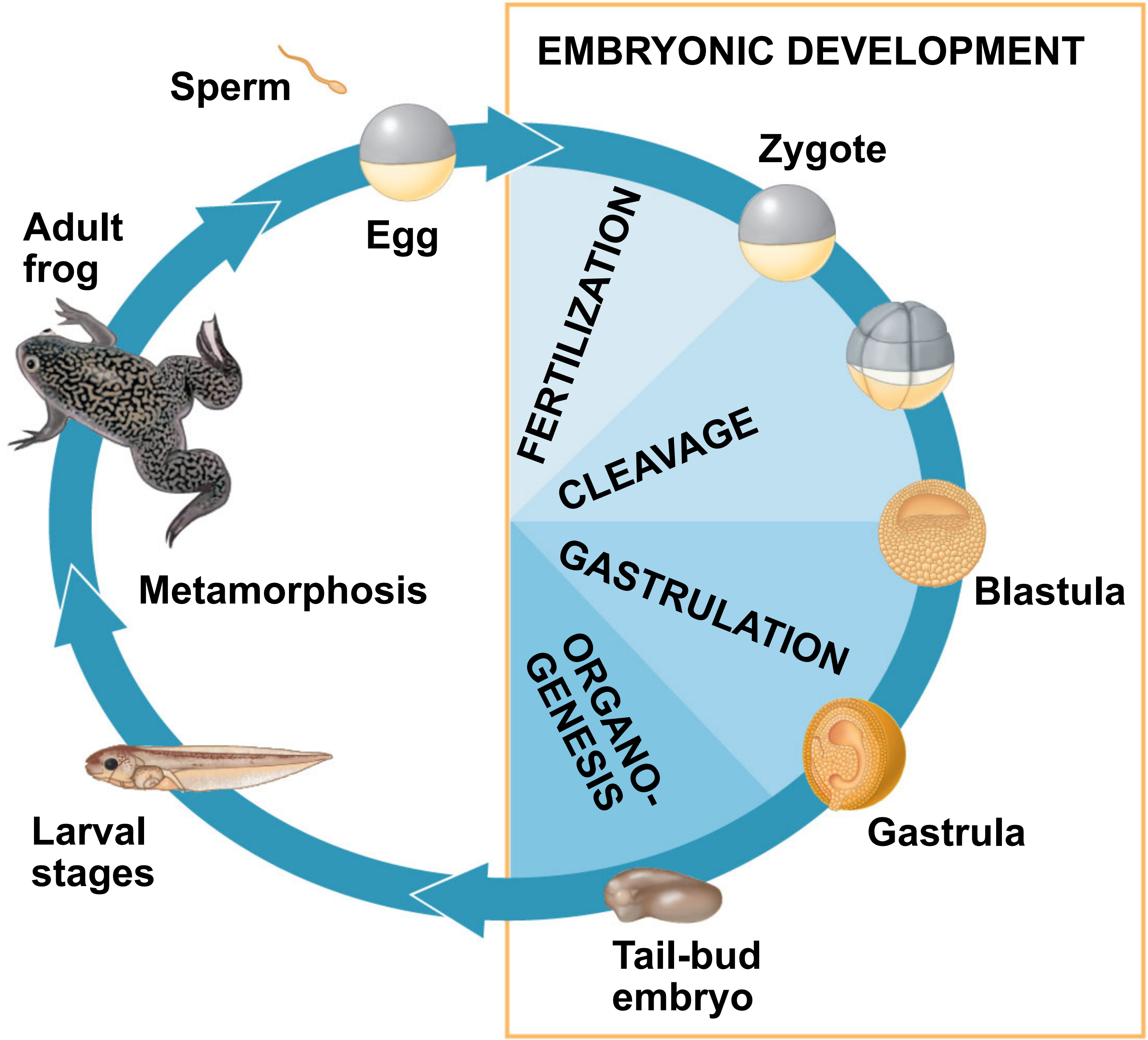
Development

27 April 2017

Development

- Development in multicellular organisms allow for cells and organ structures with specialized functions
- Development occurs at many points in the life cycle of an animal
- Although animals display different body plans, they share many basic mechanisms of development and use a common set of regulatory genes
- Biologists use **model organisms** to study development, chosen for the ease with which they can be studied in the laboratory

Figure 47.2



EMBRYONIC DEVELOPMENT
Sperm
Egg
Zygote
Adult frog
FERTILIZATION
CLEAVAGE
GASTRULATION
ORGANO-GENESIS
Metamorphosis
Blastula
Larval stages
Gastrula
Tail-bud embryo

Morphogenesis

- **Morphogenesis** in animals involves specific changes in cell shape, position, and survival
- **Morphogenesis** is the process by which cells occupy their appropriate locations
  - **Gastrulation**, the movement of cells from the blastula surface to the interior of the embryo
  - **Organogenesis**, the formation of organs

Gastrulation

- **Gastrulation** rearranges the cells of a blastula into a three-layered embryo, called a **gastrula**
- The three layers produced by gastrulation are called embryonic **germ layers**
  - The **ectoderm** forms the outer layer
  - The **endoderm** lines the digestive tract
  - The **mesoderm** partly fills the space between the endoderm and ectoderm
- Each germ layer contributes to specific structures in the adult animal

Gastrulation in Frogs

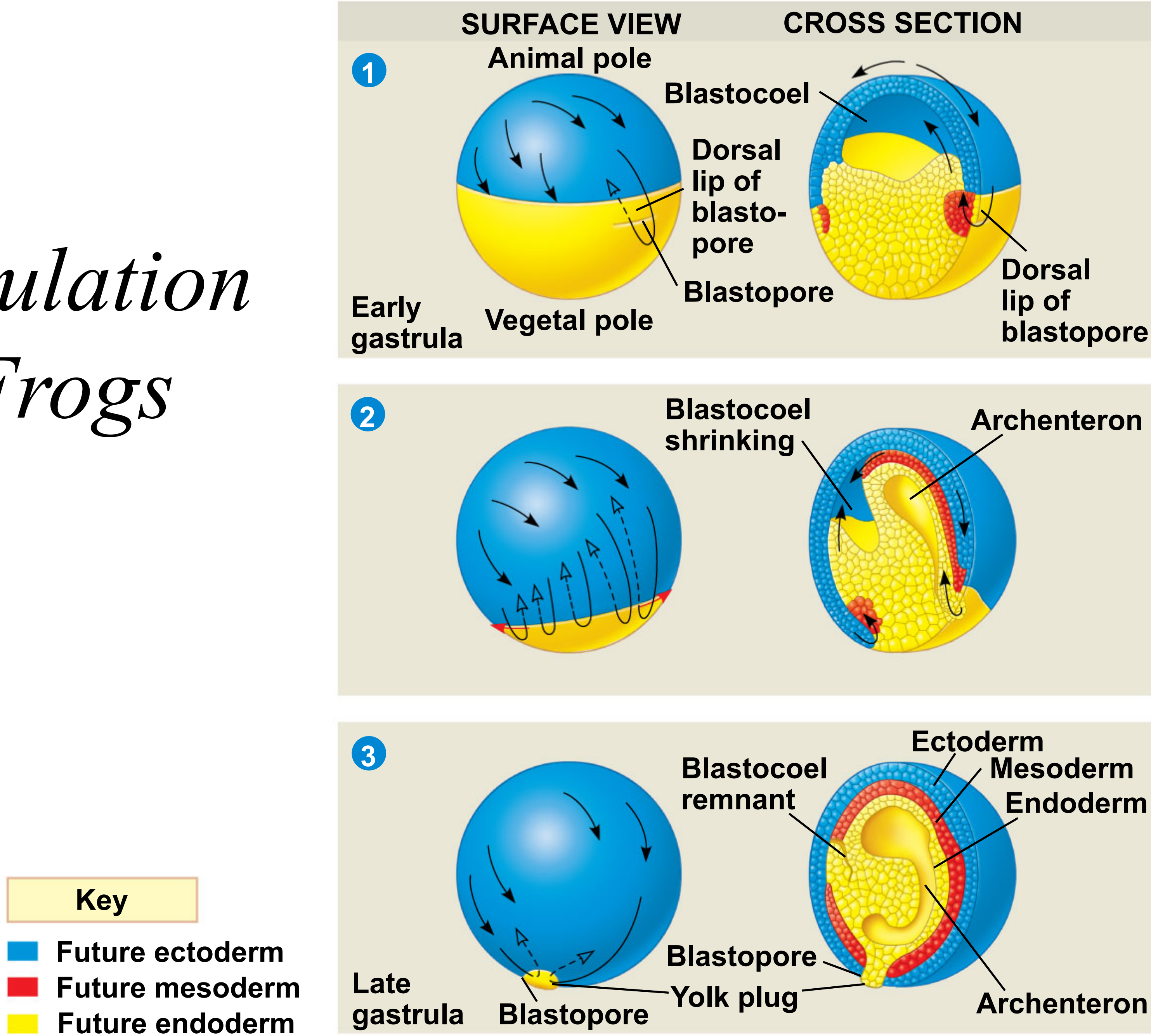
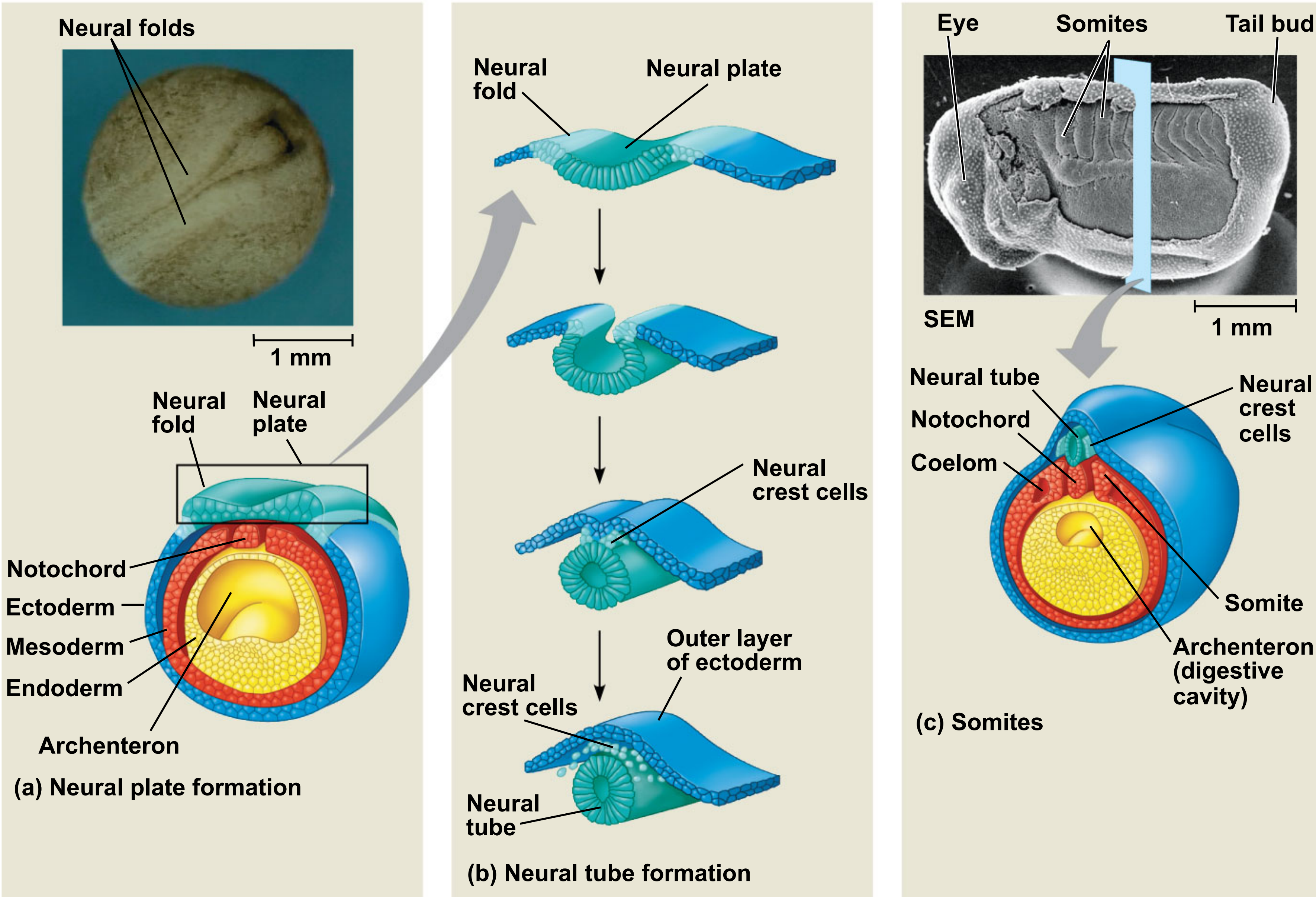


