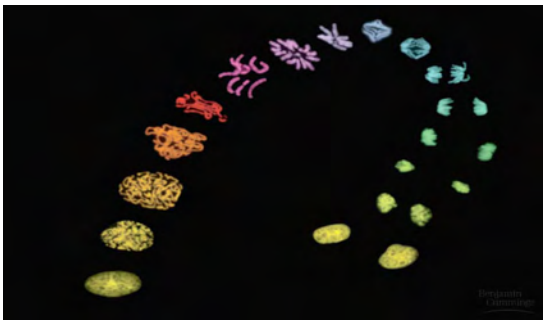
Cell Cycles, Sex, & Ploidy



The DNA Gene Theory

1. **DNA is the molecule of inheritance.**
2. **A chromosome is one long dsDNA.**
   - **In eukaryotes, the dsDNA molecule is wrapped with histones & other proteins to form *chromatin*.**
3. **A gene (a discrete unit of heredity) is a specific region of DNA on a chromosome.**
   - **Specific gene: instructions for a specific protein**
4. **Each chromosome = 100s–1000s of genes.**

The Cell Theory
"Cell Doctrine"

1. All organisms are constructed of one or more cells.
2. The cell is the basic unit of life.
3. All cells arise from previous cells.
   "Omnis cellula e cellula!"

∴ cellular reproduction must include copying & transmitting DNA

Cellula e Cellula

- Growth & Development
  - – New cells produced
  - – Need the right number of cells in the right location
    - Either too few or too many is bad.
- Cell Replacement
  - – Lost or damaged cells replaced
- Asexual Reproduction
  - – New organism formed

Sea star regenerating

Cellula e Cellula

- Cells divide to reproduce

I. **Asexual Reproduction** offspring from single parent (daughter cells have identical DNA as parent cell)

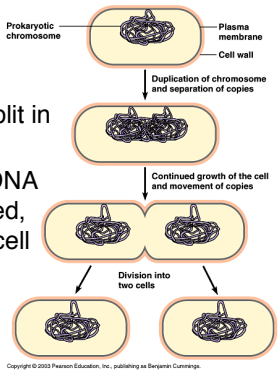
II. **Sexual Reproduction** offspring from union of egg and sperm (combine some DNA from both parent cells)

Budding *Hydra*

Sperm cells and egg cell

Prokaryotes Divide Asexually

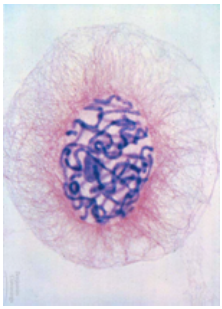
- **Binary Fission** "to split in half"
- A **Chromosome** (1 DNA molecule) is duplicated, separates, and then cell divides



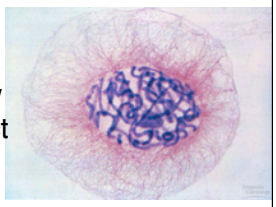
Binary fission of a bacterium

Eukaryotic Cells Have Multiple Chromosomes

- Eukaryotic cells have 5–20x more DNA per cell than do bacteria.
- Divided into linear dsDNA + histone & other proteins : **chromosomes**
- If straight, typical chromosome would be ~ 4 cm long.
- Humans have 46 different chromosomes
  - So collectively amounts to ~ 2 m long dsDNA packed into each cell nucleus!
    (4 m after replication!)

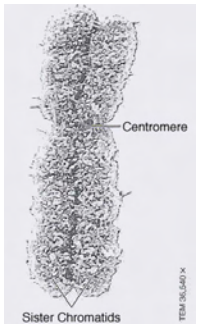


Eukaryotic Cells Have Multiple Chromosomes

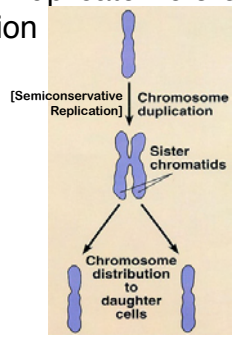


- In division, each new cell needs the correct number and kind of chromosomes
  - –Replicate and divide chromosomes in nucleus
  - –Distribution of organelles

