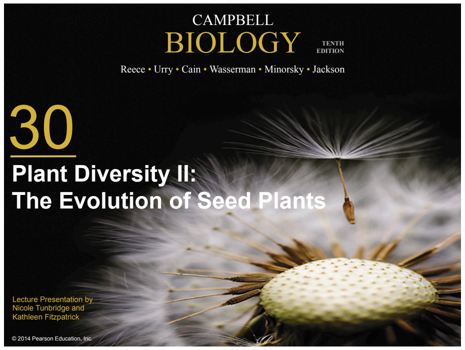


Transforming the World

- Seeds changed the course of plant evolution, enabling their bearers to become the dominant producers in most terrestrial ecosystems
- Seed plants originated about 360 million years ago
- A **seed** consists of an embryo and nutrients surrounded by a protective coat
- Seeds can disperse over long distances by wind or other means

Figure 30.1

Figure 30.1a

Fireweed seed

Figure 30.1b

Fireweed seed

Concept 30.1: Seeds and pollen grains are key adaptations for life on land

- In addition to seeds, the following are common to all seed plants
  - Reduced gametophytes
  - Heterospory
  - Ovules
  - Pollen

Advantages of Reduced Gametophytes

- The gametophytes of seed plants develop within the walls of spores that are retained within tissues of the parent sporophyte

Figure 30.2

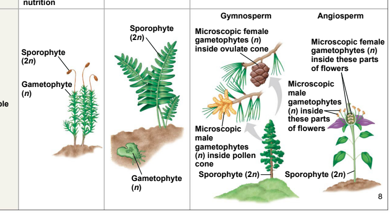
	PLANT GROUP		
	Mosses and other nonvascular plants	Ferns and other seedless vascular plants	Seed plants (gymnosperms and angiosperms)
Gametophyte	Dominant	Reduced, independent (photosynthetic and free-living)	Reduced (usually microscopic), dependent on surrounding sporophyte tissue for nutrition
Sporophyte	Reduced, dependent on gametophyte for nutrition	Dominant	Dominant
Example			

Figure 30.2a

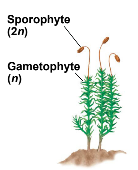
	Mosses and other nonvascular plants
Gametophyte	Dominant
Sporophyte	Reduced, dependent on gametophyte for nutrition
Example	

Figure 30.2b

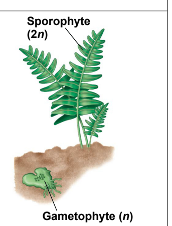
	Ferns and other seedless vascular plants
Gametophyte	Reduced, independent (photosynthetic and free-living)
Sporophyte	Dominant
Example	

Figure 30.2c

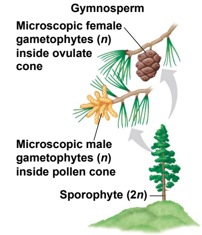
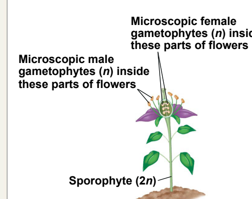
	Seed plants (gymnosperms and angiosperms)
Gametophyte	Reduced (usually microscopic), dependent on surrounding sporophyte tissue for nutrition
Sporophyte	Dominant
Example	

Figure 30.2d

	Seed plants (gymnosperms and angiosperms)
Gametophyte	Reduced (usually microscopic), dependent on surrounding sporophyte tissue for nutrition
Sporophyte	Dominant
Example	

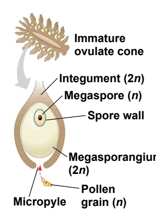
Heterospory: The Rule Among Seed Plants

- The ancestors of seed plants were likely homosporous, while seed plants are heterosporous
- Megasporangia produce megaspores that give rise to female gametophytes
- Microsporangia produce microspores that give rise to male gametophytes

