Cell Biology: Chromosomes, Linkage, and Large-Scale Mutation

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Short Answer Quiz

Answer the following questions in 2-3 sentences each.

1. Explain the analogy used to describe genes and chromosomes in relation to independent assortment.
2. What is the main difference between homologous chromosomes and sex chromosomes, particularly concerning the number and types of genes they carry?
3. Why are males considered "hemizygous" for sex-linked genes, and how does this differ from the terms used for females?
4. Describe dosage compensation in mammals, specifically mentioning the mechanism involved and its purpose.
5. What is a genetic mosaic, and how does it relate to X-chromosome inactivation in heterozygous females?
6. Distinguish between "sex-linked" and "linked genes." What context is each term used in?
7. How does crossing over explain the occurrence of recombinant types even when genes are linked?
8. Define non-disjunction and explain how it leads to aneuploidy in gametes.
9. What is a chromosomal mutation? Give two examples and briefly describe their effect.
10. Explain the concept of genetic imprinting as an epigenetic effect, and provide one example.

II. Answer Key

1. Genes are analogous to "passengers" and chromosomes to "large boats." Chromosomes (boats) independently assort, carrying all their genes (passengers) with them. This means genes do not assort in isolation; their movement is dictated by the chromosome they reside on.
2. Homologous chromosomes are truly homologous, meaning they are the same size and carry the same types of genes at the same loci. Sex chromosomes (like X and Y) are not

truly homologous; one (X) is typically much larger and carries genes not found on the other (Y), even though they both play a role in sex determination.

3. Males are hemizygous for sex-linked genes because they only have one allele for those genes (as they have only one X chromosome). Females are typically described as homozygous dominant, heterozygous, or homozygous recessive for autosomal or sex-linked genes (if they have two X chromosomes), as they possess two alleles.
4. Dosage compensation in mammals occurs via X-chromosome inactivation. One of the two X chromosomes in females is largely inactivated during embryonic development by becoming highly condensed. This mechanism balances the dosage of X-linked genes between males and females.
5. A genetic mosaic is an individual, typically a heterozygous female, in whom different populations of cells express different alleles due to random X-chromosome inactivation in early embryonic development. This can result in visible phenotypic patches, such as the different fur colors in calico cats.
6. "Sex-linked" describes a single gene located on a sex chromosome (e.g., X-linked). "Linked genes" refers to two or more different genes located on the same chromosome. The former refers to a gene's location relative to sex chromosomes, while the latter describes the relationship between two or more genes on any given chromosome.
7. Crossing over, an exchange of genetic material between homologous chromosomes during meiosis I, can separate linked genes. If a crossover event occurs between the loci of two linked genes, the alleles on the chromatids involved will be exchanged, leading to recombinant gametes and offspring.
8. Non-disjunction is the failure of homologous chromosomes or sister chromatids to separate properly during meiosis. This error results in aneuploidy, where gametes have an abnormal number of chromosomes (either too many or too few).
9. A chromosomal mutation is a large-scale change in the structure or number of chromosomes, affecting many genes. Examples include deletion (loss of a chromosome segment, e.g., region D) and duplication (repetition of a chromosome segment, e.g., BC region duplicated). Deletions can have severe consequences due to gene loss, while duplications can provide raw material for evolution.
10. Genetic imprinting is an epigenetic effect where an allele is expressed or silenced depending on which parent it was inherited from, without altering the underlying DNA sequence. This is often achieved through methylation, which prevents gene transcription. For example, in rats, a paternal allele for a certain gene might be expressed while the maternal allele is methylated and silenced, regardless of its dominant or recessive nature.

