



Podostemum ceratophyllum (may be found even in ND!)

Podostemum in North Carolina



Leaves and metabolism

- Mycoparasites
- Hemiparasites
- Phytoparasites (root and stem)

Mycoparasite



Triuris hyalina from South America

Hemiparasite



Krameria parvifolia from southern Texas

Root parasite



Stem parasite



Cuscuta europaea from Germany

15 Stem and shoot

15.1 Plant body

Structure of plant body: the first glance

- Shoot system (aboveground part: stems, leaves, buds, flowers, fruit)
- Root system (below-ground part: main roots and branches)

- Exceptions:
 - Some mosses and even ferns have only shoot system
 - Liverworts and hornworts frequently have only leaf-like thallus

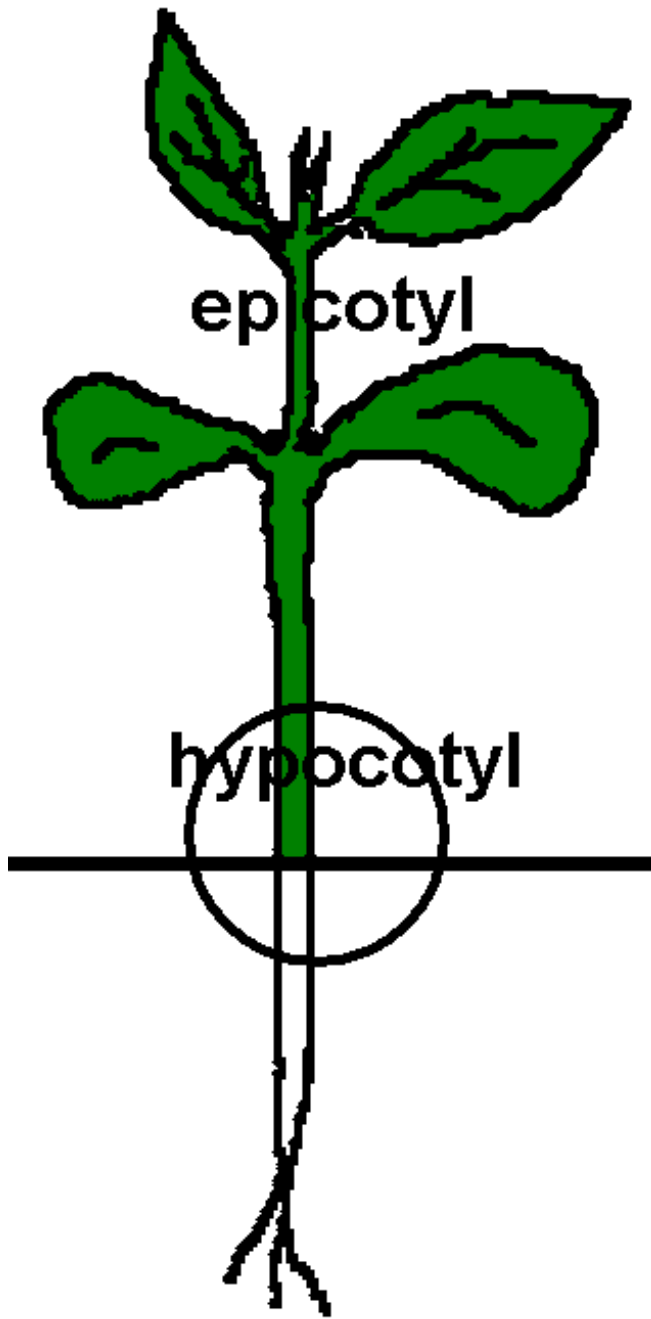
Types of plant body

- **Thallus** (flat, with non-differentiated organs)
- **Shoot** body (roots are absent)
- **Bipolar** body (root and shoot systems)

Organs of bipolar plant

- **Leaf**: flat lateral organ with restricted growth
- **Stem**: axial aerial organ with continuous growth
- **Root**: soil organ modified for absorption
- **Floral unit** (FU): stable element of generative system

Non-organs



- *Hypocotyl*: transition between stem and root
- *Epicotyl*: first internode of plant
- *Bud*: shoot “embryo”
- *Fruit*: temporary structure, ripe FU
- *Seed*: chimeric structure, has two or three genotypes

Organ systems: final

- Shoot system: vegetative and generative
- Root system

Origin of tissues and organs of plants

- Land colonization. Challenge: drying. Response: **epidermis** and **parenchyma**. Thallus body plan.
- New level of competition. Response: shoot body plan. Problem: big weight. Solution: **collenchyma**.
- Competition grows again. Response: grow higher. Weight grows. Response: use dead cells in **sclerenchyma**.
- Competition grows again. Response: grow faster. Solution: **meristems**.
- Size of plant is too big for plasmodesmata transportations. Solution: vascular tissues, **xylem** and **phloem**. Here plants with sporophyte dominance win the competition.
- Size of plant is too big for osmotic absorption of water. Solution: **absorption tissues**, roots, bipolar body plan. Now they are independent from water as much as possible—with an exception of generative system...
- Shoot system make leaves, stems and **branches**. Plants are facing new challenge!

Summary

- Water deficit results in either sclerophyte or succulent adaptations
- Water excess results in hygrophyte or even hydrophyte adaptations

Final question (2 points)

What is FU?

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

16 Questions and answers

16.1 Quiz

Final question (2 points)

What is FU?

- Floral Unit: not necessarily flower, but any stable element of generative shoot system

17 Shoot

17.1 Stem

Stem: definition and functions

- Axial vegetative organ of shoot with functions of support and transportation
- Other functions:
 - A. Photosynthesis
 - B. Storage
- Features:
 - A. Radial structure
 - B. No root hairs
 - C. Continuous growth

17.2 Development of stem tissues

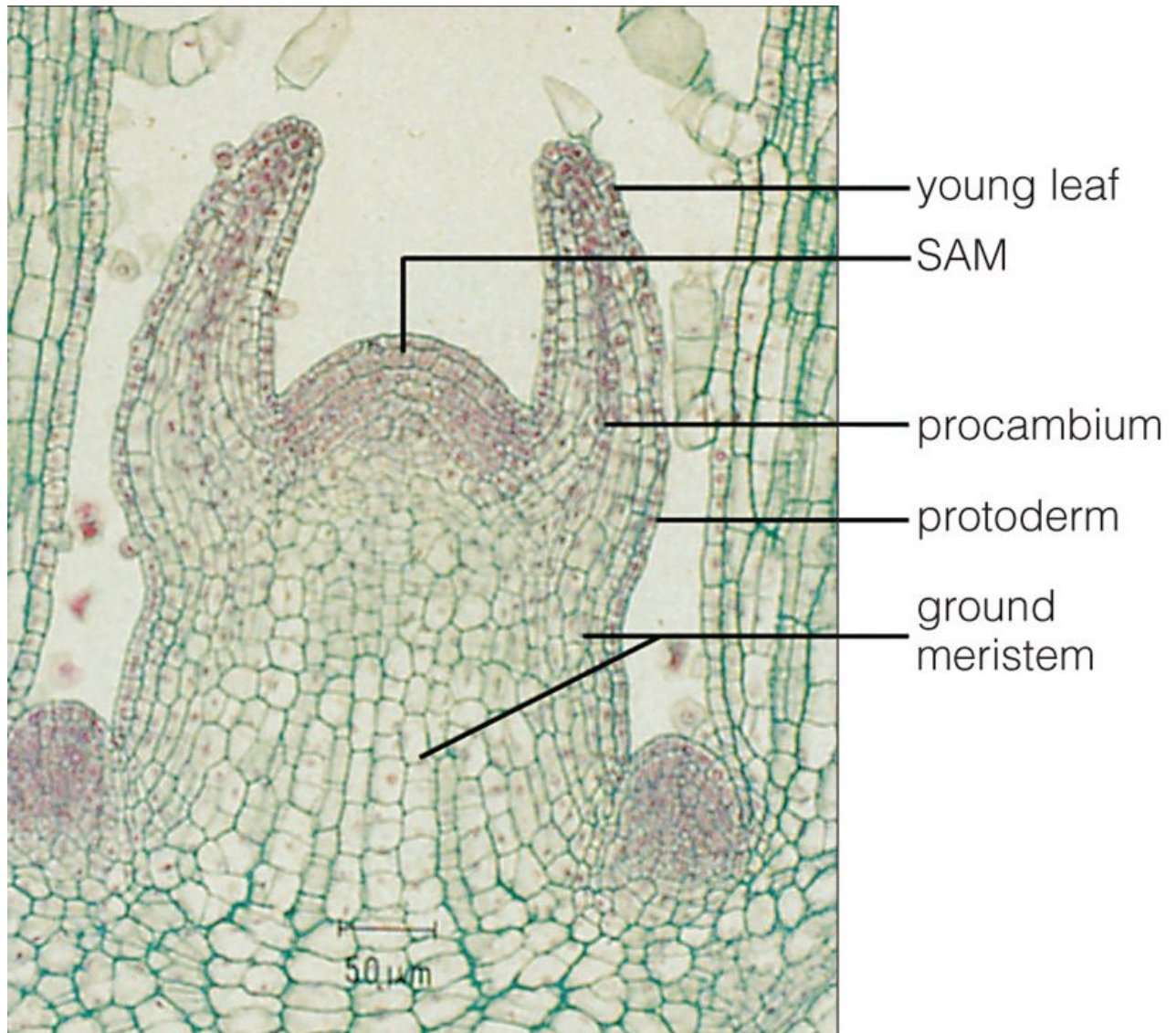
Protoderm to epidermis

- Stem apex meristem (SAM) produces **protoderm**
- Protoderm cells differentiate into epidermal cells

