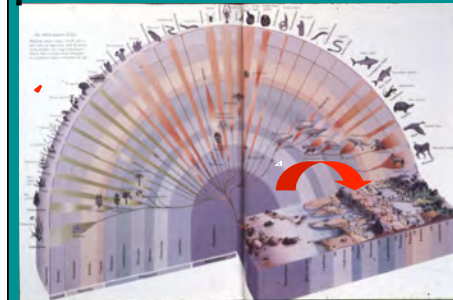


## Angiosperms or Flowering Plants the phylum Magnoliophyta



## Land Plant Evolution: Algae to Angiosperms

*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

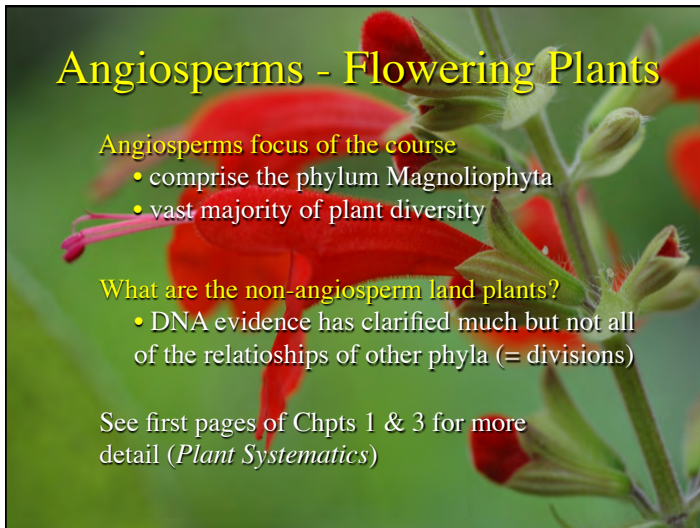
**Angiosperms focus of the course**

- comprise the phylum Magnoliophyta
- vast 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 (= divisions)

See first pages of Chpts 1 & 3 for more detail (*Plant Systematics*)

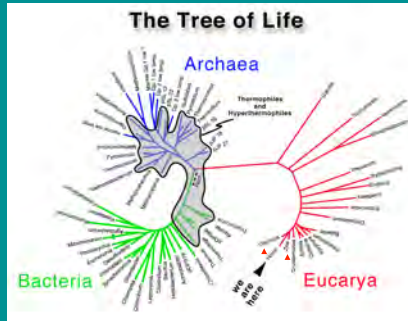


## Fungi?

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



## Fungi?

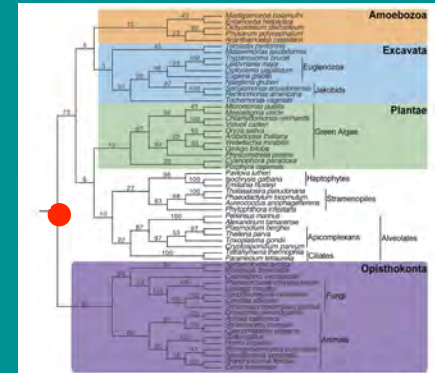


Traditional view of eukaryotic relationships

Fungi are here Green Plants are here

## Fungi?

Turning the Crown Upside Down: Gene Tree Parsimony Roots the Eukaryotic Tree of Life



Katz et al. 2012  
*Systematic Biology*

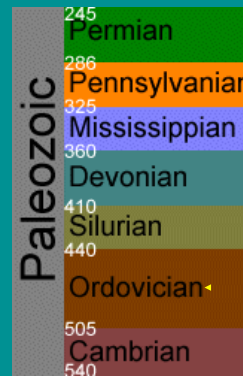
FIGURE 1. Reconciled tree of eukaryotes reveals a split between Opisthokonta and all remaining eukaryotes. Major clades indicated on colored boxes and central circles with vertical lines as described in Table 1. Tree estimated from analysis of 481 loci on the "151-locus" analysis. taxa listed in black (7 of the 20 genes (Table 1) and including merged gene trees for the 11 genes with missing sequences).

