Topic 4: Genetics I
Chromosomes

4.1.1 State that eukaryotic chromosomes are made of DNA and proteins

In eukaryotes, chromosomes always come in pairs
- Except in gametes

Humans have 23 pairs of chromosomes

Eukaryotic chromosomes are associated with proteins called histones to organize the DNA
Basic Definitions

4.1.2 Define gene, allele, and genome

- Gene: a heritable factor that controls a specific characteristic
- Allele: one specific form of a gene, differing from other alleles by one or a few bases and occupying the same gene locus as other alleles of that gene
- Genome: the complete set of an organism’s base sequences
Mutations

4.1.3 Define gene mutation

- Mutation: a random, rare change in genetic material
- The changed base sequence may code for a different amino acid
- Mutations may be beneficial or harmful to an organism
mRNA

AUU CGC GUU UCC AGG
Arg  Val  Ser

G → A
Substitution

CGC AUU UCC
Arg  Ile  Ser

G
Deletion

CGC UUU CCA
Arg  Phe  Pro

+A
Insertion

CGC AGU UUC
Arg  Ser  Phe
Sickle Cell Anemia

4.1.4 Explain the consequence of a base substitution mutation in relation to the process of transcription and translation, using the example of sickle-cell anemia

- Sickle cell anemia is a result of a substitution
- The codon GAG is changed to GTG
  - The amino acid glutamic acid becomes valine
- The amino acid change happens in the protein hemoglobin found in red blood cells
The change in hemoglobin causes the red blood cells to change their shape and not carry oxygen properly.

The misshaped red blood cells form clots in small blood vessels:
- Cause fatigue, weakness, shortness of breath.

The mutation for sickle cell anemia provides some protection from malaria.
Meiosis

- **4.2.1 State that meiosis is a reduction division of a diploid nucleus to form haploid nuclei**
- Meiosis is cell division that results in gametes
- Diploid = $2n$ = full chromosome number
- Haploid = $n$ = half the number of chromosomes
- Meiosis occurs in a series of stages that are similar to mitosis
Homologous Chromosomes

4.2.2 Define homologous chromosomes

Homologous chromosomes: a pair of chromosomes that carry the same genes

Genes are found at the same loci

Not identical, since each chromosome can have different alleles

Homologous chromosomes are similar in shape, length, and size

Also called homologues or bivalents
Overview of Meiosis

4.2.3 Outline the process of meiosis, including pairing of homologous chromosomes and crossing over, followed by two divisions, which results in four haploid cells

- Meiosis produces four haploid daughter cells
- Parent cell has to divide twice
  - In mitosis, the cell divides once
- Crossing over allows for more genetic diversity
  - Exchange of genetic information between non-sister chromatids
In crossing over, DNA from a person’s maternal chromosomes mixes with DNA from the paternal chromosomes.

Makes recombinant chromatids for the egg or sperm cells.
Meiosis I

- **Prophase I**
  - Chromosomes become visible
  - Homologous chromosomes are attracted to each other and pair up
  - Crossing over occurs
  - Spindle fibers form

- **Metaphase I**
  - Homologous chromosomes line up across the cell’s equator
  - Nuclear membrane disintegrates
Anaphase I
- Spindle fibers attach to chromosomes and pull them to opposite poles of the cell

Telophase I
- Spindle fibers disintegrate
- Chromosomes uncoil and new nuclear membranes form
- Many plants do not have a telophase I
Meiosis II

- **Prophase II**
  - DNA condenses into visible chromosomes again
  - New meiotic spindles form

- **Metaphase II**
  - Nuclear membranes disintegrate
  - Chromosomes line up along the equator in random order
  - Spindle fibers attach to the sister chromatids at the centromeres
- **Anaphase II**
  - Centromeres split, resulting in individual chromosomes
  - Spindle fibers pull chromatids to opposite poles
  - Cell membranes begin to pinch off to make four cells

