Cell Division and Inheritance

Continuing life relies on reproduction
- Individual organism—replacing dead or damaged cells
- Species—making more of same species

Reproduction
- Cells divide, grow, divide again

CELL DIVISION
- Mitosis—division of body (somatic) cells by multicelled organisms
  - Increasing number of cells during growth
  - Replaces cells that are worn-out, dead, or damaged
  - Asexual reproduction by some plants, animals, fungi, single-celled protists
  - In undifferentiated somatic cells (skin, liver, bone marrow, blood vessels), not in differentiated cells (nerve and muscle cells, adult stem cells)
- Meiosis—formation of sex (germ) cells (sperm, eggs) and spores
  - Basis for sexual reproduction
  - Creates gametes
  - Prokaryotic (Binary) fission

BINARY FISSION
- Prokaryotes have no nucleus or organelles.
- As chromosome duplicates, copies move to opposite sides of cell.
- After duplication and cell growth, membrane grows inward, dividing the cell.
- Daughter cells same genes as parent cell
  - Effectively are clones of the parent cell

CHROMOSOMES
- Basis for genetic code
- Different number of chromosomes in each species
- Copied before cell division
  - Sister chromatids

1. Plasma membrane
2. Duplication of chromosome and separation of copies
3. Continued elongation of the cell and movement of copies
4. Division into two daughter cells
CHROMOSOMES
- Chromosome number—sum total of chromosomes
- Diploid number—number of chromosomes when including pairs, “2n”
  - One set from each parent
  - Somatic cells
- Homologous chromosomes—each chromosome in a matched pair
  - Only one set of each sex chromosome
- Haploid number—half of the normal chromosome number, “n”
  - Gametes

Diploid number = 46 in humans (“2n”)
Haploid number = 23 in humans (“n”)

CHROMOSOMES
- DNA helix wraps around histones, forms nucleosome
- Multiple levels of coiling into chromatin
- Condensed into chromosome

Interphase—normal growth and function
- G1—initial growth & normal roles
- S—DNA replication
- G2—preparation to divide

Mitosis (about 10% of cell’s cycle)
- Prophase
- Metaphase
- Anaphase
- Telophase
  - Mitosis - nuclear division in the cell cycle
  - Cytokinesis - division of the cytoplasm
When a eukaryotic cell is not undergoing division, the DNA within a chromosome is a mass of thin threads called chromatin.

- Before nuclear division chromatin condenses.
- 2 identical chromatids are sister chromatids.

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**Interphase**

- **G1**
  - Most of life for many cells
  - Normal functions
- **S**
  - New strands of DNA created from existing strands
  - Chromosome doubles into connected sister chromatids
- **G2**
  - Microtubules and other structures made for cell division
  - Organelles duplicated

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**Mitosis**

- **Prophase**
  - Chromosomes become visible
  - Centrioles form spindle fibers
  - Nuclear membrane starts to break down
  - Centromeres modified into kinetochores
  - Site of spindle attachment

- **Metaphase**
  - Centrioles moved to opposite ends of the cell (“poles”)
  - Chromosomes lined up in middle of cell
  - Spindle fibers attached to centromeres

- **Anaphase**
  - Sister chromatids pulled towards each pole and separate
  - Cell elongates in direction of poles

- **Telophase**
  - Cell divides in middle, forms cleavage furrow
  - Cytokinesis—complete cell division
  - Nuclear membrane re-forms around each set of chromosomes
**Mitosis**
- Condensed chromosomes
- Nuclear envelope
- Sister chromatids
- Centromere

**Interphase**
- Early prophase
- Late prophase
- Metaphase
- Anaphase
- Telophase

**Chromosomes**
- Duplicated during S-phase of interphase
- Divide during anaphase

**Cytoplasmic Division**
- Animal cells
  - Contractile ring mechanism—actin filaments at equator contract

**Cytoplasmic Division (Cytokinesis)**
- Plant cells
  - Vesicles cluster at equator
  - Vesicle membranes fuse
  - New cell membranes form along fused vesicles
  - Cell Plate
  - Cellulose deposited between membranes, will form new cell walls

