The Other Eukaryotes…
Endosymbiotic Theory, Kingdom Protista

The Origin of Eukaryotic Cells

- Eukaryotic cells appeared first around 1.7 billion years ago
  - Some bacterial cells possess an internal structure called a nucleus
- Some bacterial cells have infoldings of their outer membranes extending into the interior
  - The endoplasmic reticulum (ER) and nuclear envelope of eukaryotes is thought to have evolved from this

Origin of the nucleus and endoplasmic reticulum.

- The endosymbiotic theory is a widely accepted explanation for the origin of energy-producing organelles in eukaryotes from bacteria
  - Present-day mitochondria and chloroplasts still contain their own DNA
    - This DNA is remarkably similar in size and character to the DNA of bacteria

The theory of endosymbiosis.

The Evolution of Sex

- A profound difference between prokaryotes and eukaryotes is that eukaryotes have the capacity for sexual reproduction
  - Sexual reproduction involves two parents contributing gametes to form the offspring
    - Gametes are usually formed by meiosis and are haploid
    - The resulting offspring are diploid
- But sexual reproduction is not the only way that eukaryotes can reproduce
  - Many eukaryotes reproduce by asexual reproduction, which is reproduction without forming gametes
    - The offspring of asexual reproduction are genetically identical to the parents
    - Many eukaryotes reproduce mainly by asexual reproduction, switching to sexual reproduction only during environmental stress

Reproduction among paramecia.

- A different asexual strategy in eukaryotes is parthenogenesis, the development of an adult from an unfertilized egg
- Many plants and marine fishes undergo a form of sexual reproduction that does not involve partners
  - This is called self-fertilization and involves one individual providing both male and female gametes
- The advantages of sexual reproduction are not immediately obvious
the segregation of chromosomes that occurs in meiosis tends to disrupt advantageous combinations of genes

- sexual reproduction may have evolved in protists because the diploid cell stage allows for chromosomal repair
  - double-strand breaks occur in the DNA are induced by dessication
  - the environmental stress of drying out triggers the diploid stage
  - perhaps the pairing up of chromosomes in the early stages of meiosis evolved originally as a mechanism for repairing double-strand damage
    - the undamaged version as a template could be used as template to guide the fixing of the damaged one

- sexual reproduction is one of the most important evolutionary innovations of eukaryotes
  - it provides a means of shuffling genes, creating genetic diversity
    - genetic diversity is the raw material of evolution
    - the greater the genetic diversity, the more rapid the evolutionary pace

- the sexual life cycle involves the production of haploid gametes by meiosis, followed by the union of two gametes in sexual reproduction

- eukaryotes are characterized by three major types of sexual life cycles
  - zygotic meiosis
  - gametic meiosis
  - sporic meiosis

- in zygotic meiosis, the zygote formed by the fusion of gametes is the only zygote cell
  - this type of sexual life cycle is common to many algae
  - the zygote is the only cell that undergoes meiosis
  - haploid cells occupy the major portion of the life cycle

Three types of Eukaryotic Life Cycles

(a) Zygotic meiosis.

- in gametic meiosis, the gametes are the only haploid cells
  - this sexual life cycle is common to most animals
  - meiosis produces the gametes
  - the diploid zygote occupies the major portion of the life cycle

Three types of Eukaryotic Life Cycles

(b) Gametic meiosis.

- in sporic meiosis, the spore-forming cells undergo meiosis
  - this life cycle is common to plants
- in plants, there is a regular **alternation of generations** between a haploid phase and a diploid phase
- the diploid phase produces spores that give rise to the haploid phase
- the haploid phase produces gametes that fuse to give rise to the diploid phase

**General Biology of Protists, the Most Ancient Eukaryotes**
- protists are eukaryotes united on the basis of a single *negative* characteristic
  - they are not fungi, plants, or animals
  - in all other respects, they are highly variable with no uniting features

*A unicellular protist.*

- cell surface varies among protists
  - all protists have plasma membranes
  - some, like algae and molds, have cell walls
  - others, like diatoms and radiolarians, secrete glassy shells of silica

- locomotor organelles also vary among protists
  - protists move by means of cilia, flagella, pseudopods or gliding mechanisms

- cyst formation occurs in protists who, despite having delicate surfaces, persist in harsh habitats
  - **cysts** are dormant forms of a cell with a resistant outer covering
    - in dormancy, the cell metabolism is more or less completely shut down