- **Telophase II**
  - Chromosomes unwind their DNA
  - Nuclear envelopes form
  - Cells prepare for cytokinesis
Nondisjunction

4.2.4 Explain that nondisjunction can lead to changes in chromosome number, illustrated by reference to Down’s syndrome (trisomy 21)

- Nondisjunction occurs when the chromosomes do not separate as they should in either meiosis I or meiosis II
- The egg or sperm may have 24 chromosomes instead of 23
- In Down’s syndrome, nondisjunction occurs in pair 21
Child ends up with three copies of chromosome 21 instead of 2 copies
  • Trisomy 21

Down’s syndrome is a syndrome because it displays a wide variety of symptoms
Parent cell

meiosis
Karyotyping

4.2.5 State that, in karyotyping, chromosomes are arranged in pairs according to their size and structure.

- A karyotype is a photograph of the chromosomes found in a cell arranged according to a standard format (size and shape).
- Pictures of the chromosomes are taken during mitotic metaphase.
- The pictures are then printed, cut out, and arranged.
Prenatal Karyotyping

4.2.6 State that karyotyping is performed using cells collected by chorionic villus sampling or amniocentesis, for prenatal diagnosis of chromosome abnormalities.

Prenatal karyotyping can identify chromosome abnormalities in fetuses (like Down’s syndrome).

In amniocentesis, a hypodermic needle is used to extract some of the amniotic fluid surrounding the fetus.

- Contains some fetal cells that can be used for karyotyping.
In chorionic villus sampling, a tissue sample is obtained from the placenta’s finger-like projections into the uterus wall.
Reading Karyotypes

4.2.7 Analyze a human karyotype to determine gender and whether nondisjunction has occurred.
Normal male karyotype
Normal female karyotype
Trisomy 21
Genetics Definitions

4.3.1 Define genotype, phenotype, dominant allele, recessive allele, codominant alleles, locus, homozygous, heterozygous, carrier, and test cross

- Genotype: the alleles possessed by an organism
- Phenotype: the characteristics or traits of an organism
- Locus: the particular position of a gene on homologous chromosomes
○ Homozygous: having two identical alleles of a gene
○ Heterozygous: having two different alleles of a gene
○ Dominant allele: an allele that has the same effect on the phenotype whether it is in the homozygous or heterozygous state
○ Recessive allele: an allele that has an effect on the phenotype only when in the homozygous state
○ Codominant allele: pairs of alleles that both affect the phenotype when present in a heterozygote
Carrier: an individual who has a recessive allele of a gene that does not have an effect on their phenotype

Test cross: testing a suspected heterozygote plant or animal by crossing it with a known homozygous recessive
Monohybrid Crosses

4.3.2 Determine the genotypes and phenotypes of the offspring of a monohybrid cross using a Punnett grid

A monohybrid cross involves only one gene

Ex: Pea plants can be tall or short. The tall allele is dominant over the short allele. Determine the genotypic and phenotypic ratio of offspring that result from the crossing of a homozygous tall plant with a homozygous short plant.
Step 1: Write an allele key that uses the capital letter for the dominant allele and a lowercase letter for the recessive allele.

\[ \text{T = tall allele } \quad \text{t = short allele} \]

Step 2: Determine the parents’ genotypes.

Homozygous tall = TT
Homozygous short = tt
Step 3: Determine the gametes the parents can give.

TT can only give T
tt can only give t

Step 4: Set up and complete a Punnett square.

```
    T  T
  t Tt  Tt
 t Tt  Tt
```
Step 5: Write out the genotypes and phenotypes of the offspring. Since this was the first cross, these individuals are the $F_1$ generation.

Genotype = 100% Tt  
Phenotype = 100% tall

Now, perform a monohybrid cross of two individuals from the $F_1$ generation to get the genotypes and phenotypes of the $F_2$ generation.
T = tall allele   t = short allele

Both parents are Tt

Tt can give T or t

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Genotype = 25% TT, 50% Tt, 25% tt
Phenotype = 75% tall, 25% short
Use the five steps in a monohybrid cross to solve the following. You must show all five steps.