Ovules and Production of Eggs

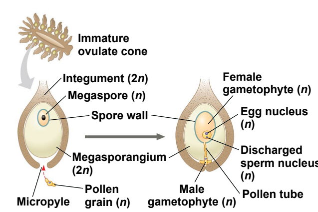
- An **ovule** consists of a megasporangium, megaspore, and one or more protective **integuments**
- Gymnosperm megasporangia have one integument
- Angiosperm megasporangia usually have two integuments

Figure 30.3-1



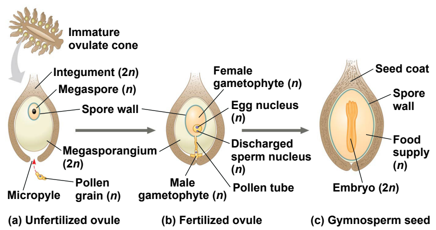
(a) Unfertilized ovule

Figure 30.3-2



(a) Unfertilized ovule (b) Fertilized ovule

Figure 30.3-3



Pollen and Production of Sperm

- Microspores develop into **pollen grains**, which contain the male gametophytes
- **Pollination** is the transfer of pollen to the part of a seed plant containing the ovules
- Pollen eliminates the need for a film of water and can be dispersed great distances by air or animals
- If a pollen grain germinates, it gives rise to a pollen tube that discharges sperm into the female gametophyte within the ovule

The Evolutionary Advantage of Seeds

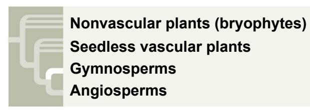
- A seed develops from the whole ovule
- A seed is a sporophyte embryo, along with its food supply, packaged in a protective coat

- Seeds provide some evolutionary advantages over spores
  - They may remain dormant for days to years, until conditions are favorable for germination
  - Seeds have a supply of stored food
  - They may be transported long distances by wind or animals

Concept 30.2: Gymnosperms bear “naked” seeds, typically on cones

- Gymnosperms means “naked seeds”
- The seeds are exposed on sporophylls that form cones
- Angiosperm seeds are found in fruits, which are mature ovaries
- Most gymnosperms are cone-bearing plants called **conifers**

Figure 30.UN02



The Life Cycle of a Pine

- Three key features of the gymnosperm life cycle are
  - Miniaturization of their gametophytes
  - Development of seeds from fertilized ovules
  - The transfer of sperm to ovules by pollen
- The life cycle of a pine provides an example

- The pine tree is the sporophyte and produces sporangia in male and female cones
- Small cones produce microspores called pollen grains, each of which contains a male gametophyte
- The familiar larger cones contain ovules, which produce megaspores that develop into female gametophytes
- It takes nearly three years from cone production to mature seed