Figure 47.10

Organogenesis

- During **organogenesis**, various regions of the germ layers develop into rudimentary organs
- Early in vertebrate organogenesis, the **notochord** forms from mesoderm, and the neural plate forms from ectoderm
- The neural plate soon curves inward, forming the **neural tube**
- The neural tube will become the central nervous system (brain and spinal cord)

Figure 47.13



(a) Neural plate formation

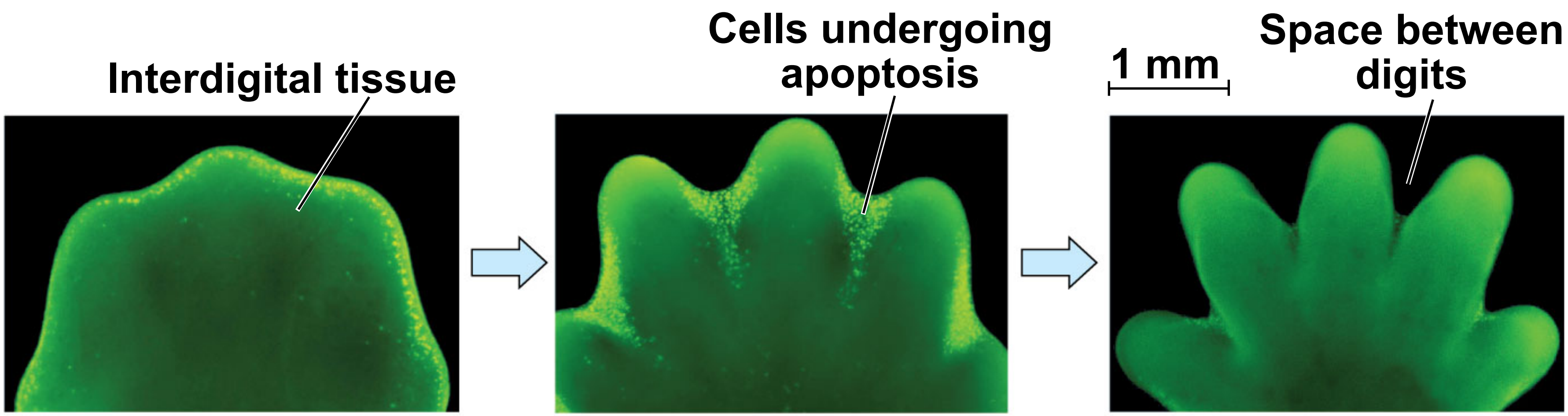
(b) Neural tube formation

(c) Somites

Programmed Cell Death

- Programmed cell death is also called **apoptosis**
- At various times during development, individual cells, sets of cells, or whole tissues stop developing and are engulfed by neighboring cells
- For example, many more neurons are produced in developing embryos than will be needed
- Extra neurons are removed by apoptosis

Figure 11.22


Interdigital tissue
Cells undergoing apoptosis
1 mm
Space between digits

Cytoplasmic determinants and inductive signals contribute to cell fate specification

- Cells in a multicellular organism share the same genome
- Differences in cell types are the result of the expression of different sets of genes
- **Determination** is the term used to describe the process by which a cell or group of cells becomes committed to a particular fate
- **Differentiation** refers to the resulting specialization in structure and function

Cell Fate Determination and Pattern Formation by Inductive Signals

- As embryonic cells acquire distinct fates, they influence each other's fates by induction

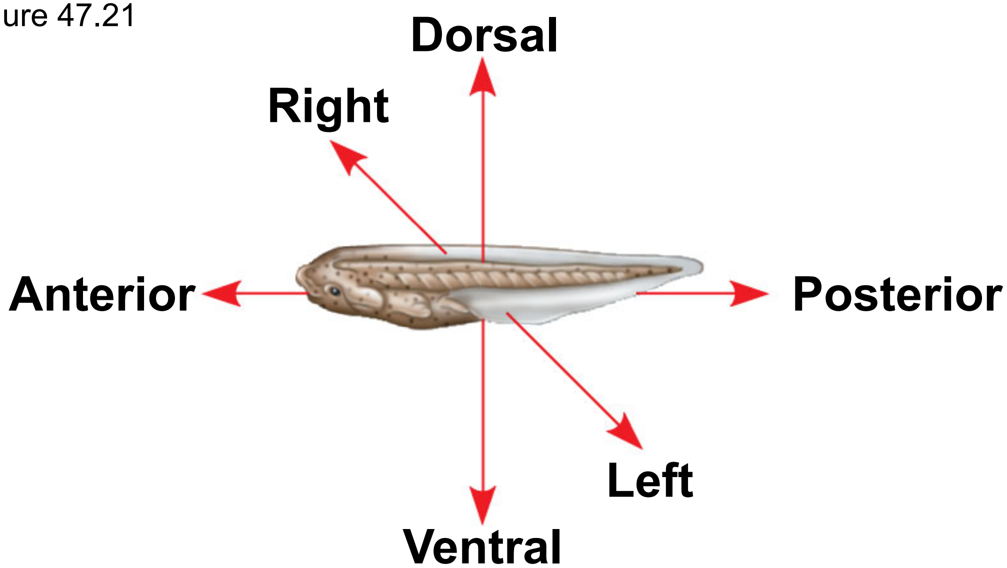
Axis Formation

- A body plan with bilateral symmetry is found across a range of animals
- This body plan exhibits asymmetry across the dorsal-ventral and anterior-posterior axes
- The right-left axis is largely symmetrical

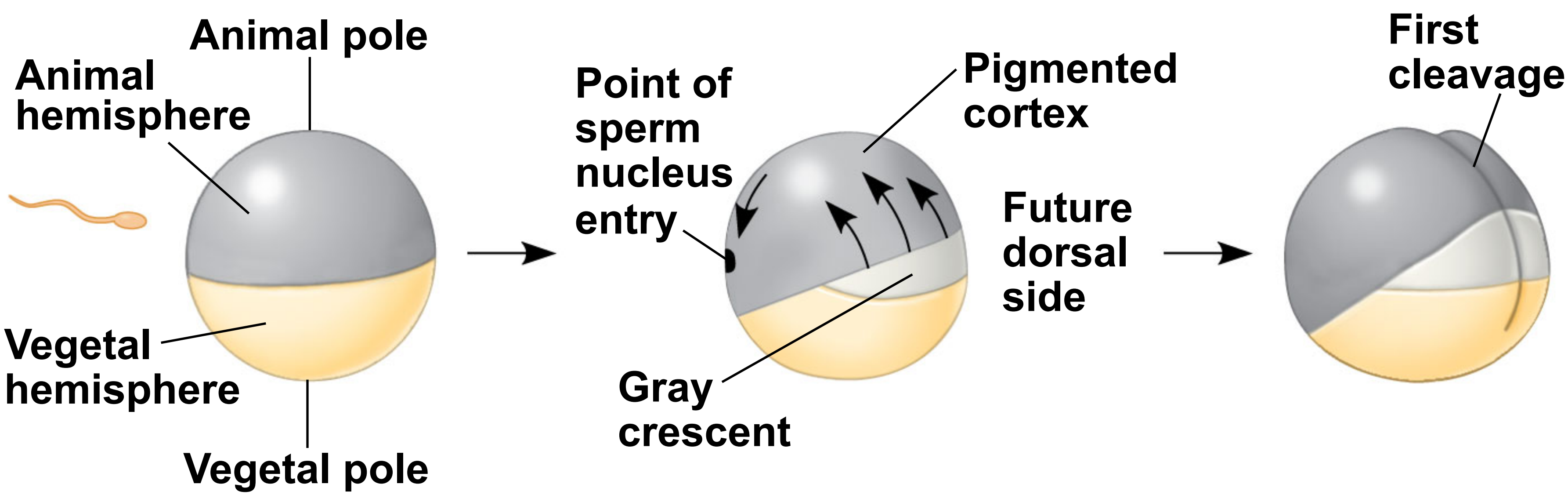
How do the axes form?

- The anterior-posterior axis of the frog embryo is determined during oogenesis
- The animal-vegetal asymmetry indicates where the anterior-posterior axis forms
- The dorsal-ventral axis is not determined until fertilization

Figure 47.21



(a) The three axes of the fully developed embryo



(b) Establishing the axes

Establishing dorsal-ventral axis

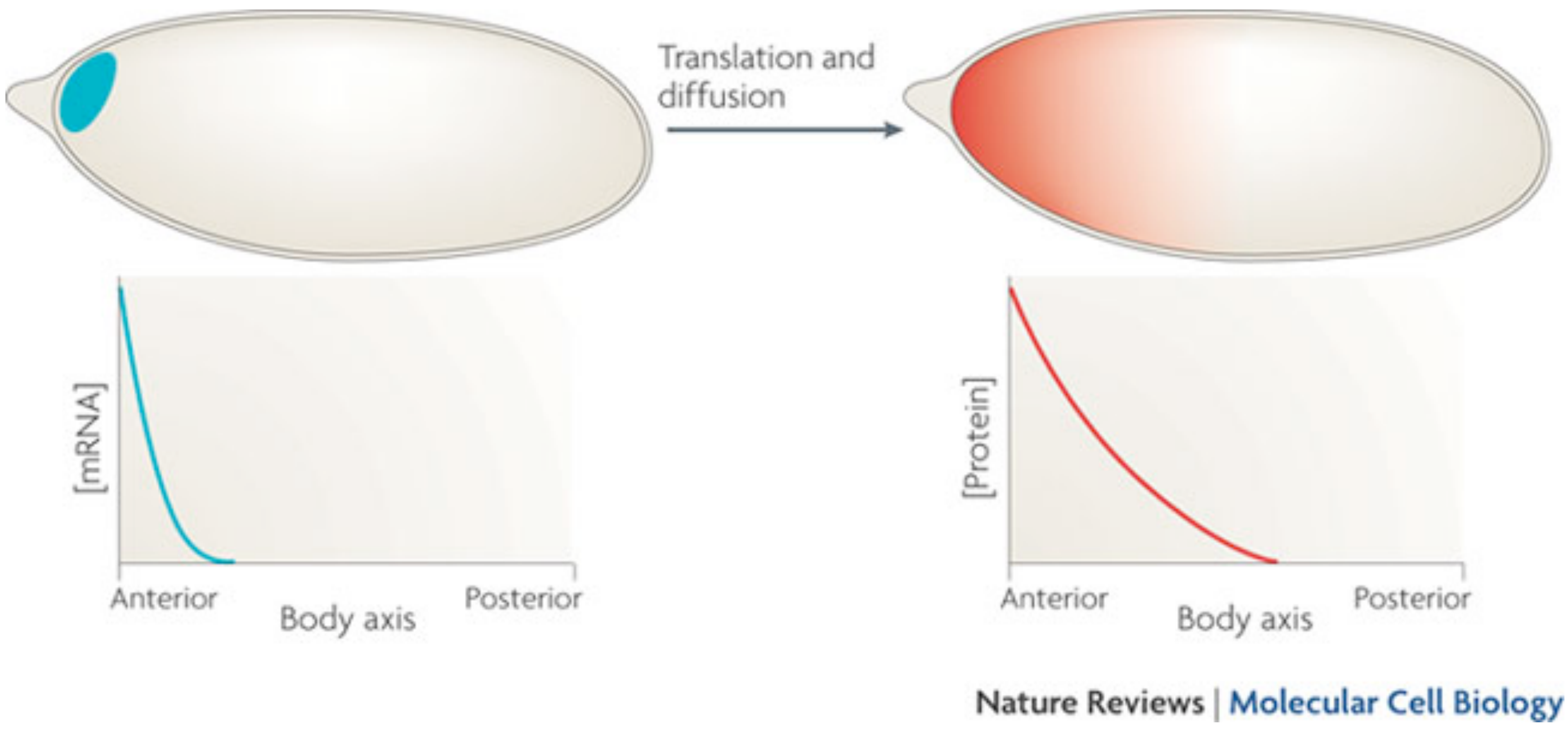
- Upon fusion of the egg and sperm, the egg surface rotates with respect to the inner cytoplasm
- This cortical rotation brings molecules from one area of the inner cytoplasm of the animal hemisphere to interact with molecules in the vegetal cortex
- This leads to expression of dorsal- and ventral-specific gene expression

