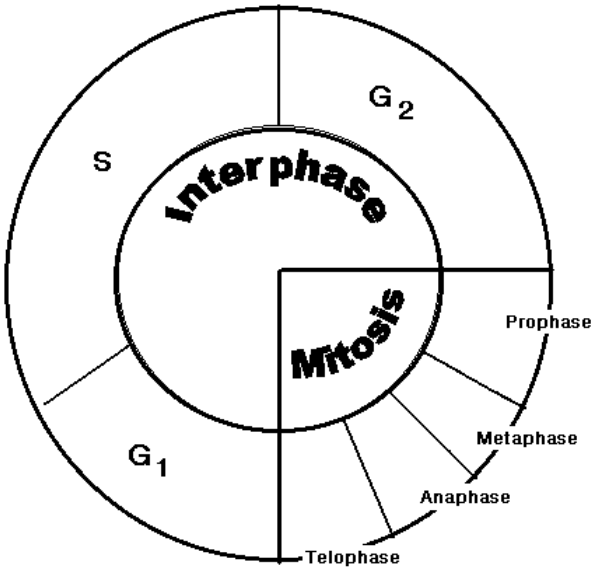
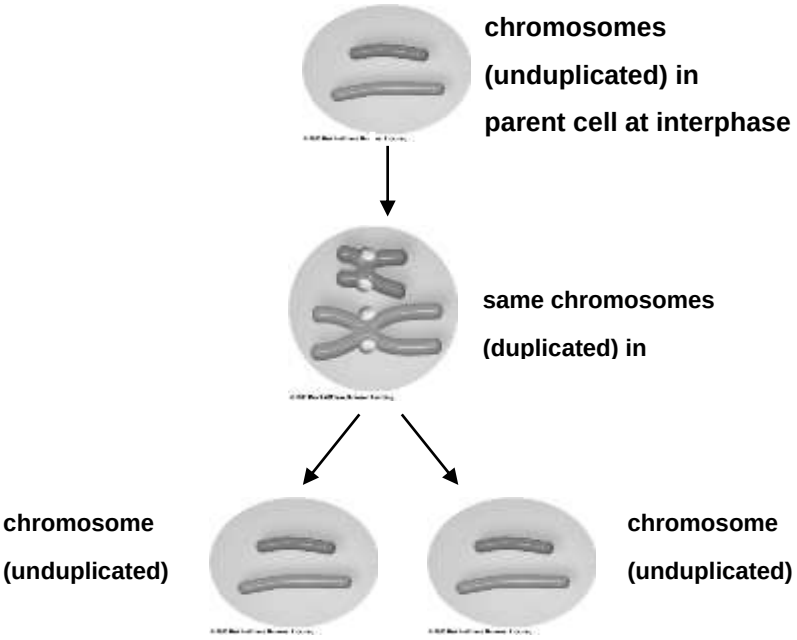
Phases of the Cell Cycle



(1) How Cells Reproduce: Mitosis and Meiosis

- Division Mechanisms
  - Eukaryotic organisms
    - Mitosis
    - Meiosis
  - Prokaryotic organisms
    - Prokaryotic fission
- Roles of Mitosis
  - Multicelled organisms
    - Growth
    - Cell replacement
  - Some protistans, fungi, plants, animals
    - Asexual reproduction
- Interphase
  - Usually the longest part of cycle
  - Cell increases in mass
  - Number of cytoplasmic components doubles
  - DNA is duplicated
- Mitosis
  - Period of nuclear division
  - Usually followed by cytoplasmic division
  - Four stages:
    - Prophase
    - Metaphase
    - Anaphase
    - Telophase
- Control of the Cycle
  - Once S begins, the cycle usually runs through G2 and mitosis
  - Cycle has a built-in molecular brake in G1
  - Cancer involves a loss of control over the cycle, malfunction of "brakes"
- Chromosome Number
  - Total number of chromosomes in a cell
  - Somatic cells
    - Chromosome number is diploid (2n)
    - Two of each type of chromosome
  - Gametes
    - Chromosome number is haploid (n)
    - One of each chromosome type
- Human Chromosome Number
  - Diploid chromosome number (n) = 46
  - Two sets of 23 chromosomes
    - One set from father
    - One set from mother
  - Mitosis produces cells with 46 chromosomes: two of each type

Maintaining Chromosome Number



- The Spindle Apparatus
  - Consists of two distinct sets of microtubules
  - Each set extends from one of the cell poles
  - Two sets overlap at spindle equator
  - Moves chromosomes during mitosis

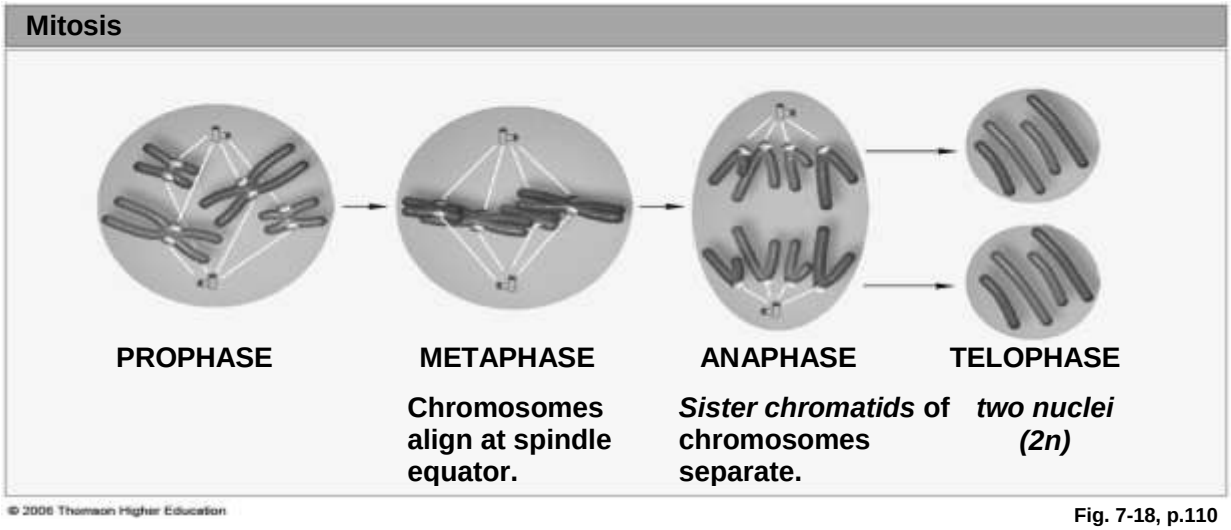


Fig. 7-18, p.110

- Stages of Mitosis
  - Early Prophase: Mitosis Begins
    - Duplicated chromosomes begin to condense
  - Late Prophase
    - New microtubules are assembled
    - One centriole pair is moved toward opposite pole of spindle
    - Nuclear envelope starts to break up
  - Metaphase
    - All chromosomes are lined up at the spindle equator
    - Chromosomes are maximally condensed

- Anaphase
  - Sister chromatids of each chromosome are pulled apart
  - Once separated, each chromatid is a chromosome
- Telophase
  - Chromosomes decondense
  - Two nuclear membranes form, one around each set of unduplicated chromosomes
- Cytoplasmic Division
  - Usually occurs between late anaphase and end of telophase
  - Two mechanisms
    - Cleavage (animals)
    - Cell plate formation (plants)
- Interphase
  - Two daughter cells
  - Each with same chromosome number as parent cell
  - Chromosomes are in unduplicated form

❖ Asexual Reproduction
- Single parent produces offspring
- All offspring are genetically identical to one another and to parent