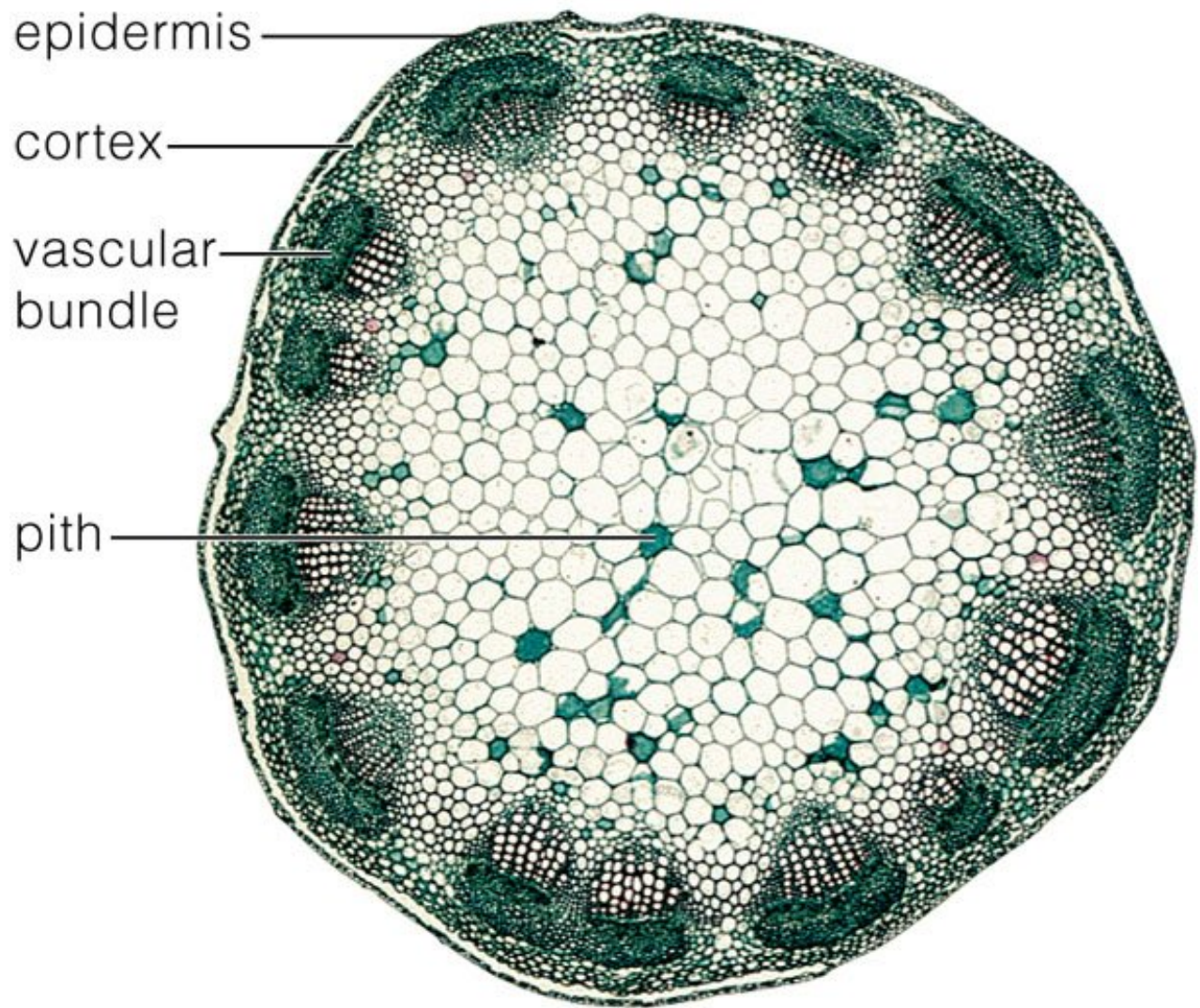
Ground meristem to cortex and pith

- SAM produces also **ground meristem**
- Ground meristem differentiates into **cortex** and **pith**
- Procambium arises between cortex and pith, it forms vascular bundles or vascular cylinder

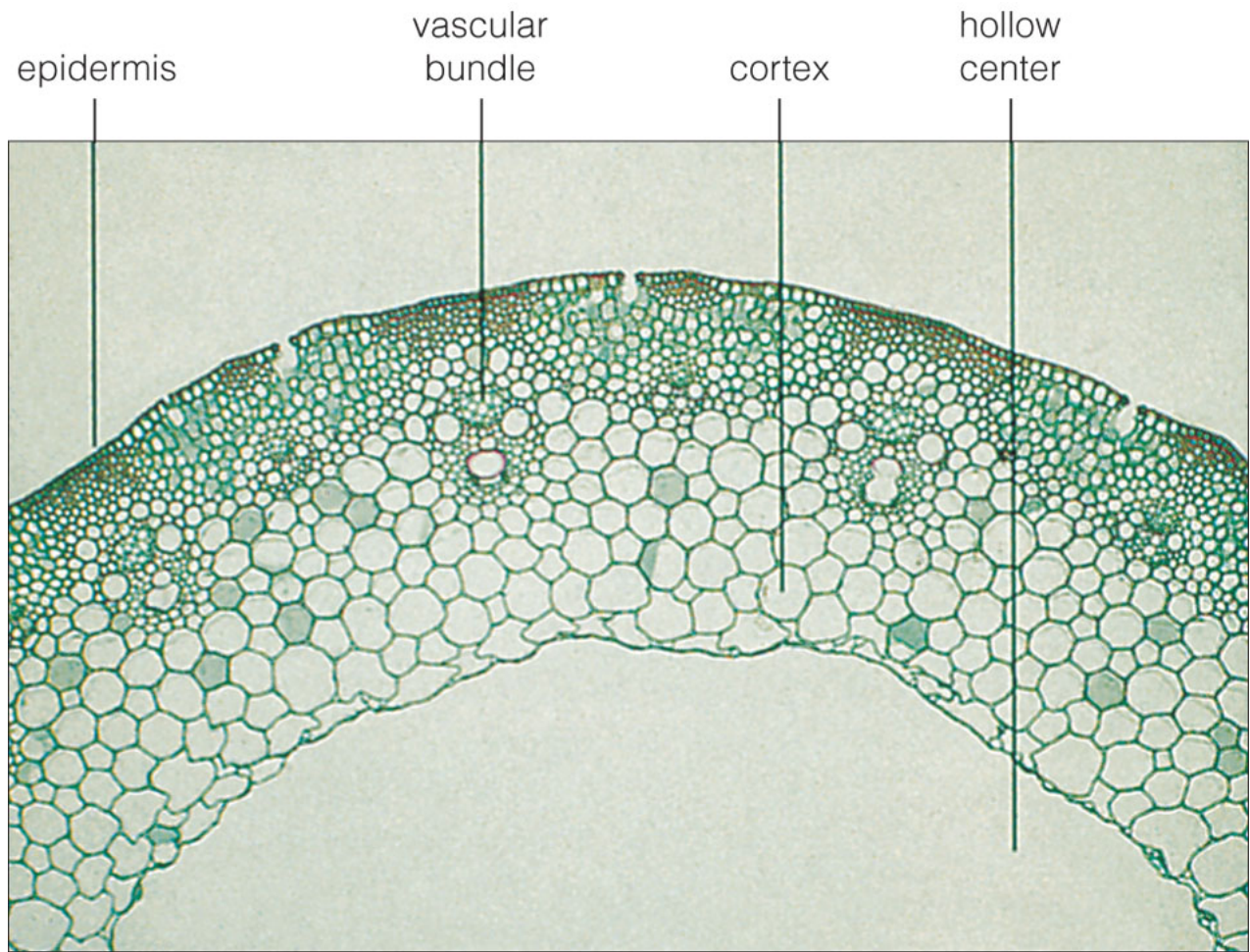
Three primary meristems: procambium, protoderm and ground meristem