Figure 30.4

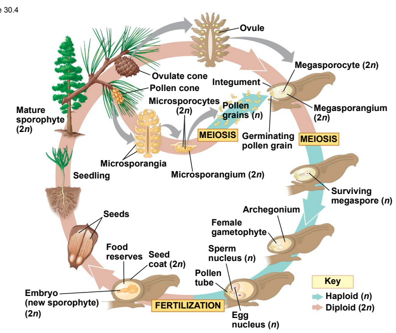


Figure 30.4a-1

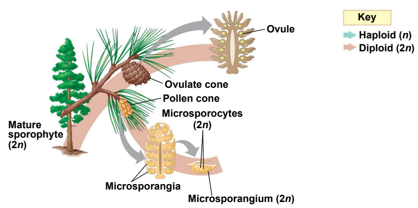


Figure 30.4a-2

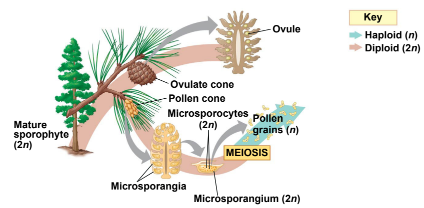


Figure 30.4a-3

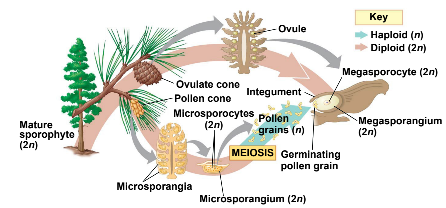


Figure 30.4b-1

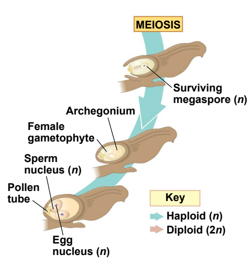


Figure 30.4b-2

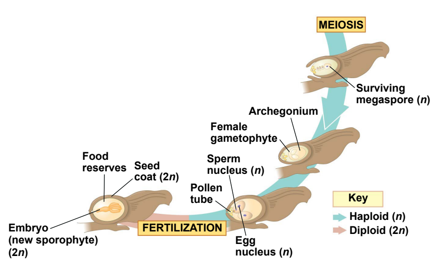
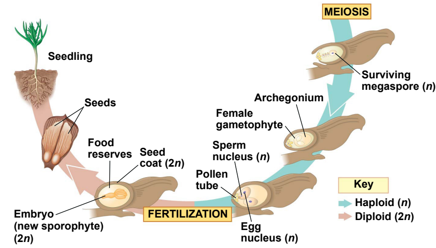
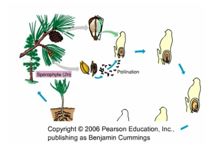


Figure 30.4b-3



Animation: Pine Life Cycle



Early Seed Plants and the Rise of Gymnosperms

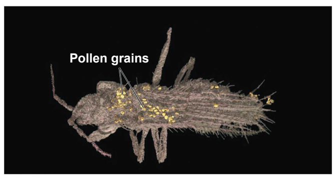
- Fossil evidence reveals that by the late Devonian period some plants had begun to acquire some features that are also present in seed plants
  - For example, *Archaeopteris* was a heterosporous tree with a woody stem, but it did not bear seeds

Figure 30.5

- Living seed plants can be divided into two clades: gymnosperms and angiosperms
- Gymnosperms appear early in the fossil record about 305 million years ago and dominated Mesozoic (251–65.5 million years ago) terrestrial ecosystems
- Gymnosperms were better suited than nonvascular plants to drier conditions

- Gymnosperms served as food for herbivorous dinosaurs
- Recent fossil discoveries show that gymnosperms were pollinated by insects over 100 million years ago
- Angiosperms began to replace gymnosperms near the end of the Mesozoic

Figure 30.6



Gymnosperm Diversity

- Angiosperms now dominate more terrestrial ecosystems, though conifers still dominate in some regions including the northern latitudes

- The gymnosperms consist of four phyla
  - Cycadophyta (cycads)
  - Gingkophyta (one living species: *Ginkgo biloba*)
  - Gnetophyta (three genera: *Gnetum*, *Ephedra*, *Welwitschia*)
  - Coniferophyta (conifers, such as pine, fir, and redwood)

Phylum Cycadophyta

- Individuals have large cones and palmlike leaves
- Unlike most seed plants, cycads have flagellated sperm
- These thrived during the Mesozoic, but most of the few surviving species are endangered

Figure 30.7a

Phylum Cycadophyta

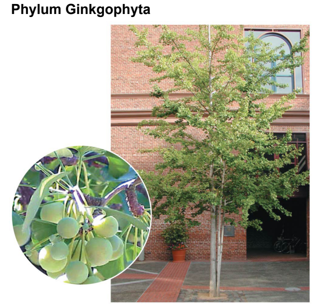
Cycas revoluta

Phylum Ginkgophyta

- This phylum consists of a single living species, *Ginkgo biloba*
- Like the cycads, this group also has flagellated sperm
- It has a high tolerance to air pollution and is a popular ornamental tree

