Land Plant Evolution: Algae to Angiosperms

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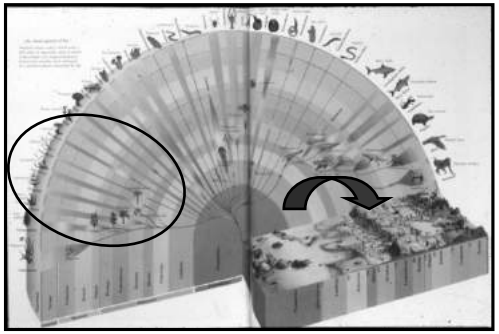
The greatest adaptive radiation . . .



- is the largest radiation of plants
- involves series of dramatic adaptations to the problem of life on land and being non-motile
- exhibits successive rounds of speciation and subsequent extinction
- sets the stage for the development of a land-based ecosystem with fungi and animals

Angiosperms - Flowering Plants

Angiosperms focus of the course
- comprise the phylum Magnoliophyta
- contains majority of plant diversity

What are the non-angiosperm land plants?
- DNA evidence has clarified much but not all of the relationships of other phyla

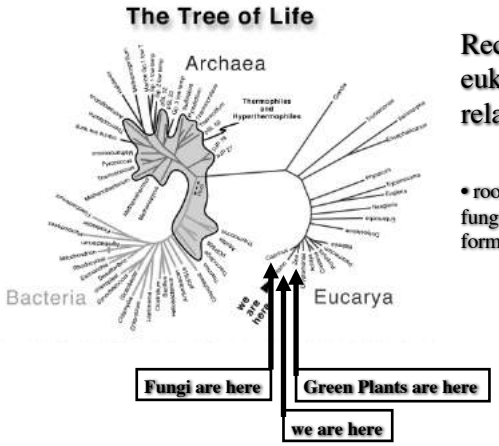
See first pages of Chpts 1 & Chpts 3-4 for more detail (*Plant Systematics*, 2nd *ed.*)

Fungi?

- Fungi collectively are not a natural group
- More closely related to animals than to plants

take Botany 332 – spring 2019

Fungi?

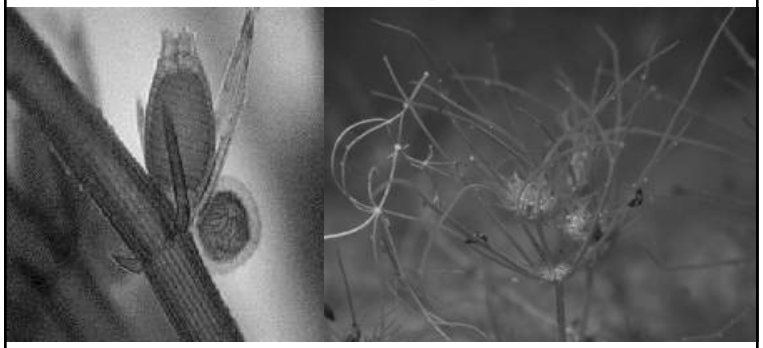


Recent view of eukaryotic relationships

- root is in microbes with fungi/animals/plants forming a crown radiation

Charales - stoneworts

- Green algal lineage take Botany 330 – fall 2019
- Closest relatives to land plants



Charales - stoneworts

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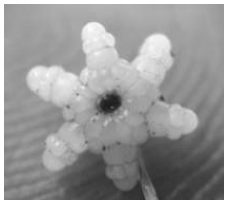
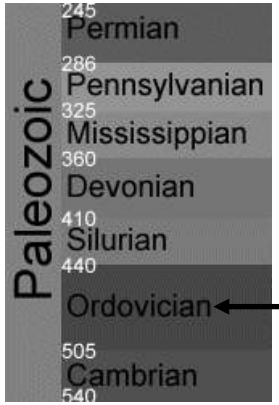


Starry stonewort *Nitellopsis obtusa* L.

Wisconsin's latest (and greatest?) lake invasive

Extinct Land Plants - the first plants



Ordovician Period (505 - 440 mya)

- First evidence of land life at 460 mya

Microfossils of spores with sporopollenin (degradation resistant material like lignin) and similar to modern day bryophytes such as liverworts

Found worldwide in shales that were deposited at the marine-terrestrial interface

bryophytes

- earliest land plants - non vascular
- gametophyte dominant, 16000 species
- 3 lineages — they are not a natural group

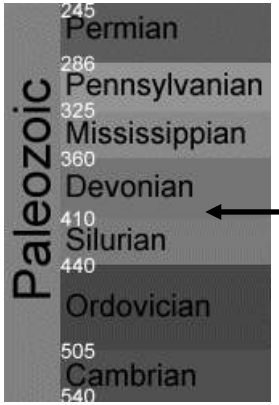
bryophytes

Liverworts - Marchantiophyta

Mosses - Bryophyta

Hornworts - Anthoceratophyta

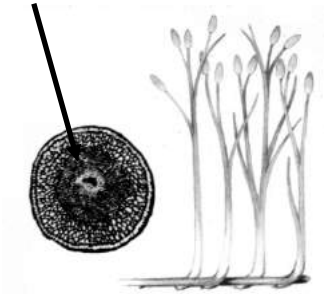
Extinct Land Plants - first vascular plants



Early Devonian Period (410 - 390 mya)

Rhynia seen in the early Devonian (Rhynie Chert fossil) is one of first vascular plants

20 cm tall, no roots, no leaves, primitive vascular tissue



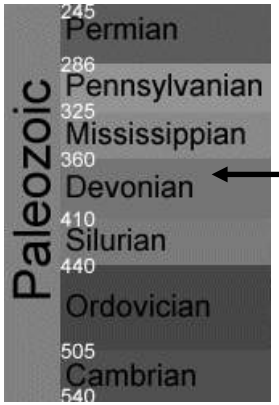
Lycopodiophyta - club mosses

- 3 families, 1150 species
- sporophyte dominant, vascular, free sporing
- they are sister to all other vascular plants

Selaginella - spike mosses

Lycopodium - club mosses

Extinct Land Plants - the first ferns



Late Devonian Period (390 - 360 mya)

First true ferns [*Protopteridium*] - free sporing with complex sporangia & megaphylls

Polypodiophyta - ferns

- 11000 species (or called "Monilophyta")
- immense variation in habit and habitat
- spores produced in specialized sporangia
- need a lot of systematic work - tropics!