Young stem with primary tissues



Older stem with hollow in the center



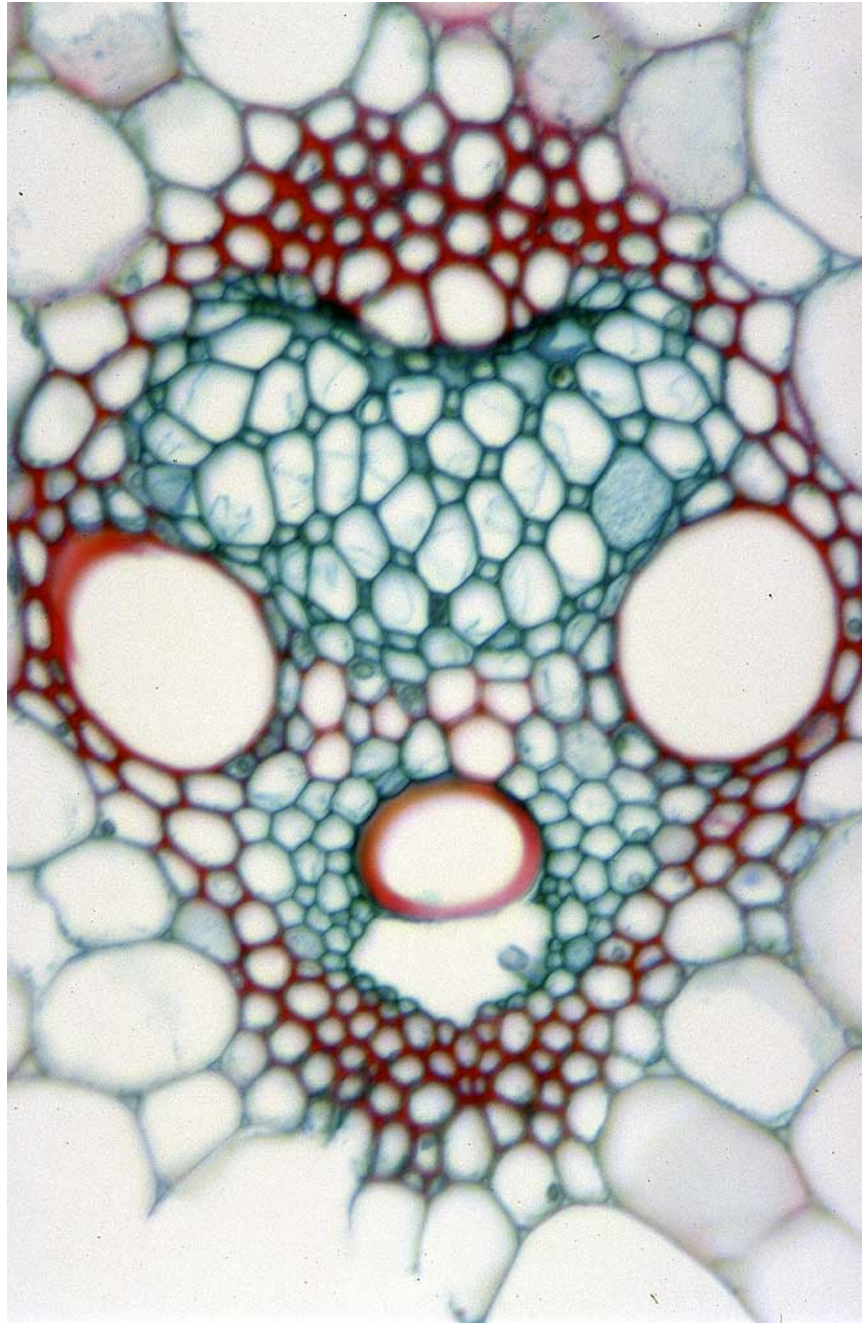
© 2006 Brooks/Cole - Thomson

Procambium to xylem and phloem

- Outer layers of procambium form **primary phloem**
- Inner layers become **primary xylem**
- Middle layer could be completely spent **or** will make cambium for the secondary thickening
- Sometimes outermost layers of procambium form **pericycle** (parenchyma cells)
- In some cases, inner layers of cortex could form **endoderm**

17.3 Anatomy of the primary stem

Vascular bundle (monocot)



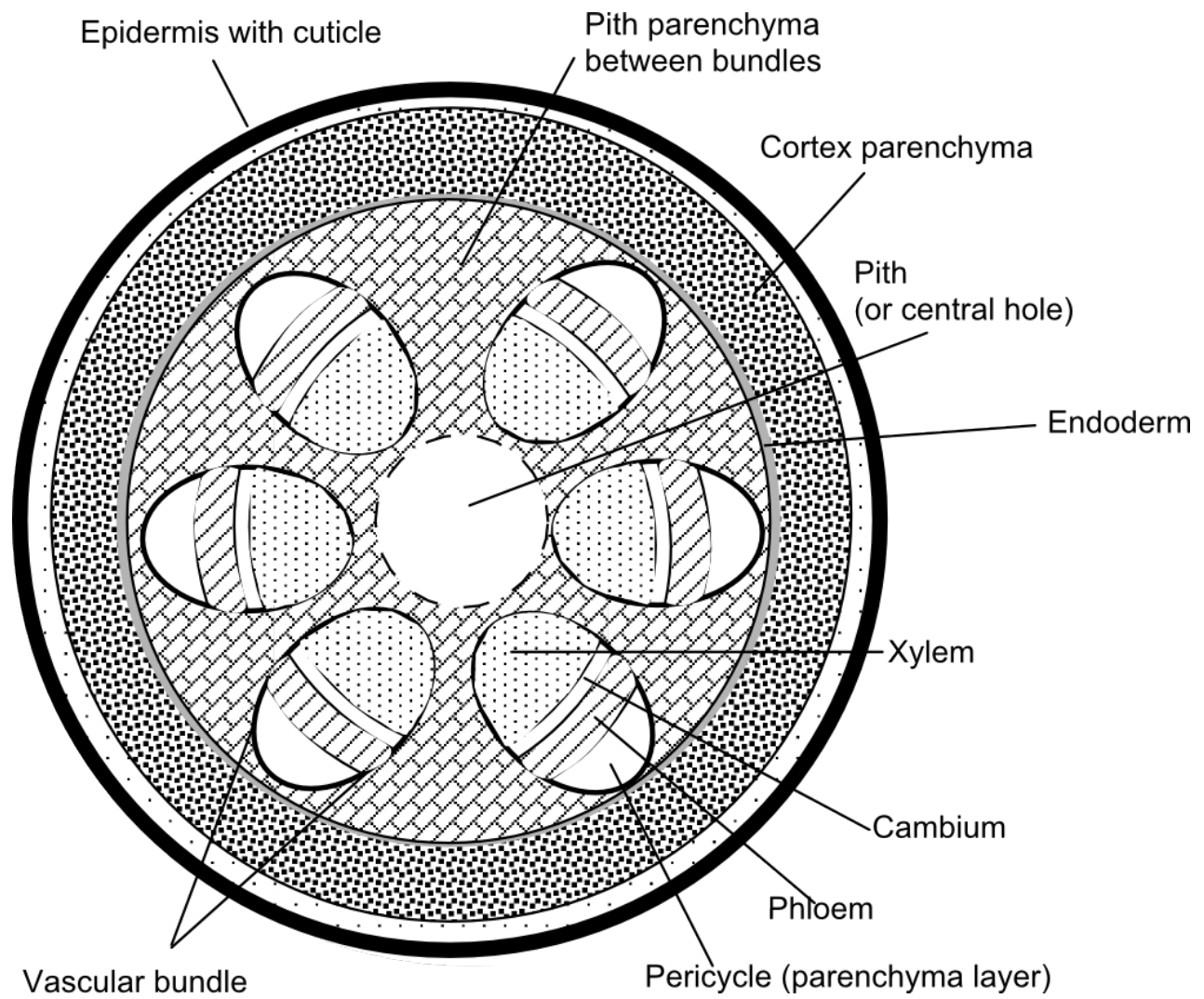
Corn (*Zea mays*) mature stem cross-section showing single vascular bundle, Brightfield (LM $\times 400$)