Chromosomes Must Duplicate Before Division



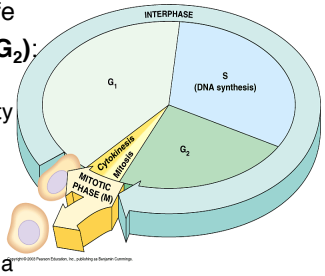
Human duplicated chromosome



Chromosome duplication and separation

The Cell Cycle

- Ordered sequence of events in a cell's life
- **Interphase (G_1/S/G_2)**: 90% of cell cycle
  - Most cellular activity
- **Mitotic phase (M)**
  - Mitosis = nucleus divides
  - Cytokinesis = cytoplasm & plasma membrane divides

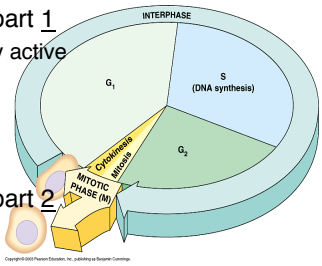


The eukaryotic cell cycle

The Cell Cycle

Interphase:

1. **G_1:** Growth stage, part 1
   - Cell is metabolically active and grows larger
2. **S:** Synthesis stage
   - DNA is replicated
3. **G_2:** Growth stage, part 2
   - More metabolism & growth

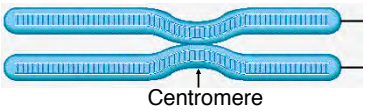


The eukaryotic cell cycle

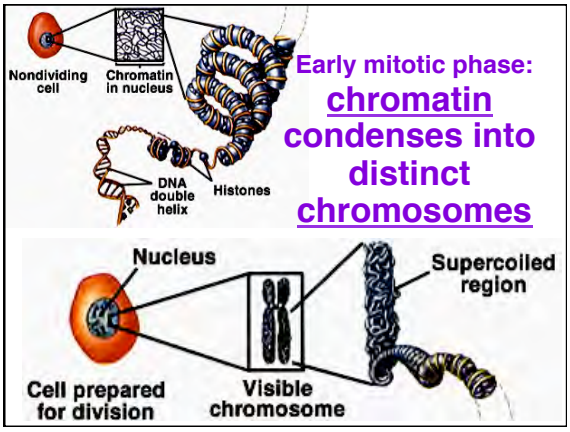
All cell reproduction requires DNA duplication

- Each cell must have its own copy of genetic material
  - –**DNA replication in S Stage of Interphase**
- Then DNA must be separated (**segregation**) so that each cell has a complete copy
  - –**Mitosis of Mitotic Phase**

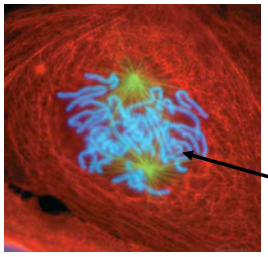
Duplicated chromosomes

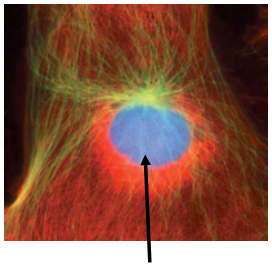


- Duplicated chromosome: two sister **chromatids**
- Sister chromatids contain identical DNA
- Sister chromatids are held together by the **centromere**



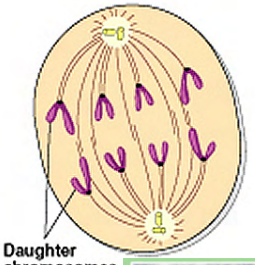
chromatin condenses into distinct chromosomes

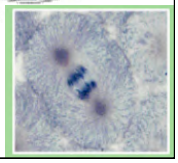




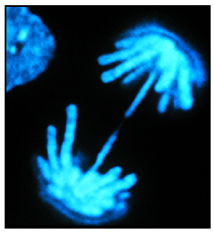
Mitosis

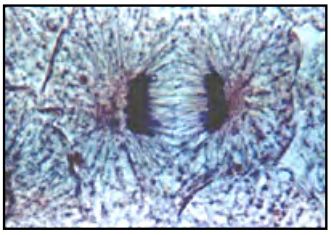
- Sister chromatids separate, move to opposite poles
- Sister chromatids are now "unduplicated chromosomes"
- Cell elongates