❖ Sexual Reproduction
- Involves
  - Meiosis
  - Gamete production
  - Fertilization
- Produces genetic variation among offspring

❖ Homologous Chromosomes Carry Different Alleles
- Cell has two of each chromosome
- Chromosome pairs: one from mother, one from father
- Paternal and maternal chromosomes carry different alleles

❖ Sexual Reproduction Shuffles Alleles
- Through sexual reproduction, offspring inherit new combinations of alleles, which lead to variations in traits
- Variation in traits is the basis for evolutionary change

❖ Gamete Formation
- Gametes are sex cells (sperm, eggs)
- Arise from germ cells in reproductive organs

❖ Chromosome Number
- Total number of chromosomes in cell
- Germ cells are diploid (2n)
- Gametes are haploid (n)
- Meiosis halves chromosome number
- Diploid To Haploid

❖ Meiosis: Two Divisions
- Two consecutive nuclear divisions
  - Meiosis I

- Meiosis II
- DNA is not duplicated between divisions
- Four haploid nuclei form

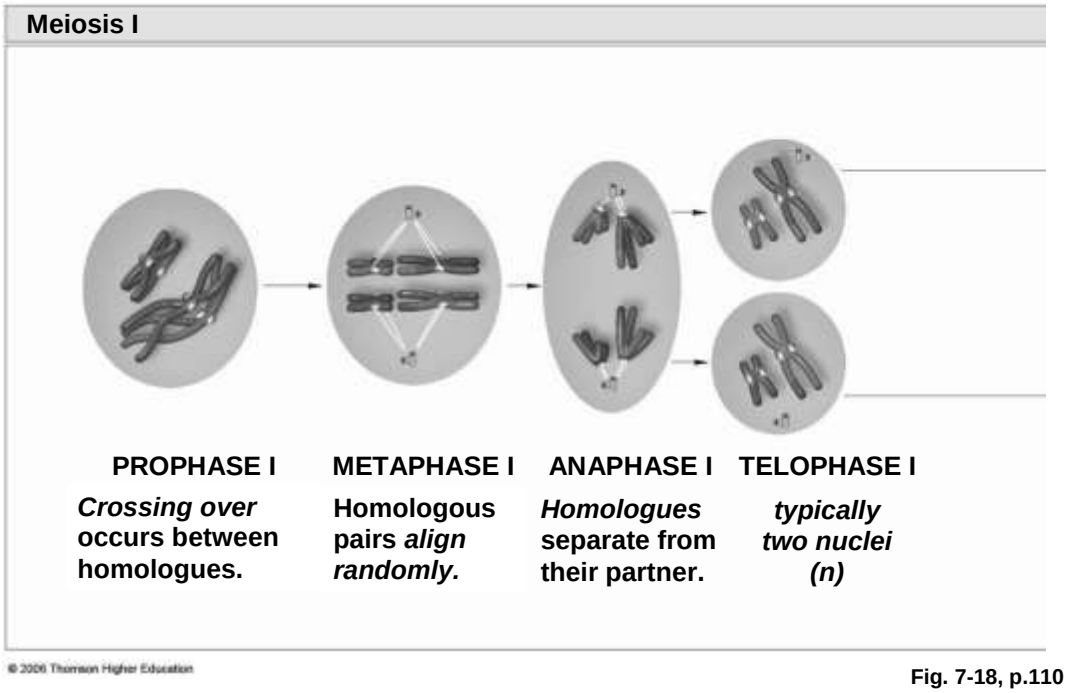


Fig. 7-18, p.110

- Prophase I
  - Each duplicated chromosome pairs with homologue
  - Homologues swap segments
  - Each chromosome becomes attached to spindle
- Metaphase I
  - Chromosomes are moved to middle of cell
  - Spindle is fully formed
- Anaphase I
  - Homologous chromosomes separate
  - Sister chromatids remain attached
- Telophase I
  - Chromosomes arrive at opposite poles
  - Usually followed by cytoplasmic division

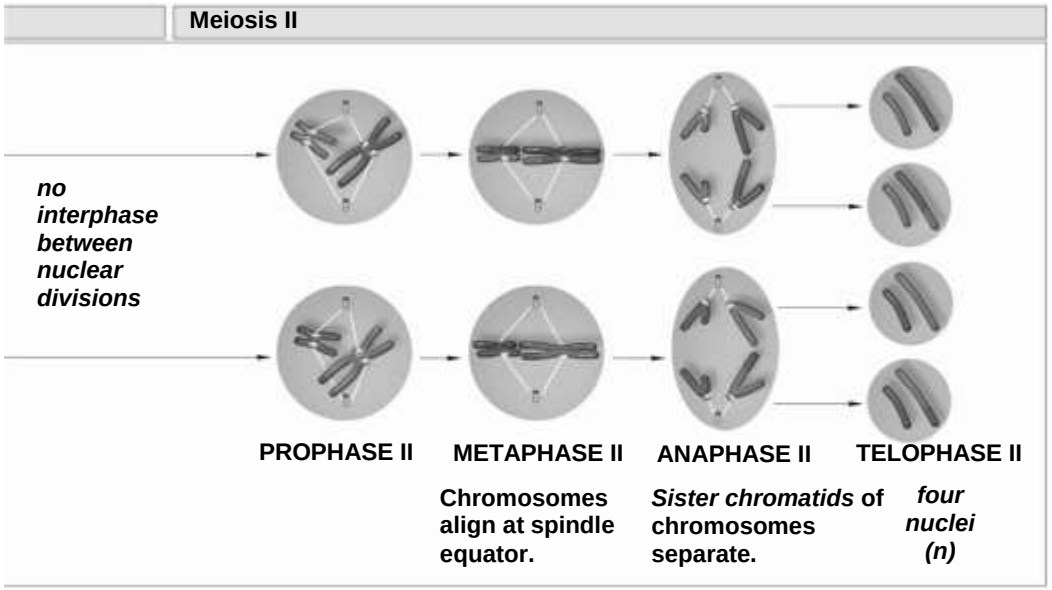
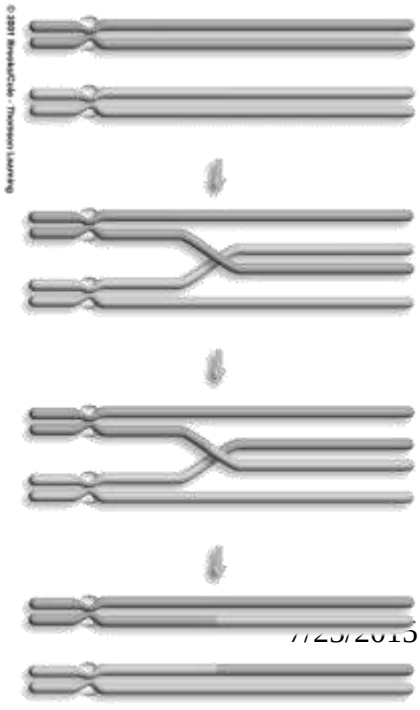


Fig. 7-18, p.110

- Prophase II
  - Microtubules attach to duplicated chromosomes
- Metaphase II
  - Duplicated chromosomes line up midway between spindle poles
- Anaphase II
  - Sister chromatids separate to become independent chromosomes
- Telophase II
  - Chromosomes arrive at opposite ends of cell
  - Nuclear envelopes form around chromosome sets
  - Four haploid cells
- Sexual Reproduction and Genetic Variation
  - Two functions of meiosis provide variation in traits:
    - crossing over
    - random alignment