## Charales - stoneworts

- Green algal lineage
- Closest relatives to land plants



## 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 - Anthocerotophyta

## Extinct Land Plants - first vascular plants



Early Devonian Period (410 - 390 mya)

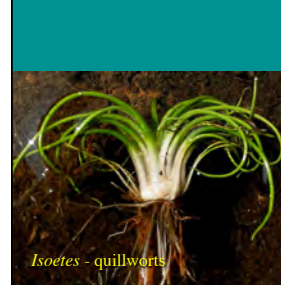
*Rhynia* seen in the early Devonian (Rhynie Chert fossil) is one of first vascular plants

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



*Isoetes* - quillworts



*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
- 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

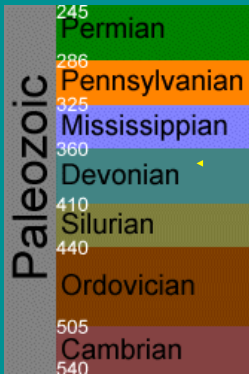


## Polypodiophyta - ferns

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



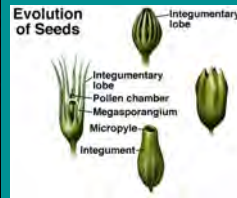
## Extinct Land Plants - the seed plants



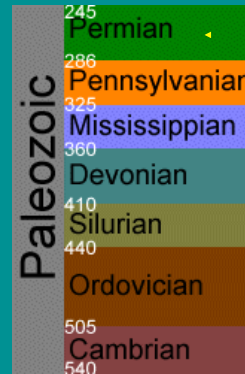
Late Devonian Period (390 - 360 mya)

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?

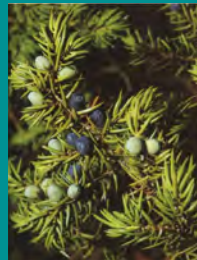
conifers



pine



spruce



juniper

## Pinophyta - gymnosperms

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



cycads



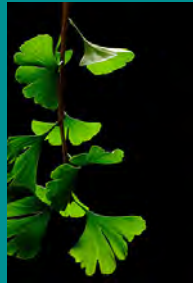
male strobilus



female strobili

## 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*

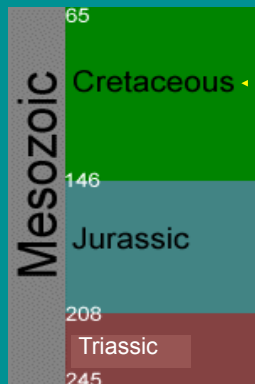


*Ephedra*



*Gnetum*

## Extinct Land Plants – first flowering plants



Cretaceous Period (146 - 65 mya)

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



*Archaeofructus*

## Magnoliophyta - angiosperms



- 275,000 + species
- 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)

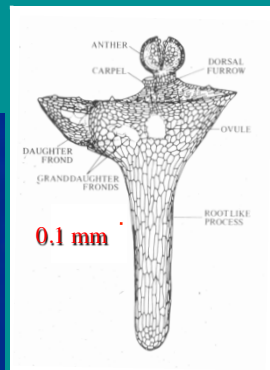
- Eucalyptus regnans* (Myrtaceae) over 100m tall and 19m dbh



## 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)

- Rafflesia arnoldii* (Rafflesiaceae) from New Guinea, up to 1m across and 20lbs



## Angiosperms - Flowering Plants

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

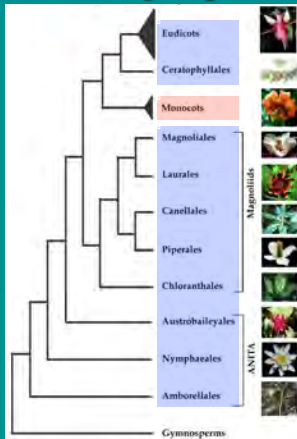


## Angiosperms - Flowering Plants

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



## Angiosperms - Flowering Plants



### Magnoliophyta classification

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

## The Flower — Why Important?

### The Flower: most significant feature of angiosperms

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

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





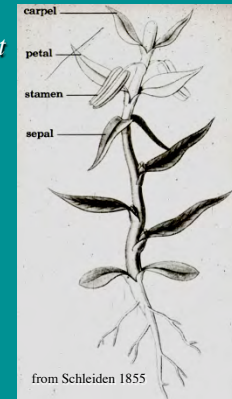
## The Flower — What is it?