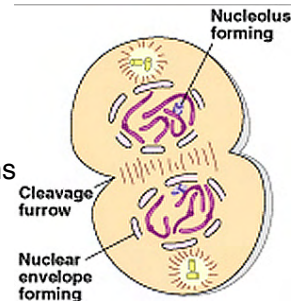
Separation of sister chromatids



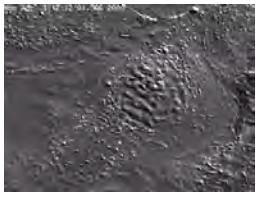


Late Mitosis

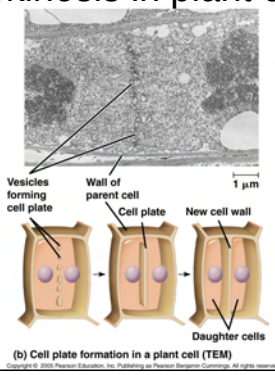
- New nuclear envelopes form
- Chromosomes de-condense
- Cytokinesis begins

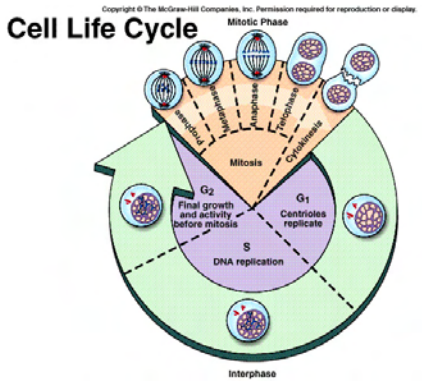


Mitosis & Cytokinesis in animal cells

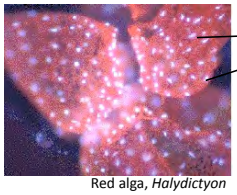


Cytokinesis in plant cells



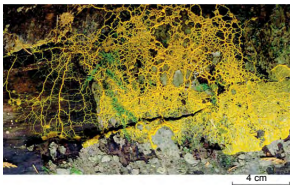


Mitosis without cytokinesis
⇒ **Coenocytic** ("shared cell")



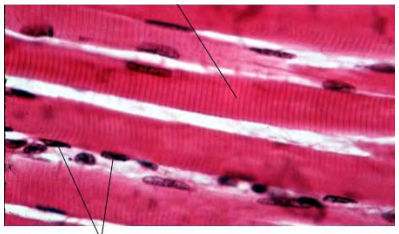
Red alga, *Halydictyon*

Plasmodial slime mold



- **Giant cell with multiple nuclei**

In contrast, multinuclear cells may also form by fusion of cells
⇒ **Syncytial** ("together cell")

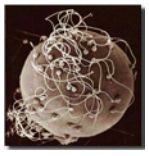


- **Multinuclear muscle fiber forms by fusion of many embryonic myoblast cells**

Cells Arise From Preexisting Cells

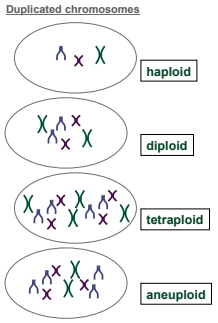
I. **Asexual (Mitotic) Reproduction**
   a. Mitosis: production of two identical nuclei
   b. Cytokinesis: physical division of the cell into two

II. **Sexual (Meiotic) Reproduction**
   a. Meiosis: production of four *non*-identical nuclei
   b. Cytokinesis: physical divisions of the cell
   c. Fertilization: fusion of two sex cells
   d. Syngamy: fusion of two nuclei

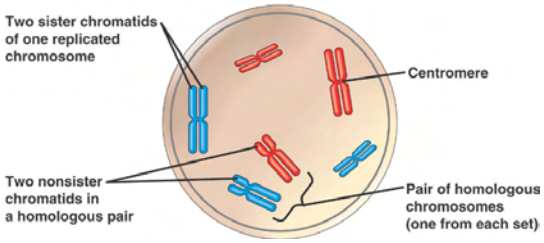


Ploidy: how many copies of the *same* chromosome?