1. In humans, free earlobes are dominant over attached earlobes. A woman with attached earlobes marries a man with free earlobes. If the man is heterozygous for the trait, what would their potential offspring look like?

2. In guinea pigs, albinism (lack of pigment) is a recessive trait. A female albino guinea pig is mated to two pigmented male guinea pigs (GP1 and GP2). Her litter with GP1 contains no albinos; her litter with GP2 does. What are the genotypes of the two male guinea pigs?
### Multiple Alleles and Codominance

- **4.3.3** State that some genes *have more than two alleles* (*multiple alleles*).
- **4.3.4** Describe **ABO blood groups** as an example of **codominance and multiple alleles**.
- Human blood types have three alleles and four phenotypes.
- **Codominance**

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
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<tr>
<td><strong>IA</strong>IA or IAi</td>
<td>Type A</td>
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<tr>
<td><strong>IB</strong>IB or IBi</td>
<td>Type B</td>
</tr>
<tr>
<td><strong>IA</strong>IB</td>
<td>Type AB (codominance)</td>
</tr>
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<td>ii</td>
<td>Type O (recessive)</td>
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Billie Jean has a baby boy and says that Michael is the father. Michael denies that the boy is his son. Billie Jean’s blood type is A, Michael’s is B, and the baby’s is O. Is it possible for Michael to be the father?

Type A can be IAIA or IAi.
Type B can be IBIB or IBi.
Type O is ii.

It is possible that Michael is the father.
In hamsters, black fur \((C_B)\) and white fur \((C_W)\) are codominant. A hamster with one black allele and one white allele is an agouti (speckled fur).

(a) Cross a black hamster with a white hamster.  
(b) Cross two members of the \(F_1\) generation.

(a)  
Black fur = \(C_B^C_B\)  
White fur = \(C_W^C_W\)

\[
\begin{array}{|c|c|}
\hline
C_B & C_B \\
\hline
C_W & C_B^C_W & C_B^C_W \\
\hline
C_W & C_B^C_W & C_B^C_W \\
\hline
\end{array}
\]

Genotype = 100\% \(C_B^C_W\)  
Phenotype = 100\% agouti
(b) Both parents are $C^B C^W$

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<td>$C^W$</td>
<td>$C^B C^W$</td>
<td>$C^W C^W$</td>
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Genotype: 25% $C^B C^B$, 50% $C^B C^W$, 25% $C^W C^W$
Phenotype: 25% black, 50% agouti, 25% white
Other codominant traits:

- sickle cell anemia
  
  \( \text{Hb}^\text{A} \text{Hb}^\text{A} = \) normal hemoglobin
  \( \text{Hb}^\text{A} \text{Hb}^\text{S} = \) 50% normal cells, 50% sickle cells
  \( \text{Hb}^\text{S} \text{Hb}^\text{S} = \) sickle cell anemia

- cattle coat color
  
  \( \text{C}^\text{R} \text{C}^\text{R} = \) red coat
  \( \text{C}^\text{W} \text{C}^\text{W} = \) white coat
  \( \text{C}^\text{R} \text{C}^\text{W} = \) roan coat

- cat coat color
  
  \( \text{C}^\text{B} \text{C}^\text{B} = \) black
  \( \text{C}^\text{O} \text{C}^\text{O} = \) orange
  \( \text{C}^\text{B} \text{C}^\text{O} = \) tortoiseshell

- snapdragon flower colors
  
  \( \text{C}^\text{R} \text{C}^\text{R} = \) red
  \( \text{C}^\text{W} \text{C}^\text{W} = \) white
  \( \text{C}^\text{R} \text{C}^\text{W} = \) pink
Gender