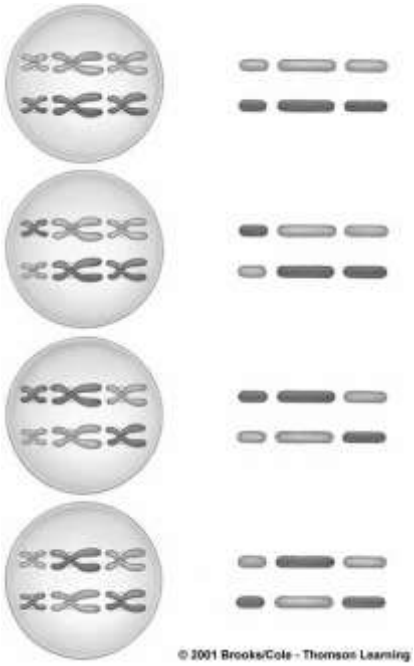
- Crossing Over
  - Occurs during Prophase I
  - Exchange of genetic material between homologous chromosomes
    - Each chromosome attaches to eats homologue
    - All four chromatids are closely aligned
    - Non-sister chromatids exchange segments



- Effects of Crossing Over
  - After crossing over, each chromosome contains both maternal and paternal segments
  - Creates new allele combinations in offspring

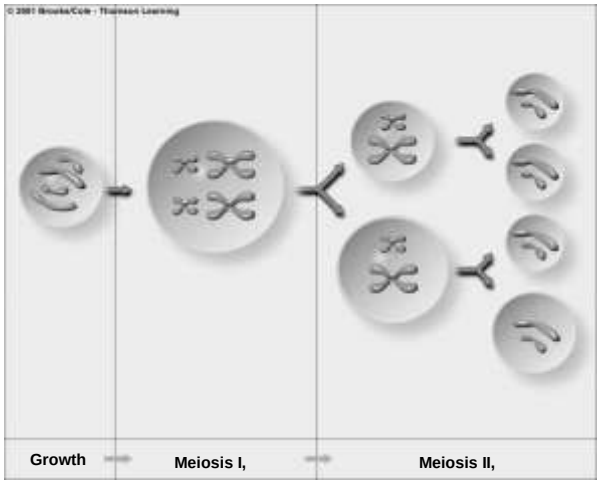
- Random Alignment
  - Between prophase I and metaphase I, chromosome pairs align randomly at metaphase plate
  - Initial contact between microtubule and either maternal or paternal chromosome is random

Possible Chromosome Combinations

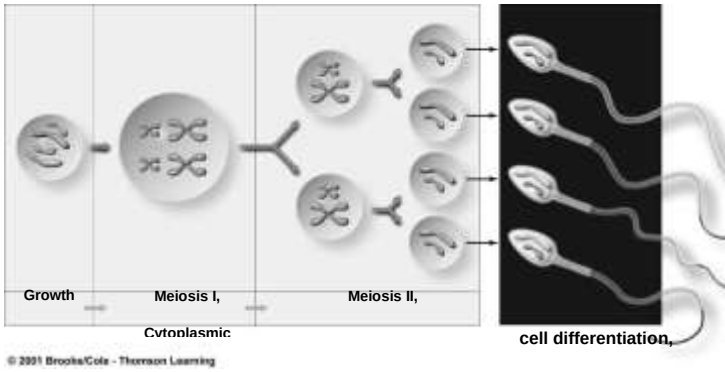


- Factors Contributing to Variation among Offspring
  - Crossing over during prophase I
  - Random alignment of chromosomes at metaphase I
  - Random combination of gametes at fertilization

Oogenesis- egg formation

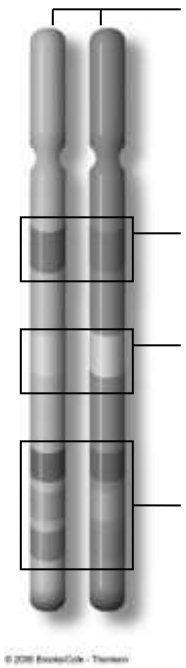


Spermatogenesis-sperm formation



- Fertilization
  - Male and female gametes unite and nuclei fuse producing diploid zygote

(2) Medelian Genetics



- Genes
  - Units of information about specific traits
  - Passed from parents to offspring
  - Each has a specific location (locus) on a chromosome
- Alleles
  - Different molecular forms of a gene found on homologous chromosomes
  - Arise by mutation
  - Dominant allele masks a recessive allele that is paired with it
- Allele Combinations
  - Homozygous
    - having two identical alleles
    - Homozygous dominant, AA
    - Homozygous recessive, aa
  - Heterozygous
    - having two different alleles
    - Aa
- Genotype & Phenotype
  - Genotype refers to particular genes an individual carries (RR or Rr or rr)
  - Phenotype refers to an individual's observable traits (flower color, seed shape, etc)
- Other Definitions
  - Dominant allele – in a heterozygous individual, a trait that is fully expressed in the phenotype
  - Recessive allele – in a heterozygous individual, a trait that is completely masked by the expression of the dominant allele
  - Pure (true) breeding – a population with only one type of allele for a given trait
  - Self cross – when individuals of a generation fertilize themselves (e.g., self-fertilized flower).

- Gregor Mendel (1822-1884)
  - Father of Genetics
  - Austrian Monk
  - Strong background in mathematics
  - observed evidence of how parents transmit genes to offspring
  - Unaware of cells, chromosomes or genes
- Mendel studied the Garden Pea
  - Mendel began by examining varieties of peas suitable for study
    - Character- an observable feature, such as flower color
    - Trait – actual flower color, such as purple or white
    - Heritable trait – is this character passed on to progeny

- Experimentally cross-pollinated

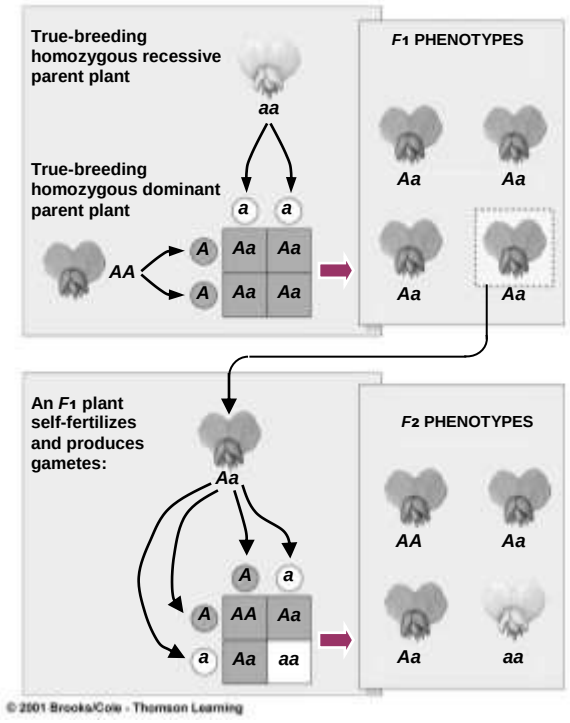
❖ Mendel's Methods
- Mendel crossed round x wrinkle seeded plants
  - P (parental generation) → round x wrinkled
  - F1 (1st filial generation offspring) → round
  - F2 (2nd filial generation offspring) → round & wrinkled

