CHAPTER 1

An introduction to cells and their organelles

William V. Dashek
Retired Faculty, Adult Degree Program, Mary Baldwin College, Staunton, VA, USA

Cells

Parenchyma, chlorenchyma, collenchyma, and sclerenchyma are the four main plant cell types (Figure 1.1, Evert, 2006). Meristematic cells, which occur in shoot and root meristems, are parenchyma cells. Chlorenchyma cells contain chloroplasts and lack the cell wall thickening layers of collenchyma and sclerenchyma. Certain epidermal cells can be specialized as stomata that are important in gas exchange (Bergmann and Sack, 2007). The diverse cell types (Zhang *et al*., 2001; Yang and Liu, 2007) are shown in Table 1.1. Photomicrographs of certain of these cell types can be found in Evert (2006), Fahn (1990), Beck (2005), Rudall (2007), Gunning (2009), MacAdam (2009), Wayne (2009), Beck (2009), Assmann and Liu (2014) and Noguchi *et al*. (2014).

How do cells arise?

Cells arise by cell divisions (see Chapter 8 for mitosis and meiosis) in shoot and root (Figures 1.2 and 1.3) meristems (Table 1.2, Lyndon, 1998; McManus and Veit, 2001; Murray, 2012). The shoot apex is characterized by a tunica–corpus organization (Steeves and Sussex, 1989). The tunica gives rise to the protoderm and its derivative, the epidermis. In contrast, the corpus provides the procambium which yields the primary xylem and phloem. In addition, the ground tissue derives from the corpus originating the pith and cortex. Following divisions, cells can differentiate into tissues (Table 1.3) and organs of the mature plant body (Leyser and Day, 2003; Sachs, 2005; Dashek and Harrison, 2006). The leaf primodium arises on the apex (Micol and Hake, 2003). The mature angiosperm leaf consists of palisade cells and spongy mesophyll cells sandwiched between the upper and the lower epidermis (Figure 1.4). The epidermis possesses guard cells with associated stomata that function in gas exchange. *KNOX* genes affect meristem maintenance and suitable patterning of organ formation (Hake *et al*., 2004). In dissected leaves, *KNOX* genes are expressed in leaf primordia (Hake *et al*., 2004). Hake *et al*. (2004) suggest that

Plant Cells and their Organelles, First Edition. Edited by William V. Dashek and Gurbachan S. Miglani.

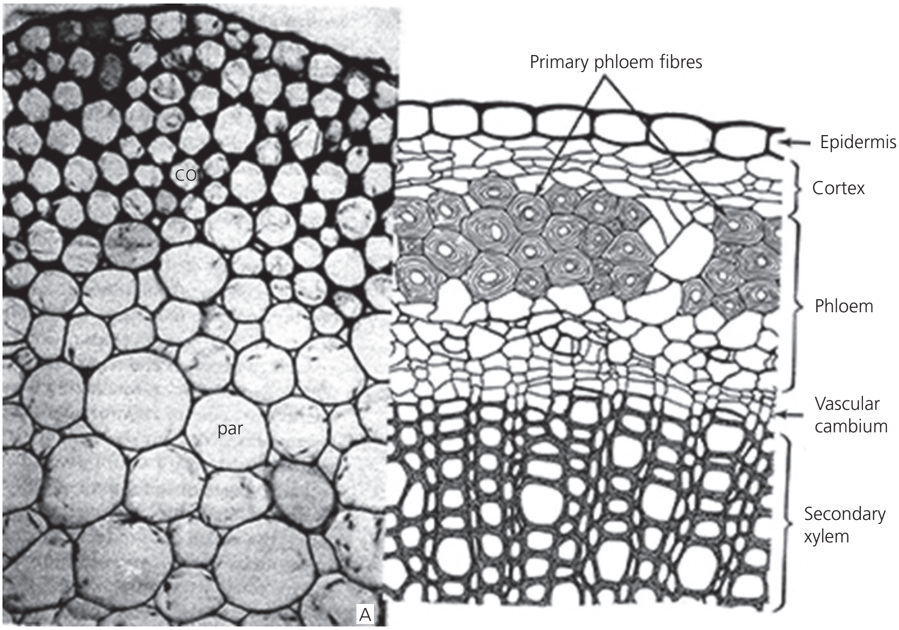


Figure 1.1 Plant cell types: Left: parenchyma (par) and collenchyma (co). Right: sclerenchyma. Source: Evert (2006). Reproduced with permission of John Wiley & Sons.

KNOX genes may be important in the diversity of leaf form. Extensive discussions of leaf development occur in Sinha (1999), Micol and Hake (2003) and Efroni *et al.* (2010). Under appropriate stimuli the vegetative apex can be converted to a floral apex (Figure 1.5). Photoperiod (Mazumdar, 2013), such as short days and long days and combinations of the two, is one such stimulus (Glover, 2007; Kinmonth-Schultz *et al.*, 2013). This induction results in the production of florigen (Turck *et al.*, 2008), the flowering hormone (Zeevaart, 2006). While early reports suggest that florigen is an mRNA species (Huang *et al.*, 2005), a more recent investigation indicates that florigen is a protein complex (Yang *et al.*, 2007; Taoka *et al.*, 2013). Taoka *et al.* state that florigen protein is encoded by the gene, Flowering Locus T, in *Arabidopsis* species (Shresth *et al.*, 2014). It is believed that florigen is induced in leaves and that it moves through the phloem to the shoot apex. Plant hormones (see Appendix A) can influence floral development (Howell, 1998). Gibberellins (Blázquez *et al.*, 1998), auxins, and jasmonic acid can affect petal development. In contrast, auxin can influence gynoecium development. The ABC model has been proposed for regulating the development of floral parts (Soltis *et al.*, 2006). The *A* gene expression is responsible for sepals, while the petals are the result of co-expression of *A* and *B* genes. The *B* and *C* genes are responsible for stamen development and carpels require *C* genes. In certain plants, vernalization (low temperature) can induce flowering in certain plants (Kemi *et al.*, 2013). A diagram of the mature angiosperm plant body is presented in Figure 1.6. Plant

Table 1.1 Plant cell types.

Cell types	Characteristics	References
Epidermal cells	Unspecialized cells; one layer of cells in thickness; outer covering of various plant parts; variable in shape but often tabular	Evert (2006)
Examples		
Guard cells	Specialized epidermal cells; crescent shaped; contain chloroplasts; form defines stomatal pore	Wille and Lucas (1984)
Subsidiary cells	Cells which subtend the stomatal guard cells	http://anubis.ru.ac.za/Main/ANATOMY/guardcells.html
Trichomes	An outgrowth of an epidermal cell; can be unicellular or multicellular	Callow (2000)
Parenchyma cells	Isodiametric, thin-walled primary cell wall; in some instances may have secondary walls; not highly differentiated; function in photosynthesis, secretion, organic nutrient and water storage; regeneration in wound healing	Evert (2006) and Sajeva and Mauseth (1991)
Examples		
Transfer cells	Specialized parenchyma cells; plasmalemma greatly expanded; irregular extensions of cell wall into protoplasm; transfer dissolved substances between adjacent cell; occur in pith and cortex of stems and roots; photosynthetic tissues of leaves; flesh of succulent fruits; endosperm of seeds	Dashek *et al.* (1971) and Offler *et al.* (2003)
Collenchyma cells	Lamellar or plate collenchyma, with thickenings on the tangential walls Angular collenchyma, with thickenings around the cell walls Present in aerial portions of the plant body	
Vascular cells		Evert (2006)
Phloem		
Sieve cells		
Sieve elements		
Companion cells	Specialized parenchyma cells; possess numerous plasmodesmatal connections	Oparka and Turgeon (1999)
Albuminous cells in gymnosperms	Absence of starch; cytoplasmic bridges with sieve cells; dense protoplasm, abundance of polysomes, highly condensed euchromatin and abundant mitochondria	Alosi and Alfieri (1972) and Sauter *et al.* (1976)
Xylem		
Tracheids	Long tapering cell with lignified secondary wall thickenings; can have pits in walls; devoid of protoplasm at maturity; not as specialized as vessels; widespread	Tyree and Zimmerman (2002)
Vessels		Fukuda (2004) and Evert (2006)

(*Continued*)

Table 1.1 (Continued)