III. Essay Format Questions

1. Compare and contrast Mendelian laws of inheritance (segregation and independent assortment) with the chromosomal basis of inheritance, explaining how the latter provides a physical explanation for the former. Discuss how the concept of linked genes

challenges simple independent assortment, and what mechanism can overcome this challenge.
2. Explain the biological significance of sex chromosomes and how they differ from autosomes. Using examples from the provided material (XY, X0, ZW, Haplo-diploid systems), describe the diverse mechanisms of sex determination across different species and how the determining parent can vary.
3. Discuss the implications of sex-linked inheritance for phenotypic ratios in offspring, particularly contrasting it with autosomal inheritance. Provide a detailed explanation of why the terms "homozygous" and "heterozygous" do not fully apply to males for X-linked genes, introducing the concept of hemizygosity and its consequences.
4. Describe the process of X-chromosome inactivation in mammals, including its timing and purpose. Explain how this mechanism leads to genetic mosaicism in heterozygous females and discuss observable phenotypic effects.
5. Elaborate on the concept of gene mapping using recombination frequencies. Explain how observing the ratios of parental versus recombinant offspring can be used to determine if genes are linked and, if so, their relative distance on a chromosome. Discuss the historical significance of this method in understanding genome organization.

IV. Glossary of Key Terms

- **Allele:** A variant form of a gene.
- **Anaphase I:** The phase in meiosis I where homologous chromosomes (and thus their alleles) separate. This is the physical basis for the Law of Segregation.
- **Aneuploidy:** A condition in which a cell has an abnormal number of chromosomes, i.e., not a multiple of the haploid number.
- **Autosomes:** Any chromosome that is not a sex chromosome. Most genes in an organism are on autosomes.
- **Characteristic:** A heritable feature that varies among individuals (e.g., seed color, eye color).
- **Chromosomal Mutation:** A large-scale change in the structure or number of chromosomes, affecting many genes. Examples include deletion, duplication, inversion, and reciprocal translocation.
- **Chromosome:** A thread-like structure of nucleic acids and protein found in the nucleus of most living cells, carrying genetic information in the form of genes. It acts as the "boat" carrying "passenger" genes.
- **Constitutive Gene:** A gene that is expressed continuously, meaning it is always turned "on."
- **Crossing Over:** The exchange of genetic material between non-sister chromatids of homologous chromosomes during prophase I of meiosis. It leads to recombination of alleles on the same chromosome.
- **Deletion (Chromosomal):** A type of chromosomal mutation where a segment of a chromosome is lost.

- **Dihybrid Cross:** A genetic cross involving two different characteristics, each with two differing traits.
- **Diploid:** A cell or organism containing two complete sets of chromosomes, one from each parent (2n).
- **Disjunction:** The normal separation of homologous chromosomes or sister chromatids during meiosis or mitosis.
- **Dosage Compensation:** Mechanisms that equalize the expression of genes on sex chromosomes between males and females, despite differences in the number of sex chromosomes.
- **Drosophila:** A genus of fruit flies commonly used in genetics experiments due to their rapid reproduction and easily observable traits.
- **Duplication (Chromosomal):** A type of chromosomal mutation where a segment of a chromosome is repeated.
- **Epigenetic:** Refers to heritable changes in gene expression that do not involve changes to the underlying DNA sequence.
- **Fertilization:** The fusion of two gametes (sperm and egg) to form a zygote.
- **Gamete:** A haploid reproductive cell (sperm or egg) that unites with another gamete to form a zygote.
- **Gene:** A unit of heredity that is transferred from a parent to offspring and is held to determine some characteristic of the offspring. It represents the instructions for building an RNA molecule, and often, a protein.
- **Gene Mapping:** The process of determining the relative locations of genes on a chromosome and the distance between them. Historically done using recombination frequencies.
- **Genetic Imprinting:** An epigenetic phenomenon where certain genes are expressed in a parent-of-origin-specific manner, often due to methylation.
- **Genetic Mosaic:** An individual composed of cells with more than one distinct genotype or, in the case of X-chromosome inactivation, different alleles expressed in different cell populations.
- **Genome:** The complete set of genetic material of an organism.
- **Haploid:** A cell or organism containing a single set of unpaired chromosomes (n).
- **Haplo-diploid System:** A sex determination system (e.g., in bees) where fertilized eggs (diploid) develop into females, and unfertilized eggs (haploid) develop into males.
- **Hemizygous:** A condition in males where they have only one allele for a gene located on a sex chromosome (e.g., X-linked genes), as they only possess one X chromosome.
- **Homologous Chromosomes:** A pair of chromosomes (one from each parent) that are similar in size, gene content, and centromere position.
- **Inversion (Chromosomal):** A type of chromosomal mutation where a segment of a chromosome is reversed end to end.
- **Karyotype:** A visual display of the complete set of chromosomes of a cell, arranged by size and shape.
- **Law of Independent Assortment:** Mendel's law stating that alleles of genes on nonhomologous chromosomes assort independently of each other during gamete formation. Physically occurs during Metaphase I.