- protists employ a variety of forms of nutritional acquisition
  - one exception, however, is chemoautotrophy, which is known only from prokaryotes
  - some protists are photosynthetic autotrophs, called **prototrophs**
  - among the heterotrophic protists, there are
    - **phagotrophs** that ingest visible particles of food
    - **osmotrophs** that ingest food in soluble form

- protists typically reproduce asexually
  - sexual reproduction is resorted only in times of stress
- asexual reproduction involves an usual form of mitosis
  - the nuclear membrane usually persists throughout mitosis and the spindle apparatus forms within the nucleus
- asexual reproduction in protists may involve spore formation or fission
  - the most common type of fission is **binary fission**, in which a cell simply splits into two nearly equal halves
  - another type of fission is called **budding**

- asexual reproduction in protists may involve spore formation or fission
• the most common type of fission is **binary fission**, in which a cell simply splits into two nearly equal halves
• another type of fission is called **budding**
  • In this case, the progeny cell is considerably smaller than its parent and then must grow to adult size
• multiple fission is called **schizogony** and is preceded by several nuclear divisions
  • this form of fission produces several individuals almost simultaneously

• sexual reproduction also takes place in many forms among protists
  ▪ **gametic meiosis** occurs in ciliates and some flagellates
  ▪ **zygotic meiosis** occurs in the sporozoans
  ▪ **sporic meiosis** occurs in the algae, producing an alternation of generations similar to that of plants

• being a single-celled organism presents certain problems
  ▪ size is limited due to surface-to-volume ratio problems

• the evolution of multicellularity alleviates the size constraints
  ▪ a multicellular organism is composed of many cells
  ▪ having multiple cells allows for specialization
    • distinct cell types can have different functions
    • this is a “division of labor”

• many protists form colonial assemblies consisting of many cells with little differentiation or integration
  ▪ a **colonial organism** is a collection of cells that are permanently associated but in which little or no integration of cell activities occurs

    **A colonial protist.**

• an **aggregation** is a more transient collection of cells that come together for a period of time and then separate
  ▪ for example, individual amoeboid cells of cellular slime molds come together to form an aggregate called a slug
    • the slug allows the aggregate of slime mold cells to move to a new feeding location as a unit

• true multicellularity occurs only in eukaryotes
  ▪ it requires that the activities of individual cells be coordinated and that the cells be in contact

• three groups of protists have independently evolved multicellularity
  ▪ brown algae (Phylum Phaeophyta)
  ▪ green algae (Phylum Chlorophyta)
• red algae (Phylum Rhodophyta)

• but not all types of algae are multicellular; there are also unicellular varieties

Classifying the Protists
• protists are the most diverse of the four kingdoms in the domain Eukarya
  ▪ there are 15 distinct phyla of protists
  ▪ taxonomists group the protists into five general groups according to some of the major shared characteristics
  ▪ the phyla of protists are, with very few exceptions, only distantly related to one another

The major protist groups.
• the characteristics used in broad attempts to classify the kingdom Protista include
  ▪ the presence or absence and type of cilia or flagella
  ▪ the presence and kinds of pigments
  ▪ the type of mitosis
  ▪ the kinds of cristae present in the mitochondria
  ▪ the molecular genetics of the ribosomal “S” subunit
  ▪ the kind of inclusions the protists may have
  ▪ overall body form
  ▪ whether the protists has a shell or other “body armour”
  ▪ modes of nutrition and movement

Kinds of Protists

Heterotrophs with No Permanent Locomotor Apparatus
• the largest of the five groups of protists are distinguished by having no permanent locomotor apparatus

• they are all heterotrophic and comprise three phyla
  ▪ Rhizopoda—amoebas
  ▪ Foraminifera—forams
  ▪ Actinopoda—radiolarians

• amoebas lack flagella and cell walls
• they move using pseudopodia, flowing projections of cytoplasm
• amoebas are abundant in soil and many are parasitic in animals
• reproduction is entirely asexual

• forams possess rigid cells and move by cytoplasmic streaming
• they are marine protists with pore-studded shells called tests
• long, thin, cytoplasmic projections called podia radiate through the test pores and are used for swimming and capturing prey
Heterotrophs with No Permanent Locomotor Apparatus

• radiolarians look like amoebas but have a glassy skeleton
• needlelike pseudopods look like thorns radiating out from the body

Heterotrophs with Flagella

• Sarcomastigophora is a strictly heterotrophic phylum
• the members of this phylum are called zoomastigotes and are flagellated
• the flagellated ancestor of all animals appears to have been a member of this group