Cell types	Characteristics	References
Specialized cells – Hydathodes (modified parts of leaves and leaf tips or margins)	Consist of terminal tracheids epithem, thin-walled chloroplast-deficient cells, a sheath with water pores; guttation discharge of liquid containing various dissolved solutes from a leaf's interior	Lersten and Curtis (1996), https://www.biosci.utexas.edu/ and Maeda and Maeda (1988)
Laticifer cells	Cells or a series of cells which produce latex	Fahn (1990), Pickard (2008) and Botweb.uwsp.Edu
Simple	Single-celled	
Compound and articulated	Union of cells compound in origin and consist of longitudinal chains of cells; wall separating cells remain intact, can become perforated or entirely removed	
Salt glands	Modified trichomes, two-celled and positioned flat on the surface in rows parallel to the leaf surface; occur in *Poaceae*;	Evert (2006), Tan *et al*. (2010), Oross *et al*. (1985) and Thomson *et al*. (1988)
	Cap cell – large nucleus and expanded cuticle	Naidoo and Naidoo (1998)
	Basal cell – numerous and large extensive partitioning invaginations of plasmalemma	
Nectaries	Found in nectarines; produce nectar, usually at the base of a flower	Fahn (1990), Nicolson and Nepi (2005) and Paiva (2009)
Idioblasts	Crystal-containing cells	Lersten and Horner (2005)
Example		
Raphides	Produce needle-shaped crystals	
Mucilage cell	Occur in a large number of dicots, common in certain cacti; slimy mucilage prevents evaporation of water by binding to water; a parenchyma cell whose dictyosomes produce mucilage as in seed coats; cell walls are cellulosic and unlignified	http://www.sbs.utexas.edu/masuetl/weblab/webchap9secretory/9.1-2.html, Western *et al*. (2000) and Arsovskia *et al*. (2010)
Oil cells	Specialized cells appear like large parenchyma cells; can occur in vascular and ground tissues of stem, and leaf cell wall has three distinct layers; cavity is formed after the inner wall layer has been deposited	Rodelas *et al*. (2008), http:brittanica.com and Lersten *et al*. (2006)
Druses	Spherical aggregates of prismatic crystals	Lersten and Horner (2005)
Cells in non-angiosperms		
Bryophytes		
Gemmae	One to many cells	http://buildingthepride.com/faculty/pgdavison/bryology_links.htm
Hydroids	Water-conducting cells	http://www.Biology-online.org
Leptoids – Pteridophytes	Organic compound-conducting cells; sporogenous cells present in sporangia of sori	

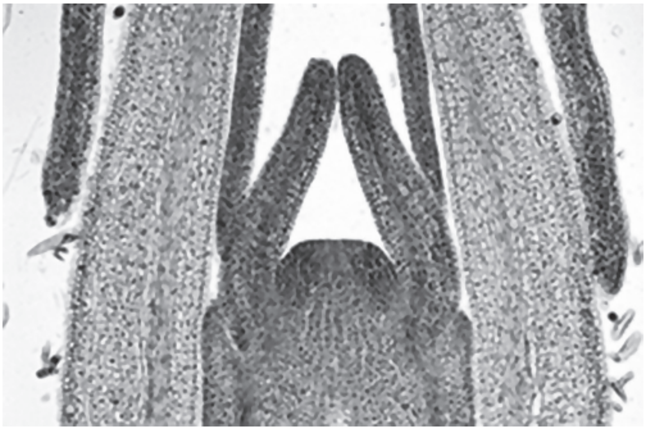


Figure 1.2 Angiosperm shoot meristem section. Source: Alison Roberts. Reproduced with permission of University of Rhode Island.

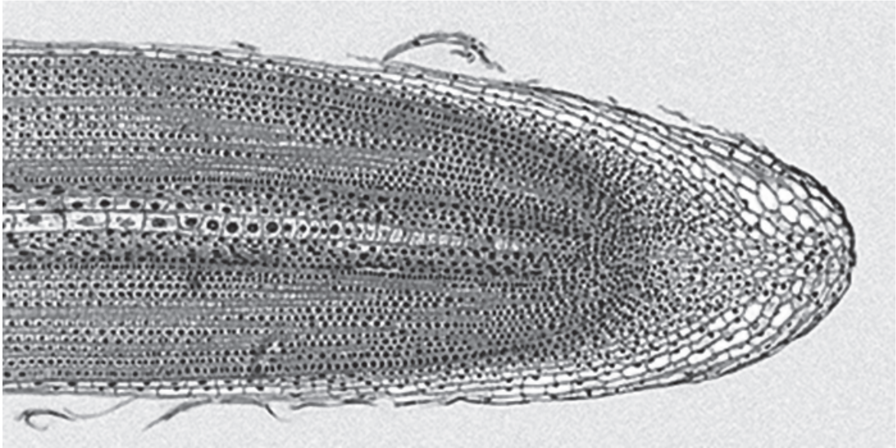


Figure 1.3 Angiosperm root meristem section. Source: Alison Roberts. Reproduced with permission of University of Rhode Island.

development is discussed in Fosket (1999), Moore and Clark (1995), Greenland (2003), Leyser and Day (2003) and Rudall (2007).

What is the composition of cells?

Certain plant components exhibit polar growth, for example, the tip growth of pollen tubes (Hepler *et al.*, 2001). The tubes elongate via the fusion of Golgi-derived vesicles with the plasmalemma and subsequent deposition of the vesicles' contents into the cell wall (Taylor and Hepler, 1997; Parton *et al.*, 2001 and others as reviewed in Malho (2006a, 2006b)). In 2007, Dalgic and Dane (2005) published a diagram depicting the now known tube-tip structural elements and physiological processes that facilitate tube elongation. The diagram represents a

Table 1.2 Meristems and their derivatives.*

Meristems	Derivatives
Primary	
Protoderm	Epidermis
From tunica (Evert, 2006)	
Procambium (provascular)	Primary xylem and phloem
From corpus (Evert, 2006)	Vascular cambium
Ground	Ground tissue: pith and cortex
Lateral	
Vascular cambium	
Fusiform initials	Secondary xylem Secondary phloem
Ray initials (Evert, 2006)	Ray cells
Cork cambium	
Phellogen Periderm (Evert, 2006)	Replaces the epidermis when cork cambium initiates stem girth increase; composed of 'boxlike' cork cells which are dead at maturity; protoplasm secretes suberin; some cork cells that are loosely packed give rise to lenticels which function in gas exchange between the air and the stem's interior. http://www.Biology-online.org, Evert (2006), http://www.vebrio.Sceince.vu.nl.en/virut
Phelloderm	Parenchyma cells produced on the inside by the cork cambium

* Meristems are discussed by Steeves and Sussex (1989).

Table 1.3 Plant tissues.

Tissue system			
Meristematic	Ground	Vascular	Dermal

significant advance over the early studies of pollen tubes as it assigns function to ultrastructural components, for example, signalling molecules, the Rho family of GTPases and phosphatidylinositol 4,5 bisphosphate appear to be localized in the apical plasma membrane. Besides pollen tubes, root hairs exhibit polar growth.

Cell organelles – an introduction

Organelles are required for plant growth, development and function (Sadava, 1993; Gillham, 1994; Herrmann, 1994, Agrawal, 2011). These organelles (Figure 1.7) are the loci for a myriad of physiological and biochemical processes (Tobin, 1992; Daniell and Chase, 2004 – see individual chapters).

There are many diagrams of a generalized plant cell. Some of these are available at www.explorebiology.com, http://www.daviddarling.info/images/plant_cell.jpg

Figure 1.4 SEM of a pecan leaf. Diagram of a leaf's interior is available at http://pics4learning.com. Source: Reproduced with permission of Asaf Gal.

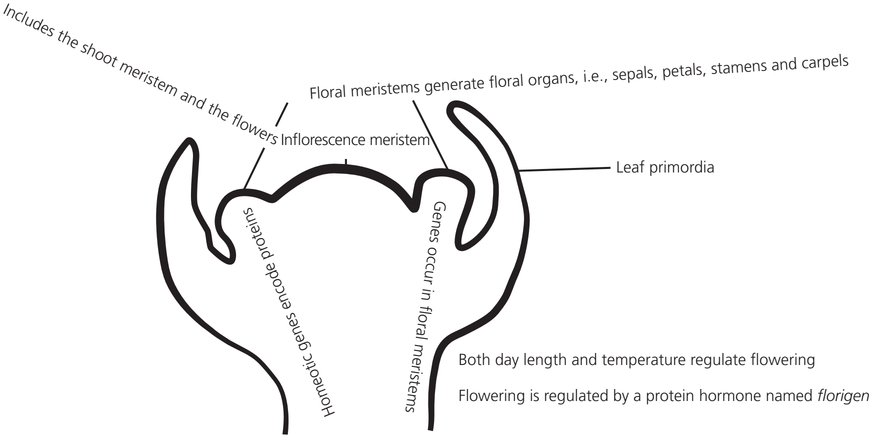


Figure 1.5 Schematic of the floral meristem.

and http://micromagnet.fsu.edu. The organelle contents of plant and animal cells in common and those unique to plant cells are depicted in Table 1.4. The dimensions of plant organelles are presented in Table 1.5. A plant organelle database (PODB) has been reviewed by Mano *et al*. (2008).