4.3.5 Explain how the sex chromosomes control gender by referring to the inheritance of X and Y chromosomes in humans

- Females have two X chromosomes (XX)
- Males have one X and one Y chromosomes (XY)
- Females can only donate gametes with an X
- Males can donate gametes with either an X or a Y
- Males therefore determine the gender of the offspring
Parents

Gametes

Offspring

Parents

Gametes

Offspring
Sex Chromosomes

- 4.3.6 State that some genes are present on the X chromosome and absent from the shorter Y chromosome in humans
- The X is longer than the Y and contains many more genes
- Sometimes alleles on X have nothing to pair up with on Y
Homologous region:
2 alleles per gene

Non-homologous region:
one allele on the X chromosome only
Sex Linkage

- 4.3.7 Define sex linkage
- 4.3.8 Describe the inheritance of colorblindness and hemophilia as examples of sex linkage
- 4.3.9 State that a human female can be homozygous or heterozygous with respect to sex-linked genes
- 4.3.10 Explain that female carriers are heterozygous for X-linked recessive alleles
- Genes found on the X or Y chromosome are sex linked
- Colorblindness is the inability to distinguish between certain colors, often green and red.
- Hemophilia is a disorder in which the blood does not clot properly.
- Sex linked traits tend to affect males more than females.
- If a gene has its locus on the X chromosome, females can be homozygous dominant, heterozygous carriers, or homozygous recessive.
  - Carriers do not have the disease.
- Males only require one allele to have the trait since they only have one X chromosome.
Example

For females:

\[ X^H X^H = \text{no hemophilia} \]
\[ X^H X^h = \text{carrier, but no hemophilia} \]
\[ X^h X^h = \text{hemophilia} \]

For males:

\[ X^H Y = \text{no hemophilia} \]
\[ X^h Y = \text{hemophilia} \]
4.3.11 Predict the genotypic and phenotypic ratios of offspring of monohybrid crosses involving any of the above patterns of inheritance

1. Barking in dogs while tracking is dominant over silence. A breeder wants to breed a litter composed entirely of silent trackers. The only two dogs he has to breed are heterozygous barkers. Cross these two dogs. Then, choose two dogs from the F\(_1\) generation to cross. Continue the process until you have 100% silent trackers.
2. A man has blood type A and his wife has blood type B. The couple has four children, each of which has a different blood type. Can these all be this couple’s children?

3. A woman and a man have a baby boy who is colorblind. Neither parent is colorblind. How is this possible?

4. A woman buys two guinea pigs. One is a solid brown color; the other is brown with white spots. The pet shop claims these pigs are sisters from the same litter, and that their parents are both solid brown. If solid brown coats are dominant over white spotted coats, can these pigs really be sisters?
Pedigree Charts

4.3.12 Deduce the genotypes and phenotypes of individuals in pedigree charts

Pedigree charts are used to show how a trait can pass from one generation to the next.

Pedigree charts use special symbols:

- ○ female
-  □ male
-  ● affected female
-  ■ affected male
Example 1: Huntington’s Disease
- caused by a dominant allele (H)
- causes severely debilitating nerve damage
- symptoms do not appear until around age 40
Example 2: Snapdragon Flowers
- Red ($C^R$) and white ($C^W$) are codominant
Example 3: Crested Guinea Pigs
- a crest is a white tuft of hair on a guinea pig’s forehead

Is a crest dominant or recessive?
Example 4: Polydactyly
- polydactyly is having six fingers instead of five

Is polydactyly dominant or recessive?
Go to [http://www.sciencecases.org/hemo/hemo.asp](http://www.sciencecases.org/hemo/hemo.asp) This shows a pedigree chart of hemophilia in the royal families of Britain, Russia, Spain, and Germany. Answer the first four questions that follow the article.
4.4.1 Outline the use of polymerase chain reaction (PCR) to copy and amplify minute quantities of DNA

- PCR is a lab technique that takes a very small quantity of DNA and copies all the nucleic acids in it to make millions of copies of the DNA.
- Only takes a few hours
- Occurs at very high temperatures
- Uses a heat-stable DNA polymerase
Heat to 95°C