Summary

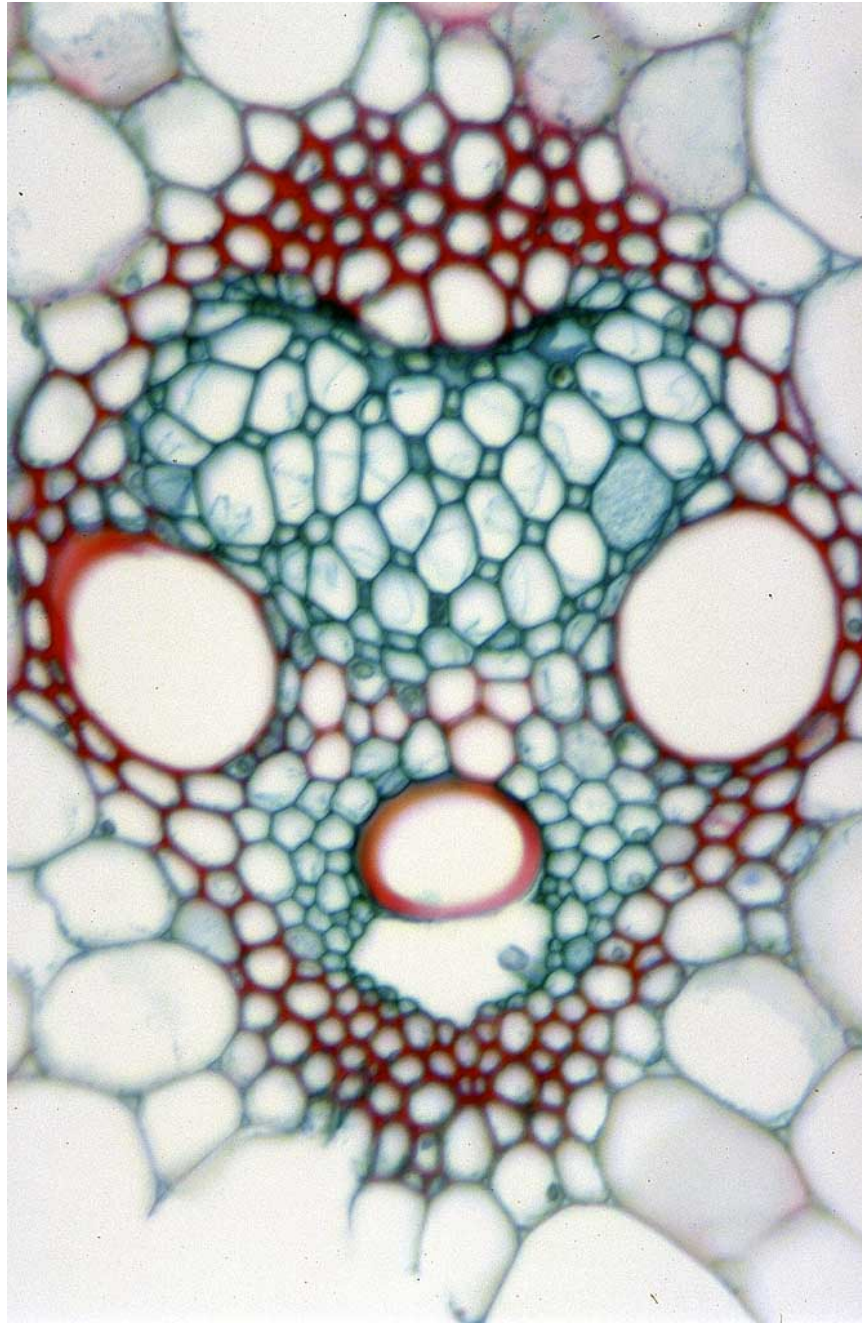
- SAM produces **protoderm** and **ground meristem**, ground meristem differentiates into **cortex** and **pith**
- Procambium forms **vascular bundles** or vascular cylinder

17.4 Anatomy of the primary stem

Primary structure of stem

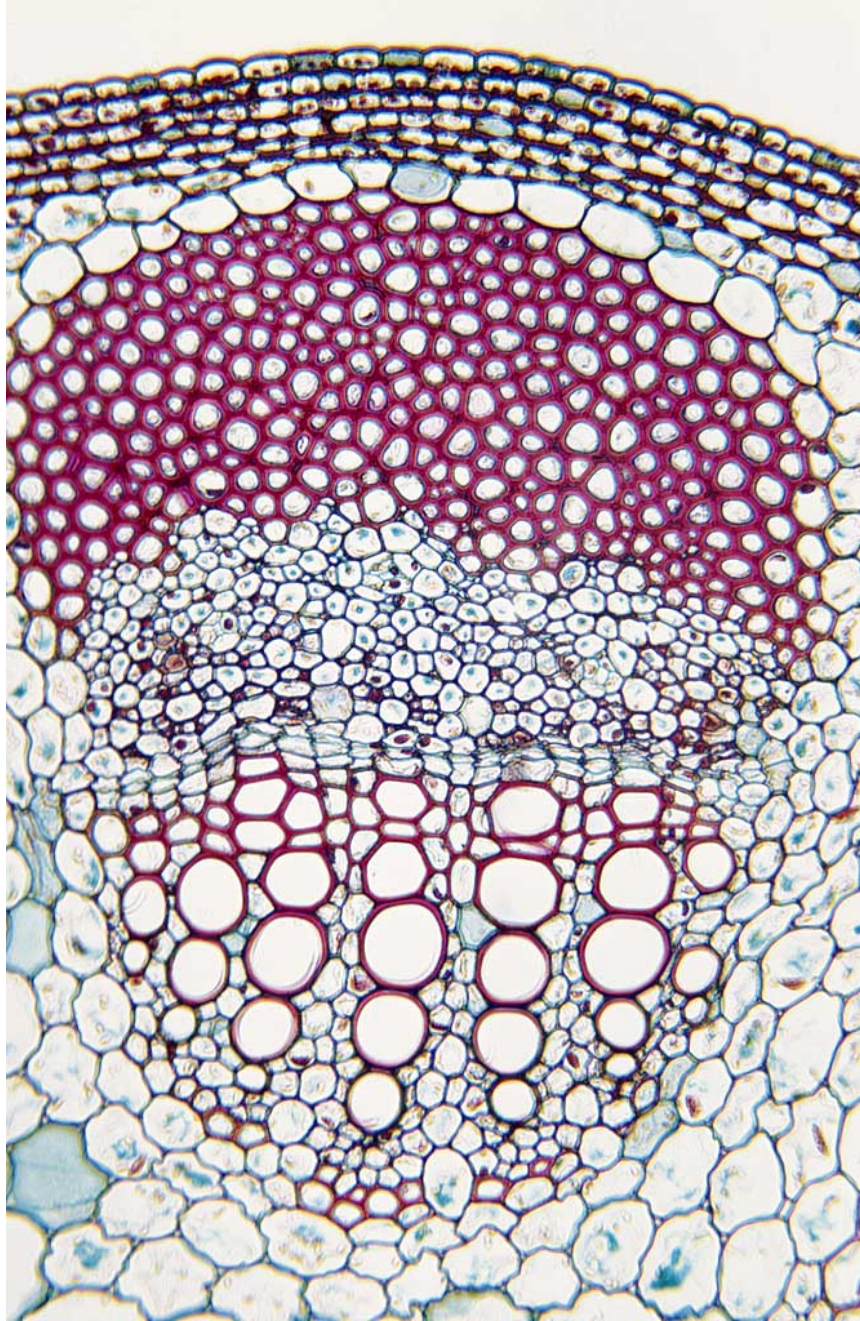


Vascular bundle (monocot)