Axes in other animals

- In chicks, gravity is involved in establishing the anterior-posterior axis
- Later, pH differences between the two sides of the blastoderm establish the dorsal-ventral axis
- In mammals, experiments suggest that orientation of the egg and sperm nuclei before fusion may help establish embryonic axes

Drosophila axis determination

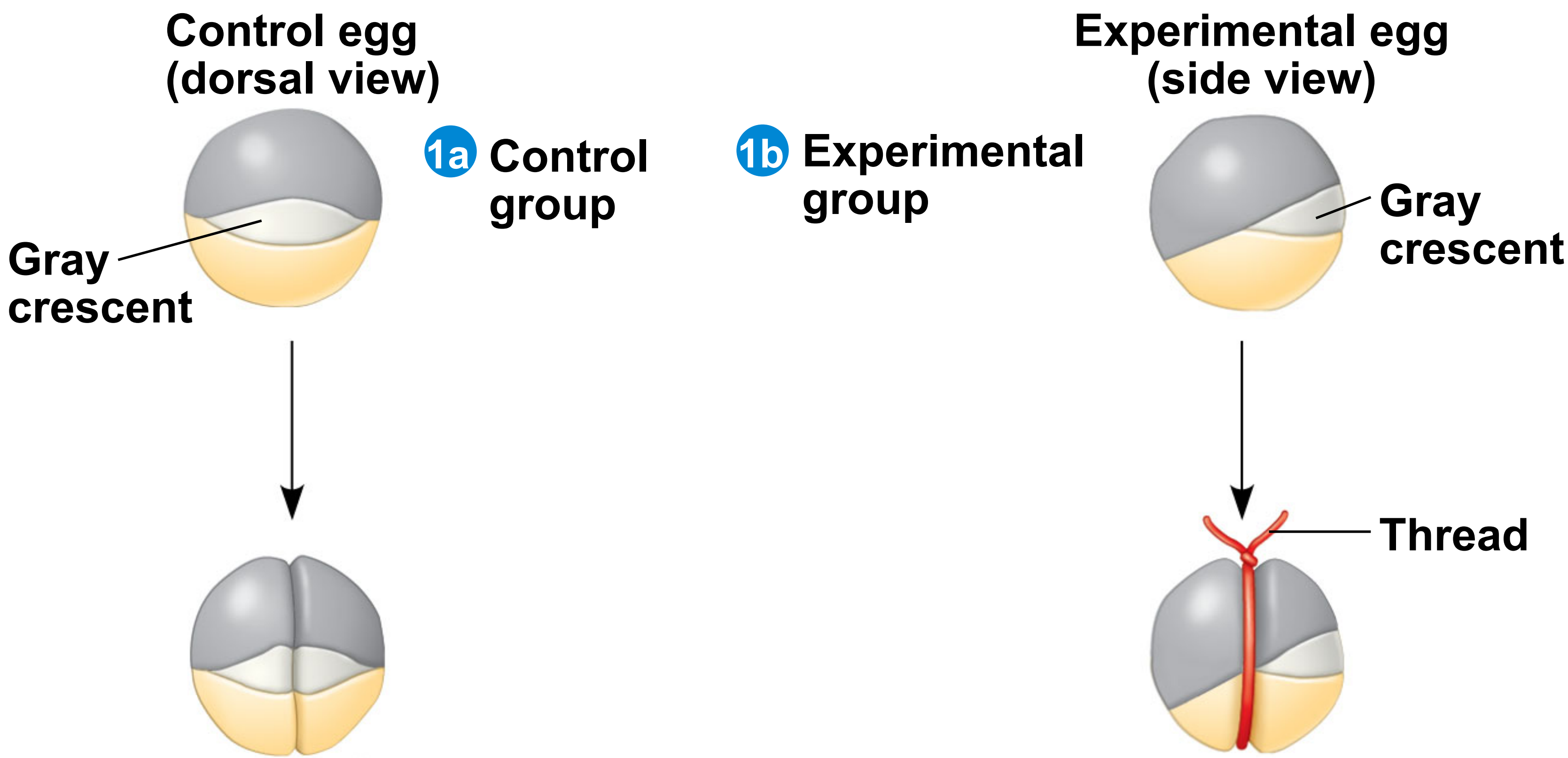
- *Bicoid* – a maternal effect gene that determines the anterior-posterior axis



Restricting Developmental Potential

- Hans Spemann performed experiments to determine a cell's developmental potential (range of structures to which it can give rise)
- Embryonic fates are affected by distribution of determinants and the pattern of cleavage
- The first two blastomeres of the frog embryo are **totipotent** (can develop into all the possible cell types)

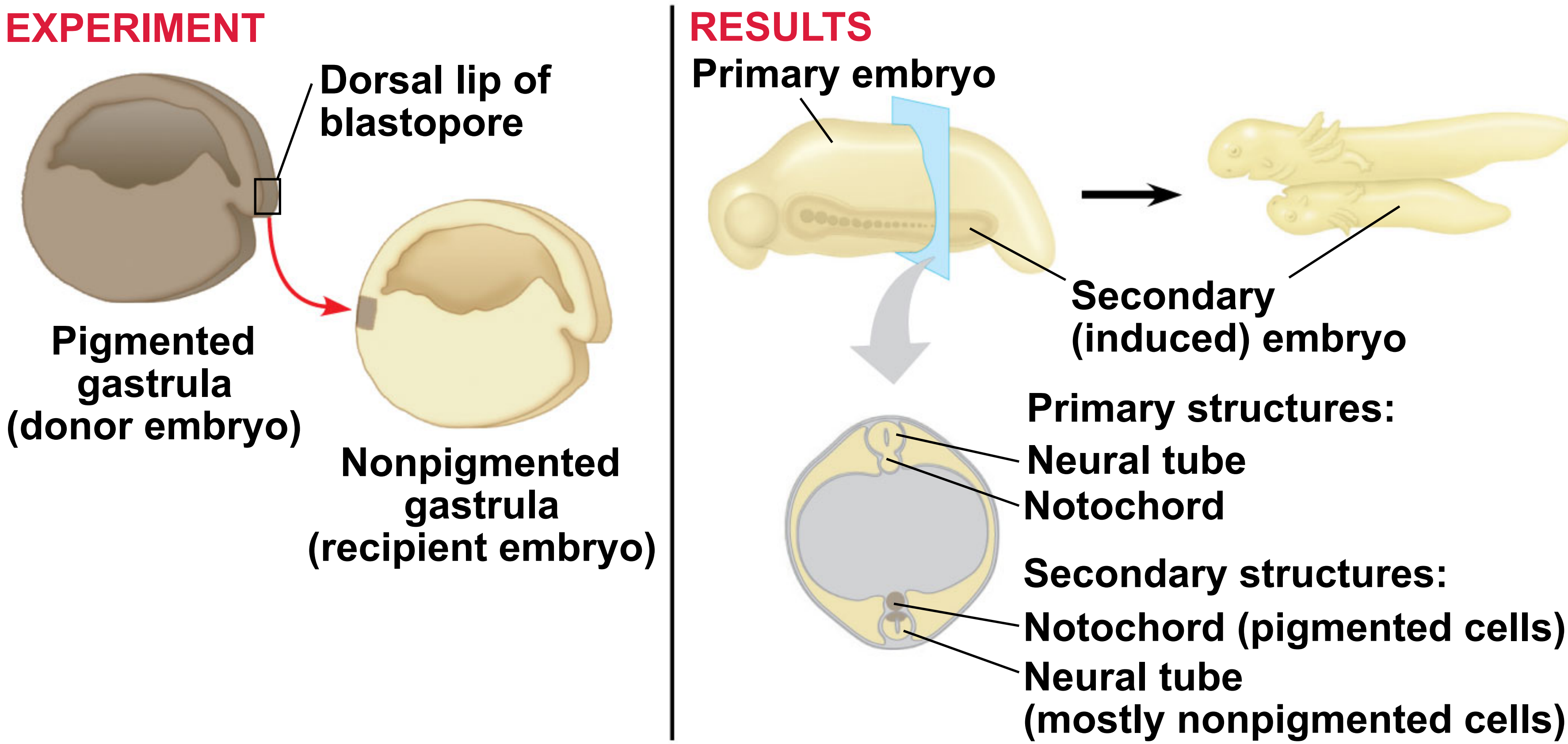
EXPERIMENT


Control egg
(dorsal view)
1a Control group
Gray crescent
1b Experimental group
Experimental egg
(side view)
Gray crescent
Thread

The "Organizer" of Spemann and Mangold

- Spemann and Mangold transplanted tissues between early gastrulas and found that the transplanted dorsal lip triggered a second gastrulation in the host
- The dorsal lip functions as an organizer of the embryo body plan, inducing changes in surrounding tissues to form notochord, neural tube, and so on