- **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)



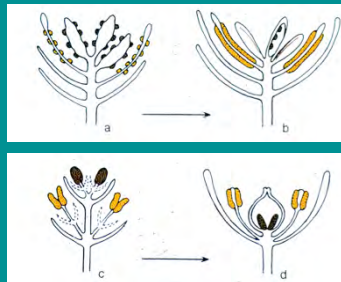
## The Flower — What is it?

- developmental/evolutionary origin of the flower still debated

1. **Euanthial** theory - (foliar theory) - single shoot

- anthers
- ovules

2. **Pseudanthial** theory - compound shoot or cone



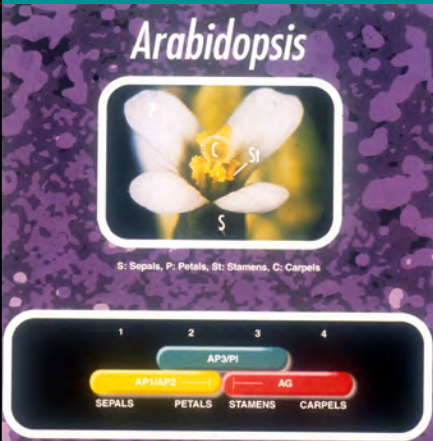
## The Flower — What is it?

- 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?



*Arabidopsis*

S: Sepals, P: Petals, St: Stamens, C: Carpels

The 'ABC' model of floral part identity

A

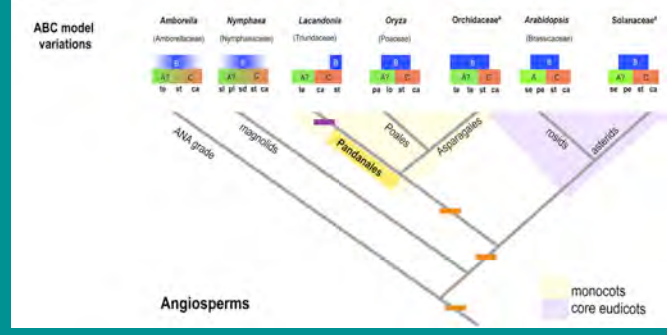
B

C

sepals   petals   stamens   carpels

## The Flower — What is it?

*The Plant Cell*, 2010




Angiosperms

The 'ABC' model of floral part identity

## The Flower — What is it?

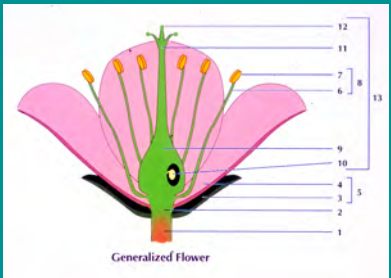
- thus, a flower is a specialized shoot that:

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

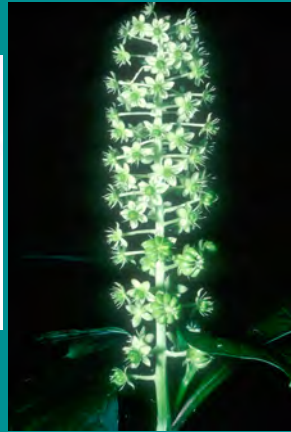
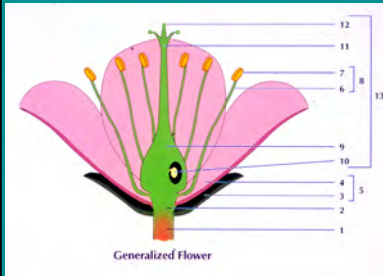
read chpt 9 in *Plant Systematics*!



Generalized Flower

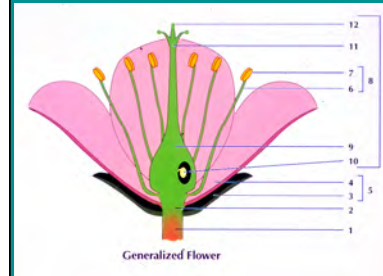
- 1st half deals with vegetative features - we will cover in lab 2 next week
- 2nd half deals with flowers/fruits - lab 3 following week

## The Flower



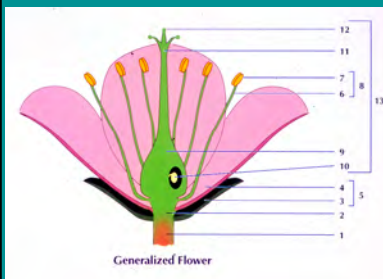
1. **Peduncle**: floral stalk, the stem supporting the flower; sometimes referred to as the **pedicel**