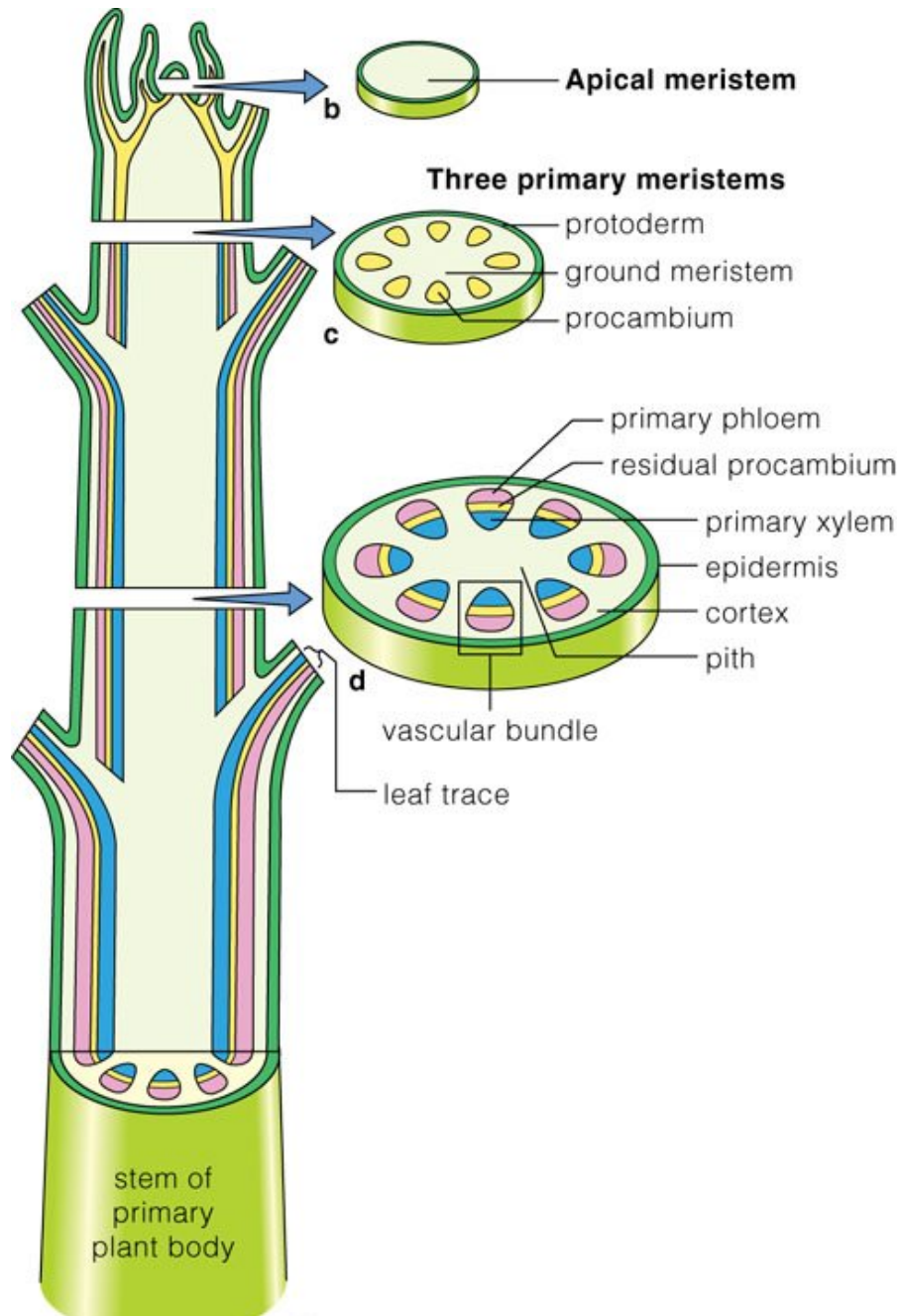
Corn (*Zea mays*) mature stem cross-section showing single vascular bundle, Brightfield (LM $\times 400$)

Vascular bundle (asterid)



Wild Sunflower (*Helianthus* sp.) with nearly mature vascular bundle (LM $\times 35$)