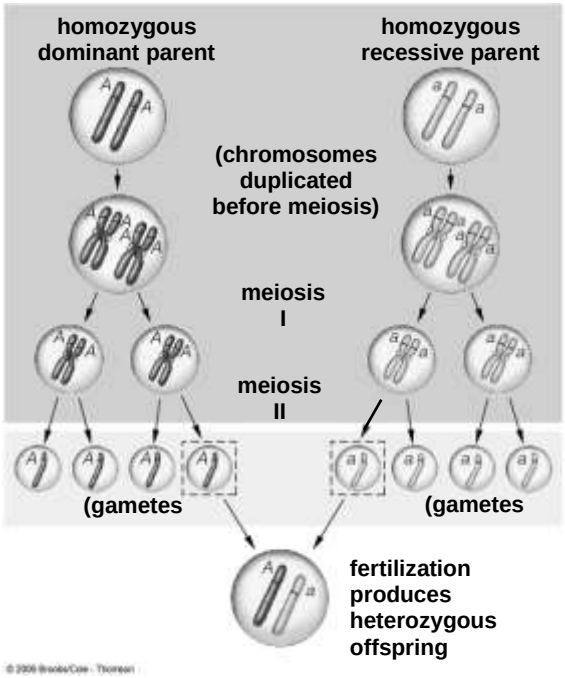
❖ Dominant / Recessive Traits
- Mendel observed each parent carried two "units" for a given trait
- We know these "units" are genes on chromosomes
- Dominant traits – show up each generation
- Recessive traits – may be masked by dominant traits

A Monohybrid Cross

❖ Monohybrid Cross
- Experimental cross between two F1 heterozygotes
  - AA x aa →Aa (F_1 monohybrids)
  - Aa x Aa → (?) F_2
    - Genotype:1 AA: 2 Aa: 1 aa
    - Phenotype: 3:1 (purple: white)
    - Mendel found 3:1 ratio in F_2 for all traits

❖ Mendel's Theory of Segregation
- Individual inherits a unit of information (allele) for a trait from each parent
- During gamete formation, the alleles segregate from each other





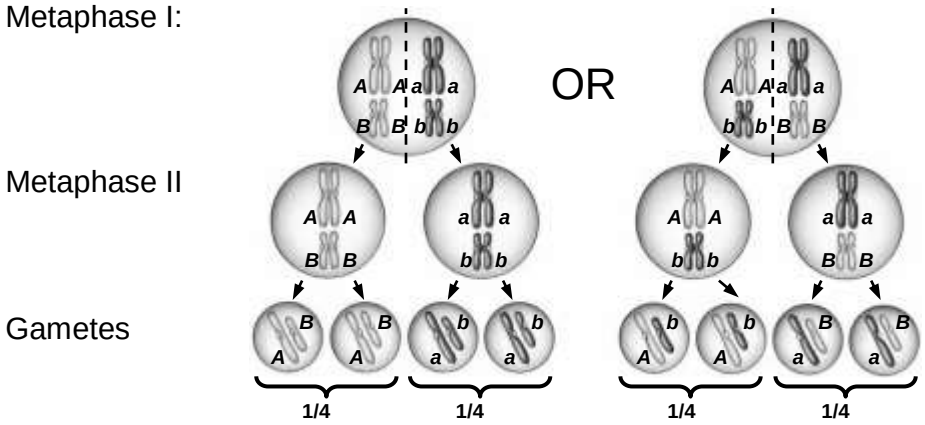
- Dihybrid Cross
  - AB x ab
    - Experimental cross between individuals that are homozygous for different versions of two traits
  - Dihybrid Cross: F1 Results
    - AABB x aabb → AaBb (F1 dihybrids)
    - All have same trait (tall with purple flowers)
  - Dihybrid Cross: F2 Results

AaBb x AaBb

	1/4 *AB*	1/4 *Ab*	1/4 *aB*	1/4 *ab*
1/4 *AB*	1/16 *AAB*	1/16 *AAB*	1/16 *AaB*	1/16 *AaB*
1/4 *Ab*	1/16 *AAB*	1/16 *AAb*	1/16 *AaB*	1/16 *Aab*
1/4 *aB*	1/16 *AaB*	1/16 *AaB*	1/16 *aaB*	1/16 *aaB*
1/4 *ab*	1/16 *AaB*	1/16 *Aab*	1/16 *aaB*	1/16 *aab*

9/16 purple-flowered, tall
3/16 purple-flowered, dwarf
3/16 white-flowered, tall
1/16 white-flowered, dwarf

- Independent Assortment
  - "Units" for one trait were assorted into gametes independently of the "units" for the other trait
  - Members of each pair of homologous chromosomes are randomly sorted into gametes during meiosis

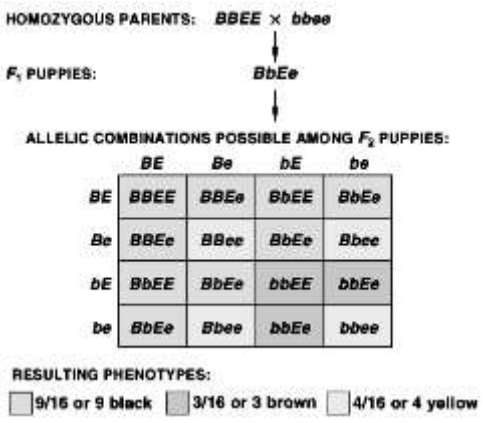


- Tremendous Variation
  - Number of genotypes possible in offspring as a result of independent assortment and hybrid crossing is 3^n (n is the number of gene loci at which the parents differ)

(3). Post-Mendelian Genetics

- Dominance Relations
  - Complete dominance
  - Incomplete dominance
  - Codominance
- Codominance: ABO Blood Types
  - Gene that controls ABO type codes for enzyme that determines structure of a glycolipid on blood cells
  - Two alleles (IA and IB) are codominant when paired
  - Third allele (i) is recessive to others
- ABO and Transfusions
  - Type O is universal donor – neither type A nor type B antigens produced
  - Type AB is universal receiver – no immune response to A or B antigens
- Incomplete Dominance
  - F_2 shows three phenotypes in 1:2:1 ratio
  - Example: crossing white and red flowered snap dragons appears to produce pink flowered hybrids.

- Pleiotropy
  - Alleles at a single locus may affect two or more traits
  - Marfan syndrome
  - Cystic fibrosis
  - Color and crossed eyes in Siamese cats
- Gene interactions and phenotypic expression
  - Genes may interact with each other: one gene influences phenotypic expression of others
  - Complex variations: phenotype influenced by gene interactions and/or environmental conditions
- Interactions among Gene Pairs
  - Common among genes for hair color in mammals
  - Genetics of Coat Color in Labrador Retrievers
    - Epistasis: phenotypic expression of one gene governed by another
    - Two genes involved
      - One gene influences melanin production
        - Two alleles - *B* (black) is dominant over *b* (brown)
      - Other gene influences melanin deposition
        - Two alleles - *E* promotes pigment deposition and is dominant over *e*



- Continuous Variation
  - A continuous range of small differences in a given trait among individuals
  - The greater the number of genes and environmental factors that affect a trait, the more continuous the variation in that trait
    - Examples in humans:
      - Eye color: involves two genes
      - Height: multiple genes, alleles and environmental conditions
      - Skin Color: three genes with multiple alleles
- Environmental Effects on Phenotype
  - Genotype and environment can interact to affect phenotype
    - Himalayan rabbit ice pack experiment
    - Transplantation of plant cuttings to different elevations
    - Human depression
    - Hydrangeas and Soil
  - Phenotypic Plasticity
    - Phenotype change in response to the environment. Examples:
      - Humans tan in response to sun exposure; increased melanin protects cells from harmful solar radiation
      - Mussels exposed to seastar "scents" develop stronger adductor muscles
      - Mussels exposed to dog whelk "scent" develop thicker shells
- Human Genetics and Linkages
  - Autosome Linkages
  - Sex chromosome linkages
  - Linkage group; all of the genes along the length of a chromosome
  - Full linkages stay together after cross-over
  - Incomplete linkages separate at crossover
- Sex Determination
  - The Y Chromosome
    - Small, with few genes
    - Master gene for male sex determination
      - SRY gene (sex-determining region of Y)
      - SRY present, testes form
      - SRY absent, ovaries form
  - The X Chromosome
    - Carries more than 2,000 genes
    - Most genes deal with nonsexual traits
    - Genes on X chromosome can be expressed in both males and females
- Crossover Frequency
  - Proportional to distance
  - Crossing over will disrupt linkage between *A* and *B* more often than *C* and *D*