## The Flower



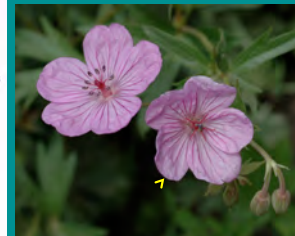
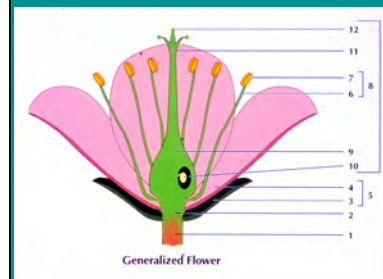
2. **Receptacle**: modified floral stem or axis from which arise the floral appendages or modified leaves

## The Flower



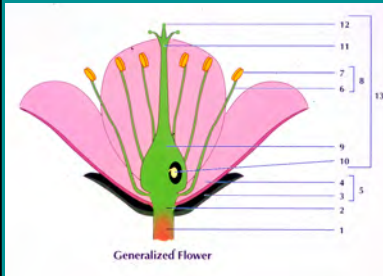
3. **Sepal**: the outer whorl of leaves, green and protective; collectively called the **calyx**

## The Flower



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

## The Flower

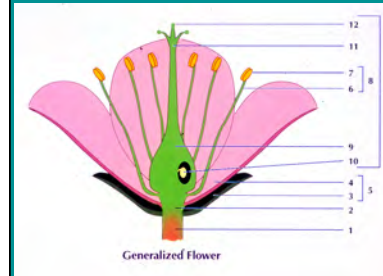


5. **Perianth:** collective term for sepals and petals

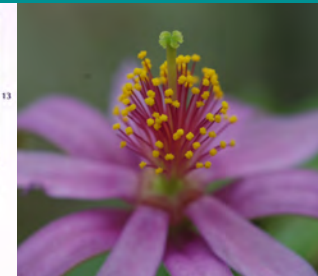


**Tepals** if both similar or if only one reduced set (sepals)

## The Flower

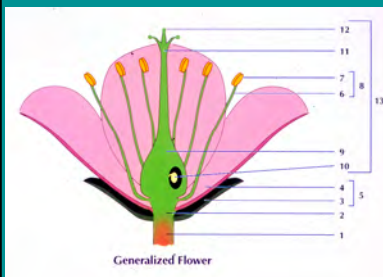


8. **Stamen:** the male structure of flower comprising **filament** and **anther**

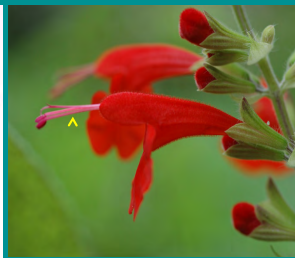


collectively, stamens are the **androecium** (= 'house of males')

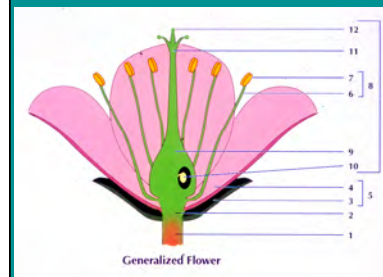
## The Flower



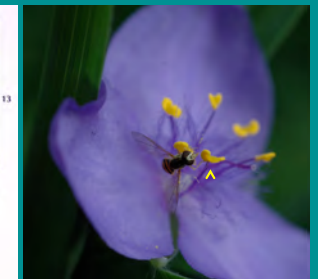
6. **Filament:** slender stalk of the stamen supporting the anther; permits exertion of anther with pollen out of flower