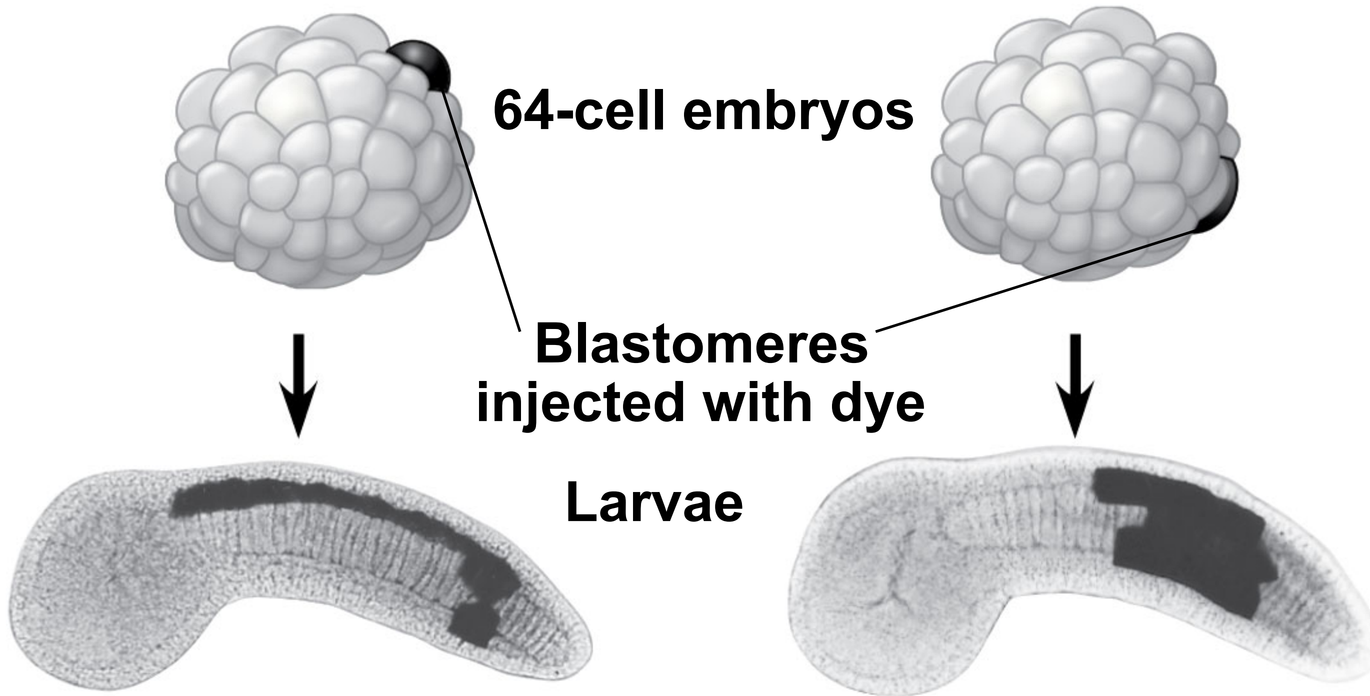
Figure 47.23


EXPERIMENT
Dorsal lip of blastopore
Pigmented gastrula (donor embryo)
Nonpigmented gastrula (recipient embryo)
RESULTS
Primary embryo
Secondary (induced) embryo
Primary structures:
Neural tube
Notochord
Secondary structures:
Notochord (pigmented cells)
Neural tube (mostly nonpigmented cells)

Fate Mapping

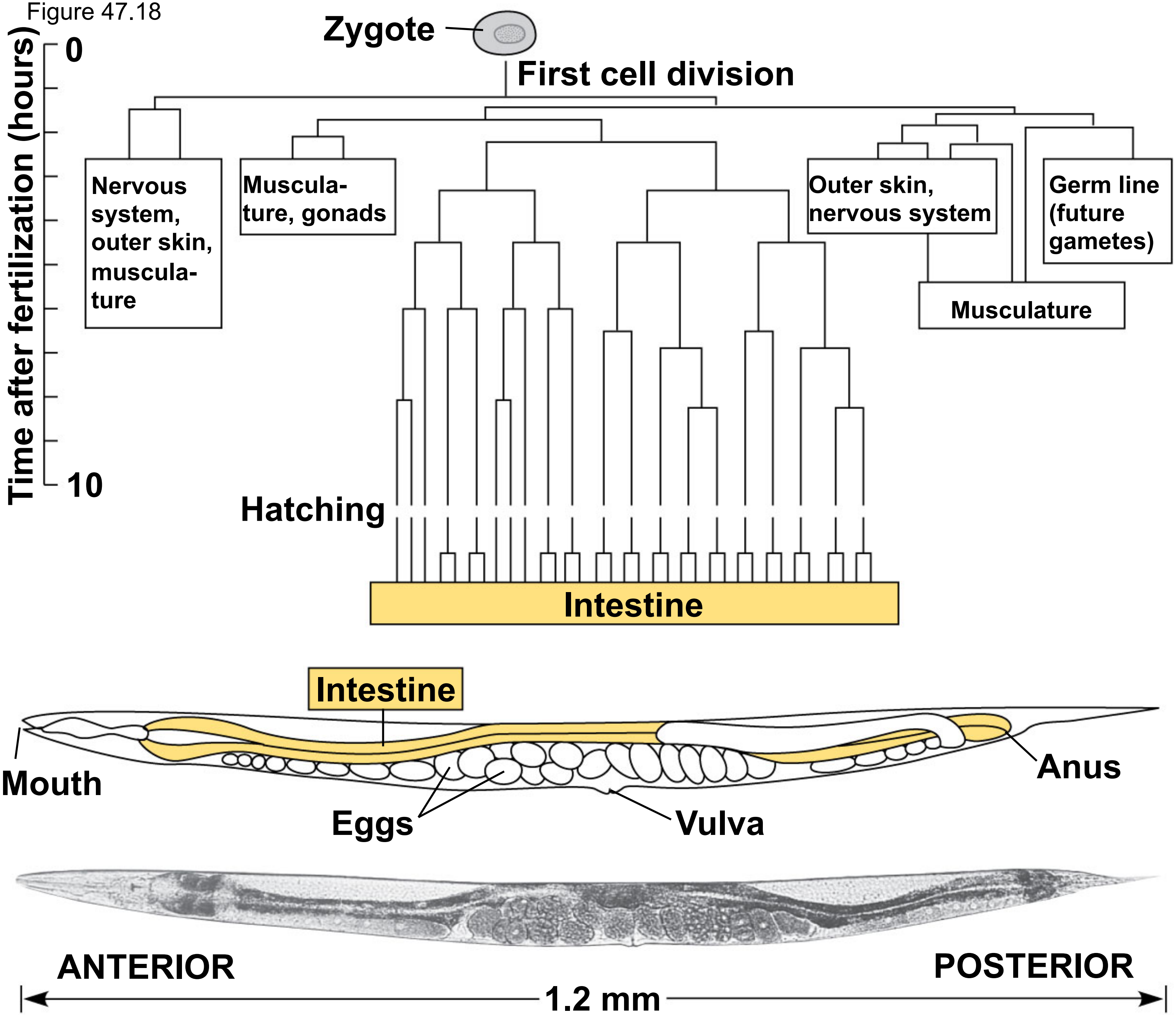
- **Fate maps** are diagrams showing organs and other structures that arise from each region of an embryo
- Classic studies using frogs indicated that cell lineage in germ layers is traceable to blastula cells
- Later studies of *C. elegans* used the ablation (destruction) of single cells to determine the structures that normally arise from each cell
- The researchers were able to determine the lineage of each of the 959 somatic cells in the worm

Figure 47.17b



(b) Cell lineage analysis in a tunicate

Figure 47.18


Time after fertilization (hours)
0
10
Zygote
First cell division
Nervous system, outer skin, muscula- ture
Muscula- ture, gonads
Outer skin, nervous system
Germ line (future gametes)
Musculature
Hatching
Intestine
Intestine
Mouth
Eggs
Vulva
Anus
ANTERIOR
POSTERIOR
1.2 mm

Summary

- Development allows for the formation of specialized cells and organ structures
- Even though specific developmental pathways can differ between species, basic mechanisms are similar
- Normal development depends on internal and external signals that are closely coordinated, both temporally and spatially

Plants

27 April 2017

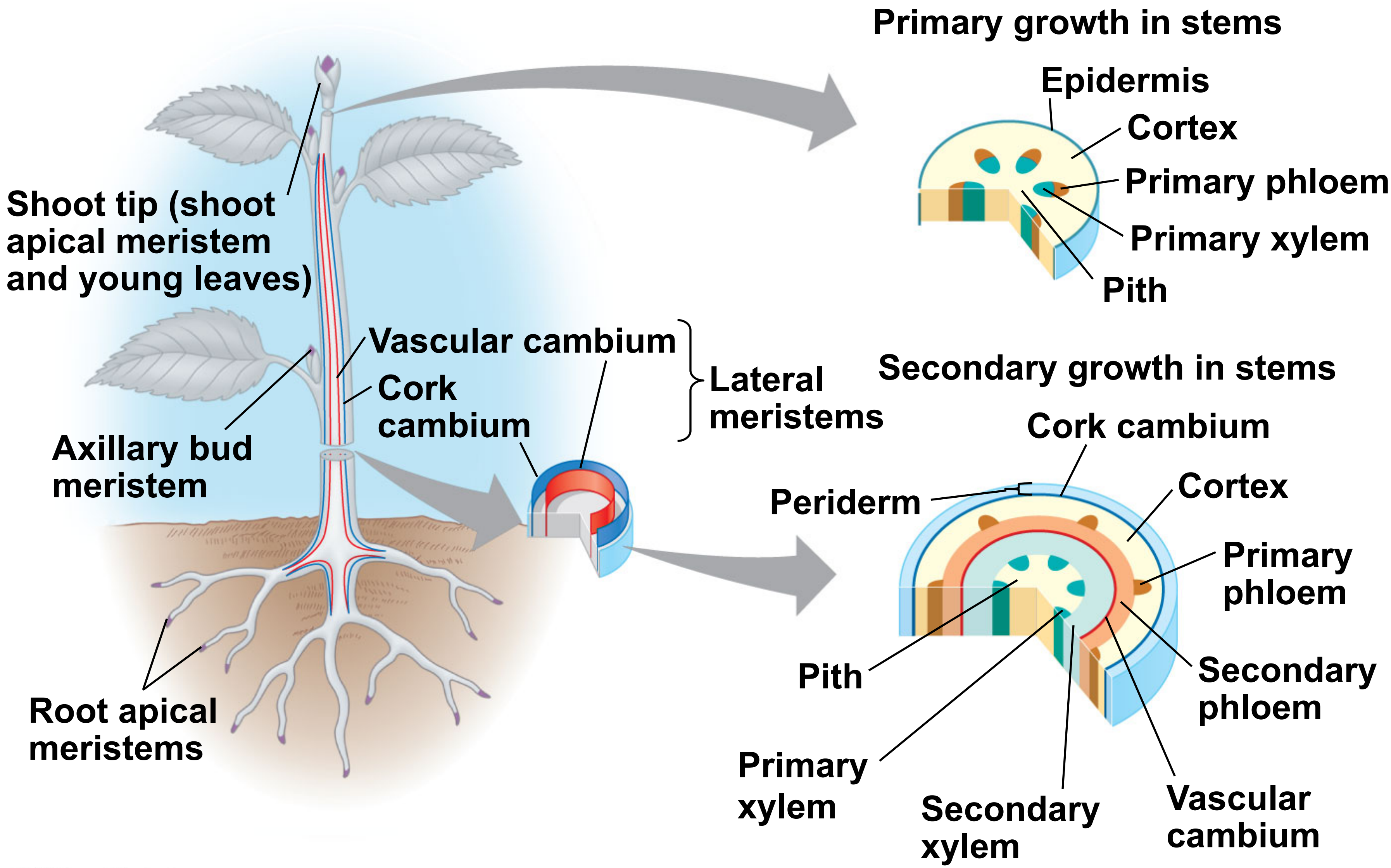
Parallels with Animal

- Development depends on spatially and temporally regulated signals
- Plants also depend on a vascular system for the transport of water and nutrients
- Despite no nervous system, plants still respond to external stimuli
  - Plants can fight infections