To enter a plant cell, molecules must traverse both the cell wall and the fluid mosaic plasmalemma (Singer and Nicolson, 1972; Leshem *et al*., 1991; Larsson and Miller, 1990). In contrast to the fluid mosaic model (Figure 1.8) of the plasmalemma,

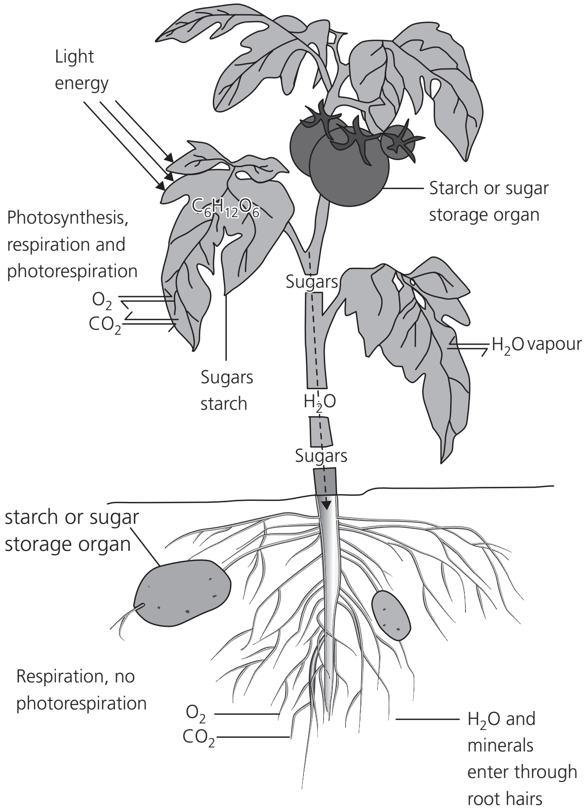


Figure 1.6 Diagram of angiosperm plant body. Source: From http://www.msu.edu/course/te/8021/science08plants/foods.html.

Figure 1.7 Electron micrograph of a plant cell and its organelles. Source: Reproduced with permission of H.J. Horner.

Table 1.4 Comparison of organelle contents of plant and animal cells.*

Organelle	Animal cell	Plant cell
Cell wall	Absent	Present
Centrioles	Present	Absent
Endoplasmic reticulum	Present	Present
Glyoxysomes	Absent	Present
Golgi apparatus	Present	Present
Microfilaments	Present	Present
Mitochondrion	Present	Present
Nucleus	Present	Present
Peroxisomes	Present	Present
Plastids	Absent	Present
Protein bodies	Absent	Present
Spindle	Present	Present
Vacuoles	Sometimes small	Present (mature cell – large central)

* Early discussions of plant cell organelles occur in Hongladarom *et al*. (1964), Pridham (1968), Reid and Leech (1980) and Tobin (1992).

Table 1.5 Dimensions of subcellular organelles.

Organelles	Dimension
Chloroplast	4–6 μm in diameter
Golgi apparatus	Individual cisternae, 0.9 μm Coated vesicles 50–280 μm in diameter
Microbodies	0.1–2.0 μm in diameter
Microtubules	0.5–1.0 μm in diameter
Mitochondria	1–10 μm
Nuclear envelope pores	30–100 μm in diameter
Nucleus	5–10 μm in diameter
Peroxisome	0.2–0.7 μm
Plasmodesmata	2–40 μm in diameter
Primary wall	1–3 μm
Protein bodies	2–5 μm in diameter
Vacuoles	30–90% of cell volume

the picket–fence model proposes the accumulation of membrane protein anchored in an actin network beneath the membrane (Kusumi *et al.*, 2012).

The plasmalemma is composed of water, protein and lipids. There are both integral and peripheral proteins (Leshem *et al.*, 1991). The integral proteins may be simple (classical α-helical structure that traverses the membrane only once) or complex (globular – composed of several α-helical loops which may span the membrane several times). Peripheral proteins can be easily isolated by altering

Fluid mosaic model of the plasmalemma

Consists of a lipid bilayer in which globular proteins are embedded; There are two types of proteins: integral and peripheral. Oliogsaccharides (2–20 monosaccharides) can be attached to the integral proteins. Phospholipids from the bilayer with a polar head on the outside and non-polar tails on the inside.

Fence model of the plasmalemma

There is a membrane skeleton with skeleton-anchored proteins and transmembrane proteins projected outwards into the cytoplasm. Cytoplasmic domains of proteins collide with the actin skeleton, yielding temporary confinement of the transmembrane proteins. The membrane can contain lipid rafts and related caveolae invaginations. The rafts are combinations of proteins and the lipids which may function in signalling. sphingolipids are prevalent in the rafts.

Picket model of the plasmalemma

Phospholipids can also be confined by the membrane skeleton. Some investigators combine the fence and picket models.

Figure 1.8 Top: Fluid mosaic model of the plasmalemma. Middle: Fence model of the plasmalemma. Bottom: picket model of the membrane.

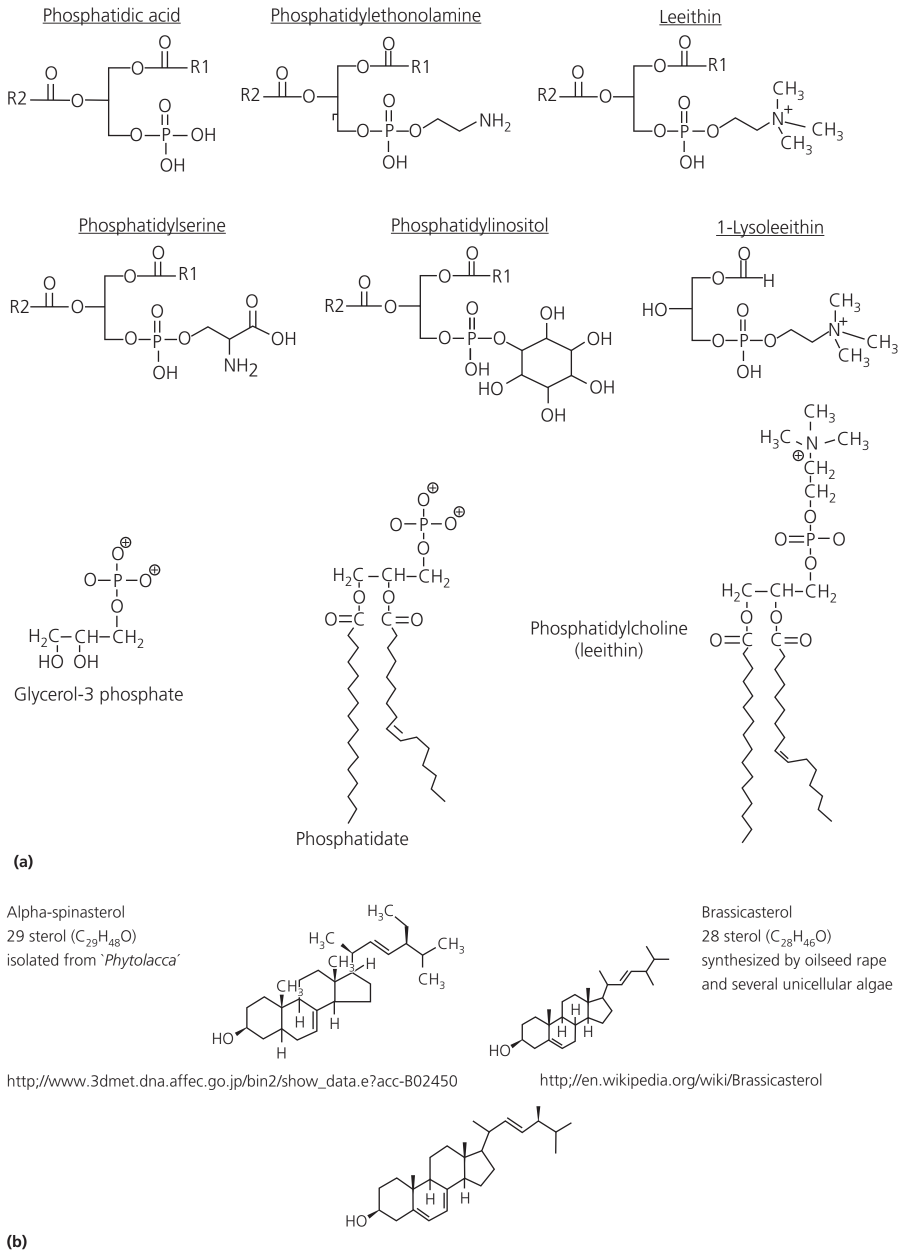
the ionic strength or pH of the encasing medium. The transport proteins are pumps, carriers or chemicals (see section on membrane transport). The lipids are electro-negative and anionic phospholipids, sphingolipids (Figure 1.9), chloroplast-specific glycerolipids and sterols (Table 1.6).

Lipid rafts are specialized phase domains containing sterols and sphingolipids which may be important in signal transitions (Gray, 2004; Furt *et al*., 2007; Grennan, 2007; Mongrand *et al*., 2004). Caveolae, which give rise to clathrin-coated vesicles (Brodsky *et al*., 2001), are anchored multifunctional platforms in lipids (Van Deurs *et al*., 2003; Patel and Insel, 2009).

The organization of the caveolae (Bastani and Parton, 2010) in the plasmalemma and clathrin-coated vesicles (Samaj *et al*., 2005) is presented in Figure 1.10. The current discussion focuses on membrane transport mechanism. Plants can internalize certain molecules by endocytosis via invaginations of the plasmalemma yielding clathrin-coated vesicles (Figure 1.11, Holstein, 2003) which become the endosome (Low and Chandra, 1994; Battey *et al*., 1999; Šamaj *et al*., 2006). Proteins involved in clathrin-dependent endocytosis appear to be clathrin, adaptor proteins and two adaptins (Pearse and Robinson, 1990; Šamaj *et al*., 2006). Plant endocytosis and endosomes (Contento and Bassham, 2012) seem to be significant in auxin-mediated cell–cell communication, gravity responses, stomatal movements, cytokinesis and cell wall morphogenesis (Šamaj *et al*., 2006).