Full Linkage

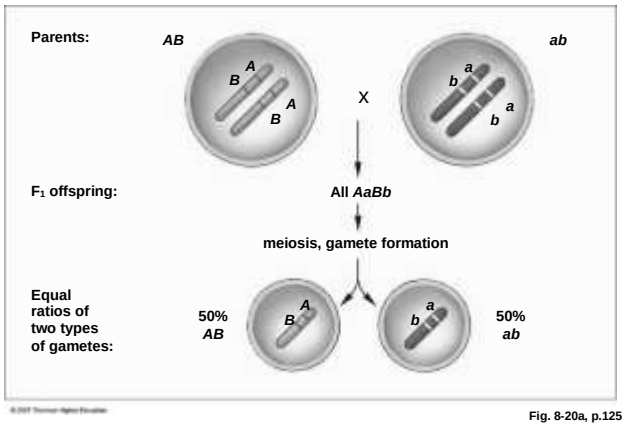


Fig. 8-20a, p.125

Incomplete Linkage

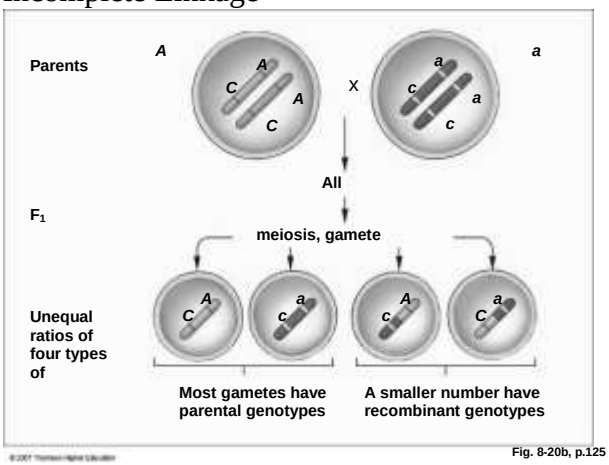
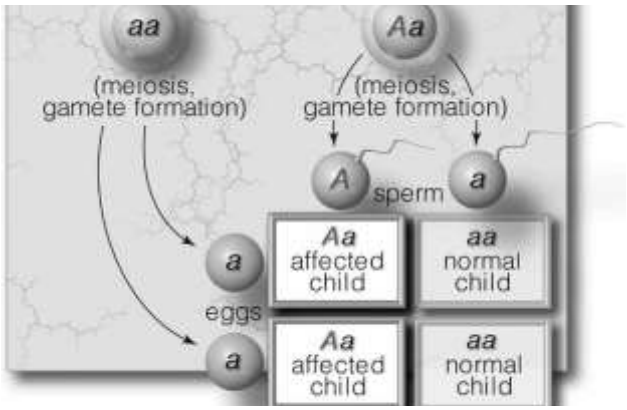


Fig. 8-20b, p.125

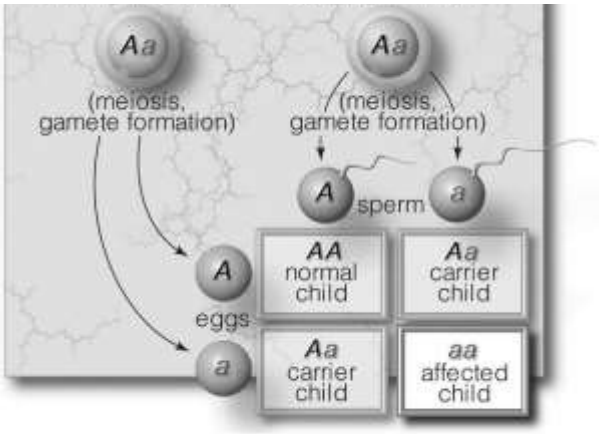
- Genetic Abnormality
  - A rare, uncommon version of a trait
  - Polydactyly
    - Unusual number of toes or fingers
    - Does not cause health problems
    - View of trait as disfiguring is subjective
- Genetic Disorder
  - Inherited conditions that cause mild to severe medical problems
  - Why don't they disappear?
    - Mutation introduces new rare alleles
    - In heterozygotes, harmful allele is masked, so it can still be passed on to offspring
- Human Inheritance Patterns
  - Autosomal Dominant Inheritance
    - Trait typically appears in every generation

Autosomal Dominant Inheritance



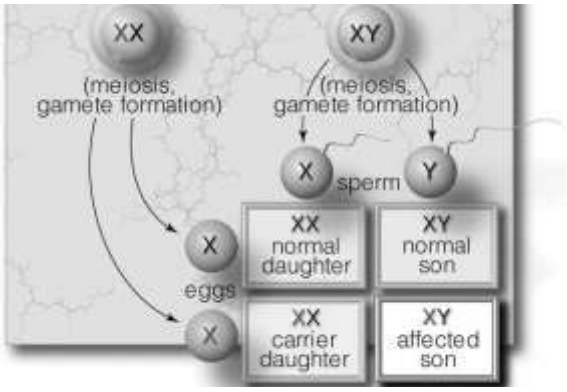
  - Achondroplasia
    - Autosomal dominant inheritance
    - Homozygous form usually leads to stillbirth
    - Heterozygotes display a type of dwarfism

Autosomal Recessive Inheritance



- Autosomal Recessive Inheritance Patterns
  - If parents are both heterozygous, child will have a 25% chance of being affected
  - Autosomal Recessive Galactosemia

- X-Linked Recessive Inheritance



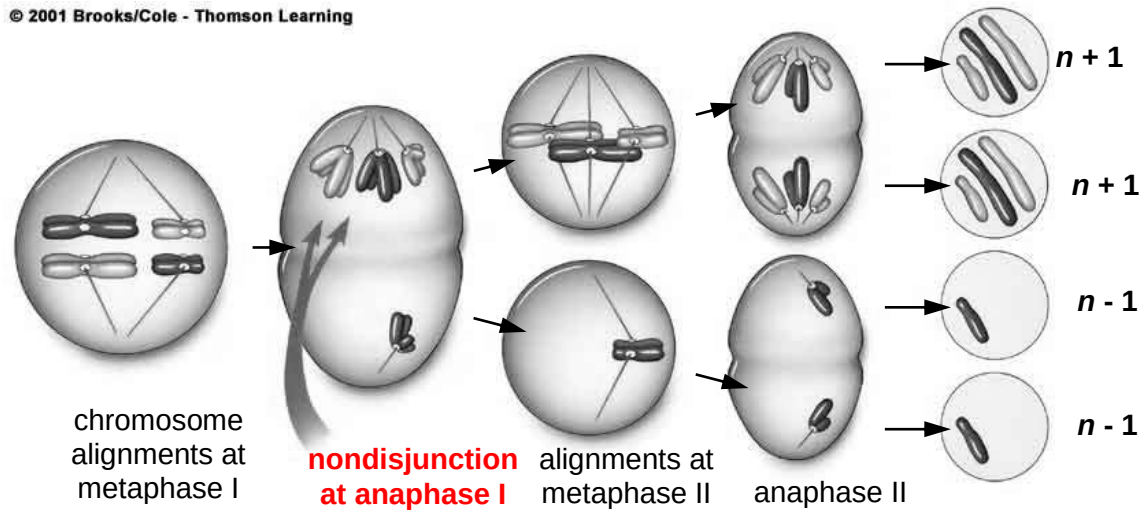
  - Males show disorder more than females
  - Son cannot inherit disorder from his father
  - Examples of X-Linked Traits
    - Color blindness
      - Inability to distinguish among some or all colors
    - Hemophilia
      - Blood-clotting disorder
      - 1/7,000 males has allele for hemophilia A
      - Was common in European royal families