Polypodiophyta - ferns

- includes the horsetails as unusual ferns!
- 15 species in *Equisetum*
- vascular plants, reduced leaves, terminal sporangia


Polypodiophyta - ferns

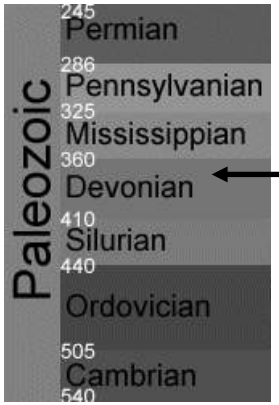
- includes the strange whisk ferns!
- 6 species in 2 genera
- vascular plants, leafless green stemmed, lateral sporangia


Psilotum habit


Psilotum branch


Psilotum sporangia

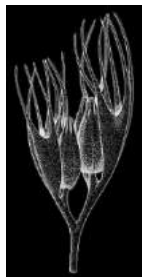
Extinct Land Plants - the seed plants

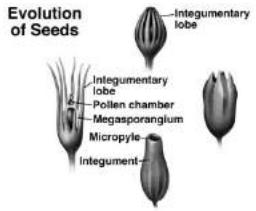


Late Devonian Period (390 - 360 mya)

First "seeds" - "seed ferns" [*Archaeosperma*]

Plants fern-like with dissected compound leaves, but produce naked seeds (embryo within protective coverings)





Extinct Land Plants – first gymnosperms

Permian Period (286 - 245 mya)

- Big trees with net-veined leaves
- Seed bearing (derived from female gametophyte) and pollen forming (from male gametophyte)

Pinophyta - gymnosperms

- 870 species
- seed plants but seeds naked
- often divided into 4 phyla
- is one closer to angiosperms?

conifers


pine


spruce


juniper

Pinophyta - gymnosperms

- 870 species
- seed plants but seeds naked
- often divided into 4 phyla
- is one closer to angiosperms?


male strobilus


female strobili


cycads

Pinophyta - gymnosperms

- 870 species
- seed plants but seeds naked
- often divided into 4 phyla
- is one closer to angiosperms?

male strobili

mature seeds

ginkgo

Pinophyta - gymnosperms

- 870 species
- seed plants but seeds naked
- often divided into 4 phyla
- is one closer to angiosperms?

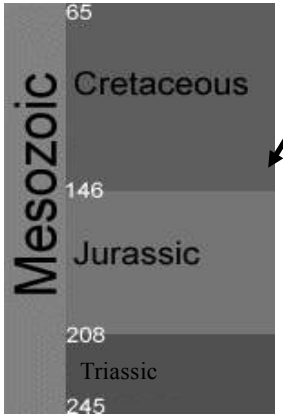
gnetophytes

Welwitschia mirabilis

Ephedra

Gnetum

Extinct Land Plants – first flowering plants



Cretaceous Period (146 - 65 mya)

Near the Jurassic/Cretaceous border, the first Angiosperms are seen

Archaefructus

Magnoliophyta - angiosperms

- 275,000 + species (400,000 ?)
- seed plants with seeds encased in ovary
- flowers a "key innovation"

Angiosperms - Flowering Plants

• tremendous adaptive radiation on land (and back into water)

Angiosperms - Flowering Plants

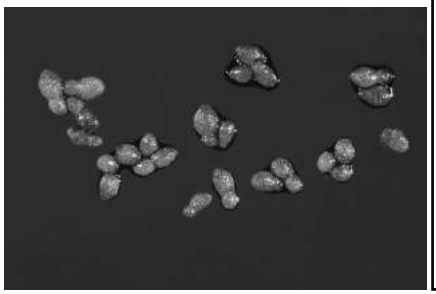
• tremendous adaptive radiation on land (and back into water)

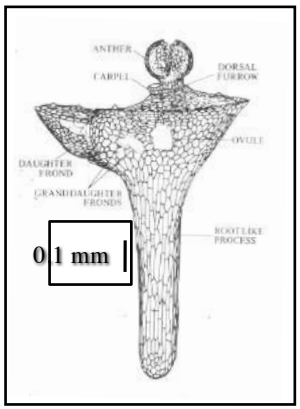
• *Eucalyptus regnans* (Myrtaceae) over 100m tall and 19m dbh

Angiosperms - Flowering Plants

• tremendous adaptive radiation on land (and back into water)

• *Wolffia microscopica* (Araceae) less than 1mm long

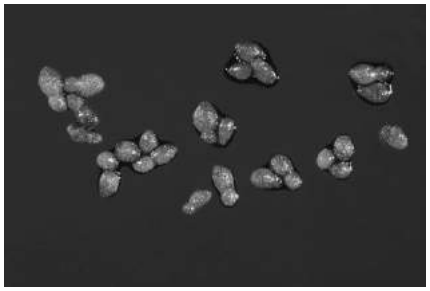




Angiosperms - Flowering Plants

• tremendous adaptive radiation on land (and back into water)

• *Wolffia microscopica* (Araceae) less than 1mm long



• *Amorphophallus titanum* (Araceae) over 2 m tall

Angiosperms - Flowering Plants

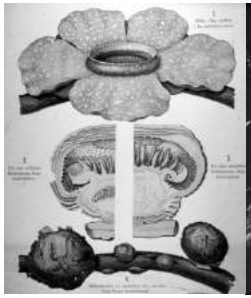
- tremendous adaptive radiation on land (and back into water)
  - largest inflorescence *Amorphophallus titanum* (Araceae)