Ion channels

Plasma membranes contain potassium (K$^+$), calcium (Ca^{++}) and anion channels (Roberts, 2006). Voltage-gated ion channels are transmembrane ion channels activated by changes in electrical potential. Gating is the precise control of ion channel opening (Krol and Trebacz, 2000). An example of an ion channel is the K$^+$ the



http;//www.3dmet.dna.affec.go.jp/bin2/show_data.e?acc-B02450

http;//en.wikipedia.org/wiki/Brassicasterol

Figure 1.9 Structures of (a) phospholipids and (b) sphingolipids.

inwardly potassium channel. This type of channel possesses a positive charge in the cell. Stomatal pore movements are mediated by a rise in intracellular K^+ and anion contents of guard cells (Schroeder and Hagiwara, 1989). Another example is the adenosine triphosphate (ATP) binding cassette transporter or ABC transporter. These transport toxic substances from the cell or into the vacuole. These

Table 1.6 Composition of certain cellular membranes.

Chemical composition	
Fatty acyl groups in membrane lipids 16:0, 16:1, t-16:1, 16:3, 18:0, 18:1, 18:2, α18:3, δ18:3, 18:4, 22:0, 22:1, 24:0, 24:1	
Electroneutral phospholipids	Phosphatidylcholine, phosphatidylethanol, phosphatidylethanolamine
Anionic phospholipids	Phosphatidylserine, phosphatidylglycerol, phosphatidylinositides
Lyo-phospholipids	Cerebrosides
Sphingolipids	Galactolipids, sulpholipids
Chloroplast-specific glycerolipids	Diphosphatidylglycerol and monophosphatidylglycerol
Mitochondrial phospholipids	
Sterols	Sitosterol Campesterol Stigmasterol Unusual sterols Cycloartenol Cholesterol, minute quantities
Sterol glycosides	
Lanosterol	Pathogenic fungal membranes
Water	
Extramembrane water	Membrane is a bilayer sandwiched between two layers of water Water located within the bilayer which is attached to or in approximate contact with the expanses of membrane constituents
Proteins	May cross the membrane once or several times and are linked either electrostatically or by means of biophysical lipophilicity to the inner domains of the bilayer
Integral proteins	
Simple integral proteins	Classic α-helical structure that traverses the membrane only once
Complex integral proteins	Globular – comprised of several α-helical loops that may span the membrane several times
Peripheral proteins	Associated with only leaflet–easily isolated by altering ionic strength or pH of the encasing medium
Transport proteins	Pumps, carrier and channel

Source: From Leshem *et al.* (1991).

transporters are composed of four core domains, two cytosolic nucleotide-binding proteins and two transmembrane domains (Malmstrom, 2006).

Besides cation channels there are anion channels regulated by voltage, but their activity is also influenced by Ca^{++}, ATP, phosphorylation or membrane stretching (Tyerman, 1992). Anion plasma membrane channels function as efflux channels when they are open.

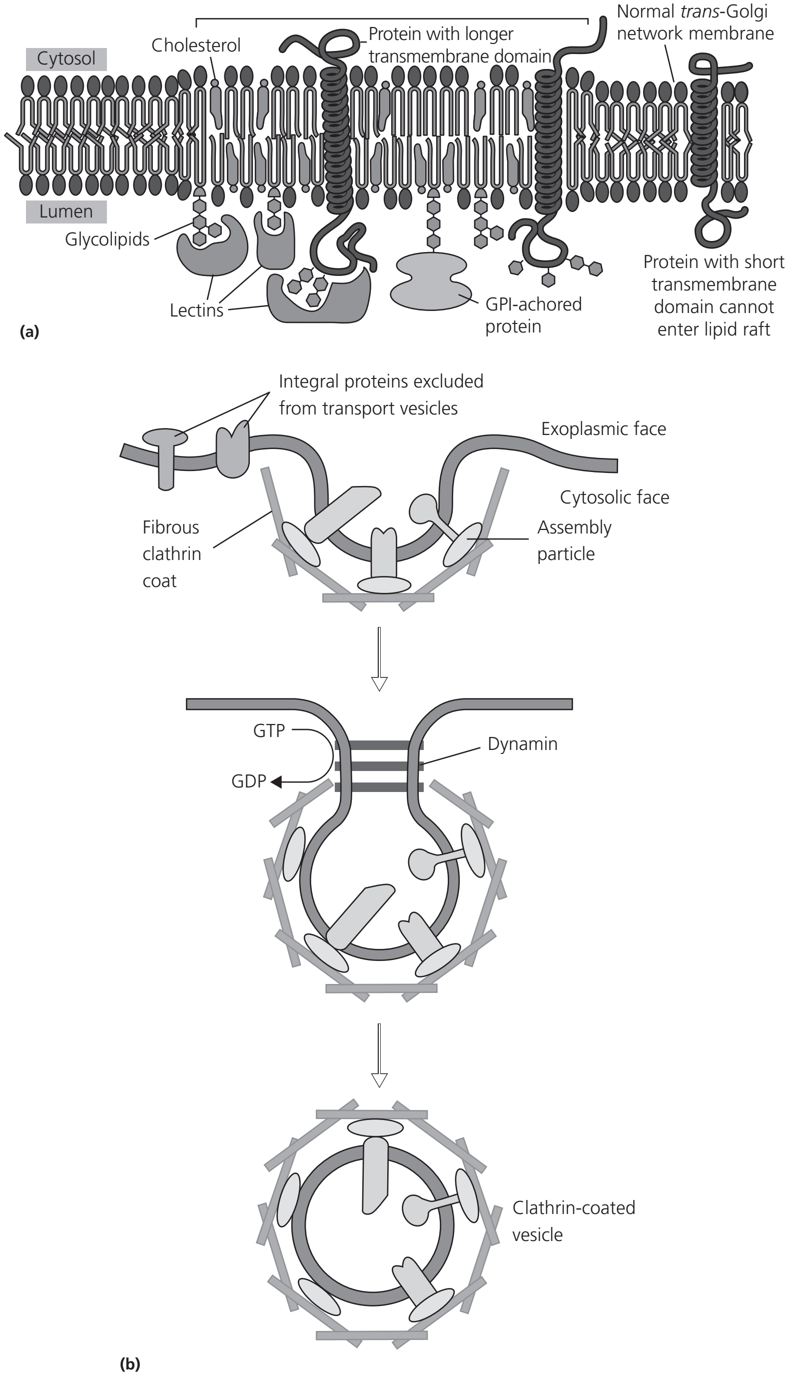
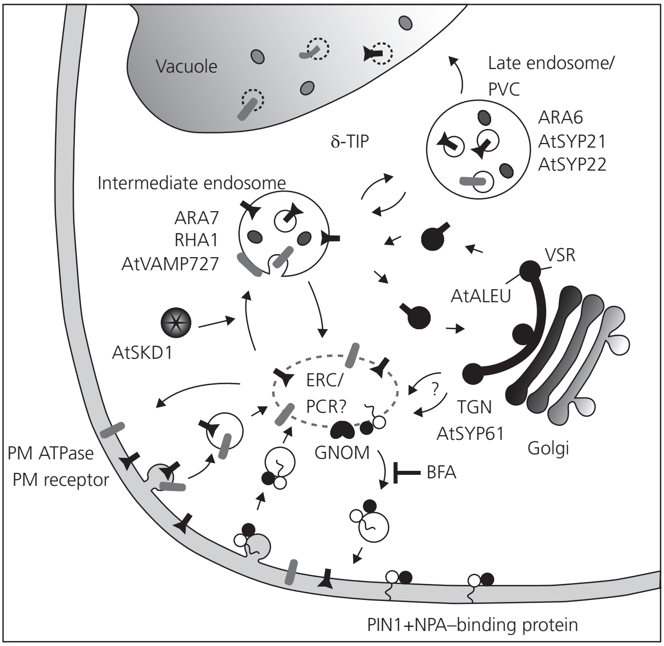


Figure 1.10 Depictions of a (a) lipid raft, (b) caveolae and a clathrin-coated vesicle. Source: Reproduced with permission of Caveolae and Clathrin Vesicle.



SVP – a syntaxin
GNOM – Plant-specific protein that participates in ADP-ribosylation
ESCRT – protein endosomal sorting complex
RHA – a member of the Rab GTPases function in trafficking pathways
ARA6 – a member of the Rab GTPases
SYP – a SNARE component of the late endosome
VSR – vacuolar sorting receptor
SKD – vacuolar protein suppressor
Ubiquitylation – signal that regulates the cell surface expression

Figure 1.11 Diagram of plant endocytosis. Source: Reproduced with permission of M. Otegui, University of Wisconsin.

Proton pumps

The transport of a substance against its electro channel gradient requires energy generated by ATP-proton pumps (Briskin and Hanson, 1992; Evert, 2006). One such pump is the V-ATPase found in both the plasmalemma and the tonoplast (Barkla and Pantoja, 1996; Vinay *et al.*, 2009). The H^+-ATPase in the plasmalemma is the P-ATPase which forms electrochemical gradients (Elmore and Coaker, 2011). Mitochondria and chloroplast membranes possess F-ATPases.