- **Haploid**: one version of each chromosome (n)
- **Diploid**: two versions of each chromosome (2n)
- **Polyploid**: many versions of each chromosome
- **Aneuploid**: abnormal number of chromosomes



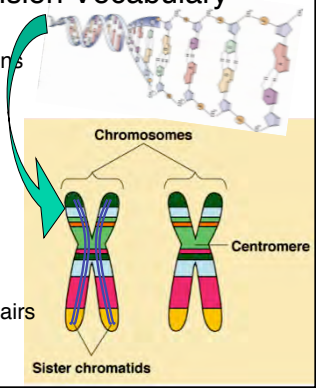
Diploid cells have homologous pairs of chromosomes: 1 set from mom, 1 set from dad.



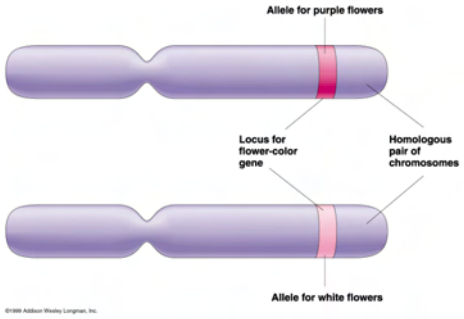
Cellular Division Vocabulary

Levels of Doubles —

- Each chromatid contains double-stranded DNA
  - Two **complementary** strands
- Each *duplicated* chromosome contains sister chromatids
  - Two **identical** sisters
- In *diploid* organisms, chromosomes are in pairs
  - Two **homologous** chromosomes

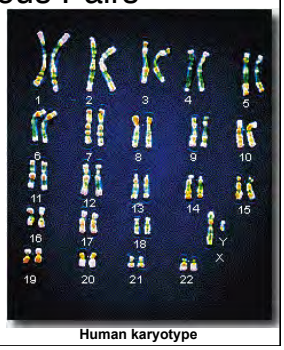


Homologous chromosomes (homologs): same set of genes, but maybe different versions of those genes (alleles)



Chromosomes Matched in Homologous Pairs

- Each human cell
  - ✓23 pairs = 46 chromosomes
  - ✓Homologs: same size, shape, band pattern, position of centromere, and gene loci



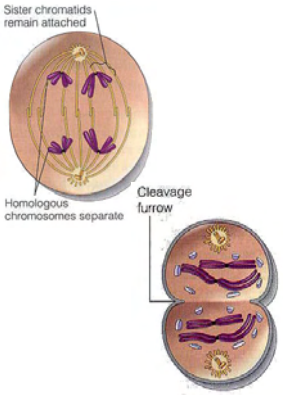
Meiosis: *Reductive* Division of ***Diploid*** Cells

— Reduces Chromosome Number in Half

- Meiosis has 2 consecutive divisions
  - **Meiosis I**: Homologs separate from homologous pairs (diploid→haploid)
  - **Meiosis II**: Sister chromatids separate (duplicated → unduplicated chromosomes)

Meiosis I

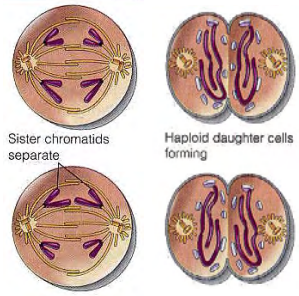
- Homologous pairs separate
- 2 new daughter cells
- Both are now **haploid**, but with duplicated chromosomes



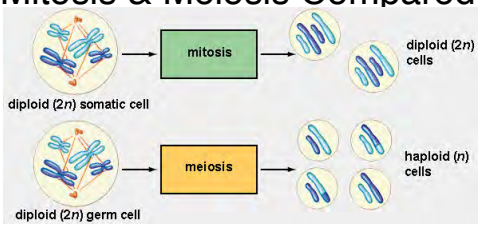
Meiosis II

In both cells from first meiotic division:

- Sister chromatids separate
- Daughter chromosomes now unduplicated
- Total of 4 haploid cells produced



Mitosis & Meiosis Compared



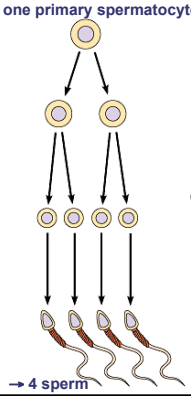
- Mitosis separates chromatids in a single division event
  - If diploid cell→ then diploid daughter cells
  - If haploid cell→ then haploid daughter cells
- Meiosis I separates homologs, then Meiosis II separates chromatids
  - **Diploid** cell→ **Haploid** daughter cells