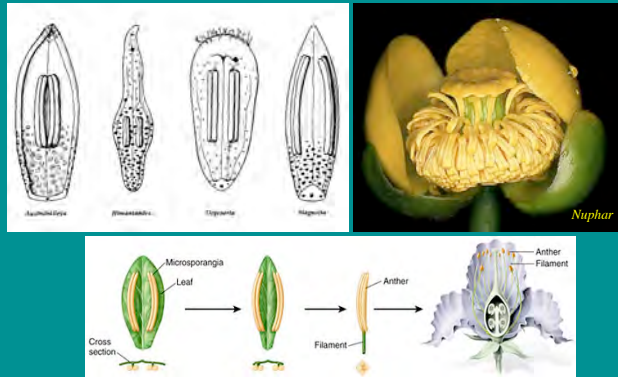
## The Flower



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

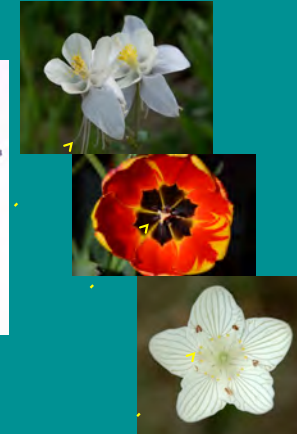
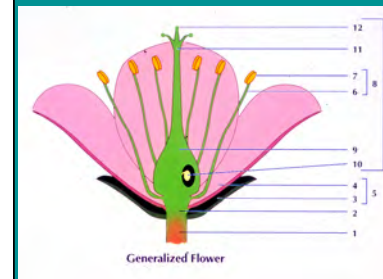


## The Flower



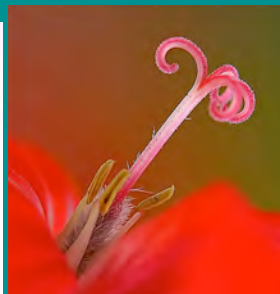
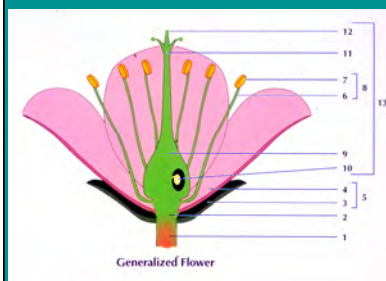
- stamens can be leaf-like in primitive angiosperms!

## The Flower



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

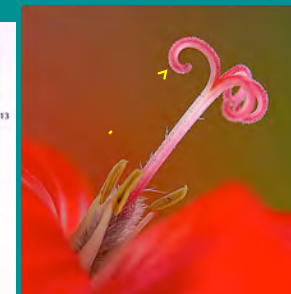
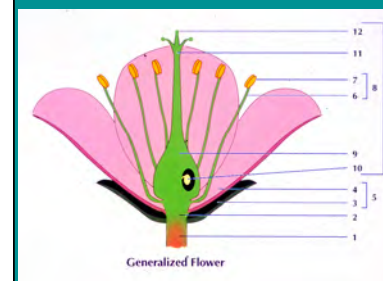
## The Flower



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’)

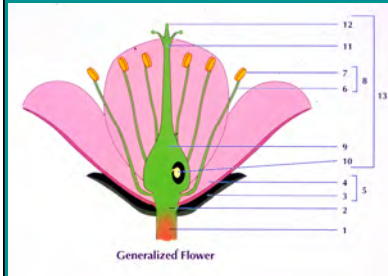
## The Flower



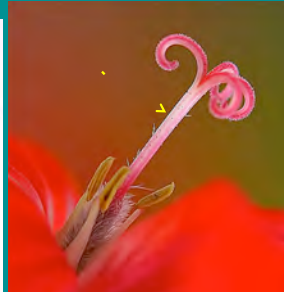
13. **Pistil**: flask-shaped, female structure comprising three main parts – often referred to as **carpel(s)**

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

## The Flower

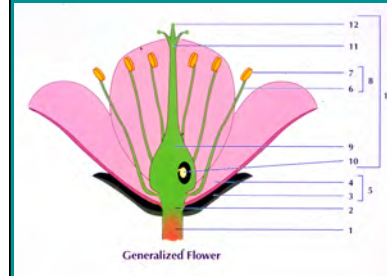


13. **Pistil:** flask-shaped, female structure comprising three main parts – often referred to as **carpel(s)**

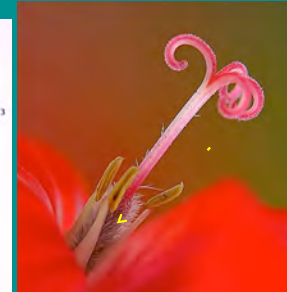


11. **Style:** slender stalk of pistil above ovary that the pollen tubes must pass through to reach eggs in ovules