Water channels

Aquaporins are channel proteins which exist in the plasmalemma in intracellular spaces (Maurel *et al.*, 2008). These proteins permit water to move freely but exclude ions and metabolites (Chrispeels and Maruel, 1994; Muller *et al.*, 2007), providing for buffering osmotic fluctuations in the cytosol. Aquaporins are major intrinsic membrane proteins which are composed of four subunits, each of which comprises six transmembrane-spanning helices. Aquaporins are encoded by multiple gene families (Johansson *et al*., 1998).

Carriers

Carriers are unitransporters and co-transporters (Evert, 2006). Unitransporters transport only one solute from one side of the membrane to the other. On the contrary, co-transporters transfer one solute with the simultaneous or sequential transfer of another solute. A thorough discussion of membrane transport processes occurs in Malmstrom (2006).

Organelle structure and function can be influenced by a variety of environmental parameters which affect plant growth. A discussion of parameters is presented because of the increasing pollution of the earth's atmosphere and ecosystem. In addition, global climate change is a current issue of urgent concern (Dashek and McMillin, 2009).

Both major and minor elements are required for growth and development (Table 1.7). Metals and metalloids at elevated levels can result from mining (Dashek and McMillin, 2009). What effects do these levels have on the structure and function of cellular organelles? (See Lepp, 1981; Medioini *et al*., 2008; Yusuf *et al*., 2011; see also Table 1.8.)

Elevated levels of SO_2, CO_2, NO_2 and O_3 (Treshow and Anderson, 1989) can occur in the atmosphere as a result of industrial and contemporary activities. Table 1.9 presents the effects of certain gases (Bell and Treshow, 2002) on the structure and function of organelles. Of special interests are the increasing levels

Table 1.7 Major and minor elements required for plant growth and development.

Element		mg/kg	Minor or major
Nitrogen	N	15 000	Major
Potassium	K	10 000	Major
Calcium	Ca	5 000	Major
Magnesium	Mg	2 000	Major
Phosphorus	P	2 000	Major
Sulfur	S	1 000	Major
Chlorine	Cl	100	Minor
Iron	Fe	100	Minor
Boron	B	20	Minor
Manganese	Mn	50	Minor
Zinc	Zn	20	Minor
Copper	Cu	6	Minor
Molybdenum	Mo	0.1	Minor

Table 1.8 Toxic metals and metalloids.

Metal or metalloid	Toxic level effects	References
Aluminium	Affects root cells of plasmalemma	Mossor-Pietraszewska (2001)
Arsenic	Pale green to yellow lesions on leaves and necrosis of leaves Defoliation Impaired nitrogen metabolism Needle abscission	Treshow and Anderson (1989)
Cadmium	General chlorosis Reduced photosynthesis Reduced transpiration; toxic effects – changes in proline levels; changes in lipid peroxidation and seed germination	Treshow and Anderson (1989), Saadati *et al*. (2012) and Khateeb (2014)
Copper	Interference with normal metabolic reactions Blocks specific enzymatic reactions	Treshow and Anderson (1989) and Shah *et al*. (2001)
Chromium	Contamination Can promote white dead patches on leaves	Treshow and Anderson (1989) and Antonovics *et al*. (1971)
Lead	Condensation of nuclear chromatin; decrease in germination of two *Brassica* cultivars	Rout and Das (2003) and Hosseini *et al*. (2007)
Nickel	Dilution of nuclear membrane	Seregin and Kozhernikova (2006)
Zinc	Disruption of cortical cell	Rout and Das (2009)

Table 1.9 Effects of environmental pollutants on organelles.

Elevated CO_2		
	Stomatal openings reduce as CO_2 increases	Woodward *et al*. (1991)
	Affects both primary and secondary meristems of shoots and roots; alternation of leaf size and anatomy; increased branching and stem diameter	Pritchard *et al*. (1999)
	Increase in the number of mitochondria and amount of chloroplast stroma thylakoid membranes	Griffin *et al*. (2001)
	Stomatal densities decrease in two species of *Spartia*	Lammertsmaa *et al*. (2011)
Acid rain	Leaching of nutrients on tree needles; damages surfaces of needles and leaves and reduces a tree's ability to withstand cold	Godbold and Hüttermann (1994), Schulze *et al*. (2000) and White and Terninko (2003)
Nitric oxide	Necrotic lesions, marginal chlorosis	Lamattina and Polacco (2007)
Ozone and its derivatives	Changes in metabolism	Roshchina and Roshchina (2003)

of CO_2 in the atmosphere, which many scientists believe causes global warming (Dashek and McMillin, 2009). Table 1.10 offers the effects of sublethal and lethal temperatures on organelles. Franklin and Wigge (2014) discuss the effects of temperature on plant development. Other environmental parameters which can

Table 1.10 Effects of temperature or subcellular organelles.*

Temperature	Effect	Reference
Sublethal	Swollen chloroplasts and loss of chlorophyll in *Elodea* leaves	Quinn (1988)
Lethal	Plasmolysis of *Elodea* and soybean leaves; disintegration of cellular membranes	Daniell *et al*. (1969)

* Other effects of elevated temperature are on photosynthetic activities (Weis and Berry, 1988) and the plant immune response (Franklin and Wigge, 2014).

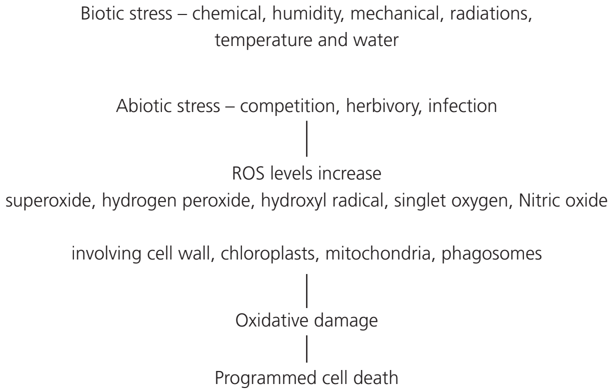


Figure 1.12 Reactive oxygen species (ROS) and plant cell death.

affect organelle structure and function are radiation (Parida *et al*., 2002; Mokobia and Anomohanran, 2005; Borzouei *et al*., 2012) and salinity (Bennici and Tani, 2009; Kumar *et al*., 2013).

Cell death

In certain mammalian systems, there appear to be two apoptotic pathways: extrinsic and intrinsic. Whereas the extrinsic pathway involves death receptor liquids, in the intrinsic pathway a variety of factors act upon mitochondria to promote loss of mitochondrial membrane potential. Whether these two pathways are significant in plant apoptosis remains to be established with certitude. Programmed cell death in plants (Bryant *et al*., 2000) is viewed as a normal phase of development (Gray, 2004; Lam, 2008). These authors state that little is known about how plant cell death occurs and is regulated. However, reactive oxygen species (ROS) seem to be involved (Karuppanapandian *et al*., 2011 – Figure 1.12). Fragmentation of nuclear DNA, involvement of Ca^{++}, alterations in protein phosphorylation, increases in nuclear heterochromatin and involvement of ROS seem to occur. Beers *et al*. (2000) conclude that proteases may possess a role in programmed cell death. In animals, caspases are significant components of programmed cell death. Although caspase attributes have been detected in plants, a role for these proteases in plant cell death is unclear (Lam, 2006). Lastly, van Doorn (2011) distinguished between ureolytic and non-ureolytic cell death. Whereas the former involves tonoplast rupture and subsequent destruction of the cytoplasm, the latter includes tonoplast rupture but not cytoplasmic destruction.

Finally, aspects of plant cells can be found in the following general plant cell biology textbooks: Batra (2009), Dashek and Harrison (2006), Gupta (2004), Pandian (2008), Pickett-Heaps and Pickett-Heaps (1994) and Wayne (2009).

References

Agrawal, G.K. (2011) Plant organelle proteomics: collaborating for optimal cell function. *Mass Spectrometry Reviews*, **30**, 772–853.

Alosi, M.C. and Alfieri, F.J. (1972) Ontogeny and structure of the secondary phloem in Ephedra. *American Journal of Botany*, **59** (8), 818–827.

Antonovics, J., Bradshaw, A.D. and Turner, R.G. (1971) Heavy metal tolerance in plants. *Advances in Ecological Research*, **7**, 1–85.

Arsovskia, A.A., Haughn, G.W. and Western, T.L. (2010) Seed coat mucilage cells of *Arabidopsis thaliana* as a model for plant cell wall research. *Plant Signaling and Behavior*, **5** (7), 796–801.

Assmann, S. and Liu, B. (2014) *Cell Biology (The Plant Sciences)*, Springer-Verlag, New York, NY.

Barkla, B.J. and Pantoja, O. (1996) Physiology of ion transport across the tonoplast of higher plants. *Annual Review Plant Physiology and Plant Molecular Biology*, **47**, 159–184.

Bastani, M. and Parton, R.G. (2010) Caveolae at a glance. *Journal of Cell Science*, **123**, 3831–3836.