Strands separate

Add primers

Cool to 40°C

Heat to 72°C

Repeat
Gel Electrophoresis

- 4.4.2 State that, in gel electrophoresis, fragments of DNA move in an electric field and are separated according to their size

- Gel electrophoresis is a lab technique that uses an electric field to separate DNA fragments by size

- Large fragments move very slowly

- Small fragments move quickly
DNA Profiling

- 4.4.3 State that gel electrophoresis of DNA is used in DNA profiling
- 4.4.4 Describe the application of DNA profiling to determine paternity and also forensic investigations
- 4.4.5 Analyze DNA profiles to draw conclusions about paternity or forensic investigations

DNA profiling is the process of matching an unknown sample of DNA with a known sample

Also called DNA fingerprinting
- Uses the gels made in electrophoresis
- DNA profiling can be used to test for paternity
  - Look for similar patterns in the banding pattern in the gel of the child and suspected father
- Can also be used in crime scene analysis
  - DNA can be extracted from blood, hair, skin, saliva, or semen
1: DNA PROFILE OF THE TECHNICIAN PREPARING THE AUTORADIOGRAPH, ADDED AS ANOTHER INTERNAL REFERENCE

2: DNA PROFILE OF THE RAPE VICTIM

3: DNA PROFILE OF DEFENDANT 1

4: DNA PROFILE OF DEFENDANT 2

6: DNA PROFILE OF FORENSIC SAMPLE (SEmen) TAKEN FROM THE VICTIM
The Human Genome Project

4.4.6 Outline three outcomes of the sequencing of the complete human genome

In 2003, the Human Genome Project announced that it had determined the order of all the bases in human DNA.

Scientists are now deciphering which sequences represent genes and which genes do what.

Can help identify genes that lead to disease.

Can lead to new medications made from molecules produced by healthy people.
- Can lead to information about human ancestry and migration
- Studying the genome can help develop new techniques of data analysis
Gene Transfer

4.4.7 State that, when genes are transferred between species, the amino acid sequence of polypeptides translated from them is unchanged because the genetic code is universal.

Gene transfer is the technique of taking a gene out of one organism (the donor) and placing it in another (the host).

Genetic engineering procedure

Works because DNA is universal
- A, T, C, G are the same in all organisms
Gene transfer was used to create a frost-resistant tomato
- DNA from fish that live in icy waters was inserted into the genome of tomatoes
- The tomatoes now make the cold-resistance proteins

Bt-corn is genetically engineered to produce toxins that kill bugs
- The toxin comes from the genes of a bacterium
Cut, Copy, and Paste

- 4.4.8 Outline a basic technique used for gene transfer involving plasmids, a host cell (bacterium, yeast, or other cell), restriction enzymes (endonucleases), and DNA ligase.

- The “scissors” used to cut genes are called restriction enzymes.

- Restriction enzymes find and recognize a specific sequence of base pairs along the DNA.

- The enzymes then cut the DNA at specified points.
When the gene is cut and removed from the DNA, it has “sticky ends”

The restriction enzyme *EcoR1* recognizes the sequence GAATTC.

![Diagram showing the cutting and creation of sticky ends with the sequence GAATTC](image)
After a gene is cut, it needs to be copied
A host cell, like *E. coli*, is used to copy the DNA in plasmids
A plasmid is a circle of extra DNA found in bacteria
The DNA to be copied is pasted into the plasmid
  1. The plasmid is removed from the *E. coli* and cut with the same restriction enzyme to make sticky ends
  2. The gene is pasted in using DNA ligase to attach the sticky ends
The result is a recombinant plasmid
EcoR1

DNA to be copied

Recombinant plasmid
- The recombinant vector is placed inside a bacterium where it can be replicated.
- The bacterium expresses the gene on the vector and begins making the protein the gene codes for.
- This process is used to get *E. coli* to make human insulin.
Genetically Modified Organisms

4.4.9 State two examples of the current uses of genetically modified crops or animals

- A genetically modified organism (GMO) is one that has had a genetic change using the techniques of gene transfer or recombinant DNA.