Angiosperms - Flowering Plants

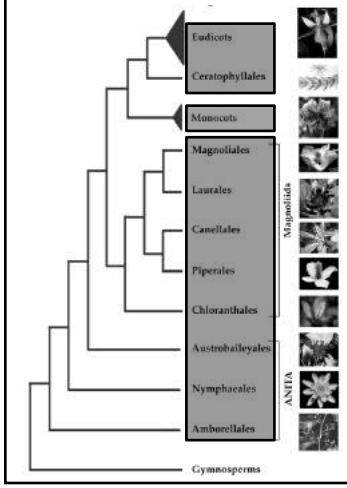
- tremendous adaptive radiation on land (and back into water)
  - largest numbers of flowers — *Corypha* palm


Angiosperms - Flowering Plants

- tremendous adaptive radiation on land (and back into water)
  - largest flower: *Rafflesia arnoldii* (Rafflesiaceae) from New Guinea, up to 1m across and 20lbs




Angiosperms - Flowering Plants



Magnoliophyta classification

- previously divided into two classes — dicots and monocots
- artificial!
- we will use Angiosperm Phylogeny Group (APG III) classification system of 2009

Angiosperms or Flowering Plants the Phylum Magnoliophyta

Today & Monday: overview of the morphology and evolution of the flower – optionally read first part of Chpt. 6 in *Plant Systematics, 2nd ed.* – available at Canvas/Learn@UW

Lab next two weeks: (1) vegetative features & conifers – 1st half of Chpt 9 in *Plant Systematics*; (2) finish overview of flower and examine floral, fruit, & inflorescence diversity – 2nd half of Chpt. 9

The Flower — Why Important?

The Flower: most significant feature of angiosperms

1. unlike anything else in other plants & extremely variable & co-evolved with animals
2. floral features used in describing and id' ing
3. plant specimens (herbarium) must include flowers or derived features
4. classification of angiosperms relies on flowers

Calochortus - fairy lanterns & mariposas (images: T. Givnish)

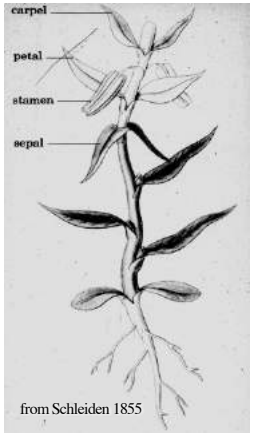
The Flower — What is it?

• specialized shoot = stem + leaves (folia)

• shoot is highly modified and determinate (ceased to grow)

The Flower — What is it?

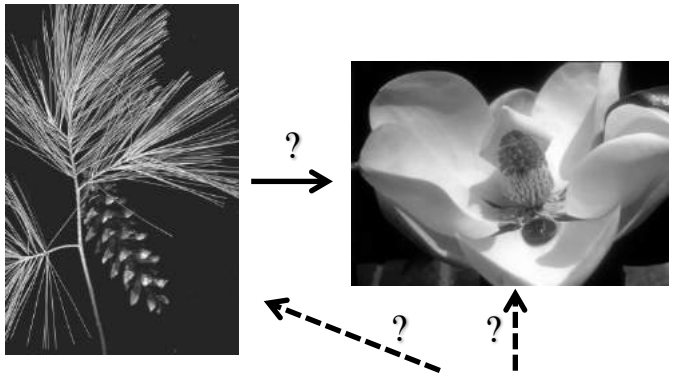
• "foliar theory" of flower - J.W. von Goethe in "*Attempt to Interpret the Metamorphosis of Plants*" (1790)



from Schleiden 1855

The Flower — What is it?

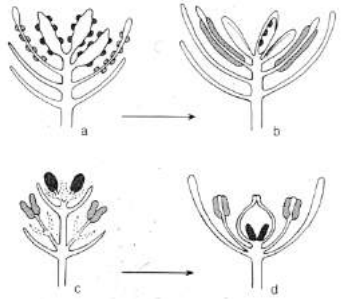
• developmental/evolutionary origin of the flower still debated



The Flower — What is it?

• developmental/evolutionary origin of the flower still debated

1. Euanthial theory - (foliar theory) - *single* shoot, cone or strobilus
   - anthers (male)
   - ovules (female)
2. Pseudanthial theory - *compound* shoot or cone, different shoots "coalesce" or "condense"

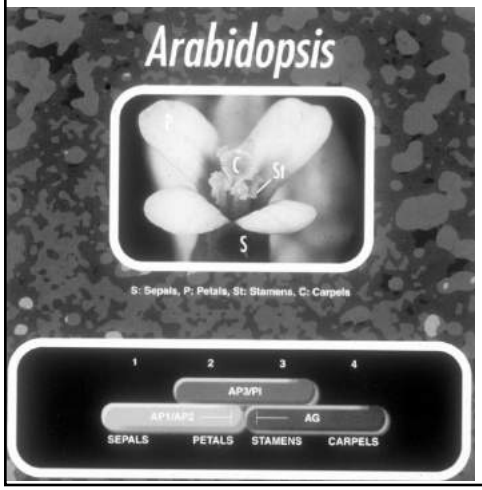


The Flower — What is it?

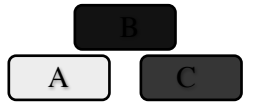
• thus, a flower is a specialized shoot that:

1. is determinate (vs. indeterminate)
2. has a modified stem with compressed internodes
3. possesses modified leaves with various functions, these determined by gene arrays (e.g., ABC model)

The Flower — What is it?