- **Law of Segregation:** Mendel's law stating that the two alleles for each gene separate (segregate) during gamete formation. Physically occurs during Anaphase I.
- **Linked Genes:** Two or more genes that are located on the same chromosome and tend to be inherited together because they are physically linked.
- **Locus (plural: Loci):** The specific position or location of a gene on a chromosome.
- **Meiosis:** A type of cell division that reduces the number of sets of chromosomes in the original cell by half, producing four haploid gamete cells.
- **Metaphase I:** The phase in meiosis I where homologous chromosome pairs (tetrads) line up at the metaphase plate, allowing for independent assortment.
- **Methyl Group:** A functional group (CH3) that can be added to DNA (methylation) to affect gene expression.
- **Methylation:** The addition of a methyl group, often to DNA, which can inhibit gene transcription.
- **Monohybrid Cross:** A genetic cross involving a single characteristic, where the two parents differ in their traits for that characteristic.
- **Non-disjunction:** The failure of homologous chromosomes or sister chromatids to separate properly during meiosis or mitosis, leading to aneuploidy.
- **Parental Types:** Offspring that have phenotypes identical to one of the original parents in a cross.
- **Philadelphia Chromosome:** A specific reciprocal translocation between chromosome 9 and chromosome 22 in humans, often associated with chronic myelogenous leukemia.
- **Point Mutation:** A mutation affecting only one or a few nucleotides in a gene sequence.
- **Punnett Square:** A diagram used to predict the genotypes and phenotypes of offspring from a genetic cross. It represents all possible fertilization events.
- **Recombinant Individuals (Recombinants):** Offspring that have a combination of traits different from either of their parents, typically due to crossing over between linked genes or independent assortment of unlinked genes.
- **Recombination:** The process of forming new combinations of alleles on a chromosome, typically through crossing over.
- **Recombination Frequency:** The percentage of recombinant offspring in a genetic cross, used to estimate the distance between linked genes on a chromosome.
- **Reciprocal Translocation:** A type of chromosomal mutation involving the exchange of segments between two non-homologous chromosomes.
- **Sex Chromosomes:** Chromosomes that determine the sex of an individual (e.g., X and Y in humans and fruit flies).
- **Sex-linked Gene (or X-linked):** A gene located on a sex chromosome, typically the X chromosome.
- **Trait:** A specific form of a characteristic (e.g., yellow seed color, white eye color).
- **Trisomy:** A type of aneuploidy where there are three copies of a particular chromosome instead of the normal two.
- **Wild Type:** The phenotype or genotype that is most commonly observed in natural populations; often, but not always, the dominant trait.

- **X-Chromosome Inactivation:** A process in mammals where one of the two X chromosomes in each female somatic cell is randomly inactivated to achieve dosage compensation.
- **X0 System:** A sex determination system (e.g., in grasshoppers) where females are XX and males are X0 (having only one X chromosome).
- **XY System:** A sex determination system (e.g., in mammals and fruit flies) where females are XX and males are XY.
- **ZW System:** A sex determination system (e.g., in birds) where females are ZW and males are ZZ.
- **Zygote:** A diploid cell formed by the fusion of two gametes during fertilization.