**Cell Cycle Control Occurs at Checkpoints**
- The cell cycle has checkpoints that can delay the cell cycle until all is well
  - Apoptosis - programmed cell death
- Cancer occurs when cell division is uncontrolled. Checkpoints fail to stop cell division, and apoptosis does not occur.
Contact Inhibition - In a culture, cells divide until they line a container in a sheet and then stop dividing
- Cells “remember” number of divisions

Telomere - repeating DNA base sequence
- Each time a cell divides some portion of a telomere is lost (approx. 70 cycles)
- When telomeres become too short, chromosomes fuse and do not duplicate

Cancer Cells Have Abnormal Characteristics
A mutation (a DNA change) causes a cell to divide uncontrollably or ignore apoptosis
- Carcinogenesis - development of cancer

Characteristics of cancer cells:
- Lack differentiation
- Have abnormal nuclei
- Form tumors
- Metastasis - establishing new tumors
- Angiogenesis - formation of new blood vessels

Normal Cell Division
- Growth Factors
  - Proteins produced by an organism that can trigger cell division
- Density-dependent inhibition
  - Crowded cells stop dividing
  - Respond to touch of bordering cells
  - Keep overgrowth from happening
- Anchorage dependence
  - Most animal cells must be in contact with a solid surface in order to divide.

Abnormal Cell Division
- Teratogens—environmental factors that cause abnormal cell division
  - Radiation (UV, x-rays, radon)
  - Organic chemicals (nicotine, pesticides)
  - Viruses (polio, German measles, chicken pox)
- Normal protective mechanisms
  - Keep cells in certain stages (such as G1)
  - Triggers to start and stop cell division & growth
  - Fix damaged DNA
  - Destroy abnormal cells

Cancer
- Controls on cell division broken
- Cells grow and divide uncontrollably
  - Ignore density-dependent inhibition
- Cytoplasm and plasma membrane altered
  - Enzyme actions within the cell shift
- Weakened adhesion
  - Break away and establish colonies—metastasis
- May be lethal
  - Chemical byproducts of tumor
  - Invading and crowding out other tissues
**SEXUAL REPRODUCTION**
- Meiosis → Gamete formation → Fertilization
- Diploid → Haploid → Fertilization → Diploid

**MEIOSIS**
- Almost identical to mitosis
- Chromosomes mix
- Cells and chromosomes divide TWICE before process ends
- Ends with 4 daughter cells, each haploid
- Pro-, Meta-, Ana-, Telophase I
- Pro-, Meta-, Ana-, Telophase II

**MEIOSIS**
- **Prophase 1**
  - Homologous chromosomes pair up (Synapsis)
  - Usually swap segments (crossing over)
  - Otherwise normal prophase
  - Crossing over during meiosis

**MEIOSIS**
- **Metaphase 1**
  - Spindle fibers attach to centromere of each type of chromosome
  - Otherwise normal metaphase
- **Anaphase 1**
  - Homologous chromosomes separated to each pole of cell
  - Otherwise normal anaphase
- **Telophase 1**
  - Cytokinesis (normal telophase)
  - Does NOT go to Interphase

**MEIOSIS**
- **Prophase II**
  - New centrioles move to poles of new cells
- **Metaphase II**
  - Spindle fibers attach to centromeres
  - Chromosomes line in middle
- **Anaphase II**
  - Sister chromatids break apart, move to poles
- **Telophase II**
  - Cytokinesis
  - Each daughter cell is haploid

**MEIOSIS**
- DNA is NOT duplicated prior to 2nd stage of Meiosis
- Interkinesis (the period between meiosis I and II)

No replication of DNA occurs during **interkinesis** (the period between meiosis I and II).
MITOSIS VS. MEIOSIS

**MITOSIS**
- Somatic cells
- Grow, replace, repair
- 2 daughter cells, 2n
- No synapsis
- No genetic diversity, minimal variation
- One division
- Used for asexual reproduction

**MEIOSIS**
- Sex cells
- Reproduction
- 4 daughter cells, n
- Frequent synapsis
- Great genetic diversity
- Two divisions
- Used for sexual reproduction

THE LIFE CYCLE OF MOST MULTICELLULAR ORGANISMS INCLUDES BOTH MITOSIS AND MEIOSIS

Life cycle - in sexually reproducing organisms, all the reproductive events from one generation to the next
- Spermatogenesis in males, occurs in the testes and produces sperm
- Oogenesis in females, occurs in the ovaries and produces eggs