Figure 30.7b

Phylum Ginkgophyta



Ginkgo biloba

Figure 30.7ba

Ginkgo biloba

Figure 30.7bb

Ginkgo biloba

Phylum Gnetophyta

- This phylum comprises three genera: *Gnetum*, *Ephedra*, and *Welwitschia*
- Species vary in appearance, and some are tropical whereas others live in deserts

Figure 30.7c

Phylum Gnetophyta

Figure 30.7ca

Welwitschia

Figure 30.7cb

Gnetum

Figure 30.7cc

Ovulate cones

Welwitschia

Figure 30.7cd

Ephedra

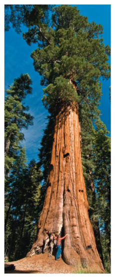
Phylum Coniferophyta

- This phylum is the largest of the gymnosperm phyla
- Most conifers are evergreens and can carry out photosynthesis year round

Figure 30.7d

Phylum Coniferophyta

Douglas fir



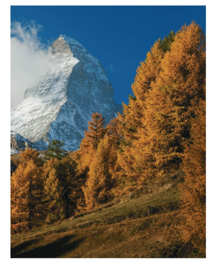
Sequoia

European larch

Figure 30.7da

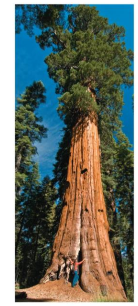
Douglas fir

Figure 30.7db



European larch

Figure 30.7dc

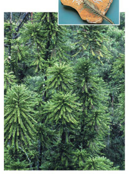


Sequoia

Figure 30.7e

Phylum Coniferophyta

Common juniper



Wollemi pine

Bristlecone pine

Figure 30.7ea

Common juniper

Figure 30.7eb

Wollemi pine

Figure 30.7ec

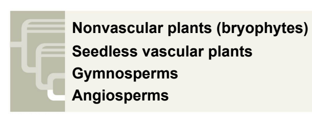
Figure 30.7ed

Bristlecone pine

Concept 30.3: The reproductive adaptations of angiosperms include flowers and fruits

- Angiosperms are seed plants with reproductive structures called flowers and fruits
- They are the most widespread and diverse of all plants

Figure 30.UN03



Characteristics of Angiosperms

- All angiosperms are classified in a single phylum, Anthophyta, from the Greek *anthos* for flower
- Angiosperms have two key adaptations
  - Flowers
  - Fruits

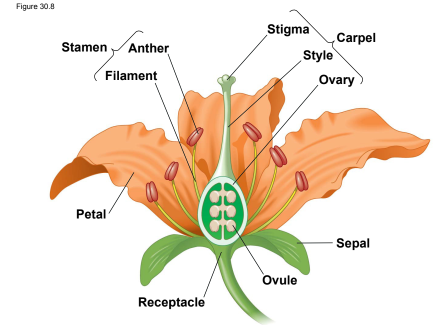
Flowers

- The **flower** is an angiosperm structure specialized for sexual reproduction
- Many species are pollinated by insects or animals, while some species are wind-pollinated

- A flower is a specialized shoot with up to four types of modified leaves called floral organs:
  - **Sepals**, which enclose the flower
  - **Petals**, which are brightly colored and attract pollinators
  - **Stamens**, which produce pollen
  - **Carpels**, which produce ovules

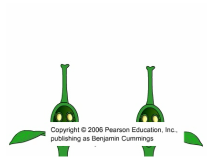
- A stamen consists of a stalk called a **filament**, with a sac called an **anther** where the pollen is produced
- A carpel consists of an **ovary** at the base and a **style** leading up to a **stigma**, where pollen is received

Figure 30.8



Video: Flower Blooming (Time Lapse)

Animation: Fruit Development



- Flowers that have all four organs are called **complete flowers**
- Those lacking one or more organs are called **incomplete flowers**

Symmetry

- Flowers may have **radial symmetry** or **bilateral symmetry**
- For flowers with radial symmetry, any imaginary line through the central axis divides the flower into two equal parts
- In bilateral symmetry, a flower can only be divided into two equal parts by a single imaginary line