The 'ABC' model of floral part identity

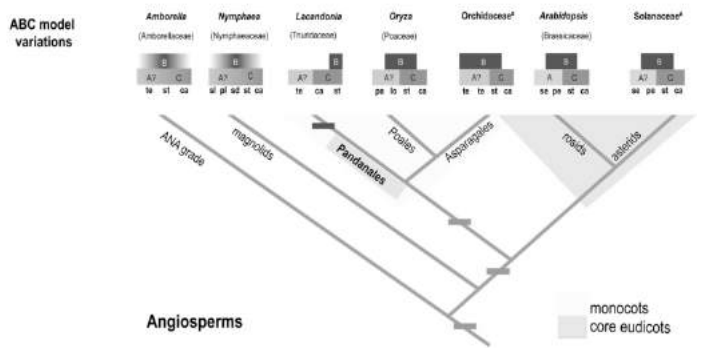


sepals petals stamens carpels

The Flower — What is it?

The evolution of the 'ABC' model of floral part identity

The Plant Cell, 2010



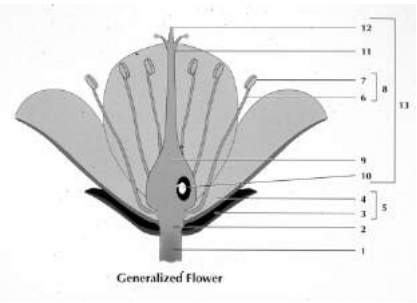
The Flower — What is it?

- thus, a flower is a specialized shoot that:

1. is determinate (vs. indeterminate)
2. has a modified stem with compressed internodes
3. possesses modified leaves with various functions, these determined by gene arrays (e.g., ABC model)
4. often clustered in an inflorescence (larger branch)

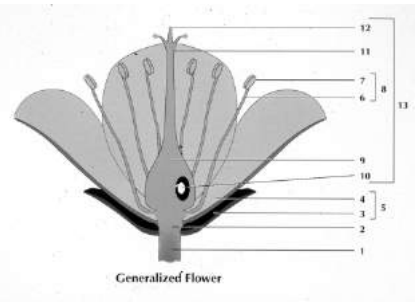
The Flower

read chpt 9 in *Plant Systematics*!



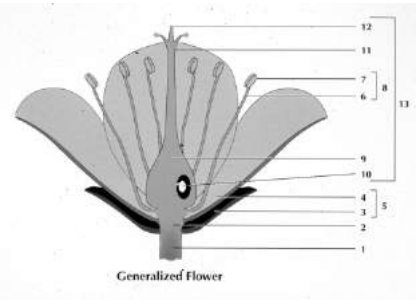
- 1st half deals with vegetative features - we will cover in lab 2 this week
- 2nd half deals with flowers/fruits - lab 3 next week

The Flower



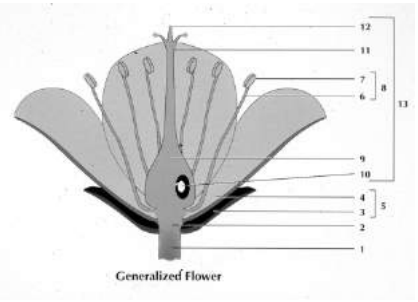
1. Peduncle: floral stalk, the stem supporting the flower; sometimes referred to as the pedicel

The Flower



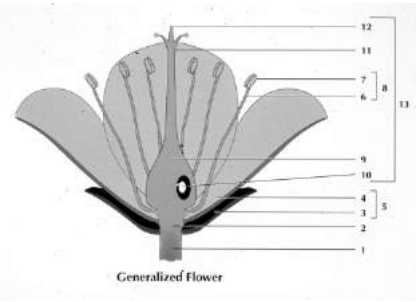
2. Receptacle: modified floral stem or axis from which arise the floral appendages or modified leaves

The Flower



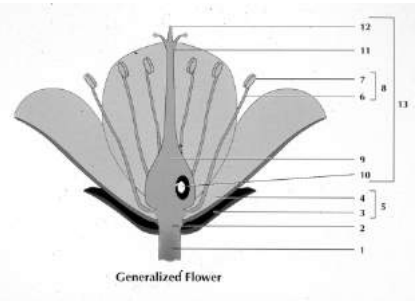
3. Sepal: the outer whorl of leaves, green and protective; collectively called the calyx (CA)

The Flower



4. Petal: the second whorl of leaves, typically brightly colored, attracting pollinators; collectively called the corolla (CO)

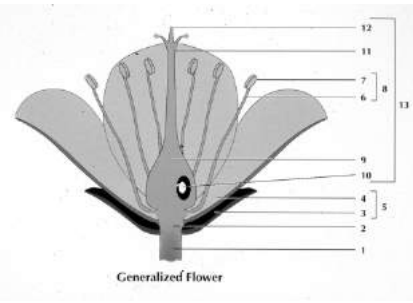
The Flower



5. Perianth: collective term for sepals and petals (P)

Tepals if both similar or if only one reduced set (sepals)

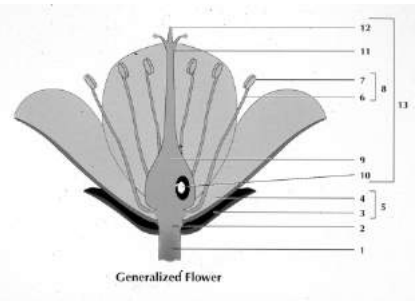
The Flower



8. Stamen: the male structure of flower comprising filament and anther

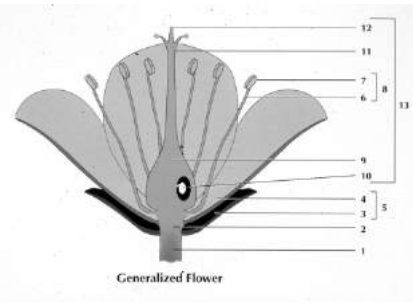
collectively, stamens are the androecium (= 'house of males') (A)