**Zygote** - product of the sperm and egg joining during fertilization, has homologous pairs of chromosomes

GENETIC VARIATION

- Allele—different forms of the same gene
  - Affects different traits—“dimple”, “no-dimple”
  - Mixing alleles results in variations of traits

**Crossover (Prophase I)**
- Switches alleles

**Homologous Alignments (Metaphase I)**

LIFE CYCLE OF HUMANS

LIFE CYCLE OF PLANTS

LIFE CYCLE OF ALGAE

43
44
45
46
47
48
Multiple possible combinations of chromosomes

In a single fertilization (one baby) there are...

- 8,388,608 combinations of homologous chromosomes
- 70,368,744,000,000 possible variations of offspring
- Including crossing over--4,951,760,200,000,000,000,000,000,000,000,000,000,000,000,000 possible genetic variations!!!!

Karyotype - picture of chromosomes in numbered pairs called homologous chromosomes or homologues

- X and Y chromosomes are the sex chromosomes because they contain the genes that determine gender
- Autosomes - all the pairs of chromosomes except the sex chromosomes
**Sex Chromosomes**

- Culture cells, stimulate mitosis, stop division at metaphase.
- Hypotonic solution swells cells, separates them & chromosomes.
- Take picture, cut & paste.
- Gives an image of the person’s/animal’s actual chromosomes.
- Can analyze for abnormalities.

**Chromosome Abnormalities**

- Changes in physical structure of chromosome.
- Cause genetic disorders or abnormalities.
- Often a disruption during crossing over.
- Rare.
- Duplication.
- Deletion.
- Inversion.
- Translocation.

**Duplication**

- DNA sequences are repeated 2 or more times.
- Unequal crossing-over.
- Broken piece of chromosome attaches to homologous chromosome.
- Huntington’s Disease:
  - Affects coordination & movement.
  - Affects mental abilities, personality.

**Deletion**

- DNA sequence deleted.
- Unequal crossing-over.
- Chemical damage.
- Most cause serious disorders or death.
- **Cri du chat syndrome**:
  - Severe developmental & neurological problems.
  - Unusual cry of infant (“cry of the cat”).
  - Unusual physical appearance.

**Inversion**

- DNA sequence reverses.
- No loss of DNA or chromosome part.
- No problem for carrier if non-crucial gene.
- Some may not know until children have problem.
- **Chromosome 9**:
  - No health problems for parent.
  - May increase risk of miscarriage.
**Translocation**
- Broken part of one chromosome attaches to another
  - Non-homologous chromosomes
  - Usually reciprocal (both exchange broken parts)
  - Often cause reduced fertility
  - Severe problems rare
  - Can include several cancers
    - Can cause death or disorders: e.g., Burkitt’s lymphoma

**Chromosome Number**
- Aneuploidy—one more one less chromosome than normal
  - Monosomy (2n - 1) only one of a type of chromosome
  - Trisomy (2n + 1) three of a type of chromosome
    - Usually fatal for humans
    - Most miscarriages
  - Nondisjunction—one or more pairs do not separate during meiosis
    - Polyploidy—cells with 3 or more copies of one or more chromosomes (e.g., triploid = 3n, tetraploid = 4n)
    - Trisomy—cells with 2n+1 of one chromosome, 2n of all others
      - Special form of polyploidy

**Nondisjunction**

- Down Syndrome (Trisomy 21)
  - Only trisomy that reaches adulthood
  - Extra copy of chromosome 21
  - Mostly through nondisjunction at meiosis
  - Abnormal mental, heart, and skeletal development
SEX CHROMOSOME ABNORMALITIES

- Turner syndrome (females)
  - Nondisjunction of sex chromosomes
  - Only one X, noted as “XO”
  - 98% of embryos miscarry
  - Adults very short, but well proportioned
  - Sterile, limited sex hormones
  - Female

- Klinefelter syndrome (male)
  - 2/3 Nondisjunction of sex chromosomes
  - XXY
  - Mostly normal, some learning disabilities
  - Lower testosterone, higher estrogen
  - “Feminized” male characteristics
  - Male