Batra, V. (2009) *Plant Cell Biology*, Oxford Book Company, Oxford, UK/New York, NY.

Battey, N.H., James, N.C., Greenland, A.J. *et al*. (1999) Exocytosis and endocytosis. *The Plant Cell*, **11**, 643–660.

Beck, C.B. (2005) *An Introduction to Plant Structure and Development*, Cambridge University Press, Cambridge, UK.

Beck, C.B. (2009) *An Introduction to Plant Structure and Development: Plant Anatomy for the Twenty-First Century*, Cambridge University Press, Cambridge, UK.

Beers, E.P., Woofenden, B.J. and Zhao, C. (2000) Plant proteolytic enzymes: possible roles during programmed cell death. *Plant Molecular Biology*, **44**, 399–415.

Bell, J.N.B. and Treshow, M. (2002) *Air Pollution and Plant Life*, John Wiley & Sons, Inc., Chichester, UK.

Bennici, A. and Tani, C. (2009) Ultrastructural effects of salinity in Nicotiana bigelovii var. bigelovii callus cells and Allium cepa roots. *Caryologia*, **62** (2), 124–133.

Bergmann, D.C. and Sack, F.D. (2007) Stomatal development. *Annual Review of Plant Biology*, **58**, 163–168.

Blázquez, M.A., Green, R., Nilsson, O., Sussman, M.R. and Weigela, D. (1998) Gibberellins promote flowering of Arabidopsis by Activating the *LEAFY* promoter. *The Plant Cell*, **10**, 791–800.

Borzouei, A., Kafi, M., Akbari-Ghogdi, E. and Mousavi-Shalmani, M. (2012). Longterm salinity stress in relation to lipid peroxidation, super oxide dismutaseactivity and proline content of salt sensitive and salt-tolerant wheat cultivars. *Chilean Journal of Agricultural Research*, **72**, 476–482.

Briskin, D.P. and Hanson, J.B. (1992) How does the plant plasma membrane H^+-ATPase pump protons? *Journal of Experimental Botany*, **43** (3), 269–289.

Brodsky, F.M., Chen, C.Y., Knuehl, C. *et al*. (2001) Biological basket weaving: formation and function of clathrin-coated vesicles. *Annual Review of Cell and Developmental Biology*, **17**, 517–568.

Bryant, J.A., Hughes, S.F. and Garland, J. (2000) *Programmed Cell Death in Animals and Plants*, Taylor & Francis, Abingdon, UK.

Callow, J.A. (2000) *Plant Trichomes*, 1st ed, Academic Press, London, UK.

Chrispeels, M.J. and Maurel, C. (1994) Aquaporins: the molecular basis of facilitated water movement through living plant cells? *Plant Physiology*, **105**, 1, 9–13.

Contento, A.L. and Bassham, D.G. (2012) Structure and function of endosomes and plant cells. *Journal of Cell Science*, **125**, 1–8.

Dalgic, O. and Dane, F. (2005) Some of the molecular components of pollen tube growth and guidance. *Asian Journal of Plant Science*, **4**, 702–710.

Daniell, H. and Chase, C. (2004) *Molecular Biology and Biotechnology of Plant Organelles*, Springer, New York, NY.

Daniell, J.W., Chapell, W.E. and Couch, H.B. (1969) Effect of sublethal and lethal temperature on plant cells. *Plant Physiology*, **44**, 1684–1689.

Dashek, W.V. and Harrison, M. (2006) *Plant Cell Biology*, Science Publishers, Enfield, NH.

Dashek, W.V. and McMilin, D.E. (2009) *Biological Environmental Science*, Science Publishers, Enfield, NH.

Dashek, W.V., Thomas, H.R. and Rosen, W.G. (1971) Secretory cells of lily pistils II: electron microscope cytochemistry of canal cells. *American Journal of Botany*, **58**, 909–920.

Efroni, I., Eshed, Y. and Lifschitz, E. (2010) Morphogenesis of simple and compound leaves: review. *The Plant Cell*, **22**, 1019–1032.

Elmore, J.M. and Coaker, G. (2011) The role of the plasma membrane H^+-ATPase in plant-microbe interaction. *Molecular Plants*, **4**, 416–427.

Evert, R. (2006) *Esau's Plant Anatomy Meristems, Cells and Tissues: Their Structure, Function and Development*, John Wiley & Sons, Inc., Chichester, UK.

Fosket, D.E. (1999) *Plant Growth and Development: A Molecular Approach*, Academic Press, New York, NY.

Franklin, K. and Wigge, P. (2014) *Temperature and Plant Development*, Wiley-Blackwell, Chichester, UK.

Fukuda H. 2004. Signals that control plant vascular cell differentiation. *Nature Reviews Molecular Cell Biology*, **5**, 379–391.

Furt, F., Lefebvre, B., Gullimore, J. *et al*. (2007) Plant lipid rafts. *Plant Signaling and Behavior*, **2**, 508–511.

Gillham, N.W. (1994) *Organelle Genes and Genomes*, Oxford University Press, Oxford, UK.

Glover, B.J. (2007) *Understanding Flowers and Flowering: An Integrated Approach*, Oxford University Press, Oxford, UK.

Godbold, D.L. and Hüttermann, A. (1994) *Effects of Acid Rain and Forest Processes*, Wiley-Liss, New York, NY.

Gray, J. (2004) *Programmed Cell Death in Plants*, CRC Press, Boca Raton, FL.

Greenland, A.J. (2003) *Control of Plant Development*, Garland Science, London, UK.

Grennan, A.K. (2007) Lipid rafts in plants. *Plant Physiology*, **143**, 1083–1085.

Griffin, K.L., Anderson, O.R., Gastrich, M.D., Lewis, J.D., Lin, G. *et al*. (2001) Plant growth in elevated CO_2 alters mitochondrial number and chloroplast fine structure. *Proceedings of the National Academy of Sciences of the United States of America*, **98** (5), 2473–2478.

Gunning, B.E.S. (2009) *Plant Cell Biology on DVD*, Springer, New York, NY.

Gupta, G.P. (2004) *Plant Cell Biology*, Discovery, New Delhi, India.

Hake, S., Smith, H. and Magnani, E. *et al*. (2004) The role of genes in plant development. *Annual Review of Cell and Developmental Biology*, **20**, 125–151.

Hepler, P.K., Vidali, L. and Cheung, A.Y. (2001) Polarized cell growth in higher plants. *Annual Review of Cell and Developmental Biology*, **117**, 159–187.

Herrmann, R.G. (1994) *Cell Organelles (Plant Gene Research)*, Springer, New York, NY.

Holstein, S.H.E. (2003) Clathrin and plant endocytosis. *Traffic*, **3**, 614–620.

Hongladarom, T., Shigeru, I., Honda, S.I. and Wildman, S.G. (1964) *Organelles in Living Plant Cells*. Videotape available from University of California Extension Center for Media and Independent Learning, Berkeley, CA.

Hosseini, R.-H., Khanlarian, M. and Ghorbanti, M. (2007) Effect of lead on germination, growth and activity of catalase and peroxidase enzyme in root and shoot of two cultivars of *Brassica napus* L. *Journal of Biological Sciences*, **7**, 592–598.

Howell, S.H. (1998) *Molecular Genetics of Plant Development*, Cambridge University Press, Cambridge, UK.

Huang, T., Bohlenius, H., Erikssans, S. *et al*. (2005) The mRNA of the *Arabidopsis* gene *FT* moves from leaf to shoot apex and induces flowering. *Science*, **309**, 1694–1696.

Johansson, I., Karlsson, M., Shukla, V.K., Chrispeels, M.J., Larsson, C. and Kjellbom, P. (1998) Water transport activity of the plasma membrane aquaporin PM28A is regulated by phosphorylation. *The Plant Cell*, **10**, 451–459.

Karuppanapandian, T., Moon, J.-C., Kim, C. *et al*. (2011) Reactive oxygen species in plants. Their generation, signal transduction and scavenging mechanisms. *Australian Journal of Crop Science*, **5**, 709–725.

Kemi, U., Nittyvuopo, A., Tolvaines, T. *et al*. (2013) Role of vernalization and of duplicated FLOWERING LOCUS C in the perennial *Arabidopsis lyrata*. *The New Phytologist*, **197**, 323–335.

Khateeb, W.A. (2014) Cadmium-induced changes in germination, seedlings growth, and DNA fingerprinting of '*in vitro*' grown *Cichorium pumilum* Jacq. *International Journal of Biology*, **6**, 65 pp.

Kinmonth-Schultz, H.A., Golembeski, G.S. and Imaizumi, T. (2013) Circadian clock-regulated physiological outputs: dynamic responses in nature. *Seminars in Cell and Developmental Biology*, **24** (5), 407–413.

Krol, E. and Trebacz, K. (2000) Ways of ion channel gating in plant cells. *Annals of Botany*, **86** (3), 449–469.

Kumar, S., Gupta, R., Kumar, G., Sahoo, D. and R.C. Kuha (2013) Bioethanol production from *Gracilaria verrucosa*, a red alga, in a biorefinery approach. *Bioresource Technology*, **135**, 150–156.