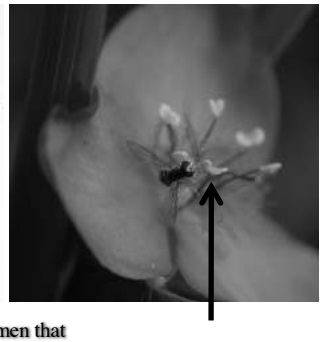
The Flower



6. Filament: slender stalk of the stamen supporting the anther; permits exsertion of anther with pollen out of flower

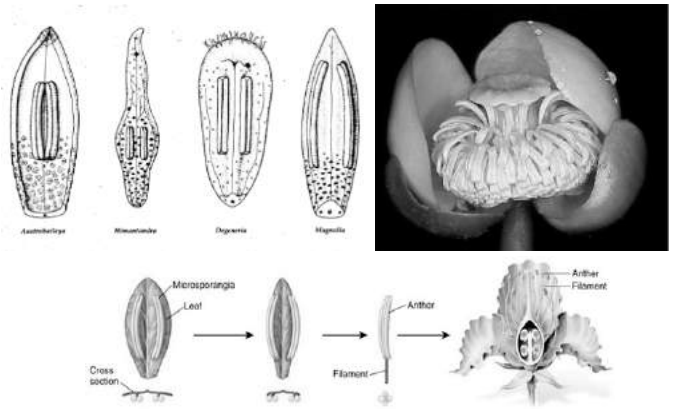
The Flower





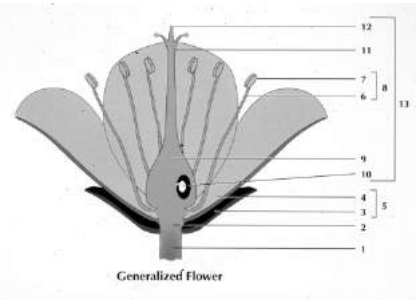
7. Anther: fertile portion of stamen that dehisces to release pollen grains; composed of anther sacs

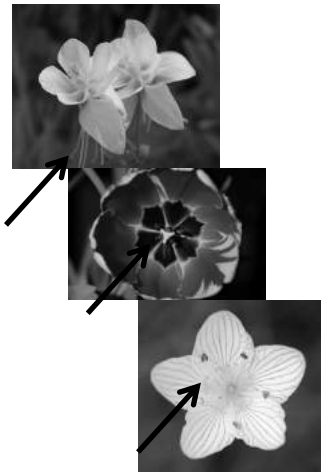
The Flower



• stamens can be leaf-like in primitive angiosperms!

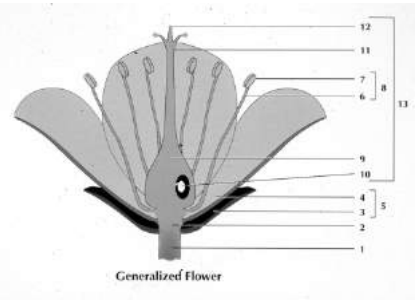
The Flower





Nectaries often near base of stamens - produce nectar reward for visitors who will move pollen ('pollinators')

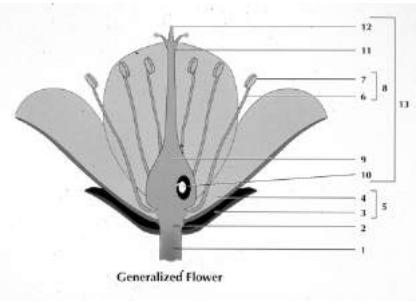
The Flower

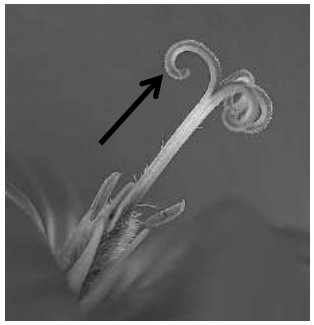


13. Pistil: flask-shaped, female structure comprising three main parts – often referred to as carpel(s)

• all pistils (1 or more) are referred to as the gynoecium (= 'house of females') (G)

The Flower

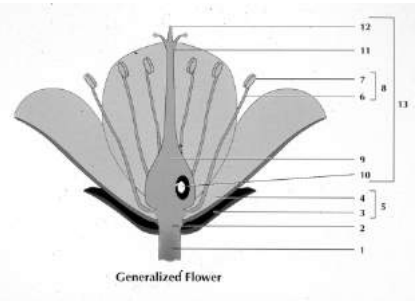


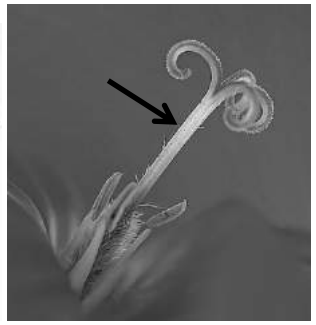


13. Pistil: flask-shaped, female structure comprising three main parts – often referred to as carpel(s)

12. Stigma: receptive portion at top of style that receives and recognizes pollen

The Flower

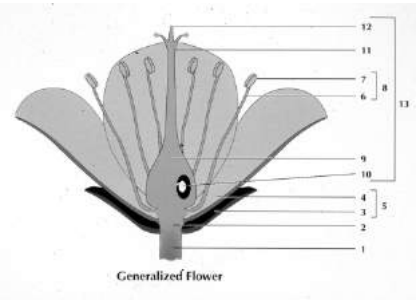




13. Pistil: flask-shaped, female structure comprising three main parts – often referred to as carpel(s)

11. Style: slender stalk of pistil above ovary that the pollen tubes must pass through to reach eggs in ovules

The Flower



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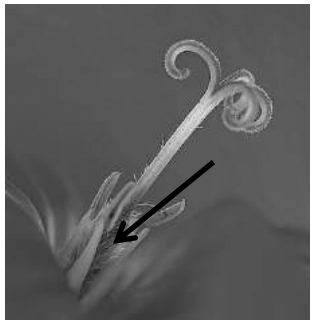
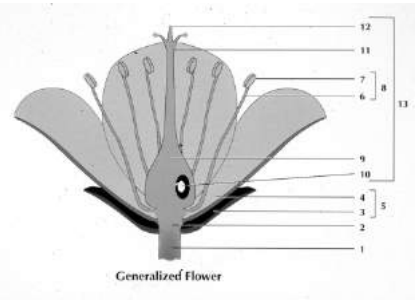