Spermatogenesis:
one primary spermatocyte →

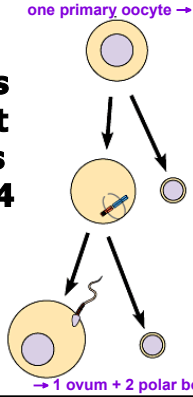
but

Oogenesis:
one primary oocyte →

Meiosis doesn't always create 4 cells.



→ 4 sperm



→ 1 ovum + 2 polar bodies

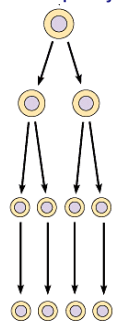
One microsporocyte →

but

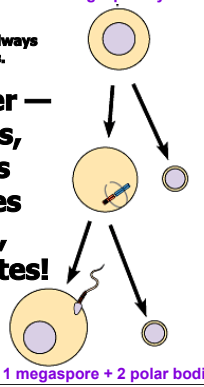
One megasporocyte →

Meiosis doesn't always create 4 cells.

Remember — in plants, meiosis produces spores, not gametes!

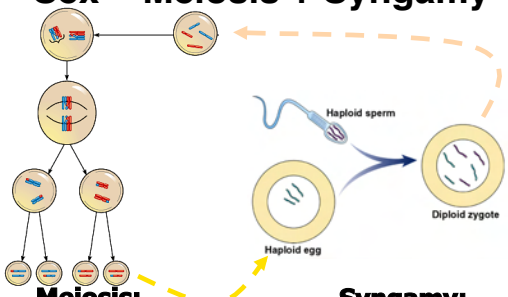


→ 4 microspores



→ 1 megaspore + 2 polar bodies

Sex = Meiosis + Syngamy



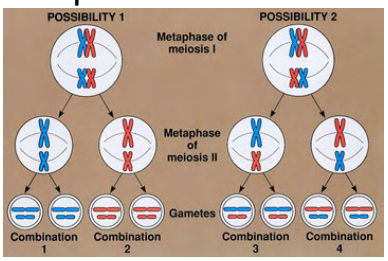
Meiosis:
2n → 1n
Diploid → haploid

Syngamy:
1n → 2n
Haploid → diploid

Sexual Reproduction Produces Genetic Variation

- Variation arises from
  - I. Independent chromosome assortment in meiosis
  - II. Crossing-over between homologous chromosomes in meiosis
  - III. Random process of fertilization

I. Independent Assortment



- Homologs line up by chance in Meiosis I
- Results in many different possible chromosome combinations in gametes
- 2^n possible combinations (2^{23} = >8 mill. for humans)

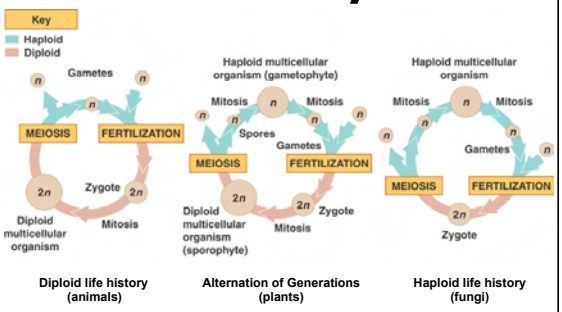
III. Random Fertilization

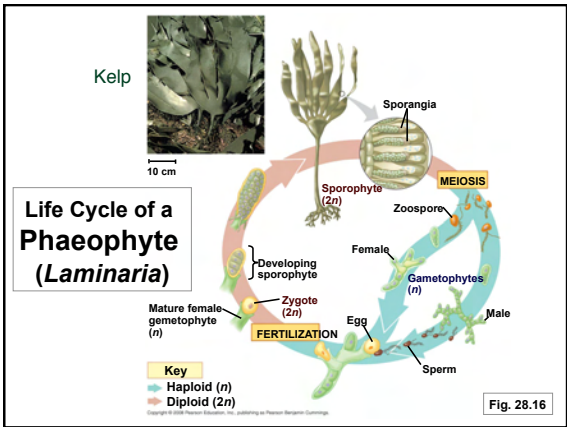
- Fertilization is a random process
- A **gamete** (sex cell) from one individual unites with one from another individual
- Given that a man can produce 2^{23} genetically different sperm, and a woman can produce 2^{23} genetically different ova:
- One mating couple can produce a diploid zygote with any of **>70 trillion** combinations of chromosomes! (2^{23} x 2^{23})
- (Not even counting variation from crossing-over!)