Figure 30.9

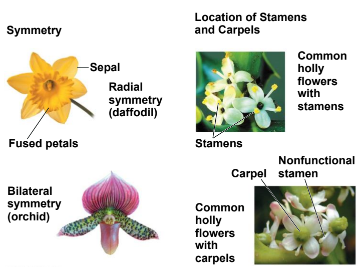


Figure 30.9a

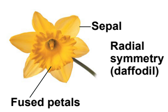


Figure 30.9b

Location of Stamens and Carpels

- Most species have flowers with both functional stamens and carpels, but in some species they occur on separate flowers
- Flowers with stamens may be on the same plant as those with carpels, or they may occur on different plants

Figure 30.9c

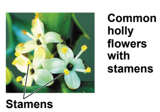
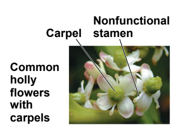


Figure 30.9d



Fruits

- A **fruit** is formed when the ovary wall thickens and matures
- Fruits protect seeds and aid in their dispersal
- Mature fruits can be either fleshy or dry

Figure 30.10

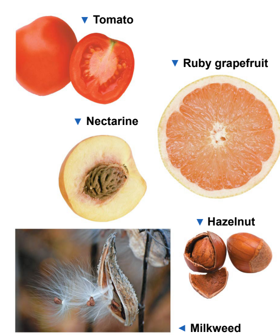
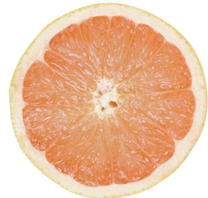


Figure 30.10a

Tomato, a fleshy fruit with soft outer and inner layers of pericarp (fruit wall)

Figure 30.10b



Ruby grapefruit, a fleshy fruit with a firm outer layer and soft inner layer of pericarp

Figure 30.10c

Nectarine, a fleshy fruit with a soft outer layer and hard inner layer (pit) of pericarp

Figure 30.10d

Milkweed, a dry fruit that splits open at maturity

Figure 30.10e

Hazelnut, a dry fruit that remains closed at maturity

- Various fruit adaptations help disperse seeds
- Seeds can be carried by wind, water, or animals to new locations

Figure 30.11

Figure 30.11a

Some plants have mechanisms that disperse seeds by explosive action.

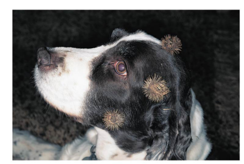
Figure 30.11b

Wings enable maple fruits to be carried by the wind.

Figure 30.11c

Seeds within berries and other edible fruits are often dispersed in animal feces.

Figure 30.11d



The barbs of cockleburs facilitate seed dispersal by allowing the fruits to "hitchhike" on animals.

Figure 30.11e

The barbs of cockleburs facilitate seed dispersal by allowing the fruits to "hitchhike" on animals.

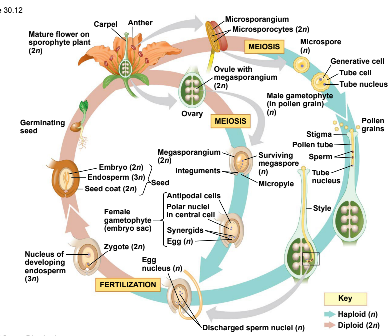
The Angiosperm Life Cycle

- The flower of the sporophyte is composed of both male and female structures
- Male gametophytes are contained within pollen grains produced by the microsporangia of anthers
- The female gametophyte, or **embryo sac**, develops within an ovule contained within an ovary at the base of a stigma
- Most flowers have mechanisms to ensure **cross-pollination** between flowers from different plants of the same species

- A pollen grain that has landed on a stigma germinates and the pollen tube of the male gametophyte grows down to the ovary
- The ovule is entered by a pore called the **micropyle**
- **Double fertilization** occurs when the pollen tube discharges two sperm into the female gametophyte within an ovule