- Structural Changes in Chromosomes
  - Duplication
    - Segment of DNA is copied twice
  - Deletion
    - Loss of some segment of a chromosome
    - Most are lethal or cause serious disorder
  - Inversion
    - A linear stretch of DNA is reversed within the chromosome
  - Translocation
    - DNA segment translocated to non-homologous chromosome

- Changes in Chromosome Number
  - Aneuploidy
  - Polyploidy
  - Most changes in chromosome number are due to nondisjuction
- Aneuploidy
  - Individuals have one extra or one less chromosome (2n + 1 or 2n - 1)
    - Major cause of human reproductive failure
    - Most human miscarriages are aneuploids

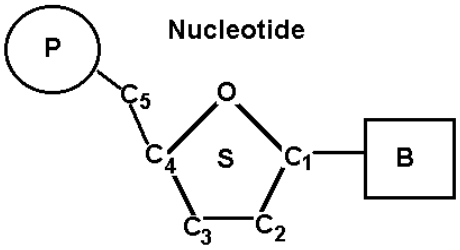
- Polyploidy
  - Individuals have three or more of each type of chromosome (3n, 4n)
    - Common in flowering plants
    - Lethal for humans
    - 99% die before birth
    - Newborns die soon after birth

Nondisjunction

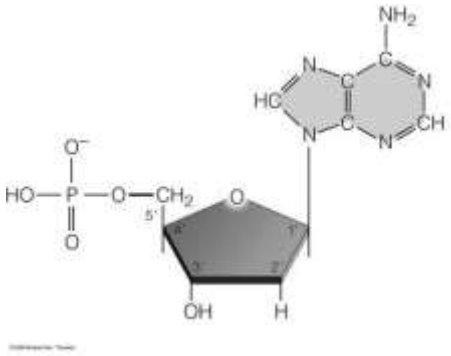


  - Down Syndrome
    - Trisomy of chromosome 21
    - Mental impairment and a variety of additional defects
    - Can be detected before birth
    - Risk of Down syndrome increases dramatically when mothers are over age 35
  - Turner Syndrome
    - Inheritance of only one X (XO)
    - 98% spontaneously aborted
    - Survivors are short, infertile females
    - No functional ovaries
    - Secondary sexual traits reduced
    - May be treated with hormones, surgery
  - Klinefelter Syndrome
    - XXY condition
    - Results mainly from nondisjunction in mother (67%)
    - Phenotype is tall males
    - Sterile or nearly so
    - Feminized traits (sparse facial hair, somewhat enlarged breasts)
    - Treated with testosterone injections
  - XYY Condition
    - Taller than average males
    - Most otherwise phenotypically normal
    - Some mentally impaired
    - Once mistakenly associated with criminal behavior

(4) DNA Structure and Function

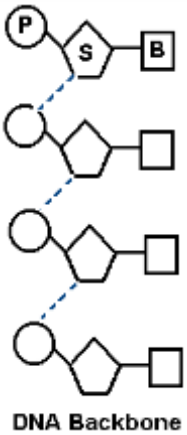


- Nucleotide monomer
  - Nitrogenous Bases (B)
  - 5-C Sugar (S)
  - Phosphate (P)
- Nucleotide Structure
  - 5-C sugar
    - RNA – ribose
    - DNA – deoxyribose
- Nitrogenous Base
  - N – attaches to 1'C of sugar
  - Double or single ring
    Four Bases – Adenine, Guanine, Thymine, Cytosine



- Phosphate
  - Attached to 5'C of sugar
- Nucleic Acids
  - Polymer of nucleotide monomers:
    - DNA – deoxyribonucleic acid
      - The heredity compound of life
      - Directs cellular activities
      - Sequence of nucleotide bases is unique for each individual
    - RNA – ribonucleic acid
      - Sugar – contains ribose sugar instead of deoxyribose
      - Bases – Uracil replaces Thymine found in DNA
      - Involved in protein synthesis
    - ATP – Adenosine Triphosphate
      - nucleotide consisting of ribose sugar, adenine & 3 phosphates
    - Coenzyme – NAD, FAD, NADP
      - nucleotides that assist enzymes by carrying electrons & hydrogen

- DNA Backbone



- Composition of DNA
  - Chargaff showed amount of :
    - adenine = thymine or A=T
    - guanine = cytosine or G=C
      - Therefore if A = 22%, determine the amount of G

- Structure of the Hereditary Material
  - Experiments in the 1950s showed that DNA is the hereditary material
  - Scientists raced to determine the structure of DNA
  - 1953 - Watson and Crick proposed that DNA is a double helix

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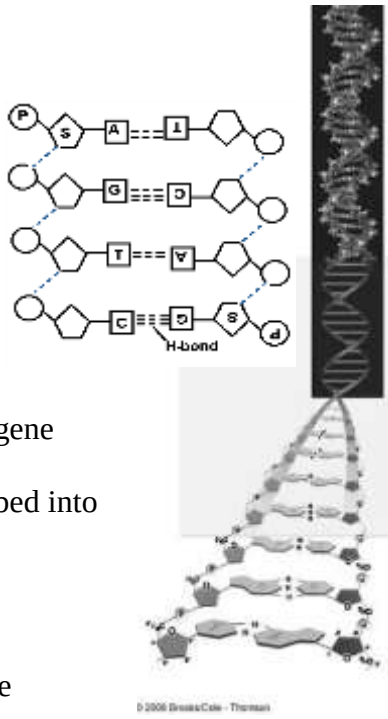
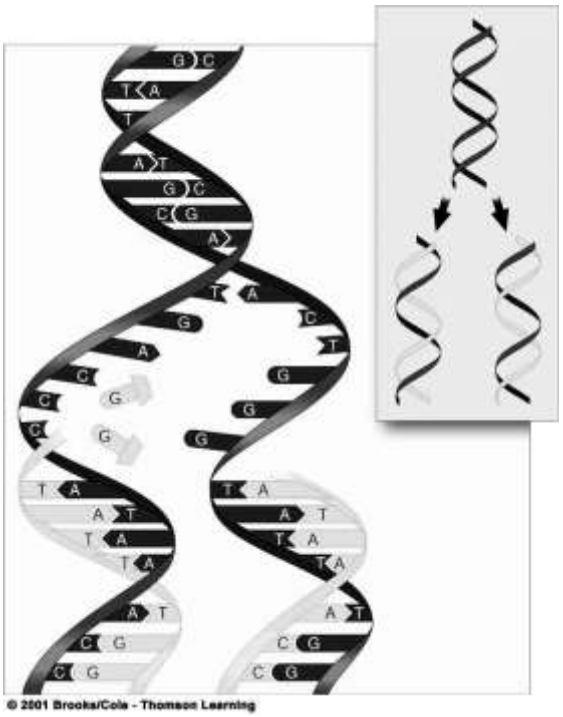
- Watson-Crick Model
  - DNA consists of two nucleotide strands
  - Strands run in opposite directions
  - Strands held together by hydrogen bonds between bases
  - A binds with T and C with G
  - Molecule is a double helix