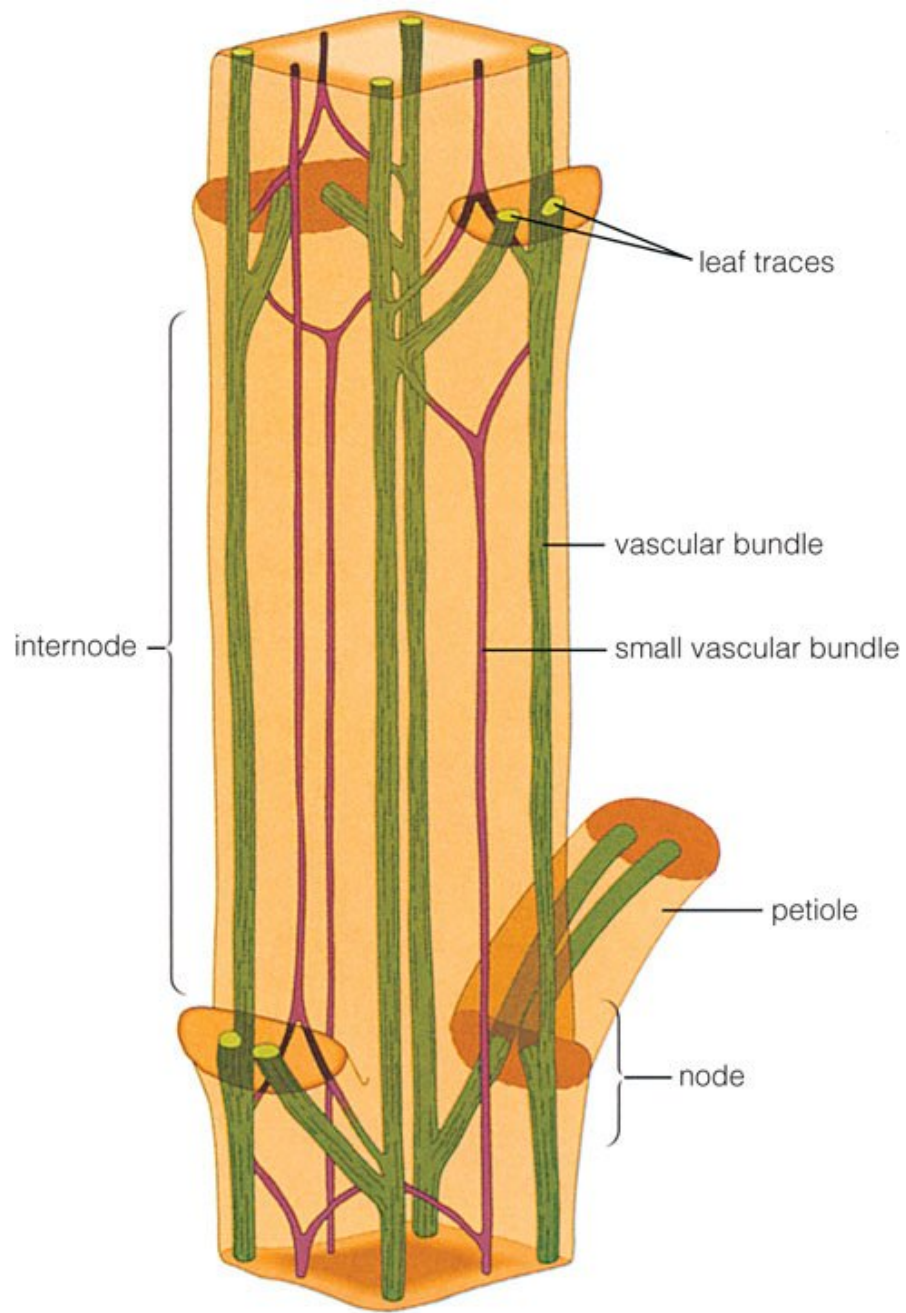
Origin of vascular bundles



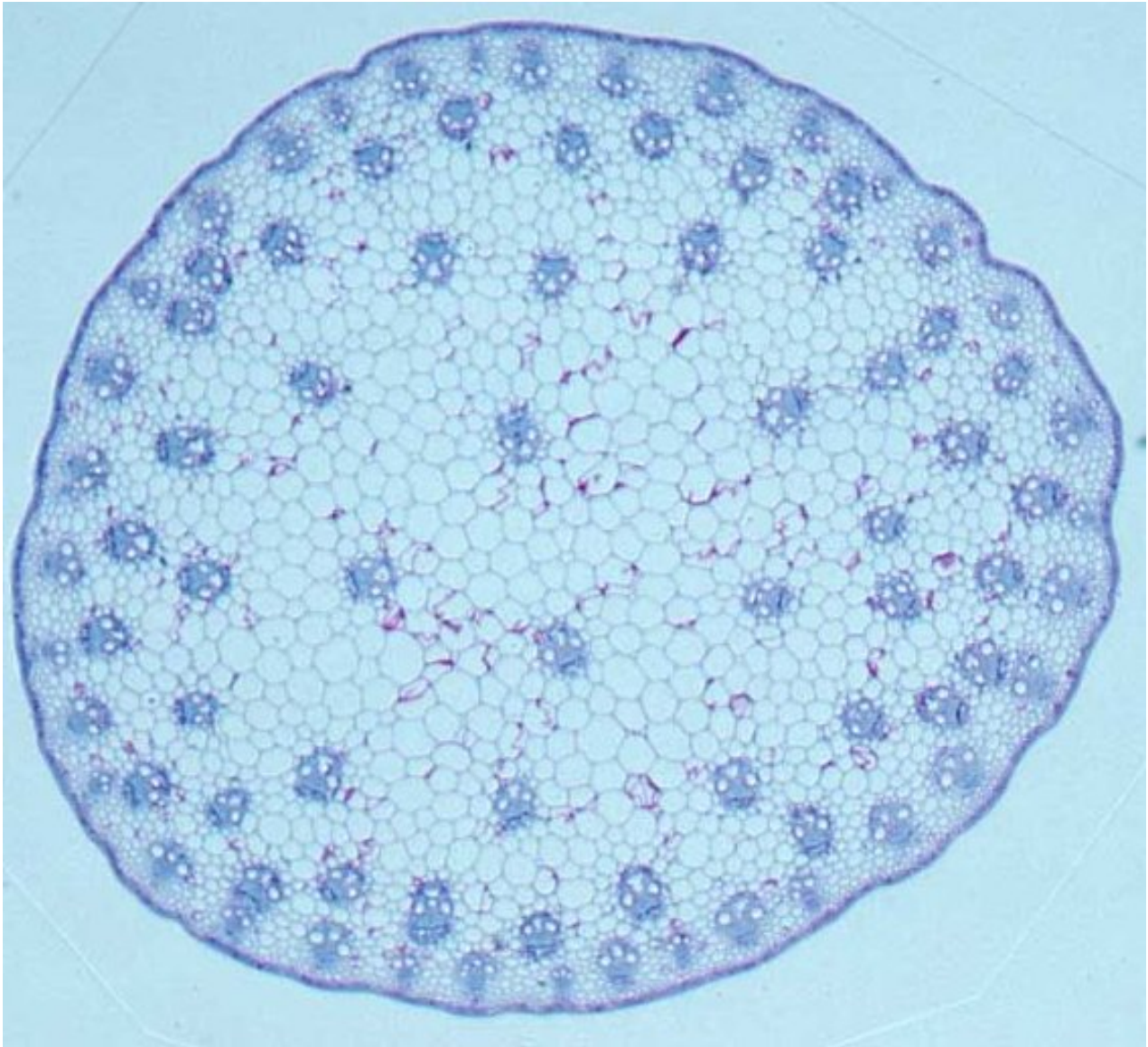
Vascular bundles

- Vascular bundles connect leaves and stems
- In many plants, they form **ring** on the cross-section of stem (“dicot” stem)
- Monocot stems usually have **dispersed** vascular bundles

Vascular bundles and leaf traces



Monocot stem

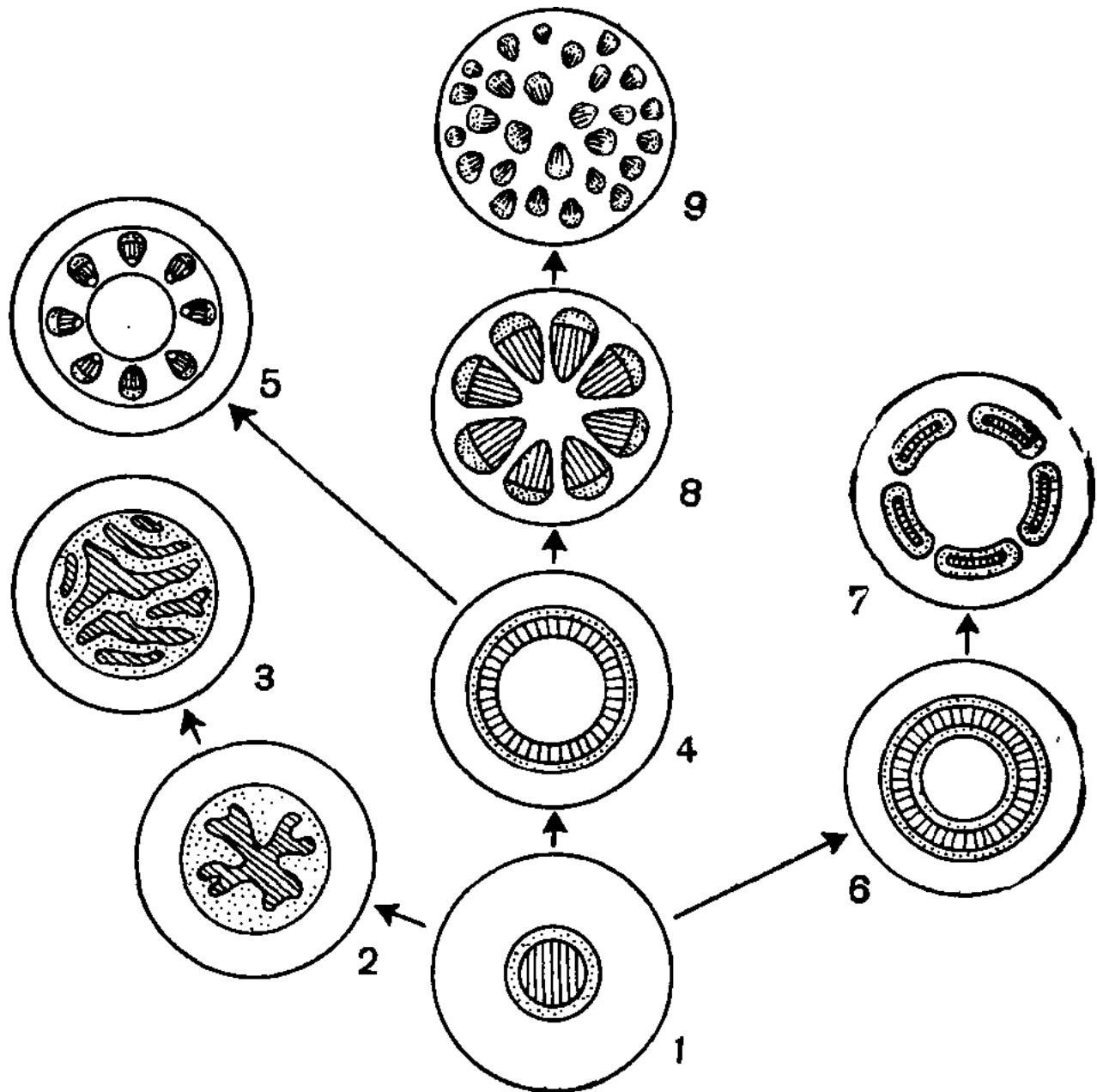


Corn (*Zea mays*) stem (LM $\times 4$)