## The Flower

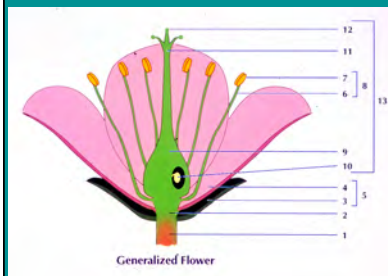


13. **Pistil:** flask-shaped, female structure comprising three main parts – often referred to as **carpel(s)**

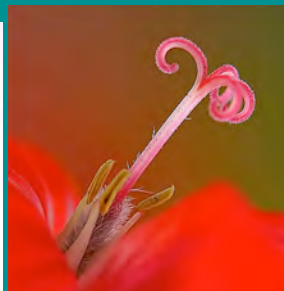


9. **Ovary:** basal portion of pistil that contains ovules; at maturity becomes **fruit** with seeds

## The Flower



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

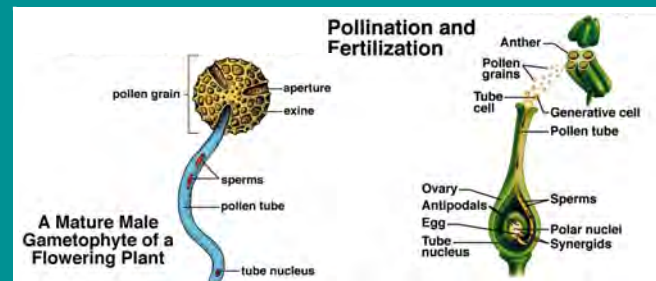


10. **Ovules:** fertile portions of pistil that contain a female gametophyte (embryo sac); develop into **seeds** after fertilization

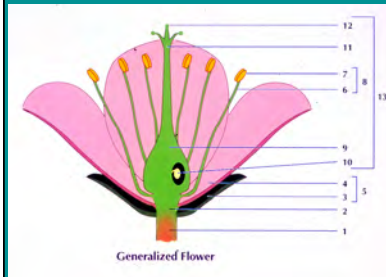
## The Flower

### 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

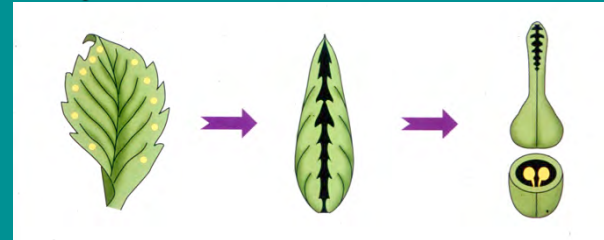
1. Monocarpic
2. Apocarpic

Carpels fused

3. Syncarpic

## The Flower

Monocarpic



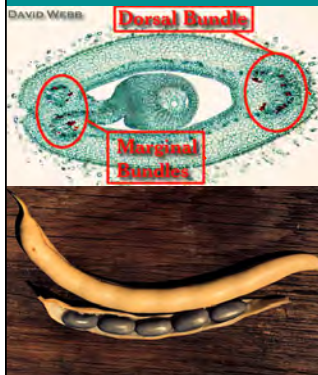
1 floral 'leaf' in gynoecium

Folded 'leaf'

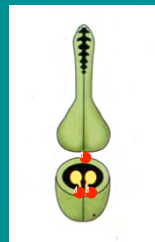
1 carpel = 1 pistil

- This gynoecium is **monocarpic** (one carpel)

## The Flower



legumes



1 carpel = 1 pistil

- This gynoecium is **monocarpic** (one carpel)

## The Flower

Apocarpic

- If 6 leaves **separately** form carpels,
- then the flower has 6 carpels and 6 pistils,
- gynoecium is **apocarpic** (separate carpels)