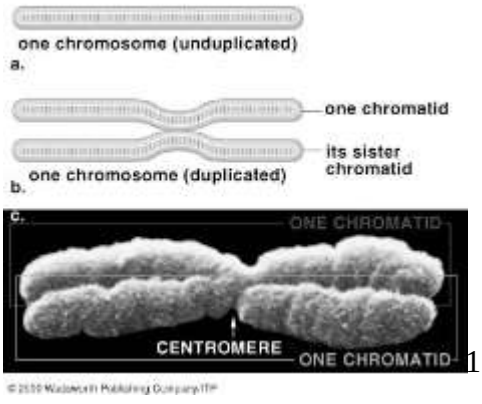


- DNA
  - Information center of the cell
  - Particular sequence of nucleotide bases forms a gene
  - Gene codes for proteins
  - Before a protein is made, genes must be transcribed into RNA

- DNA Replication
  - DNA must be copied before cell division
  - Synthesis of DNA – during S-phase of interphase
  - DNA Replication Semi-Conservative Model



- Chromosome Structure
  - Chromatin – relaxed form of genetic material is necessary during protein synthesis
  - Chromosomes – condensed form of genetic material necessary during cell division
    - unduplicated (no chromatids)
    - Replicated (two chromatids
  - Centromere – point along the chromosome that holds 2 sister chromatids together



(5) Protein Synthesis

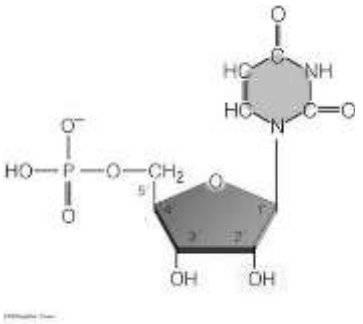
- Steps from DNA to Proteins
  - Two steps produce all proteins:

  - Transcription
    - DNA is transcribed to form RNA
    - Occurs in the nucleus
    - RNA moves into cytoplasm
  - Translation
    - RNA is translated to form polypeptide chains which fold to become proteins
- Three Classes of RNAs
  - Messenger RNA
    - Carries protein-building instruction
  - Ribosomal RNA
    - Major component of ribosomes
  - Transfer RNA
    - Delivers amino acids to ribosomes

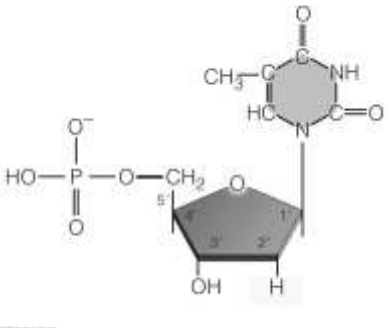
Nucleic Acids

	RNA	DNA
Sugar	Ribose	Deoxyribose
Bases	Adenine Guanine Cytosine Uracil	Adenine Guanine Cytosine Thymine
Strands	Single-stranded	Double-stranded

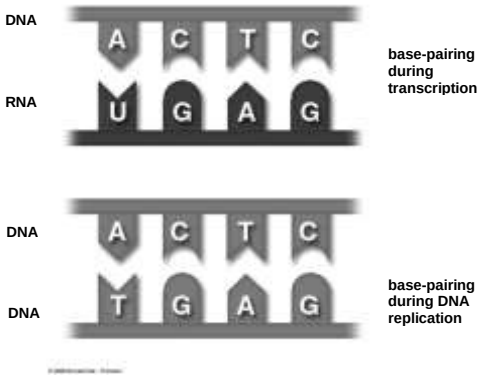
RNA Nucleotide (uracil)



DNA Nucleotide (Thymine)

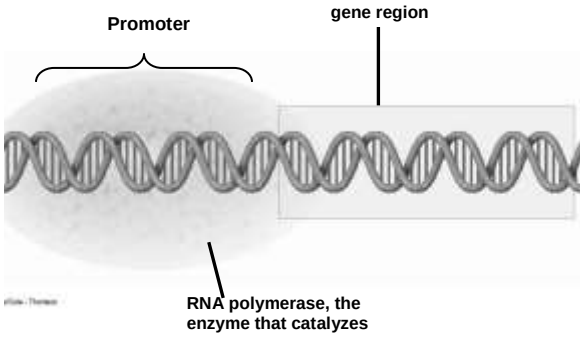


- Base Pairing

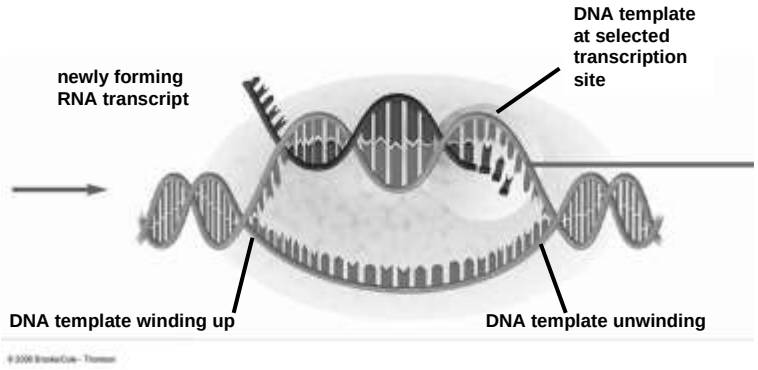


- Transcription
  - Like DNA replication
    - Nucleotides added in one direction
  - Unlike DNA replication
    - Only small section is template
    - RNA polymerase catalyzes nucleotide addition
    - Product is a single strand of RNA
- Promoter
  - A base sequence in the DNA that signals the start of a gene
  - For transcription to occur, RNA polymerase must first bind to a promoter

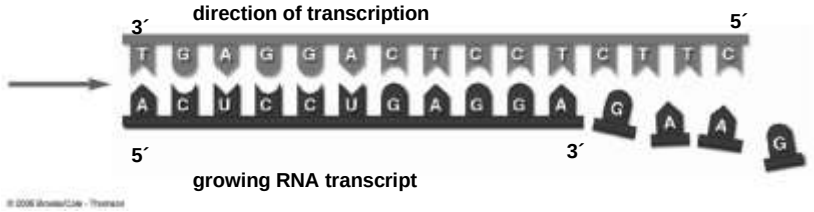
RNA polymerase binds DNA at promoter



Gene Transcription



- RNA Transcript: Adding Nucleotides



- mRNA Transcript modification
  - Exons are important regions that remain in final mRNA (exit nucleus)
  - Introns are instructional regions that are spliced out (remain in nucleus)