Steles

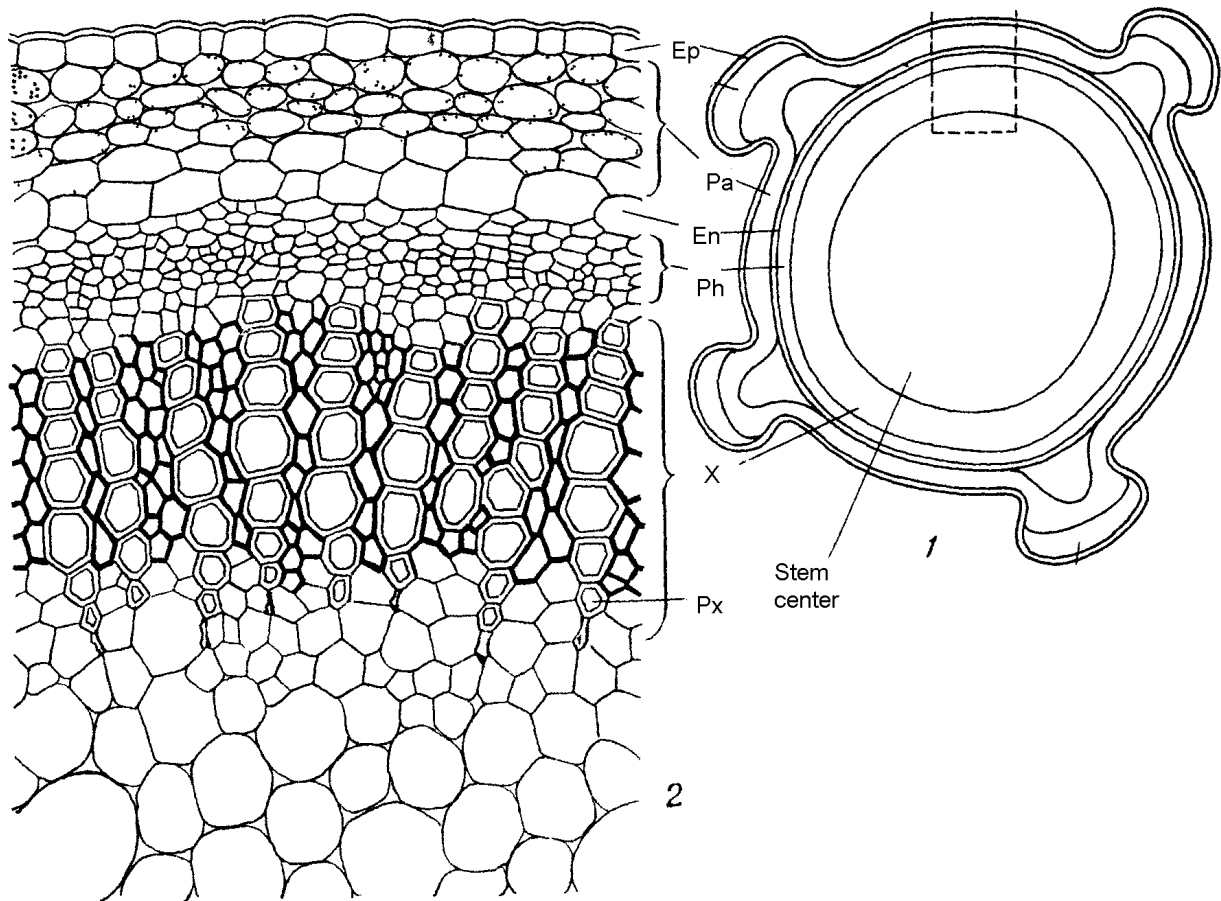
- **Stele** is an overall configuration of primary vascular system of plant stem
- The most important kinds of steles are: **protostele**, **solenostele**, **eustele** and **ataktostele**

Diversity of steles



(1) is protostele, (4) solenostele, (8) eustele ("dicot" stem), (9) ataktostele (monocot stem)

Vascular cylinder: alternative to ring of bundles



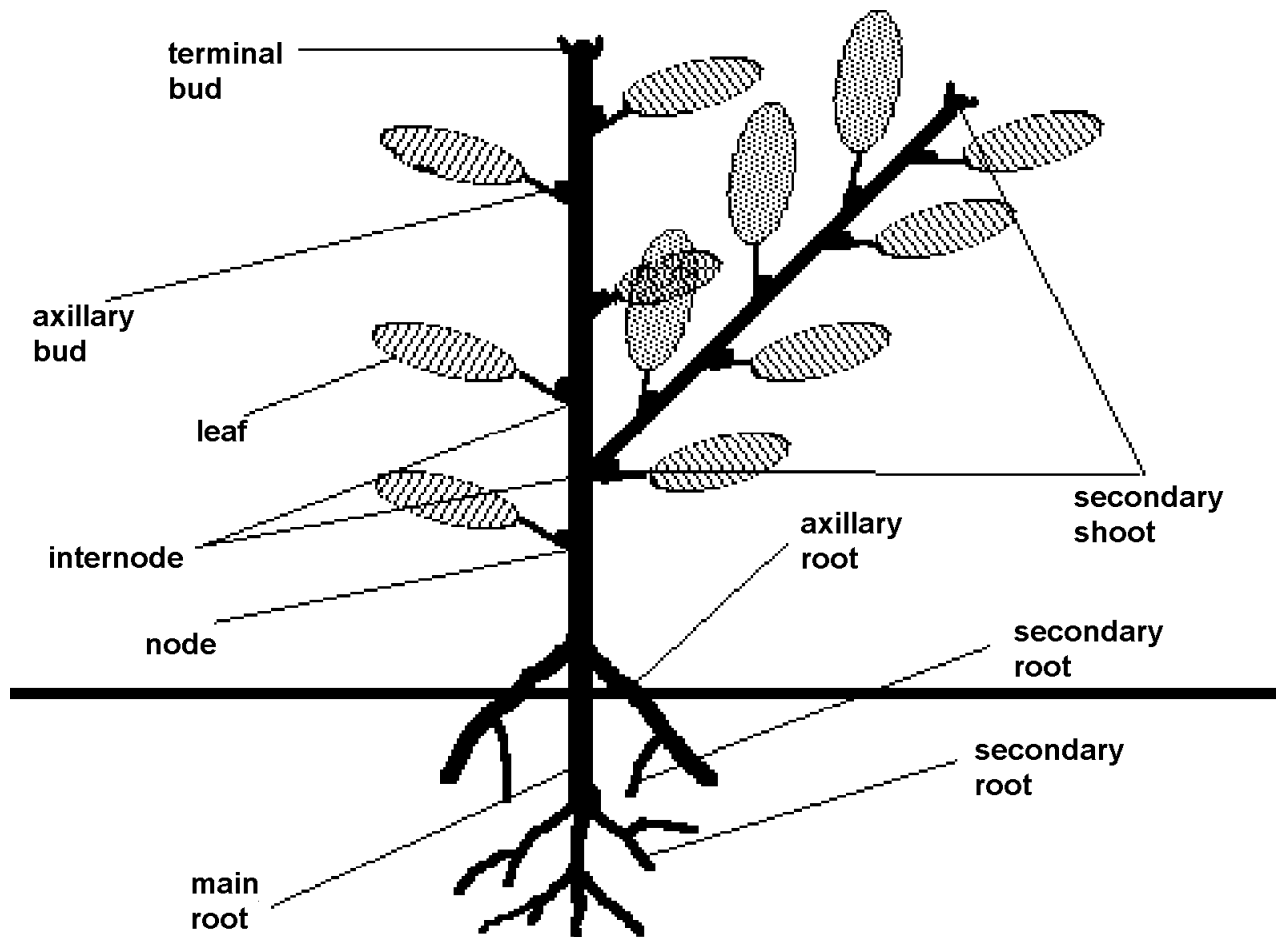
Sometimes, vascular bundles are so dense that they form almost a cylinder. We may call this vascular cylinder “solenostele” (#4 on the scheme of steles)

17.5 Components of shoot

Components of vegetative shoot system

- A. Main and secondary shoots
- B. Terminal and axillary (lateral) buds
- C. Nodes and internodes
- D. Leaves