- One of the main reasons for producing a GMO is to make it more competitive in food production.

- The “Flavr Savr” tomato was modified to delay ripening and rotting.
  - Good idea, but failed as a business venture.
Another species of tomato was engineered to be more tolerant of high levels of salt in the soil
  - The salt tolerance gene came from a weed, **Arabidopsis thaliana**
  - The tomato can be grown in soil that would be otherwise sterile
A species of rice was engineered to produce beta carotene
  - Beta carotene is used to make retinol
  - Retinol is needed for a healthy immune system, normal vision, and growth
  - The gene for retinol came from the **Erwinia** bacterium or from the daffodil
Species of corn, cotton, and soybeans have been engineered to resist the herbicide glyphosate (Roundup)

- Herbicide kills the weeds but not the crops
- Gene gives the crop an enzyme that breaks down the glyphosate
Transgenic Animals

- Transgenic sheep can be made to produce factor IX for hemophiliacs.
- Factor IX is a protein required to clot blood.
- The sheep produces the protein and secretes it in its milk.
- 1. A ewe is treated with fertility drugs so she super-ovulates.
- 2. Eggs are inseminated.
- 3. Each fertilized egg is injected with the gene for factor IX and implanted into a surrogate.
4. Transgenic lambs are born, each with the ability to make factor IX
5. Once mature, each lamb produces factor IX in its milk
6. Factor IX is isolated and purified from the milk
Pros and Cons of GMOs

4.4.10 Discuss the potential benefits and possible harmful effects of one example of genetic modification

Benefits:

- Increased crop and meat yields, especially in areas of low production
- Yields of crops with increased vitamins and minerals
- Crops do not spoil as quickly during storage
- Crops can make their own pesticides, so fewer chemical pesticides need to be used
Using GMOs to produce medicines and vaccines is less costly and less polluting than synthesizing these in a lab.

**Possible dangers**

- The transgenic genes may escape into the environment.
- Crops that produce their own pesticides may be dangerous for human consumption.
- People may be allergic to GMOs.
- No one knows the long-term effects of eating GMOs.
4.4.11 Define clone

- A clone is a group of genetically identical organisms or a group of cells artificially derived from a single parent.
- Requires laboratory techniques.
- Today, clones can be made from differentiated cells.
- Dolly the sheep was cloned from a differentiated udder cell.
### Dolly, the Cloned Sheep

4.4.12 Outline a technique for cloning using differentiated animal cells

1. An udder cell from the sheep to be cloned was collected and cultured.
2. The nucleus was removed from the cultured cell.
3. An unfertilized egg was collected from another sheep and its nucleus was removed.
4. Using electrical current, the egg cell and the nucleus from the udder cell were fused.
5. The new cell developed in vitro to a zygote and started to form an embryo
6. The embryo was implanted into a surrogate sheep
7. The embryo developed normally
8. Dolly, a clone of the original donor sheep, was born.
unfertilized egg

donates eggs

surrogate

donates udder cell

udder cell

cultured cells

Dolly
Therapeutic Cloning

4.4.13 Discuss the ethical issues of therapeutic cloning in humans

Therapeutic cloning is used to make copies of cells instead of a whole organism.

Aims to develop cells which have not yet gone through differentiation.

This is also called stem cell research since it creates human embryos.
Stem cell research has already been used to study the possibilities of

- Growing skin to repair serious burns
- Growing new heart muscle to repair a damaged heart
- Growing new kidney tissue to repair a failing kidney

Many people believe that creating human embryos for the sole purpose of experiments or using them as “spare parts” is immoral

Stem cell research (therapeutic cloning) is not the same as cloning a human being (reproductive cloning)