Meristems

- **Meristems** are perpetually embryonic tissue and allow for indeterminate growth
- **Apical meristems** are located at the tips of roots and shoots and at the axillary buds of shoots
- Apical meristems elongate shoots and roots, a process called **primary growth**
- **Lateral meristems** add thickness to woody plants, a process called **secondary growth**

Figure 35.11



Shoot tip (shoot apical meristem and young leaves)
Axillary bud meristem
Root apical meristems
Vascular cambium
Cork cambium
Lateral meristems
Primary growth in stems
Epidermis
Cortex
Primary phloem
Primary xylem
Pith
Secondary growth in stems
Cork cambium
Periderm
Cortex
Primary phloem
Pith
Secondary phloem
Primary xylem
Secondary xylem
Vascular cambium

Plant hormones help coordinate growth, development, and responses to stimuli

- Plant **hormones** are chemical signals that modify or control one or more specific physiological processes within a plant
- Plant hormones are produced in very low concentration, but a minute amount can greatly affect growth and development of a plant organ
- In general, hormones control plant growth and development by affecting the division, elongation, and differentiation of cells

The Discovery of Plant Hormones

- Any response resulting in curvature of organs toward or away from a stimulus is called a **tropism**
- In the late 1800s, Charles Darwin and his son Francis conducted experiments on **phototropism**, a plant’s response to light
- They observed that a grass seedling could bend toward light only if the tip of the coleoptile was present

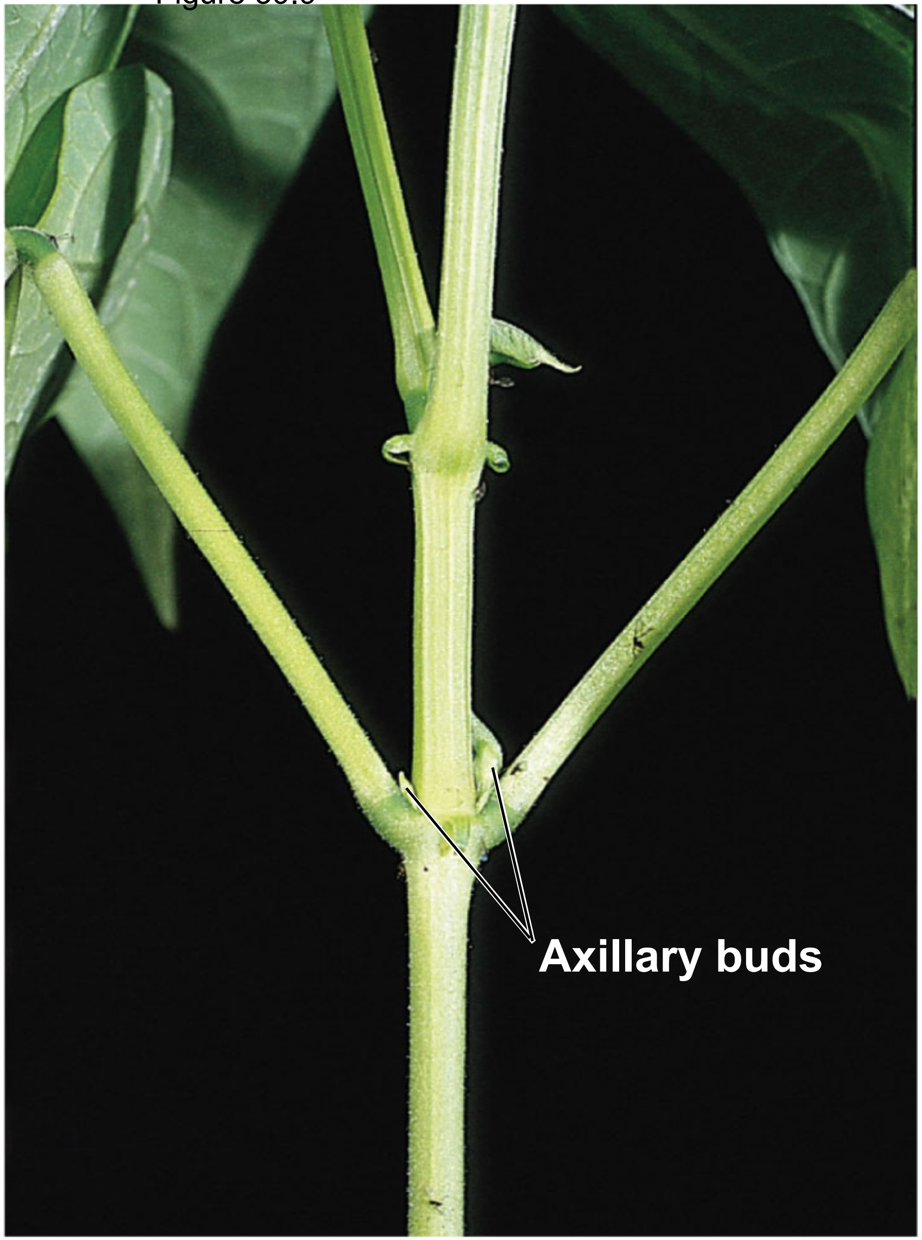
Auxin

- The term **auxin** refers to any chemical that promotes elongation of coleoptiles
- Indoleacetic acid (IAA) is a common auxin in plants; in this lecture the term *auxin* refers specifically to IAA
- Auxin is produced in shoot tips and is transported down the stem
- Auxin transporter proteins move the hormone from the basal end of one cell into the apical end of the neighboring cell

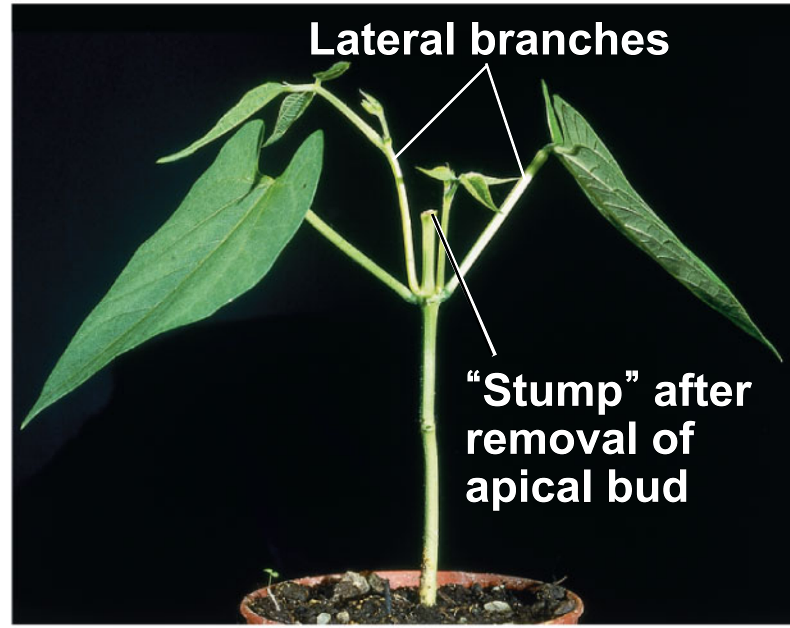
Auxin's Role in Plant Development

- Polar transport of auxin plays a role in pattern formation of the developing plant
- Reduced auxin flow from the shoot of a branch stimulates growth in lower branches
- Auxin transport plays a role in phyllotaxy, the arrangement of leaves on the stem
- Polar transport of auxin from leaf margins directs leaf venation pattern

Figure 39.9



(a) Apical bud intact (not shown in photo)



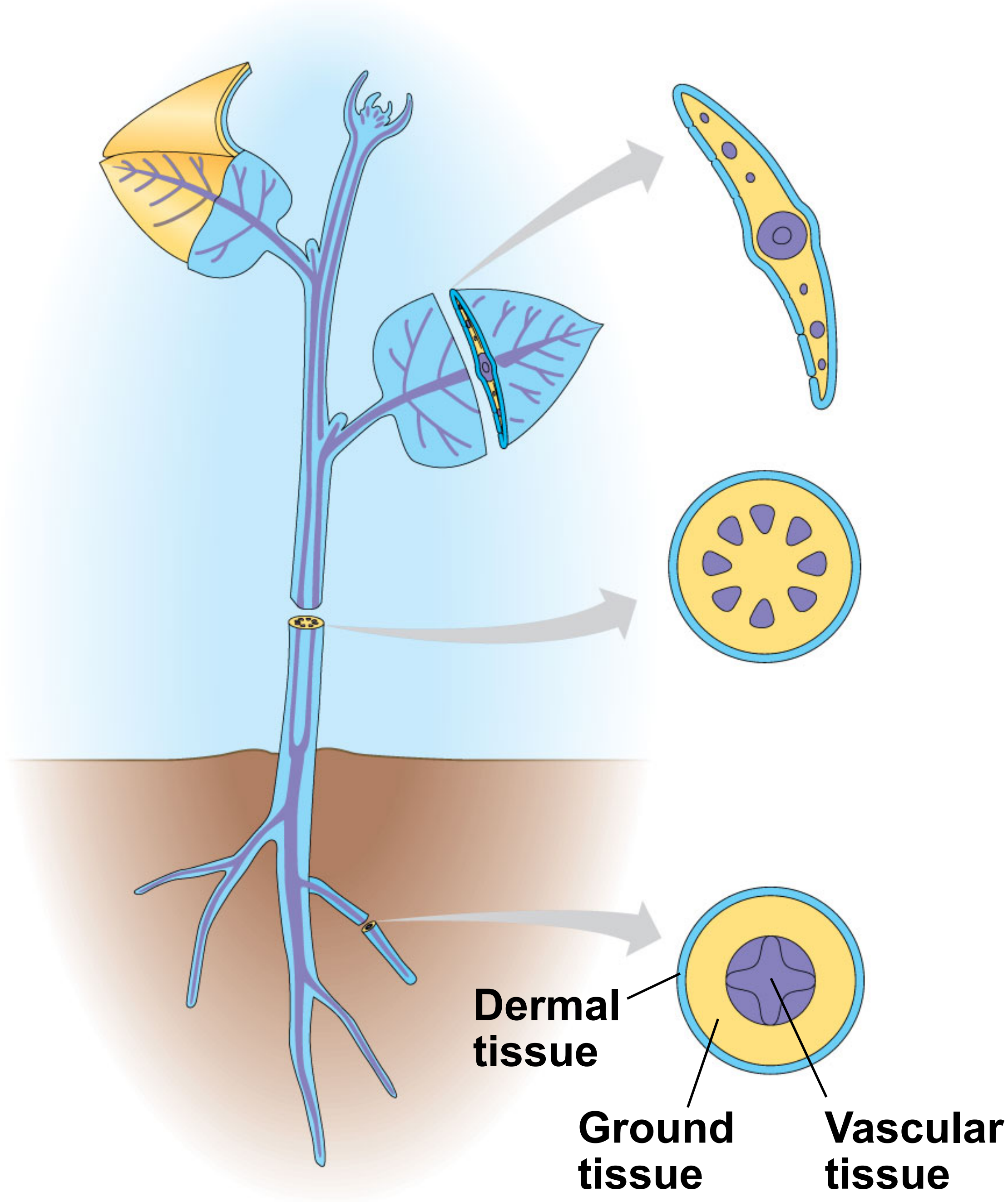
(b) Apical bud removed

(c) Auxin added to decapitated stem

Ethylene

- A burst of ethylene production in a fruit triggers the ripening process
- Ethylene triggers ripening, and ripening triggers release of more ethylene
- Fruit producers can control ripening by picking green fruit and controlling ethylene levels