- One sperm fertilizes the egg, while the other combines with two nuclei in the central cell of the female gametophyte and initiates development of food-storing **endosperm**
- The triploid endosperm nourishes the developing embryo
- Within a seed, the embryo consists of a root and two seed leaves called **cotyledons**

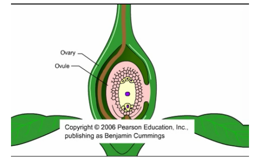
Figure 30.12



Video: Flowering Plant Life Cycle (Time Lapse)

Animation: Plant Fertilization

Animation: Seed Development



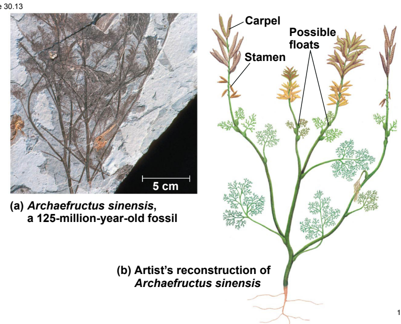
Angiosperm Evolution

- Darwin called the origin of angiosperms an "abominable mystery"
- Progress is being made through the study of fossils and phylogenetic analysis, but the mystery of the sudden appearance of angiosperms has not been resolved

Fossil Angiosperms

- Angiosperms originated at least 140 million years ago and began to dominate terrestrial ecosystems by 100 million years ago
- Chinese fossils of 125-million-year-old angiosperms share some traits with living angiosperms but lack others
- *Archaefructus sinensis,* for example, has anthers and seeds but lacks petals and sepals

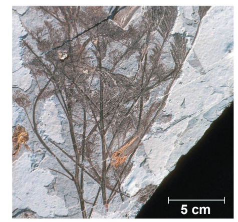
Figure 30.13



(a) *Archaefructus sinensis*, a 125-million-year-old fossil

(b) Artist's reconstruction of *Archaefructus sinensis*

Figure 30.13a

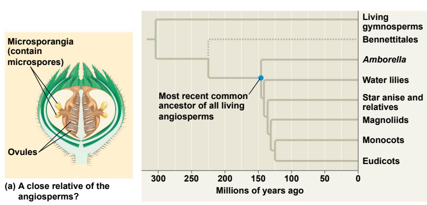


(a) *Archaefructus sinensis*, a 125-million-year-old fossil

Angiosperm Phylogeny

- The ancestors of angiosperms and gymnosperms diverged about 305 million years ago
- Angiosperms may be closely related to Bennettitales, extinct seed plants with flowerlike structures
- *Amborella* and water lilies are likely descended from two of the most ancient angiosperm lineages

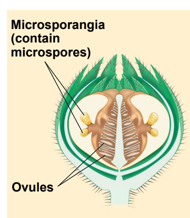
Figure 30.14



(a) A close relative of the angiosperms?

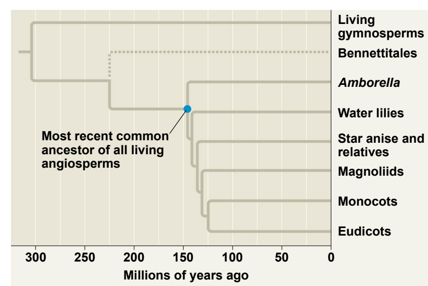
(b) Angiosperm phylogeny

Figure 30.14a



(a) A close relative of the angiosperms?

Figure 30.14b



(b) Angiosperm phylogeny

- Based on the features of ancestral and basal taxa, including *Amborella*, early angiosperms were likely small-flowered shrubs with simple water-conducting cells

Evolutionary Links with Animals

- Animals influence the evolution of plants and vice versa
  - For example, animal herbivory selects for plant defenses
  - For example, interactions between pollinators and flowering plants select for mutually beneficial adaptations

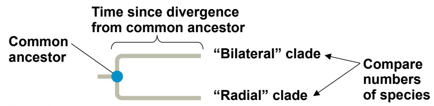
- Bilateral symmetry affects the movement of pollinators and reduces gene flow in diverging populations
- Plants with bilateral symmetry may have increased rates of speciation
- This hypothesis can be tested by comparing the number of species in closely related "bilateral" and "radial" clades