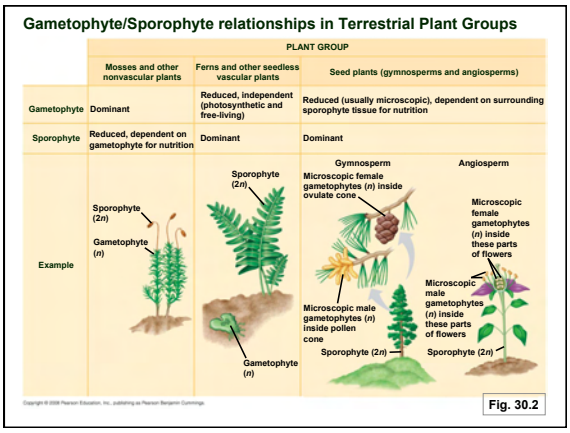
Fertilization

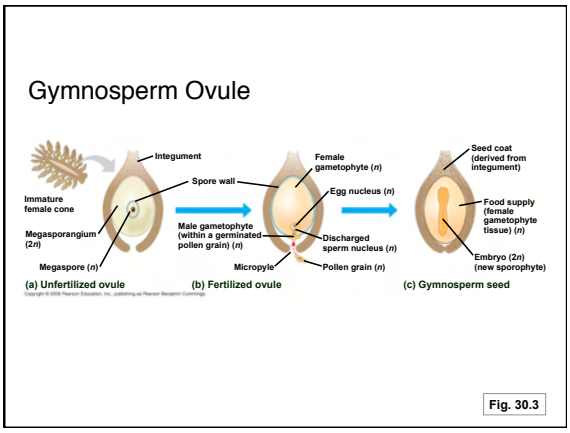
- Two haploid sex cells (**gametes**) → one diploid cell (**zygote**)
  1. **Plasmogamy**: fusion of gamete cell plasma membranes
     - → **Syncytial** cell (cell with >1 nuclei resulting from fusion of cells)
     - → **Heterokaryotic**: non-identical nuclei
  2. **Syngamy** or **Karyogamy**: fusion of 2 haploid nuclei
     - → 1 diploid nucleus
- **Isogametes**: both gametes contribute significant cytoplasm to the zygote.
  - Mating types: **+** or **–**
- **Heterogametes**: one gamete (**ova**) contributes most/all of zygote's cytoplasm.
  The other gamete (**sperm**) only provides the second haploid nucleus.
  - Mating types: **female** or **male**