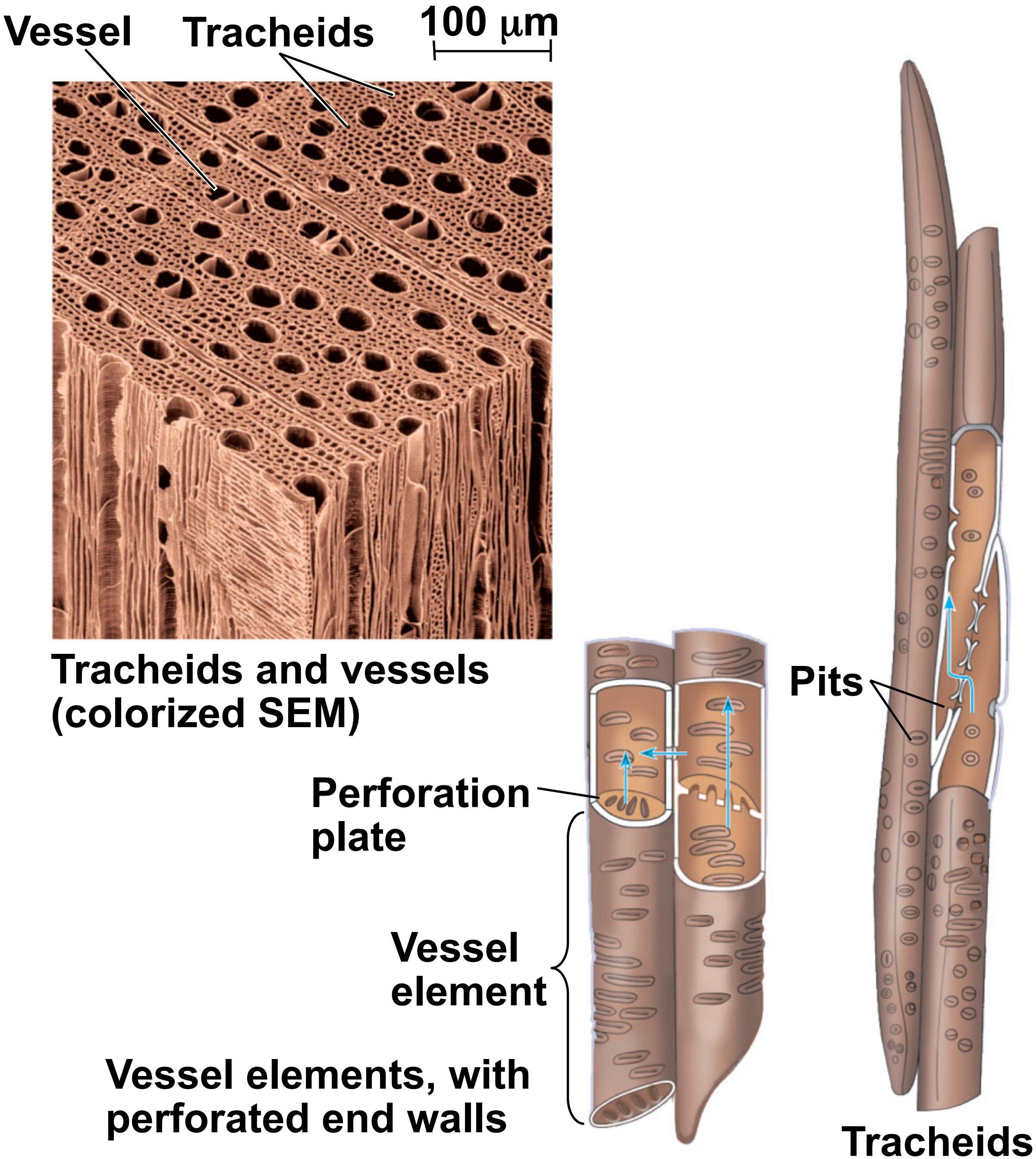
Figure 35.8



Plant vascular tissues

- The **vascular tissue system** carries out long-distance transport of materials between roots and shoots
- **Xylem** conveys water and dissolved minerals upward from roots into the shoots
  - **Transpiration** drives the transport of water and minerals from roots to shoots via the xylem
- **Phloem** transports organic nutrients from where they are made to where they are needed

Figure 35.

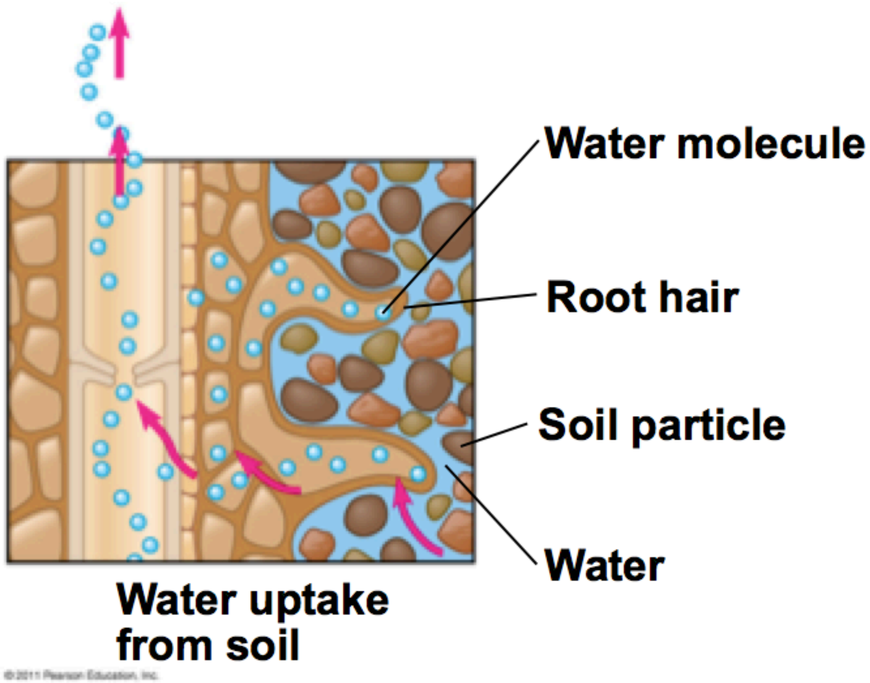

Vessel
Tracheids
100 µm
Tracheids and vessels (colorized SEM)
Perforation plate
Vessel element
Vessel elements, with perforated end walls
Pits
Tracheids

Bulk Flow Transport via the Xylem

- **Xylem sap**, water and dissolved minerals, is transported from roots to leaves by bulk flow
- The transport of xylem sap involves **transpiration**, the evaporation of water from a plant's surface
- Transpired water is replaced as water travels up from the roots
- Is sap pushed up from the roots, or pulled up by the leaves?

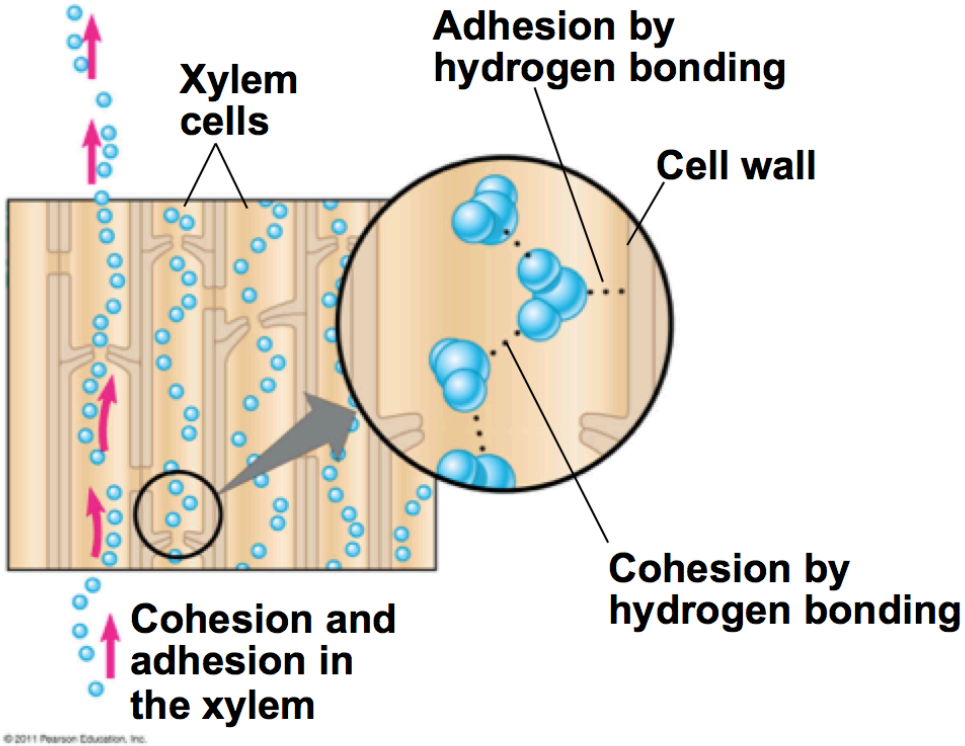
Pushing Xylem Sap: Root Pressure

- At night root cells continue pumping mineral ions into the xylem of the vascular cylinder, lowering the water potential
- Water flows in from the root cortex, generating **root pressure**



Pulling Xylem Sap: The Cohesion-Tension Hypothesis

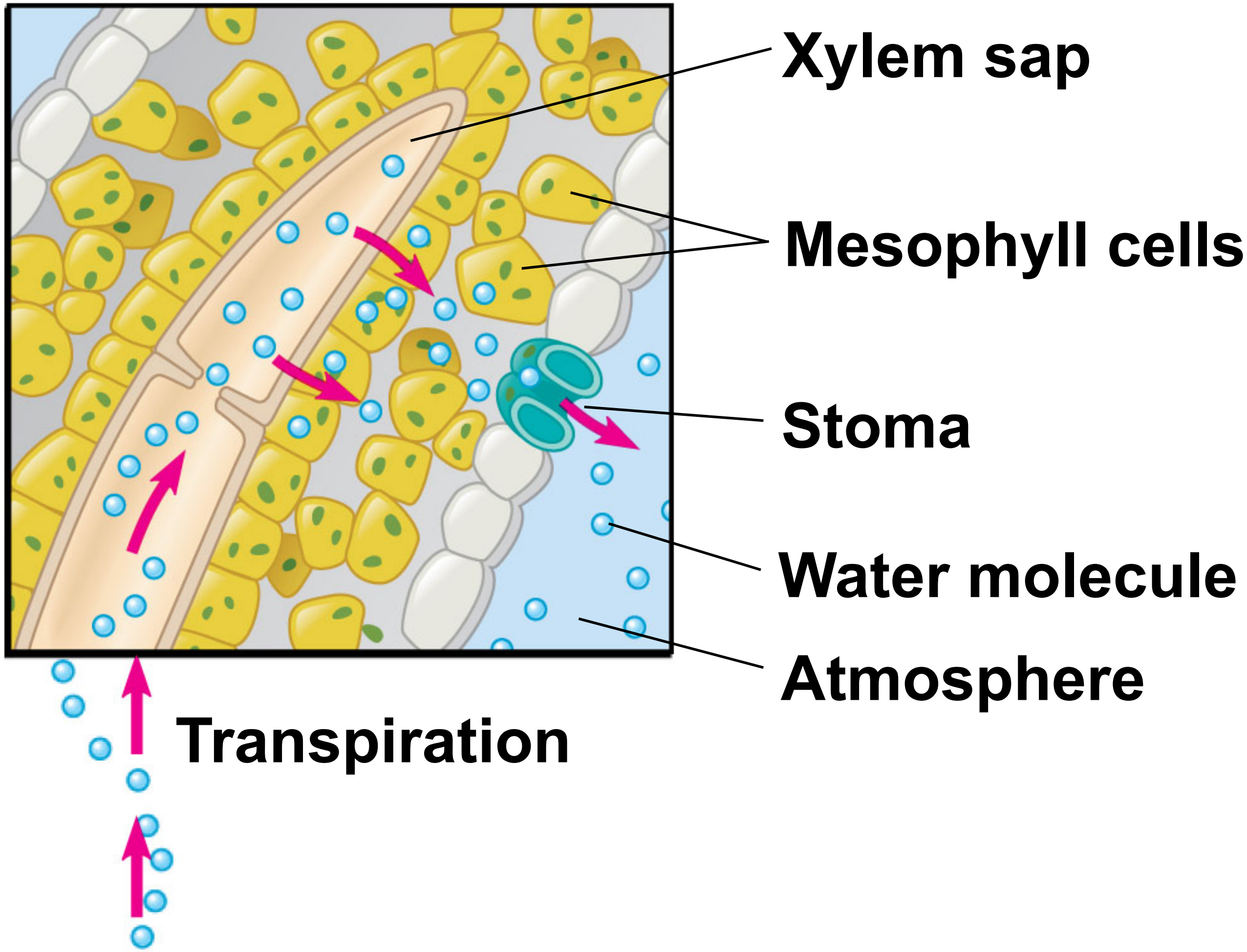
- According to the **cohesion-tension hypothesis**, transpiration and water cohesion pull water from shoots to roots
- Xylem sap is normally under negative pressure, or tension