Figure 30.15

Video: Bat Pollinating *Agave* Plant

Video: Bee Pollinating

Figure 30.UN04



Angiosperm Diversity

- Angiosperms comprise more than 250,000 living species
- Previously, angiosperms were divided into two main groups
  - **Monocots** (one cotyledon)
  - **Dicots** (two dicots)
- DNA studies suggest that dicots are paraphyletic

- The clade **eudicot** ("true" dicots) includes most dicots
- The rest of the former dicots form several small lineages
- **Basal angiosperms** include the flowering plants belonging to the oldest lineages
- **Magnoliids** share some traits with basal angiosperms but evolved later

Figure 30.16

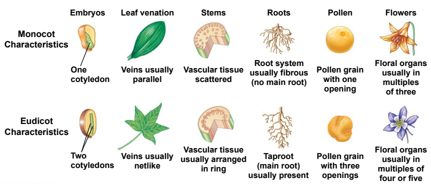


Figure 30.16a

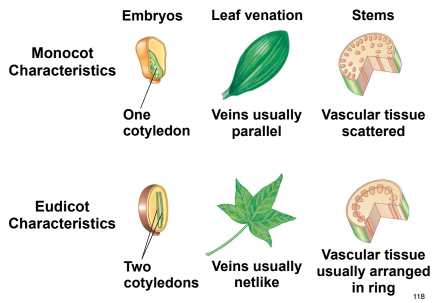
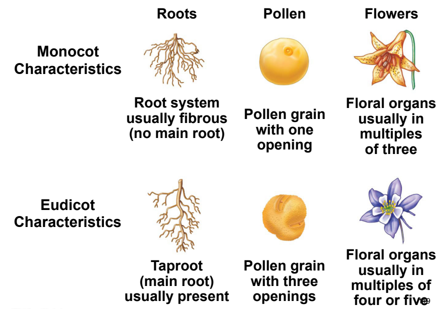


Figure 30.16b



Basal Angiosperms

- Three small lineages constitute the basal angiosperms
- These include *Amborella trichopoda*, water lilies, and star anise

Figure 30.17a

Basal angiosperms


Water lily (*Nymphaea "Rene Gerard"*)


Star anise (*Illicium*)


Amborella trichopoda

Figure 30.17aa

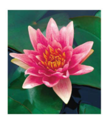

Water lily (*Nymphaea "Rene Gerard"*)

Figure 30.17ab


Star anise (*Illicium*)

Figure 30.17ac

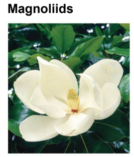

Amborella trichopoda

Magnoliids

- Magnoliids include magnolias, laurels, and black pepper plants
- Magnoliids are more closely related to monocots and eudicots than basal angiosperms

Figure 30.17b

Magnoliids

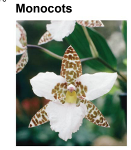

Southern magnolia (*Magnolia grandiflora*)

Monocots

- More than one-quarter of angiosperm species are monocots
- The largest groups are the orchids, grasses, and palms

Figure 30.17c

Monocots


Orchid (*Lemboglossum rossii*)


Pygmy date palm (*Phoenix roebelenii*)


Barley (*Hordeum vulgare*), a grass

Figure 30.17ca

Orchid
(Lemboglossum rossii)

Figure 30.17cb

Pygmy date palm *(Phoenix roebelenii)*

Figure 30.17cc

Barley *(Hordeum vulgare)*, a grass

Eudicots

- More than two-thirds of angiosperm species are eudicots
- Eudicots include the large legume family and the economically important rose family

Figure 30.17d

Eudicots

Snow pea *(Pisum sativum)*, a legume

Dog rose *(Rosa canina)*, a wild rose

Pyrenean oak
(Quercus pyrenaica)