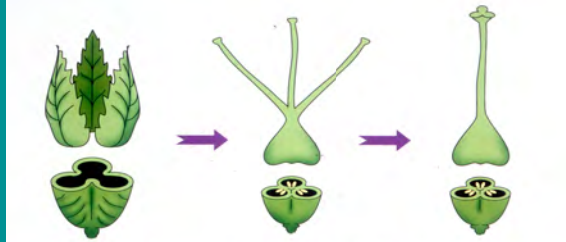


*Caltha palustris* - Marsh marigold

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

## The Flower

Syncarpic



3 floral 'leaves' in gynoecium fuse

3 carpels = 1 pistil  
3 styles

3 carpels = 1 pistil  
1 style

This gynoecium is syncarpic

This gynoecium is syncarpic

## The Flower

Syncarpic



tomato – 2 carpels

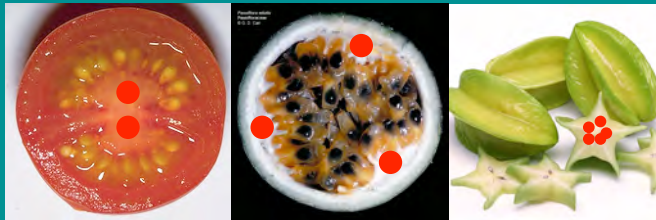
passion fruit – 3 carpels

starfruit – 5 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

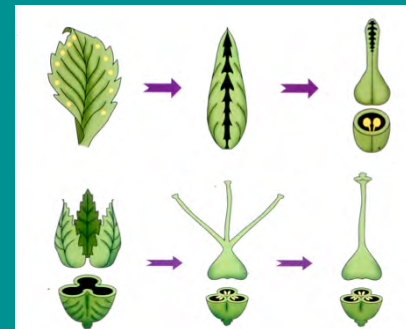
starfruit – 5 carpels

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

● = placenta tissue

## The Flower

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



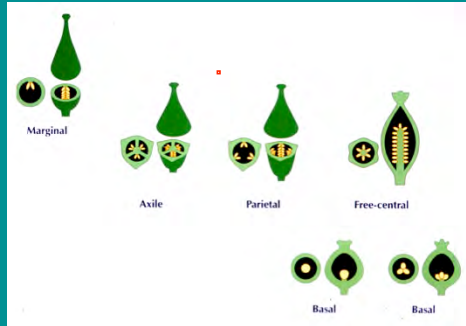
Marginal - found in almost all monocarpic or apocarpic pistils

Axile - found in some syncarpic pistils



## The Flower

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

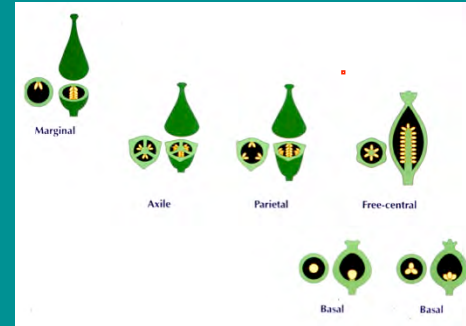


Parietal - found in some syncarpic pistils



## The Flower

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

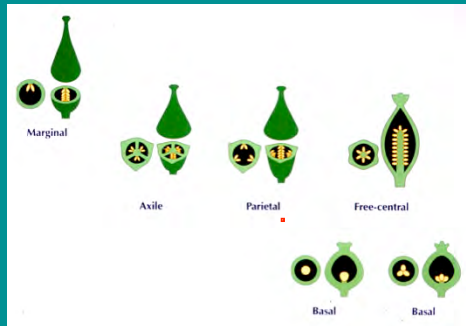


Free-central - found in a few syncarpic pistils



## The Flower

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

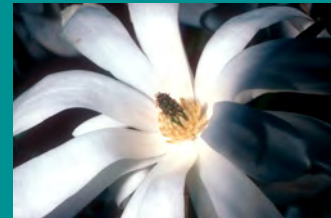


Basal - found in some monocarpic, apocarpic, or syncarpic pistils



## 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

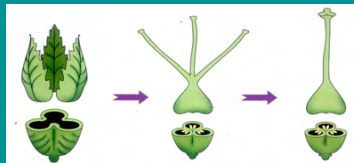


Flowers **radially** symmetrical  
 Flowers **actinomorphic**



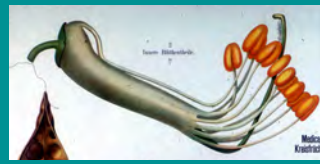
Flowers **bilaterally** symmetrical  
 Flowers **zygomorphic**