Transpirational Pull

- Water vapor in the airspaces of a leaf diffuses down its water potential gradient and exits the leaf via stomata
- As water evaporates, the air-water interface retreats further into the mesophyll cell walls
- The surface tension of water creates a negative pressure potential
- This negative pressure pulls water in the xylem into the leaf
- The transpirational pull on xylem sap is transmitted from leaves to roots

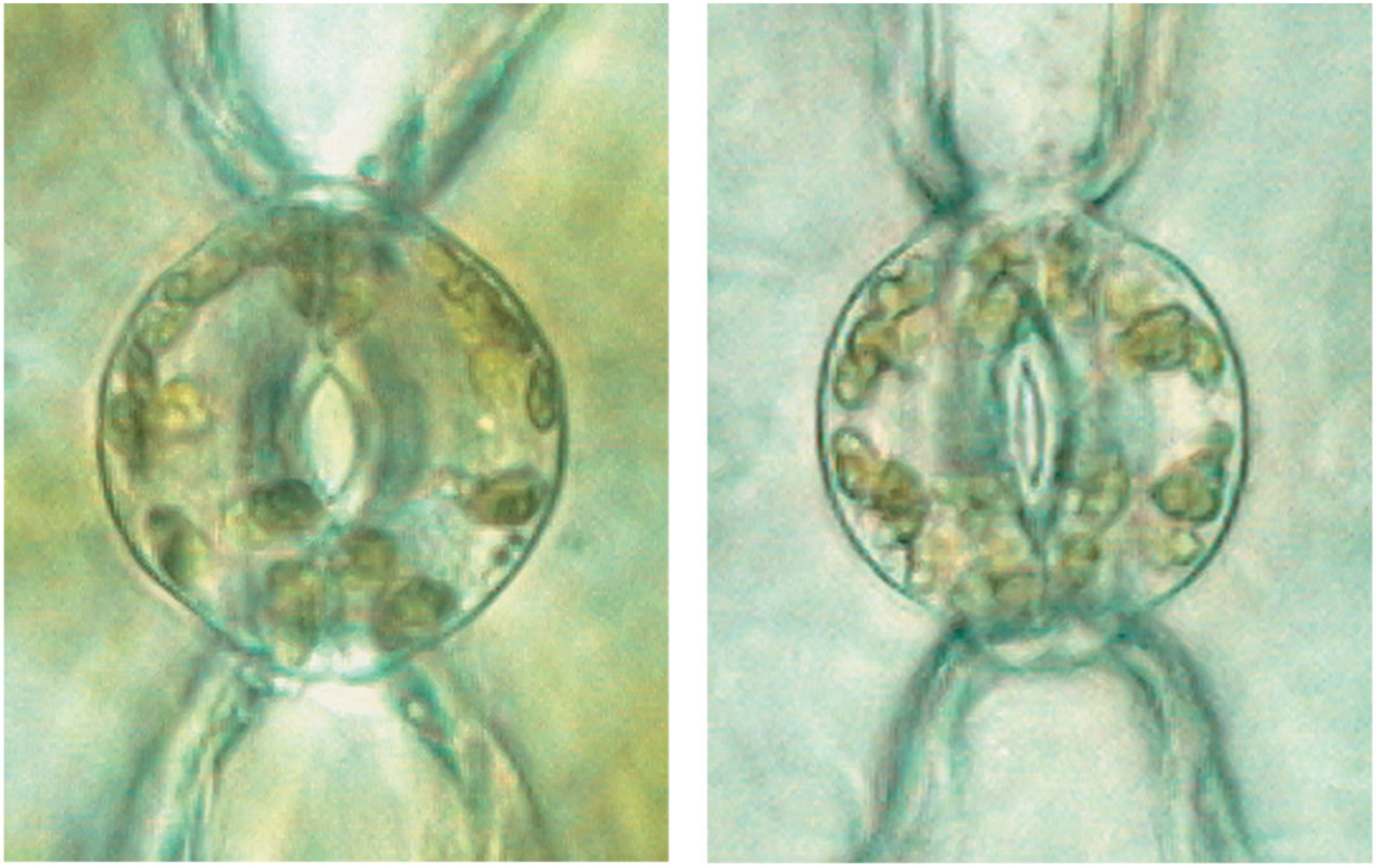
Figure 36.13c



Stomata regulate the rate of transpiration

- Leaves generally have broad surface areas and high surface-to-volume ratios
- These characteristics increase photosynthesis and increase water loss through stomata
- Guard cells help balance water conservation with gas exchange for photosynthesis

Figure 36.14



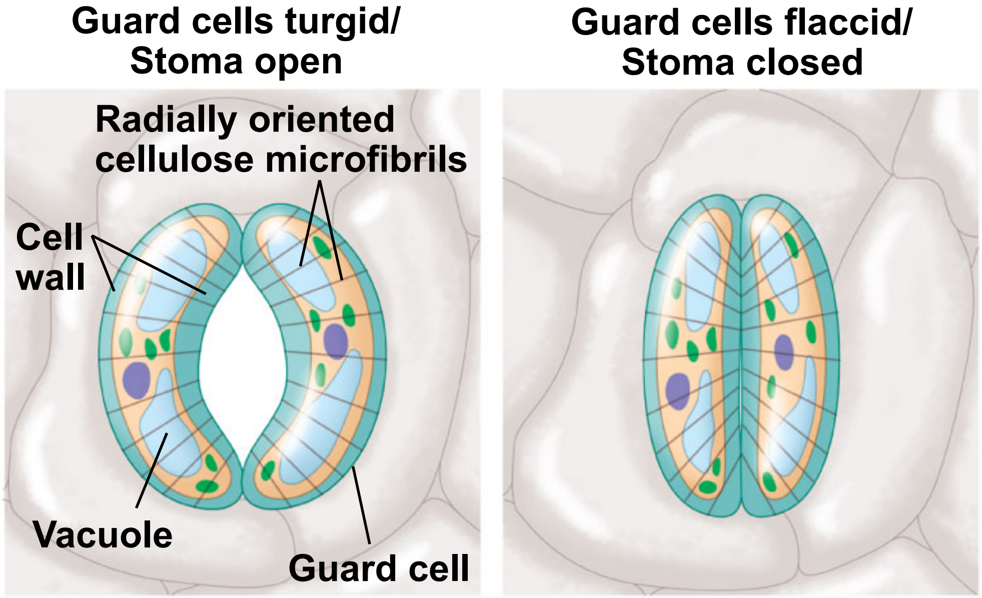
Stomata: Major Pathways for Water Loss

- About 95% of the water a plant loses escapes through stomata
- Each stoma is flanked by a pair of guard cells, which control the diameter of the stoma by changing shape
- Stomatal density is under genetic and environmental control

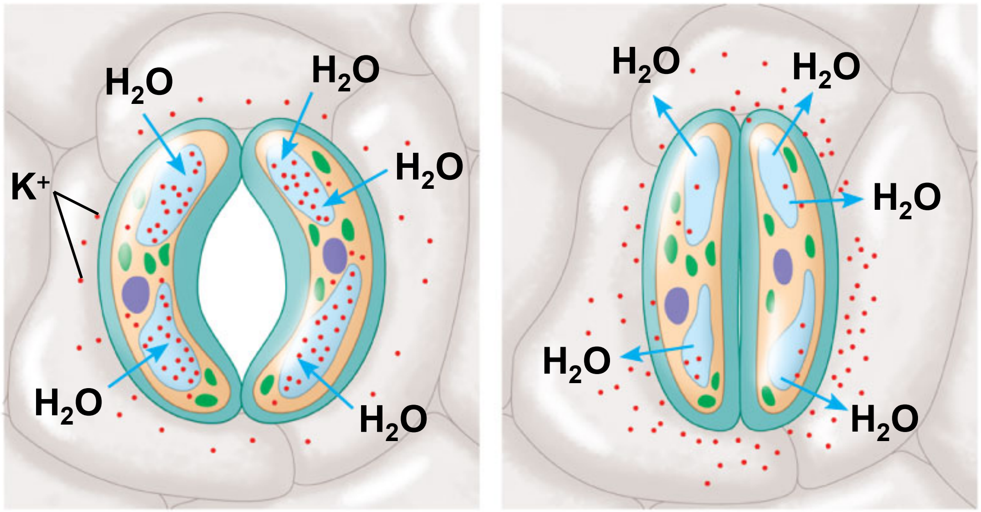
Stomatal Opening and Closing

- Changes in turgor pressure open and close stomata
  - When turgid, guard cells bow outward and the pore between them opens
  - When flaccid, guard cells become less bowed and the pore closes

Figure 36.15



(a) Changes in guard cell shape and stomatal opening and closing (surface view)