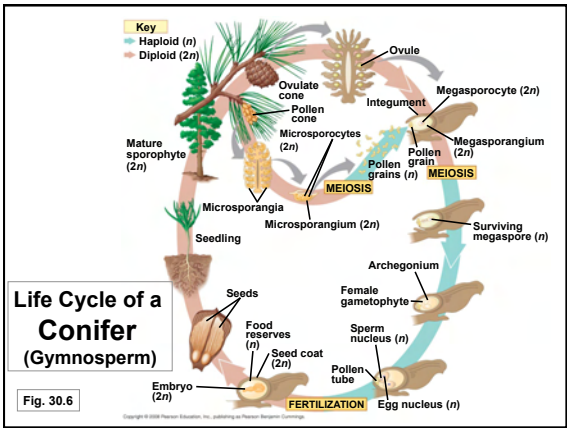
Sexual Life Cycles

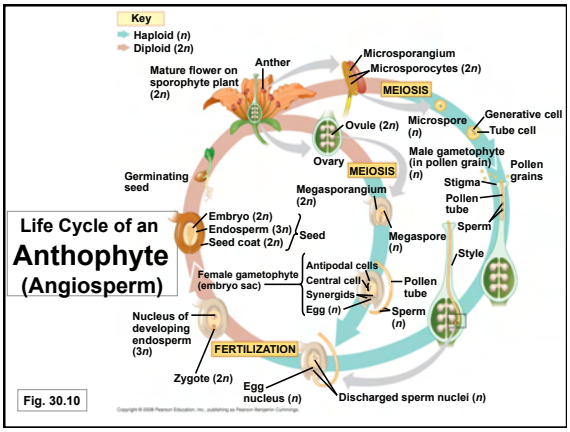






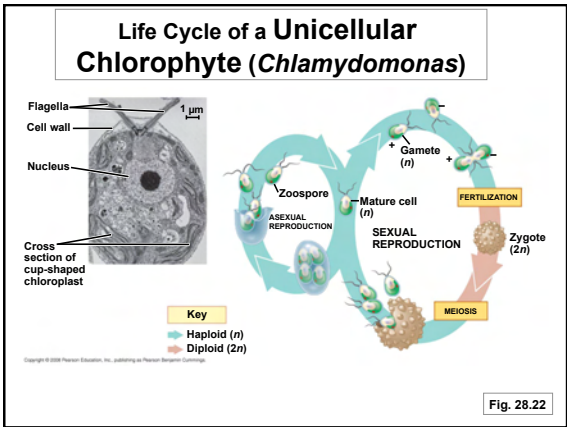


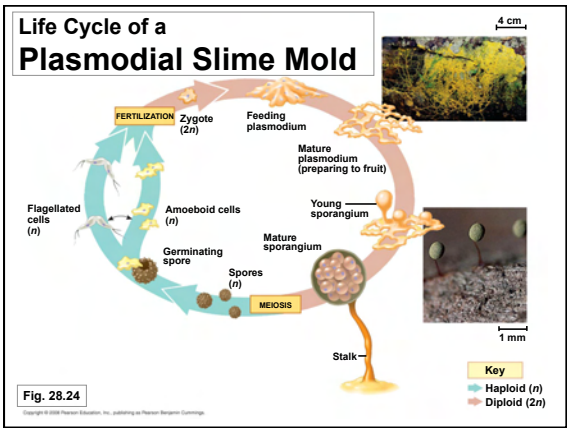


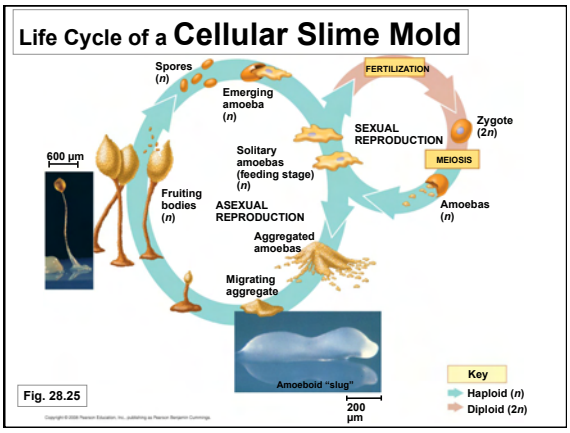


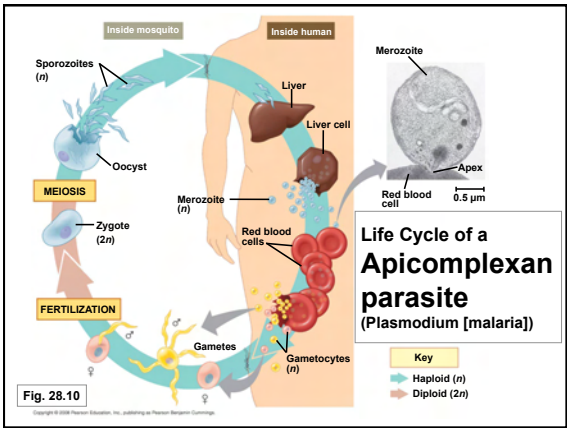
Sexual Variants in the Protista

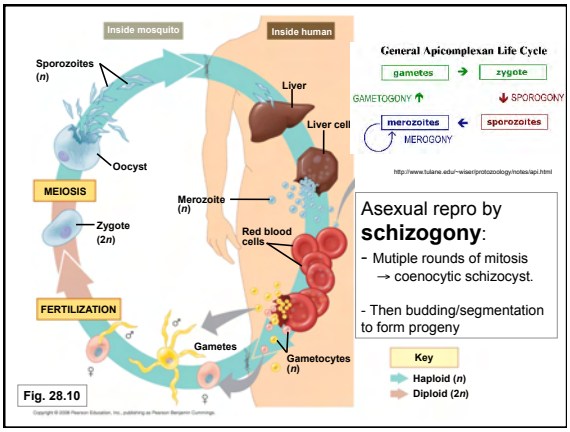
- **Unicellular Chlorophyte**
- **Plasmodial Slime Mold**
- **Cellular Slime Mold**
- **Apicomplexan parasite**
- **Ciliate**

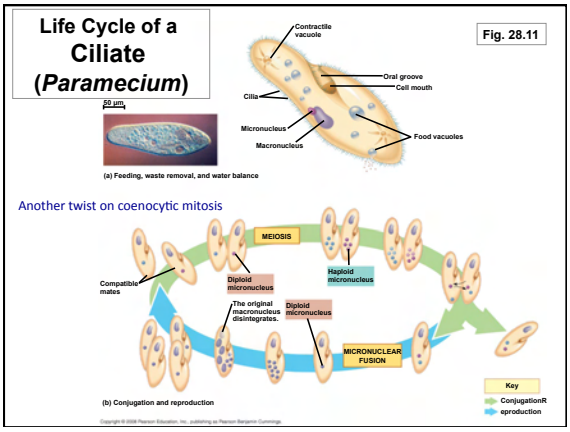



Life Cycle of a
Plasmodial Slime Mold
4 cm
FERTILIZATION
Zygote (2n)
Feeding plasmodium
Mature plasmodium (preparing to fruit)
Young sporangium
Mature sporangium
Stalk
Spores (n)
MEIOSIS
Germinating spore
Flagellated cells (n)
Amoeboid cells (n)
1 mm
Key
Haploid (n)
Diploid (2n)
Fig. 28.24


Life Cycle of a Cellular Slime Mold
Spores (n)
Emerging amoeba (n)
FERTILIZATION
Zygote (2n)
SEXUAL REPRODUCTION
MEIOSIS
Amoebas (n)
600 µm
Solitary amoebas (feeding stage) (n)
Fruiting bodies (n)
ASEXUAL REPRODUCTION
Aggregated amoebas
Migrating aggregate
Amoeboid "slug"
200 µm
Key
Haploid (n)
Diploid (2n)
Fig. 28.25


Inside mosquito