Heterotrophs with Flagella

• ciliates belong to the phylum Ciliophora and all members possess large numbers of cilia
• ciliates have a defined cell shape and two nuclei per cell
• the pellicle is a proteinaceous scaffold, found inside the plasma membrane, that confers flexible support
• asexual reproduction is by fission while sexual reproduction is by conjugation

Heterotrophs with Restricted Mobility

• slime molds and water molds are heterotrophic protists and not fungi
  ▪ protistan molds have cell walls made of cellulose
  ▪ protistan molds carry out normal mitosis
  ▪ there are three unrelated phyla of protistan molds

Heterotrophs with Restricted Mobility

• cellular slime molds belong to the phylum Acrasiomycota
  ▪ although more closely resembling amoebas, the members of this phylum can form aggregates in times of stress

Heterotrophs with Restricted Mobility

• plasmodial slime molds belong to the phylum Myxomycota
• the cells in members of this phylum stream long as a plasmodium, a nonwalled multinucleate mass of cytoplasm
• the plasmodium can withstand drying out or starvation by dividing into spore-producing mounds

Heterotrophs with Restricted Mobility

• water molds belong to the phylum Oomycota
• all members of this grouping either parasitize living organisms or feed on dead organic matter
• many water molds are important plant pathogens

Photosynthetic protists

• dinoflagellates are members of the phylum Pyrrhophyta
• they are photosynthetic unicellular protists, usually bearing two flagella of unequal
These flagella beat uniquely, beating the body like a spinning top
• dinoflagellates reproduce asexually using a unique type of mitosis in which their chromosomes remain condensed

**Dinoflagellates.**

**Photosynthetic Protists**
• euglenoids belong to the phylum Euglenophyta and have two flagella
  ▪ about one-third are photosynthetic and have chloroplasts
  ▪ the remaining types lack chloroplasts and are heterotrophic
  ▪ the photosynthetic forms can become heterotrophic when light levels are low

**Photosynthetic protists**
• some dinoflagellates produce powerful toxins
  ▪ “red tides” are population explosions of these kinds of dinoflagellates

**Photosynthetic Protists**
• *Euglena* is a representative euglenoid
  • it possesses a pellicle like ciliates
  • it has a contractile vacuole to help regulate the osmotic pressure within the organism
  • it has a light-sensitive stigma which helps this photosynthetic form find light
  • reproduction in this group is entirely asexual

**Photosynthetic Protists**
• diatoms are photosynthetic protists that belong to the phylum Chrysophyta
  • they are encased by unique double wall of silica
  • they reproduce by either asexual or sexual reproduction

**Photosynthetic Protists**
• the phylum Chrysophyta, in addition to diatoms, also includes the golden algae
  • the golden algae do not resemble the three phyla of true algae in any important aspect
  • they are named because pigments in their chloroplasts give them a golden color
  • they can be unicellular or colonial and occur in freshwater only
  • they can form resistant cysts when ponds and lakes dry out in summer

**Photosynthetic Protists**
• red algae comprise the phylum Rhodophyta and have red pigments
  • most are multicellular and marine
  • they grow more deeply than other photosynthetic algae

  • the laboratory medium component, agar, is made from red algae

**Photosynthetic Protists**
• green algae are members of the phylum Chlorophyta and are of evolutionary interest because the ancestor of plants belonged to this group
- green algal chloroplasts are similar to plants and contain similar chlorophyll types
- green algae are mostly mobile and aquatic but a few species occur in moist soil or on tree trunks

Green algae.

Photosynthetic Protists
- most green algae are microscopic and unicellular, but some are intermediate or colonial, while others are large and multicellular
- some green algae, like *Ulva*, exhibit an alternation of generations between a multicellular haploid gametophyte and a multicellular diploid sporophyte

A green algae life cycle: *Ulva*.

Photosynthetic Protists
- brown algae comprise the phylum Phaeophyta
- these algae are the longest, fastest-growing, and most photosynthetically productive living things
- they are conspicuous seaweeds in the ocean
  - for example, kelp may grow to over 100 m
- all are multicellular and most are marine
- their life cycle has alternating generations

Nonmotile Spore-Formers
- sporozoans belong to the phylum Apicomplexa
- they are nonmotile, unicellular, parasites that form spores
- they cause many diseases in humans and domestic animals
- they have complex life cycles that involve both asexual and sexual phases, often involving an alternation between different hosts

A sporozoan life cycle.