Kusumi, A., Fujiwara, T., Morone, N., *et al*. (2012). Membrane mechanisms for signal transduction: the coupling of the meso-scale raft domains to membrane-skeleton-induced compartments and dynamic protein complexes. *Seminars in Cell and Developmental Biology*, **23**, 126–144.

Lam, E. (2006) Plant programmed cell death. *eLS*, doi:10.1002/9780470015902.a0001689.pub2.

Lam, E. (2008) Programmed cell death in plants: orchestrating an intrinsic suicide program within walls. *Critical Reviews in Plant Sciences*, **27**, 413–423.

Lamattina, L. and Polacco, J. (2007) *Nitric Oxide in Plant Growth, Development and Stress Physiology*, Plant Cell Monographs, Springer, New York, NY.

Lammertsmaa, E.I., de Boerb, H.J., Dekkerb, S.C., Dilcherc, D.L., Lottera, A.F. and Wagner-Cremera, F. (2011) Global CO_2 rise leads to reduced maximum stomatal conductance in Florida vegetation. *Proceedings of the National Academy of Sciences of the United States of America*, **108** (10), 4035–4040.

Larsson, C. and Miller, I.M. (1990) *The Plant Plasma Membrane. Structure, Function and Molecular Biology*, Springer, New York, NY.

Lepp, N.W. (1981) *Effects of Heavy Metal Pollution on Plants*, Applied Science Publishers, London, UK.

Lersten, N.R. and Curtis, J.D. (1996) Survey of leaf anatomy, especially secretory structures, of tribe Caesalpinieae (Leguminosae, Caesalpinioideae). *Plant Systematics and Evolution*, **200**, 21–39.

Lersten, N.R. and Horner, H.T. (2005) Macropattern of styloid and druse crystals in Quillaja (Quillajaceae) bark and leaves. *International Journal of Plant Science* **166**, 705–711.

Lersten, N.R., Czlapinski, A.R., Curtis, J.D., Freckmann, R. and Horner, H.T. 2006. Oil bodies in leaf mesophyll cells of angiosperms: Overview and a selected survey. *American Journal of Botany*, **93** (12), 1731–1739.

Leshem, Y.Y., Shewfelt, R.L., Willner, C.M. and Pantoja, O. (1991) *Plant Membranes: A Science*, Elsevier, New York, NY.

Leyser, O. and Day, S. (2003) *Mechanisms in Plant Development*, Blackwell, Malden, MA.

Low, P.S. and Chandra, S. (1994) Endocytosis in plants. *Annual Review of Plant Physiology and Plant Molecular Biology*, **45**, 609–631.

Lyndon, R.F. (1998) *The Shoot Apical Meristem: Its Growth and Development*, Cambridge University Press, Cambridge, UK.

MacAdam, J.W. (2009) *Structure and Function of Plants*, Wiley-Blackwell, New York, NY.

Maeda, E. and Maeda, K. (1988) Ultrastructural studies of leaf hydathodes. *Japanese Journal of Crop Science*, **57** (4), 733–742.

Malho, R. (2006a) *The Pollen Tube: A Cellular and Molecular Perspective*, Springer-Verlag, Berlin, Germany.

Malho, R. (2006b) The pollen tube: a model system for cell and molecular biology studies. *Plant Cell Monographs*, **3**, 10.1007/7089_041.

Malmstrom, S. (2006) Movement of molecules across membranes. In: *Plant Cell Biology* (Dashek, W.V. and Harrison, M., eds), Science Publishers, Enfield, NH, pp. 131–196.

Mano, S., Miwa, T., Nishikawa, S. *et al.* (2008) The plant organelles database (PODB): a collection of visualized plant organelles and protocols for plant organelle research. *Nucleic Acids Research*, **36** Database issue, D929–D937.

Maurel, C., Verdoucq, L., Luu, D.T. *et al.* (2008) Plant aquaporins: membrane channels with multiple integrated functions. *Annual Review of Plant Biology*, **59**, 595–624.

Mazumdar, R.C. (2013) *Photoperiodism and Vernalization in Plants*, Daya Publishing House, New Delhi, India.

McManus, H. and Veit, B.E. (2001a) Meristematic tissues. In: *Plant Growth and Development*, Sheffield Academic Press, New York, NY.

Medioini, C., Holune, G., Chaboute, M.E. *et al.* (2008) *Cadmium and Copper Genotoxicity in Plants*, Springer, New York, NY.

Micol, J.L. and Hake, S. (2003) The development of plant leaves. *Plant Physiology*, **131**, 389–394.

Mokobia, C.E. and Anomohanran, O. (2005) The effect of gamma irradiation on the germination and growth of certain Nigerian agricultural crops. *Journal of Radiological Protection*, **25**, 181.

Mongrand, S., Morel, J., Laroche, J., Claverol, S., Carde, J.P., Hartmann, M.A., *et al.* (2004). Lipid rafts in higher plant cells purification and characterization of triton X-100-insoluble microdomains from tobacco plasma membrane. *The Journal of Biological Chemistry*, **279**, 36277–36286.

Moore, A.L. and Clark, R.B. (1995) *Botany, Plant, Form and Function*, Win C. Brown Publ., Dubuque, IA.

Mossor-Pietraszewska, T. (2001) Effect of aluminum on plant growth and metabolism. *Acta Biochimica Polonica*, **48** (3), 673–686.

Muller, J., Mettback, U., Menzel, D. *et al.* (2007) Molecular dissection of endosomal compartments in plants. *Plant Physiology*, **145**, 293–304.

Murray, J.A.H. (2012) Systems analysis of shoot apical meristem growth and development. *The Plant Cell*, **24**, 3907–3919.

Naidoo, Y. and Naidoo, G. (1998) *Sporobolus virginicus* leaf salt glands: morphology and ultrastructure. *South African Journal of Botany*, **64**, 198–204.

Nicolson, S.W. and Nepi, M. (2005) Dilute nectar in dry atmosphere: nectar secretion patterns in *Aloe castanea* (Asphodelaceae). *International Journal of Plant Sciences*, **166**, 227–233.

Noguchi, T., Kawano, S., Tsukaya, H. *et al.* (2014) *Atlas of Plant Cell Structure*, Springer, New York, NY.

Offler, C.E., McCurdy, D.W., Patrick, J.W. *et al.* (2003) Transfer cells: cells specialized for a special purpose. *Annual Review of Plant Biology*, **54**, 431–454.

Oparka, K.J. and Turgeon, R. (1999) Sieve elements and companion cells—traffic control centers of the phloem. *The Plant Cell*, **11**, 739–750.

Oross, J.W., Leonard, R.T. and Thomson, W.W. (1985) Flux rate and a secretion model for salt gland of grasses. *Israel Journal of Botany*, **34**, 69–77.

Paiva, E.A.S. (2009) Ultrastructure and post-floral secretion of the pericarpial nectaries of *Erythrina speciosa* (Fabaceae). *Annals of Botany*, **104**, 937–944.

Pandian, I.D. (2008) *Botanical Analysis of Plant Cell*, A.K. Pub., New Delhi, India.

Parida, A., Das, A.B. and Das, P. (2002) NaCl stress causes changes in photosynthetic pigments, proteins and other metabolic components in the leaves of a true mangrove, *Bruguiera parviflora*, in hydroponic cultures. *Journal of Plant Biology*, **45**, 28–36.

Parton, R.M., Fischer-Parton, S., Watahiki, M.K. *et al.* (2001) Dynamics of the apical vesicle accumulation and the rate of growth are related in individual pollen tubes. *Journal of Cell Science*, **114**, 2685–2695.

Patel, H.H. and Insel, P.A. (2009) Lipid rafts and caveolae and their role in compartmentation of index signaling. *Antioxidants and Index Signaling*, **11**, 1357–1372.

Pearse, B.M.F. and Robinson, M.S. (1990) Clathrin, adaptors, and sorting. *Annual Review of Cell Biology*, **6**, 151–171.

Pickard, W.F. (2008) Laticifers and secretory ducts: two other tube systems in plants. *The New Phytologist*, **177**, 877–888.

Pickett-Heaps, J.D. and Pickett-Heaps, J. (1994) *VHS: Living Cells: Structure and Diversity*, Sinauer Associates Inc., Sunderland, MA.

Pridham, J.B. (1968) *Plant Cell Organelles*, Academic Press Inc., New York, NY.

Pritchard, S.F., Rogers, H.H., Prior, S.A. *et al.* (1999) Elevated CO_2 and plant structure: a review. *Global Change Biology*, **5**, 807–837.

Quinn, P.J. (1988) Effects of temperature on cell membranes. *Symposia of the Society for Experimental Biology*, **42**, 237–258.

Reid, R.A. and Leech, R.M. (1980) *Biochemistry and Structure of Cell Organelles*, Blackie, Glasgow, UK.

Roberts, S.K. (2006) Plasma membrane anion channels in higher plants and their putative functions in roots. *The New Phytologist*, **169**, 647–666.

Rodelas, A.J.D., Regalodo, E.S., Bela-ong, D.B. *et al.* (2008) Isolation and characterization of the oil bodies and oleosin of coconut (*Cocos nucifera* L.). *The Philippine Agricultural Scientist*, **91**, 389–394.