Inside human
Sporozoites (n)
Liver
Liver cell
Merozoite
Apex
Red blood cell
0.5 µm
Oocyst
MEIOSIS
Merozoite (n)
Zygote (2n)
Red blood cells
FERTILIZATION
Gametes
Gametocytes (n)
Life Cycle of a
Apicomplexan parasite
(Plasmodium [malaria])
Key
Haploid (n)
Diploid (2n)
Fig. 28.10


Inside mosquito
Inside human
Sporozoites (n)
Liver
Liver cell
Oocyst
MEIOSIS
Merozoite (n)
Zygote (2n)
Red blood cells
FERTILIZATION
Gametes
Gametocytes (n)
General Apicomplexan Life Cycle
gametes
zygote
GAMETOGONY
SPOROGONY
merozoites
sporozoites
MEROGONY
Asexual repro by schizogony:
- Mutiple rounds of mitosis → coenocytic schizocyst.
- Then budding/segmentation to form progeny
Key
Haploid (n)
Diploid (2n)
Fig. 28.10


Life Cycle of a
Ciliate
(Paramecium)
Fig. 28.11
Contractile vacuole
Oral groove
Cell mouth
Cilia
Micronucleus
Macronucleus
Food vacuoles
50 µm
(a) Feeding, waste removal, and water balance
Another twist on coenocytic mitosis
MEIOSIS
Compatible mates
Diploid micronucleus
Haploid micronucleus
The original macronucleus disintegrates.
Diploid micronucleus
MICRONUCLEAR FUSION
(b) Conjugation and reproduction
Key
ConjugationR
eproduction