## The Flower

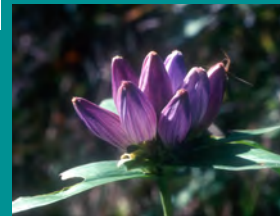


Fusion of carpels → Syncarpic pistil

**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

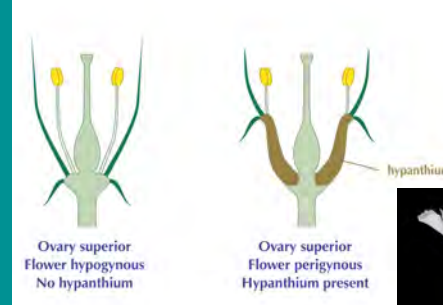


## The Flower

e.g., cherry & rose

**Adnation:** fusion of floral parts from **different whorls**

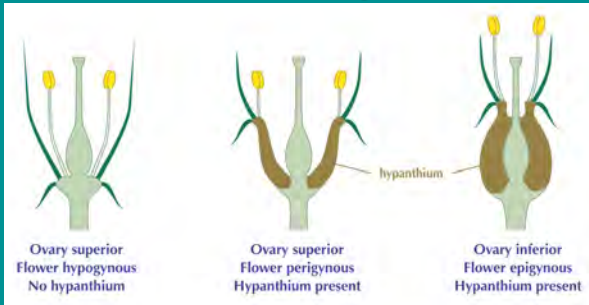
Adnation of calyx, corolla, & stamens = **hypanthium**



## The Flower

e.g., horse gentian & fuchsia

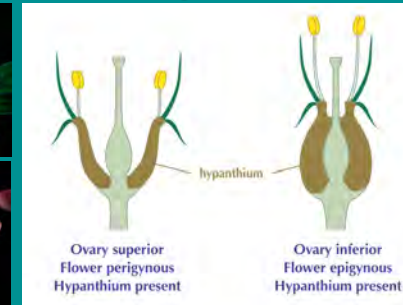
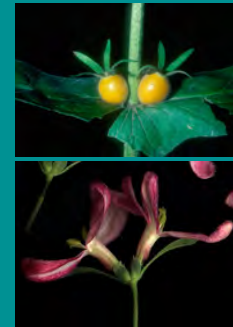
**Adnation:** fusion of floral parts from **different whorls**



## The Flower

e.g., horse gentian & fuchsia

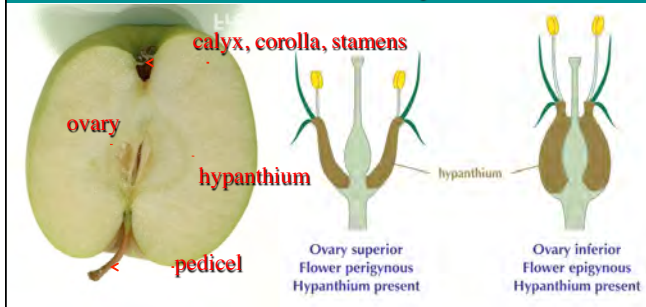
**Adnation:** fusion of floral parts from **different whorls**



## The Flower

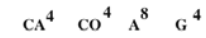
e.g., horse gentian & fuchsia

**Adnation:** fusion of floral parts from **different whorls**



## The Flower

Floral formula - shorthand notation



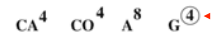
- 4 sepals (CAlyx)
- 4 petals (COrolla)
- 8 stamens (Androecium)
- 4 carpels (Gynoeceium)



*Oenothera biennis*  
Evening primrose  
Onagraceae

## The Flower

Floral formula - shorthand notation



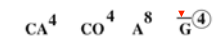
- 4 sepals (CAlyx)
- 4 petals (COrolla)
- 8 stamens (Androecium)
- 4 carpels (Gynoeceium)
- Carpels fused = 1 pistil



*Oenothera biennis*  
Evening primrose  
Onagraceae

## The Flower

Floral formula - shorthand notation



- 4 sepals (CAlyx)
- 4 petals (COrolla)
- 8 stamens (Androecium)
- 4 carpels (Gynoeceium)
- Carpels fused = 1 pistil
- Ovary inferior

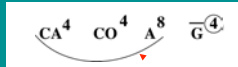


*Oenothera biennis*  
Evening primrose  
Onagraceae

## The Flower



Floral formula - shorthand notation



4 sepals (CAlyx)  
4 petals (COrolla)  
8 stamens (Androecium)  
4 carpels (Gynoecium)

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)