Components of shoot

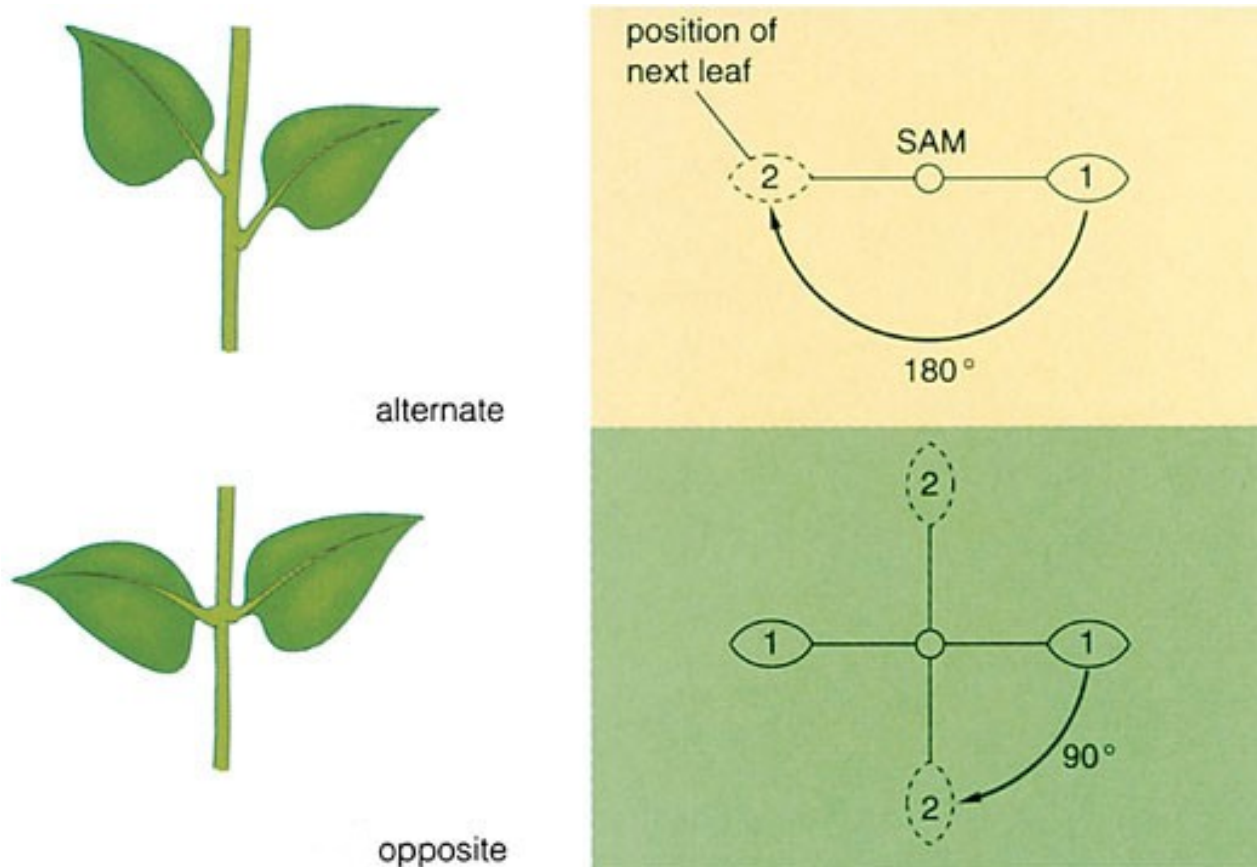


17.6 Phyllotaxis

Arrangement of leaves: phyllotaxis

- One leaf per node: **spiral**, or **alternate** arrangement
- Two leaves per node: **opposite** arrangement, they may be:
 - All in same plane
 - Each pair will rotate on 90°
- > 2 leaves per node: **whorled** arrangement (each whorl can also rotate)
- Each type of phyllotaxis has its own *angle of divergence*

Alternate and opposite phyllotaxes



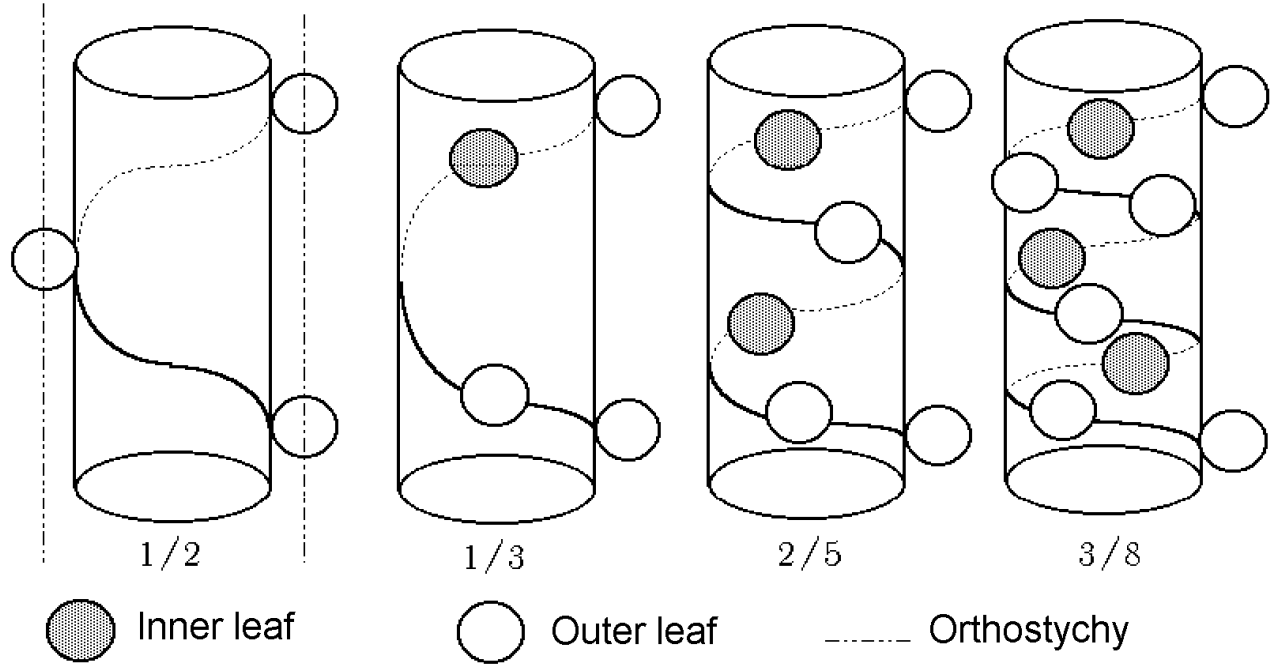
Spiral phyllotaxis: Fibonacci rule

- Multiple types of leaf spiral leaf arrangement mostly follow **Fibonacci rule**
- Formulas of leaf arrangements is very similar to Fibonacci fractions: $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, *et cetera*
- Numerator is number of spiral circulations, denominator is number of leaves in a series (counted from zero)
- Denominator gives the number of **orthostychy** (this is plural)

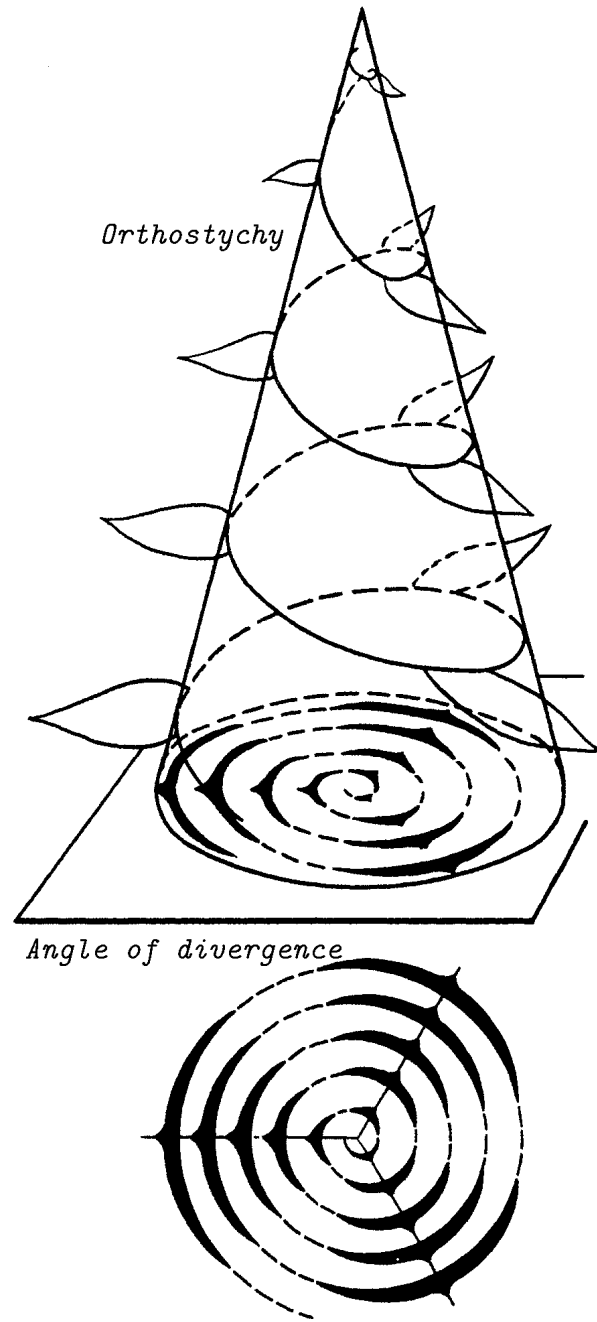
Spiral phyllotaxis: how to make a formula

- Take a branch, find any leaf (it will be leaf #0)
- Find the second one which is located in the same position (exactly above or exactly below leaf #0)
- Count how many leaves are in this series (start from 0), this will be a denominator
- Imagine (or use a real thread) a spiral which go from leaf #0 to the last leaf of series, count how many times this spiral circulate the stem—this is a numerator

Spiral phyllotaxis: orthostychy



Spiral phyllotaxis: angles of divergence for $1/3$



Final question (2 points)

What is procambium?

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: http://ashipunov.info/shipunov/school/biol_154