Figure 30.17da

Snow pea (*Pisum sativum*), a legume

Figure 30.17db

Dog rose (*Rosa canina*), a wild rose

Figure 30.17dc

Pyrenean oak
(Quercus pyrenaica)

Concept 30.4: Human welfare depends on seed plants

- Seed plants are key sources of food, fuel, wood products, and medicine
- Our reliance on seed plants makes preservation of plant diversity critical

Products from Seed Plants

- Most of our food comes from angiosperms
- Six crops (wheat, rice, maize, potatoes, cassava, and sweet potatoes) yield 80% of the calories consumed by humans
- Modern crops are products of relatively recent genetic change resulting from artificial selection
- Many seed plants provide wood
- Secondary compounds of seed plants are used in medicines

Table 30.1

Table 30.1 Examples of Plant-Derived Medicines

Compound	Source	Use
Atropine	Belladonna plant	Eye pupil dilator
Digitalin	Foxglove	Heart medication
Menthol	Eucalyptus tree	Throat soother
Quinine	Cinchona tree	Malaria preventive
Taxol	Pacific yew	Ovarian cancer drug
Tubocurarine	Curare tree	Muscle relaxant
Vinblastine	Periwinkle	Leukemia drug

Threats to Plant Diversity

- Destruction of habitat is causing extinction of many plant species
- In the tropics 55,000 km^2 are cleared each year
- At this rate, the remaining tropical forests will be eliminated in 200 years
- Loss of forests reduces the absorption of atmospheric CO_2 that occurs during photosynthesis

Figure 30.18

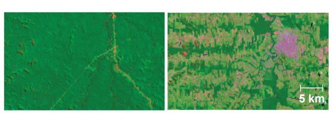


Figure 30.18a

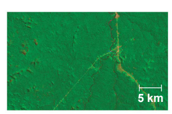


Figure 30.18b

- Loss of plant habitat is often accompanied by loss of the animal species that plants support
- At the current rate of habitat loss, 50% of Earth's species will become extinct within the next 100–200 years
- The tropical rain forests may contain undiscovered medicinal compounds

Figure 30.UN01a

	Fraction of Carbon-14 Remaining
Seed 1 (not planted)	0.7656
Seed 2 (not planted)	0.7752
Seed 3 (germinated)	0.7977

Figure 30.UN01b

Figure 30.UN05

Five Derived Traits of Seed Plants		
Reduced gametophytes	Microscopic male and female gametophytes (n) are nourished and protected by the sporophyte ($2n$)	Male gametophyte; Female gametophyte
Heterospory	Microspore (gives rise to a male gametophyte); Megaspore (gives rise to a female gametophyte)	
Ovules	Ovule (gymnosperm)	Integument ($2n$); Megaspore (n); Megasporangium ($2n$)
Pollen	Pollen grains make water unnecessary for fertilization	
Seeds	Seeds: survive better than unprotected spores, can be transported long distances	Seed coat; Food supply; Embryo

Figure 30.UN05a

Five Derived Traits of Seed Plants		
Reduced gametophytes	Microscopic male and female gametophytes (n) are nourished and protected by the sporophyte ($2n$)	Male gametophyte; Female gametophyte
Heterospory	Microspore (gives rise to a male gametophyte); Megaspore (gives rise to a female gametophyte)	

Figure 30.UN05b

Five Derived Traits of Seed Plants		
Ovules	Ovule (gymnosperm)	Integument ($2n$); Megaspore (n); Megasporangium ($2n$)
Pollen	Pollen grains make water unnecessary for fertilization	
Seeds	Seeds: survive better than unprotected spores, can be transported long distances	Seed coat; Food supply; Embryo

Figure 30.UN06

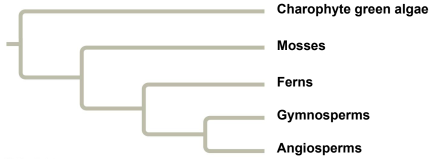


Figure 30.UN07