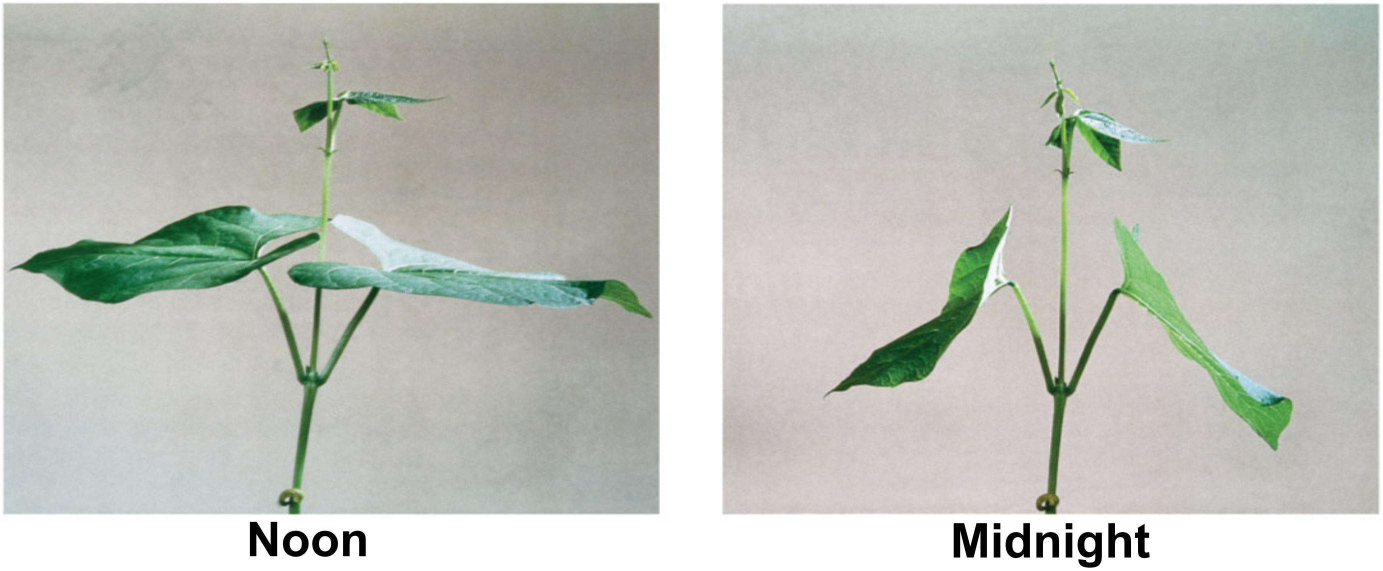


(b) Role of potassium in stomatal opening and closing

Plant response to external stimuli

Biological Clocks and Circadian Rhythms

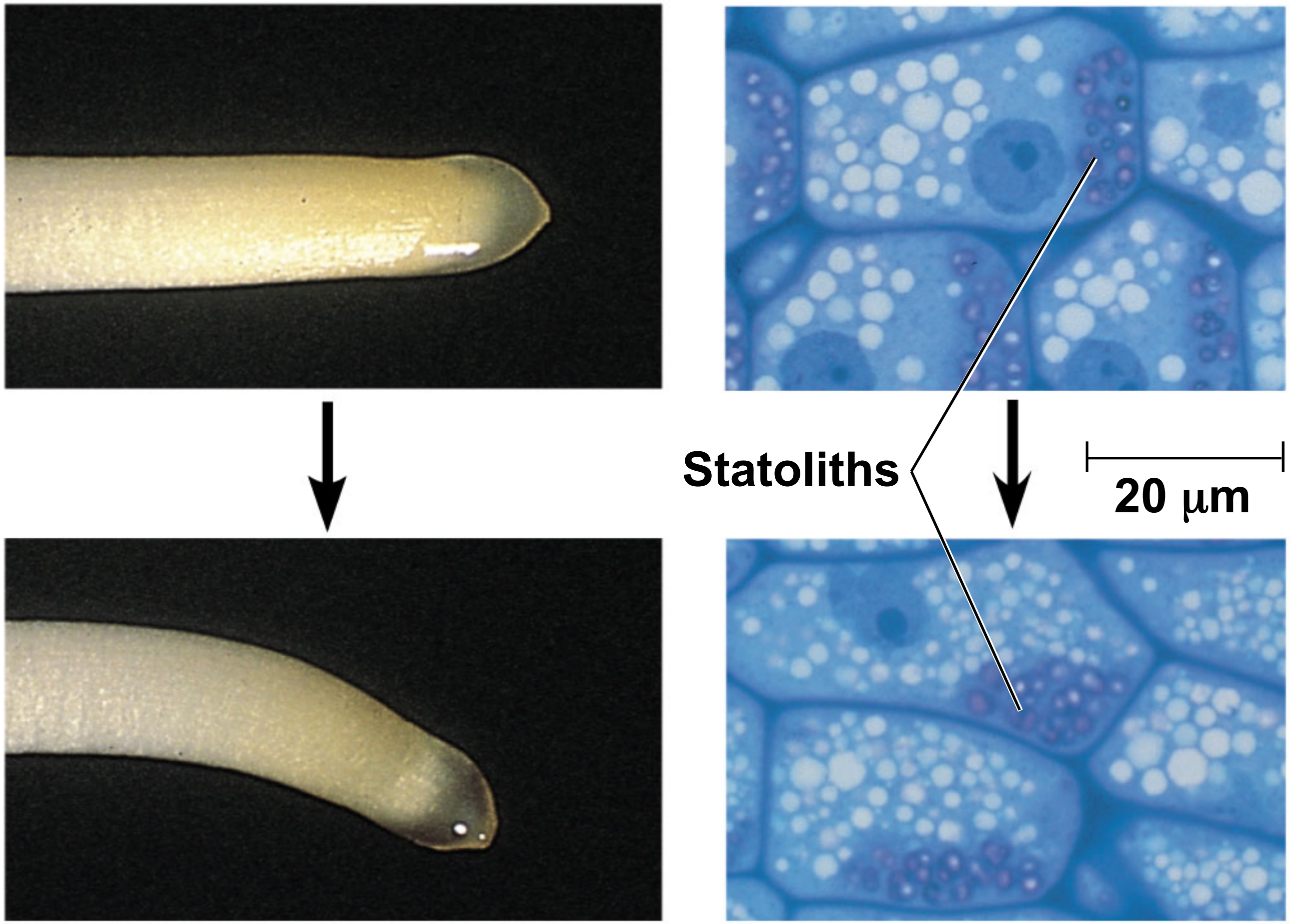
- Many plant processes oscillate during the day
- Many legumes lower their leaves in the evening and raise them in the morning, even when kept under constant light or dark conditions



Gravity

- Response to gravity is known as **gravitropism**
- Roots show positive gravitropism; shoots show negative gravitropism
- Plants may detect gravity by the settling of **statoliths**, dense cytoplasmic components

Figure 39.24



(a) Primary root of maize bending gravitropically (LMs)

(b) Statoliths settling to the lowest sides of root cap cells (LMs)

Environmental Stresses

- Environmental stresses have a potentially adverse effect on survival, growth, and reproduction
- Stresses can be **biotic** (living) or **abiotic** (nonliving)
- Biotic stresses include herbivores and pathogens
- Abiotic stresses include drought, flooding, salt stress, heat stress, and cold stress

Defenses Against Pathogens

- A plant's first line of defense against infection is the barrier presented by the epidermis and periderm
- If a pathogen penetrates the dermal tissue, the second line of defense is a chemical attack that kills the pathogen and prevents its spread
- This second defense system is enhanced by the inherited ability to recognize certain pathogens

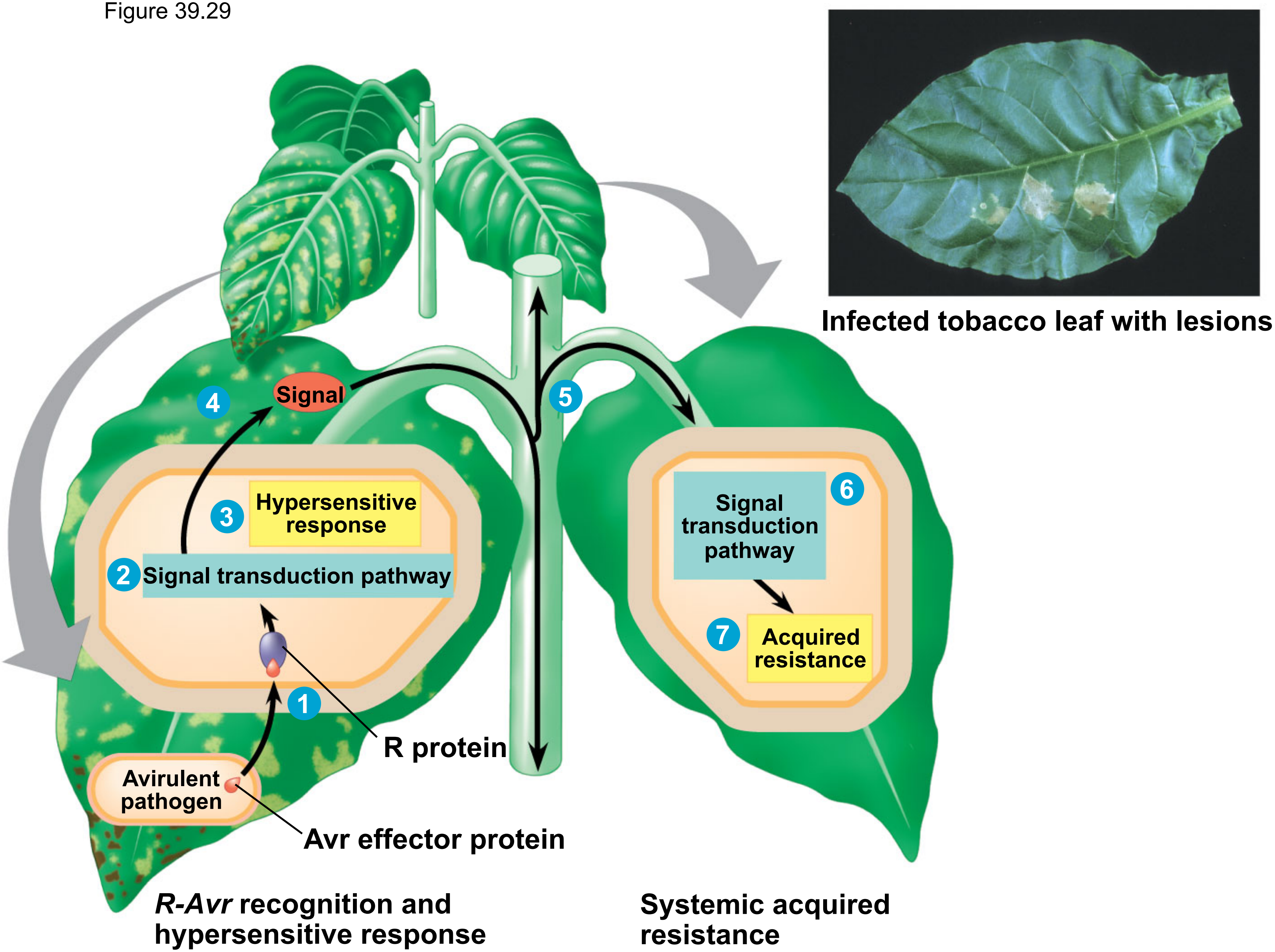
Host-Pathogen Coevolution

- A **virulent** pathogen is one that a plant has little specific defense against
- An **avirulent** pathogen is one that may harm but does not kill the host plant

The Hypersensitive Response

- The **hypersensitive response**
  - Causes cell and tissue death near the infection site
  - Induces production of phytoalexins and PR proteins, which attack the pathogen
  - Stimulates changes in the cell wall that confine the pathogen
- Analogous to innate immune response in animals

Figure 39.29


Infected tobacco leaf with lesions
Signal
4
5
3
Hypersensitive response
2
Signal transduction pathway
1
R protein
Avirulent pathogen
Avr effector protein
6
Signal transduction pathway
7
Acquired resistance
R-Avr recognition and hypersensitive response
Systemic acquired resistance

Systemic Acquired Resistance

- **Systemic acquired resistance** causes systemic expression of defense genes and is a long-lasting response
- **Salicylic acid** is synthesized around the infection site and is likely the signal that triggers systemic acquired resistance

Salt Stress

- Salt can lower the water potential of the soil solution and reduce water uptake
- Plants respond to salt stress by producing solutes tolerated at high concentrations
- This process keeps the water potential of cells more negative than that of the soil solution

Drought

- During drought, plants reduce transpiration by closing stomata, slowing leaf growth, and reducing exposed surface area
- Growth of shallow roots is inhibited, while deeper roots continue to grow

Flooding

- Enzymatic destruction of root cortex cells creates air tubes that help plants survive oxygen deprivation during flooding