9. Ovary: basal portion of pistil that contains ovules; at maturity becomes fruit with seeds

The Flower



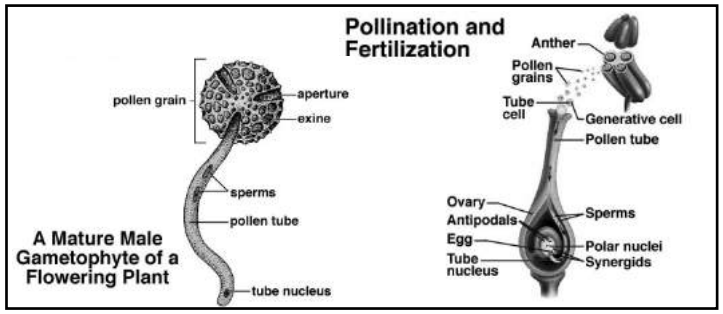
13. Pistil: flask-shaped, female structure comprising three main parts – often referred to as carpel(s)

10. Ovules: fertile portions of pistil that contain a female gametophyte (embryo sac); develop into seeds after fertilization

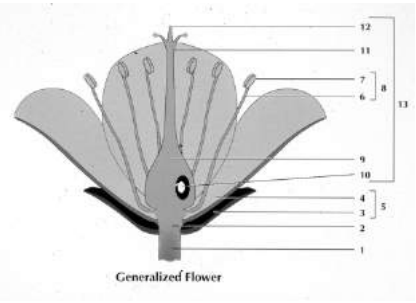
The Flower

Pollination biology

Study of the pollen, its transfer, and movement down the style



The Flower



Pistil vs. carpel

How do you know?

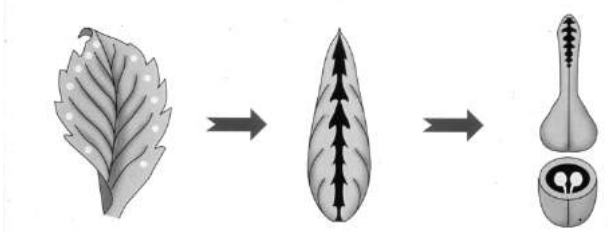
3 examples

Carpels not fused
1. Monocarpic
2. Apocarpic

Carpels fused
3. Syncarpic

The Flower

When pistil = carpel



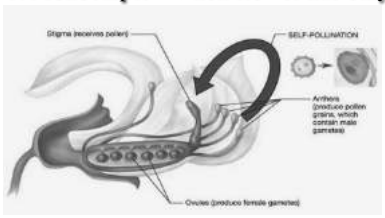
1 floral 'leaf' in gynoecium Folded 'leaf' 1 carpel = 1 pistil

The pistil (vase-shaped structure) is made up of ONE carpel

The Flower

When pistil = carpel

1. Monocarpic – when flower has only 1 pistil



legume flower

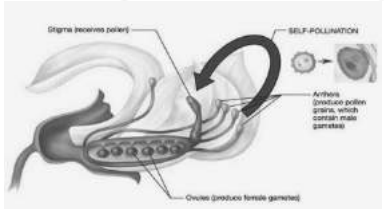
1 carpel = 1 pistil

This gynoecium is monocarpic (one carpel)

The Flower

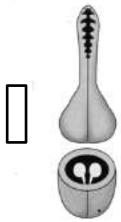
When pistil = carpel

1. Monocarpic – when flower has only 1 pistil



legume flower

legume fruit



1 carpel = 1 pistil

This gynoecium is monocarpic (one carpel)

The Flower

When pistil = carpel

2. Apocarpic – when flower has 2+ pistils

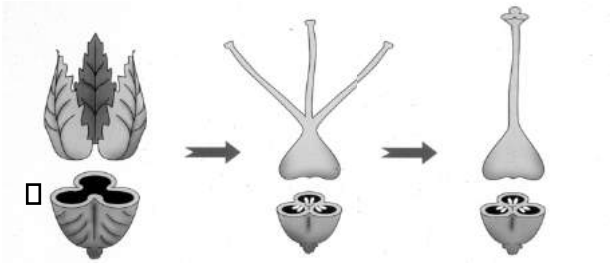
- e.g., 6 leaves (carpels) separately form pistils
- then the flower has 6 carpels and 6 pistils.