Roshchina, V.V. and Roshchina, V.D. (2003) *Ozone and Plant Cell*, Springer, New York, NY.

Rout, G. and Das, P. (2003) Effect of metal toxicity on plant growth and metabolism: I. Zinc. *Agronomie*, **23** (1), 3–11.

Rout, G.R. and Das, P. (2009) Effect of metal toxicity in plant growths and metabolism. I, Zinc. *Sustainable Agriculture*, **33**, 873–884.

Saadati, M., Motesharezadeh, B. and Ardala, M. (2012) Study of concentration changes of proline and potassium for two varieties of pinto beans under cadmium stress. *International Research Journal of Applied and Basic Sciences*, **3**, 344–352.

Sachs, T. (2005) *Pattern Formation in Plant Tissues*, Cambridge University Press, Cambridge, UK.

Sadava, D. (1993) *Cell Biology: Organelles, Structure and Function*, Jones and Bartlett, Sudbury, MA.

Sajeva, M. and Mauseth, J.D. (1991). Leaflike structure in the photosynthetic, succulent stem of cacti. *Annals of Botany*, **68**, 405–411.

Samaj, J., Read, N.D., Volkmann, D. *et al.* (2005) The endocytic network in plants. *Trends in Cell Biology*, **15**, 425–433.

Šamaj, J., Müller, J., Beck, M., Böhm, N. and Menzel, D. (2006) Vesicular trafficking, cytoskeleton and signalling in root hairs and pollen tubes. *Trends in Plant Science*, **11** (12), 594–600.

Sauter, J.J., Dorr, I. and Kollmann, R. (1976) The ultrastructure of Strasburger cells (=albuminous cells) in the secondary phloem of *Pinus nigra* var. *austraiaca* (Hoess) Badoux. *Protoplasma*, **88**, 31–49.

Schroeder, J.I. and Hagiwara, S. (1989) Cytosolic calcium regulates ion channels in the plasma membrane of *Vicia faba* guard cells. *Nature*, **338**, 427–430.

Schulze, E.-D., Högberg, P., vanOene, H., Persson, T., Harrison, A.F., Read, D., Kjøller, A. and Matteucci, G. (2000) Interactions between the carbon- and nitrogen cycle and the role of biodiversity: a synopsis of a study along a north-south transect through Europe, in: *Carbon and Nitrogen Cycling in European Forest Ecosystems, Ecological Studies* (Schulze, E.-D., ed), Springer Verlag, Heidelberg, Germany.

Seregin, I. and Kozhevnikova, A. (2006) Physiological role of nickel and its toxic effects in higher plants. *Russian Journal of Plant Physiology*, **5**, 251–277.

Shah, K., Kumar, R.G., Verma, S. and Dubey, R.S. (2001). Effect of cadmium on lipid peroxidation, superoxide anion, germination and activities of antioxidant enzymes in rice seedlings. *The Plant Science*, **161**, 1135–1144.

Shresth, R., Gómez-Ariza, J., Brambilla, V. and Fornara, F. (2014) Molecular control of seasonal flowering in rice, arabidopsis and temperate cereals. *Annals of Botany*, **114** (7), 1445–1458.

Singer, S.J. and Nicolson, G.L. (1972) The fluid mosaic model of the structure of cell membranes. *Science*, **175**, 720–731.

Sinha, N. (1999) Leaf development in angiosperms. *Annual Review of Plant Physiology and Plant Molecular Biology*, **50**, 419–446.

Soltis, D., Soltis, P. and Leeben-Mack, J. (2006) *Developmental Genetics of the Flower*, Academic Press, New York, NY.

Steeves, T.A. and Sussex, I.M. (1989) *Patterns in Plant Development: A Molecular Approach*, Academic Press, New York, NY.

Tan, W., Lim, T. and Loh, C. (2010) A simple, rapid method to isolate salt glands for three-dimensional visualization, fluorescence imaging and cytological studies. *Plant Methods*, **6**, 24.

Taoka, K., Chai, I., Tsuji, H. *et al.* (2013) Structure and function of florigen and the receptor complex. *Trends in Plant Science*, **14**, 287–294.

Taylor, L.P. and Hepler, P. (1997) Pollen germination and tube growth. *Annual Review of Plant Physiology and Plant Molecular Biology*, **48**, 461–491.

Thomson, W.W., Faraday, C.D. and Oross, J.W. (1988) Salt glands. In: *Solute Transport in Plant Cells and Tissues* (Baker, D.A. and Hall, J.L., eds), Longman Scientific and Technical, Harlow, Essex, UK, pp. 498–537.

Tobin, A.K. (1992) *Plant Organelles: Compartmentation of Metabolism in Photosynthetic Tissue*, Cambridge University Press, Cambridge, UK.

Treshow, M. and Anderson, F.K. (1989) *Plant Stress from Air Pollution*, John Wiley & Sons, Inc., Chichester, UK.

Turck, F., Formara, F. and Coupland, G. (2008) Regulation and identity of florigen: FLOWERING LOCUS T moves center stage. *Annual Review of Plant Biology*, **59**, 573–594.

Tyerman, S.D. (1992) Anion channels in plants. *Annual Review of Plant Physiology and Plant Molecular Biology*, **43**, 351–373.

Tyree, M.T. and Zimmermann, M.H. (2002) *Xylem Structure and the Ascent of Sap*, Springer Science and Business Media, Berlin, Germany.

van Deurs, B.V., Roepstorff, K., Hommelgaard, A.M. *et al.* (2003) Caveolae: anchored, multifunctional platforms in the lipid ocean. *Trends in Cell Biology*, **13**, 92–100.

Van Doorn, W.G. (2011) Classes of programmed cell death in plants, compared to those in animals. *Journal of Experimental Botany*, **62**, 4749–4761.

Vinay, S., Nilima, L.K. and Blunni, N.T. (2009) V-ATPase in plants: an overview structure and role in plants. International Journal of Biotechnology and Biochemistry, **22**, High Beam Research 23, http:www.highbeam.com (accessed May 24, 2016).

Wayne, R.O. (2009) *Plant Cell Biology: From Astronomy to Zoology*, Academic Press, New York, NY.

Weis, E. and Berry, J.A. (1988) Plants and high temperature stress. *Symposia of the Society for Experimental Biology*, **42**, 329–346.

Western, T.L., Skinner, D.J., and G.W. Haughn. (2000) Differentiation of mucilage secretory cells of the Arabidopsis seed coat. *Plant Physiology*, **122**, 345–355.

White, J.C. and Terninko, J. (eds.) (2003) Acid rain: Are the Problems Solved? Conference proceedings. Sponsored and organized by the Center for Environmental Information, Washington, DC, May 2–3, 2001. American Fisheries Society, Bethesda, MD.

Wille, A.C. and Lucas, W.J. (1984) Ultrastructural and histochemical studies on guard cells. *Planta*, **160** (2), 129–142.

Woodward, F.I., Thompson, G.B. and McKee, I.F. (1991) The effects of elevated concentrations of carbon dioxide on individual plants, populations, communities and ecosystems. *Annals of Botany*, **67**, 23–38.

Yang, Z. and Liu, B. (2007) Celebrating plant cells: a special issue on plant cell biology. *Journal of Integrative Plant Biology*, **49**, 1089–1278.

Yang, Y., Klejinot, Y., Yu, X. *et al.* (2007) Florigen (II) mobile protein. *Journal of Integrative Plant Biology*, **49**, 1665–1669.

Yusuf, M., Faridudchin, Q., Hugart, S. and Ahmod, D. (2011) Nickel an overview of and toxicity in plants. *Environmental Toxicology*, **86**, 11–17.

Zeevaart, J.A. (2006) Florigen coming of age after 70 years. *The Plant Cell*, **18**, 1783–1789.

Zhang, X., Zhang, L., Dong, F., Gao, J., Galbraith, D.W. and Song, C.P. (2001). Hydrogen peroxide is involved in abscisic acid-induced stomatal closure in *Vicia faba*. *Plant Physiology*, **126**, 1438–1448.

Further reading

Alberts, B., Johnson, A., Lewis, J., *et al.* (2014) *Molecular Biology of the Cell*, 6th edition, Garland Science, New York.

Buchanan, B. and Gruissem, W. (2015) *Biochemistry and Molecular Biology of Plants*, Wiley, Chichester, UK.

Mano, S., Miwa, T., Nishikawa, S., Mimura, T. and Nishimura, M. (2011) The plant organelle databases 2 (PODB2): An updated resource containing movie data of plant organelle dynamics, *Plant Cell Physiology*, **52** (2), 244–253.

Mano, S., Nakamura, T., Kondo, M. *et al.* (2014) The plant organelles database 3 (PODB3) Update 2014: Integrating electron micrographs and new options for plant organelle research, *Plant Cell Physiology*, **55** (1), e1, doi: 10.1093/pcp/pct140.

Nick, P. and Opatrny, Z. (2014) *Applied Plant Cell Biology: Cellular Tools and Approaches for Plant Biotechnology*, Springer, New York, NY.

Plopper, G., Sharp, D. and Sikorski, E. (2015) *Lewin's Cells*, 3rd edition, Jones & Bartlett, New York.