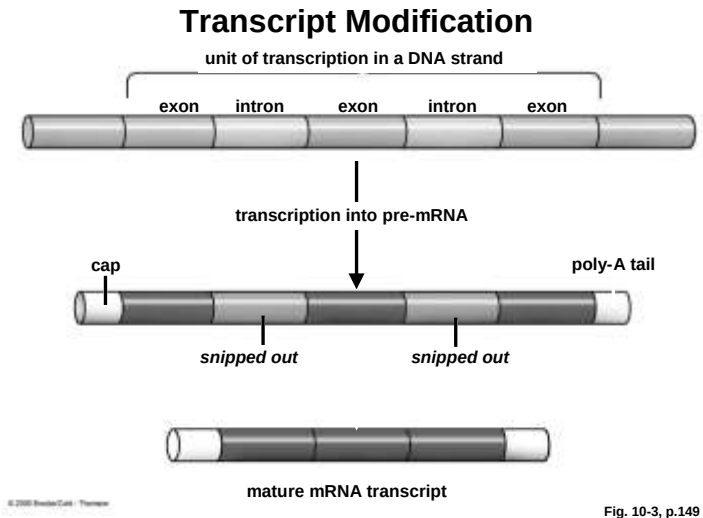
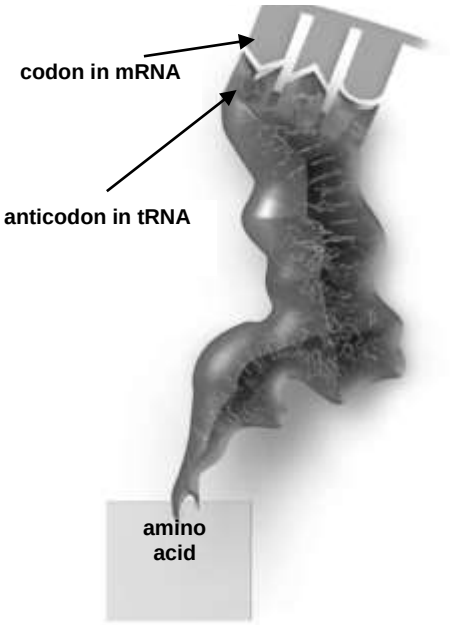


Fig. 10-3, p.149

- Genetic Code
  - Set of 64 base triplets
  - Codons
    - 61 specify amino acids
    - 3 stop translation

tRNA Structure



Amino acids that correspond to base triplets:

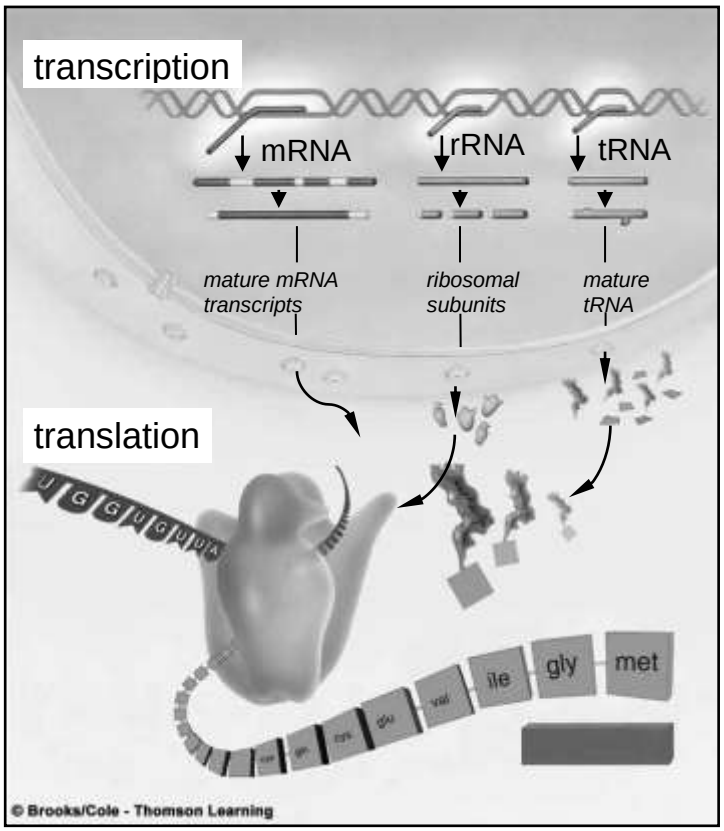
FIRST BASE	SECOND BASE OF A CODON: U	C	A	G	THIRD BASE
U	phenylalanine	serine	tyrosine	cysteine	U
	phenylalanine	serine	tyrosine	cysteine	C
	leucine	serine	STOP	STOP	A
	leucine	serine	STOP	tryptophan	G
C	leucine	proline	histidine	arginine	U
	leucine	proline	histidine	arginine	C
	leucine	proline	glutamine	arginine	A
	leucine	proline	glutamine	arginine	G
A	isoleucine	threonine	asparagine	serine	U
	isoleucine	threonine	asparagine	serine	C
	isoleucine	threonine	lysine	arginine	A
	methionine (or START)	threonine	lysine	arginine	G
G	valine	alanine	aspartate	glycine	U
	valine	alanine	aspartate	glycine	C
	valine	alanine	glutamate	glycine	A
	valine	alanine	glutamate	glycine	G

- Three Stages of Translation
  - Initiation
  - Elongation
  - Termination

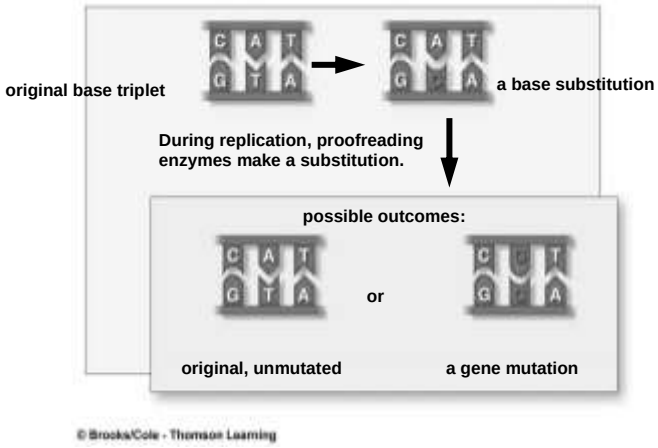
- Initiation
  - Initiator tRNA binds to small ribosomal subunit
  - Small subunit/tRNA complex attaches to mRNA and moves along it to an AUG "start" codon
  - Large ribosomal subunit joins complex
  - Binding Sites
- Elongation
  - mRNA passes through ribosomal subunits
  - tRNAs deliver amino acids to the ribosomal binding site in the order specified by mRNA
  - Peptide bonds form between amino acids and the polypeptide chain grows
- Termination
  - A stop codon moves into place
  - No tRNA with anticodon
  - Release factors bind to the ribosome
  - mRNA and polypeptide are released

- What Happens to New Polypeptides?
  - Some enter the cytoplasm
  - Many enter the endoplasmic reticulum and move through the endomembrane system where they are modified

Overview of Protein Synthesis

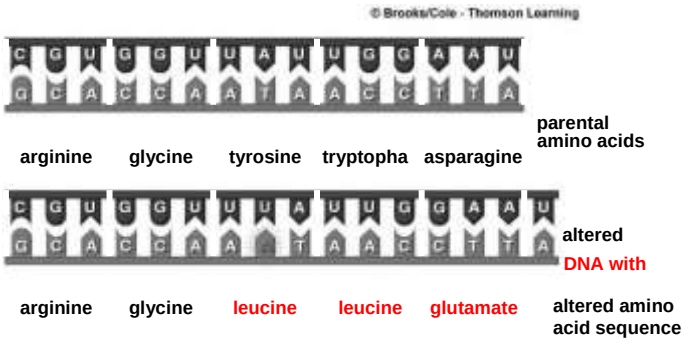


- Gene Mutations
  - Base-pair substitutions
  - Insertions
  - Deletions
- Base-Pair Substitution



- Frameshift Mutations
  - Insertion
    - Extra base added into gene region
  - Deletion
    - Base removed from gene region
  - Both shift the reading frame
  - Result in altered amino acid sequence

Frameshift Mutation



- Transposons
  - DNA segments that move spontaneously about the genome
  - When they insert into a gene region, they usually inactivate that gene

- Mutations
  - Each gene has a characteristic mutation rate
  - Natural and synthetic chemicals, and radiation, increase mutation rate
  - Only mutations that arise in germ cells can pass on to next generation
  - Important evolutionary consequences
- Mutagens
  - Ionizing radiation (x-rays)
  - Nonionizing radiation (UV)
  - Natural and synthetic chemicals