6 fruits (pistils) from 1 flower
Gynoecium is apocarpic with 6 carpels and 6 pistils

Caltha palustris - Marsh marigold

The Flower

When pistil ≠ carpel



3 floral 'leaves' in gynoecium fuse

3 carpels = 1 pistil
3 styles

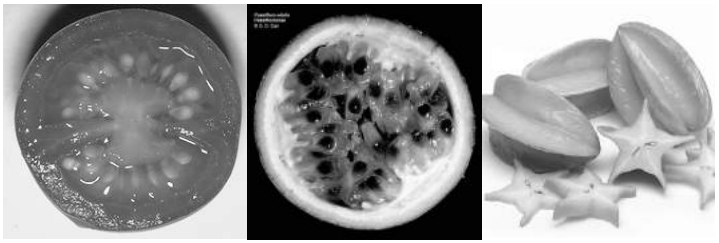
This gynoecium is syncarpic

3 carpels = 1 pistil
1 style

This gynoecium is syncarpic

3. Syncarpic – when flower has only 1 pistil but 2+ carpels

The Flower



tomato – 2 carpels

passion fruit– 3 carpels

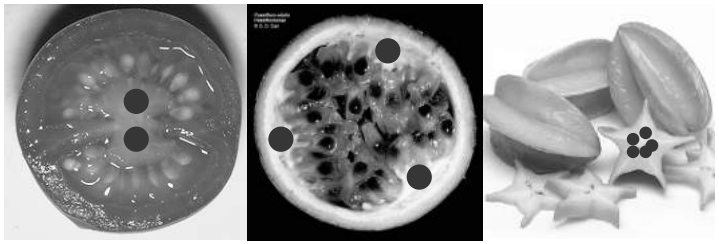
starfruit – 5 carpels

3. Syncarpic – when flower has only 1 pistil but 2+ carpels

• number of fused carpels is often clear in a cross section of the fruit

The Flower

Placentation types - arrangement of ovules, provides hints to the number of carpels



tomato – 2 carpels

passion fruit– 3 carpels

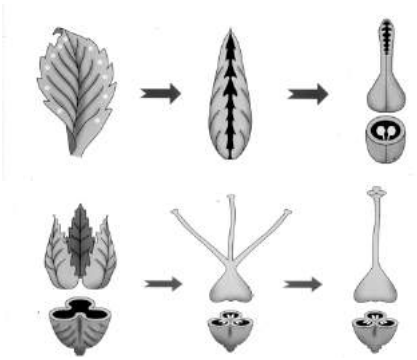
starfruit – 5 carpels

● = placenta tissue

• number of fused carpels is often clear in a cross section of the fruit

The Flower

Placentation types - arrangement of ovules, provides hints to the number of carpels

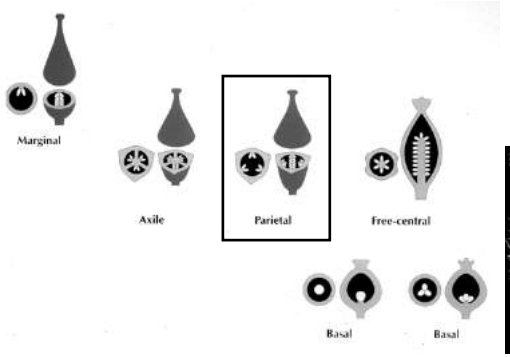


Marginal - found in almost all monocarpic or apocarpic pistils

Axile - found in some syncarpic pistils

The Flower

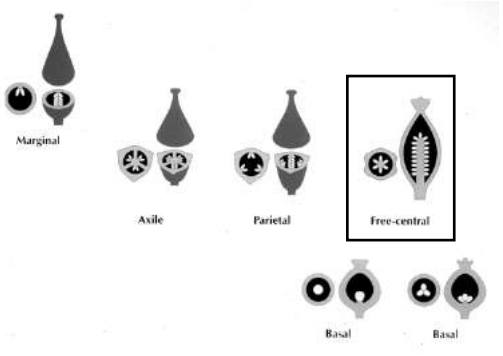
Placentation types - arrangement of ovules, provides hints to the number of carpels



Parietal - found in some syncarpic pistils

The Flower

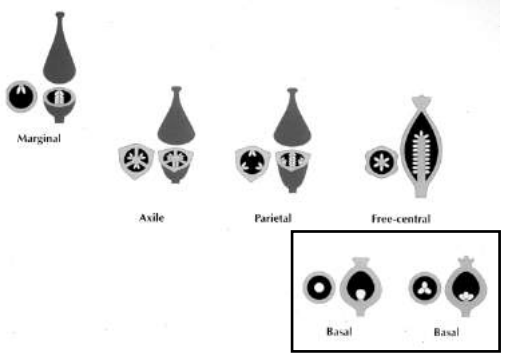
Placentation types - arrangement of ovules, provides hints to the number of carpels



Free-central - found in a few syncarpic pistils

The Flower

Placentation types - arrangement of ovules, provides hints to the number of carpels



Basal - found in some monocarpic, apocarpic, or syncarpic pistils

The Flower

Numerical plan - merosity, arrangement of perianth
- not necessarily stamens or carpels

perianth spiralled

Common in primitive angiosperms

perianth 5-merous

Common in eudicots

The Flower

Numerical plan - merosity, arrangement of perianth
• not necessarily stamens or carpels

perianth 4-merous

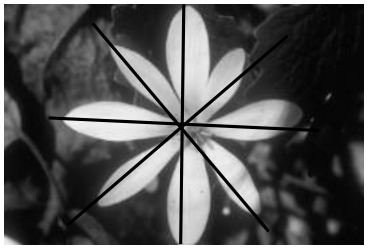
Occasional in eudicots

perianth 3-merous

Common in monocots & some primitive angiosperms

The Flower

Symmetry plan - perianth arrangement important in pollination biology



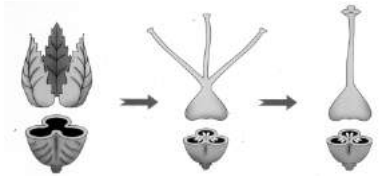
Flowers radially symmetrical

Flowers actinomorphic

Flowers bilaterally symmetrical

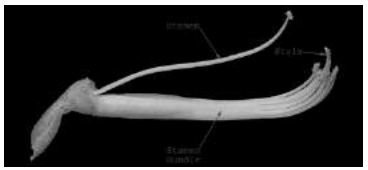
Flowers zygomorphic

The Flower



Fusion of carpels → Syncarpic pistil

Connation: fusion of floral parts from the same whorl



Fusion of stamens → Staminal tube

Fusion of petals → Corolla tube

The Flower

Adnation: fusion of floral parts from different whorls

• Simple adnation

Stamens fused onto inner surface of fused (connation) petals

• Complex adnation

Sepals, petals, and stamens fuse to form a hypanthium

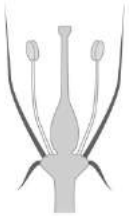
The Flower

e.g., Drimys & sandwort

Adnation: fusion of floral parts from different whorls

No adnation!

Connation (fusion of similar parts) may or may not occur



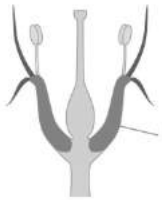
Ovary superior
Flower hypogynous
No hypanthium

The Flower

e.g., cherry & rose

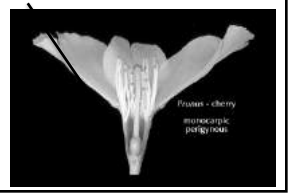
Adnation: fusion of floral parts from different whorls

Ovary superior
Flower hypogynous
No hypanthium



Ovary superior
Flower perigynous
Hypanthium present

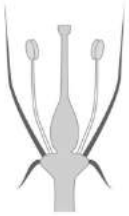
Adnation of calyx, corolla, & stamens = hypanthium



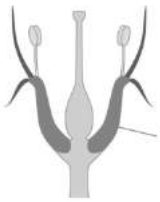
The Flower

e.g., feverwort, honeysuckle, apple

Adnation: fusion of floral parts from different whorls



Ovary superior
Flower hypogynous
No hypanthium



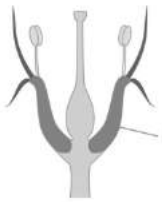
Ovary superior
Flower perigynous
Hypanthium present

Ovary inferior
Flower epigynous
Hypanthium present

The Flower

e.g., feverwort, honeysuckle, apple

Adnation: fusion of floral parts from different whorls



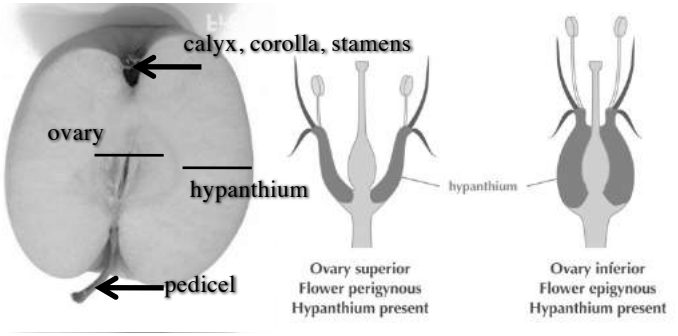
Ovary superior
Flower perigynous
Hypanthium present

Ovary inferior
Flower epigynous
Hypanthium present

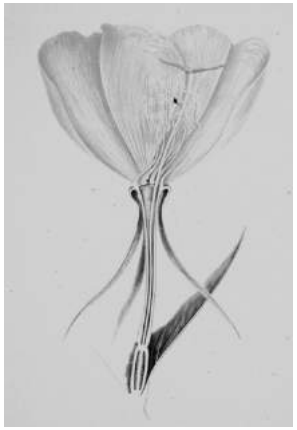
The Flower

e.g., feverwort, honeysuckle, apple

Adnation: fusion of floral parts from different whorls



The Flower



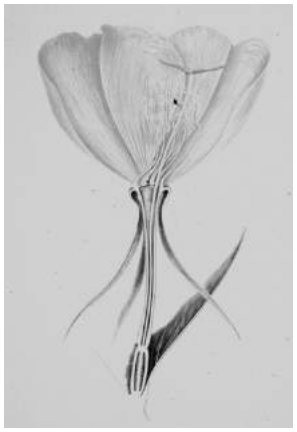
Floral formula - shorthand notation

$CA^{4}\ CO^{4}\ A^{8}\ G^{4}$

4 sepals (**CA**lyx)
4 petals (**CO**rolla)
8 stamens (**A**ndroecium)
4 carpels (**G**ynoecium)

Oenothera biennis
Evening primrose
Onagraceae

The Flower



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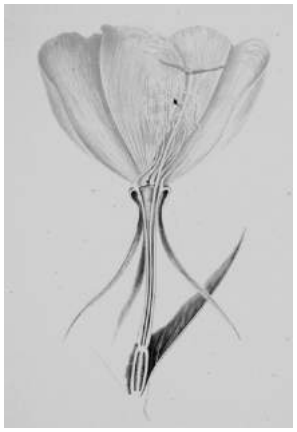
- Carpels fused = 1 pistil

Oenothera biennis
Evening primrose
Onagraceae

The Flower



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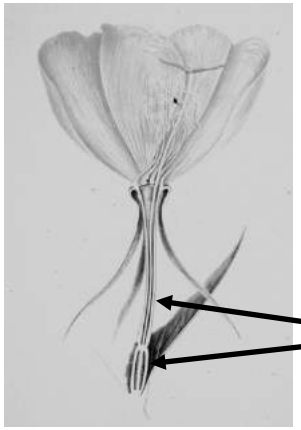
Carpels fused = 1 pistil

- Ovary inferior

Oenothera biennis
Evening primrose
Onagraceae

The Flower



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4 carpels (**G**ynoecium)

Carpels fused = 1 pistil

Ovary inferior

• Hypanthium (+ hypanthium tube)

Oenothera biennis
Evening primrose
Onagraceae

The "flower" — what is it?

• a flower is a specialized shoot that:

1. is determinate (vs. indeterminate)
2. has a modified stem with compressed internodes
3. possesses modified leaves with various functions, these determined by gene arrays (e.g., ABC model)
4. often clustered in an inflorescence (larger branch)