ST ANDREW'S SECONDARY SCHOOL

Secondary 4 Biology (6093)

Chapters 19: Heredity

Name: _____ ( ) Class: _____ Date: _____

15. Inheritance

Content

- The Passage of Information from Parent to Offspring
- The Nature of Genes and Alleles, and their Role in Determining the Phenotype
- Monohybrid Crosses
- Variation
- Natural and Artificial Selection

Learning Outcomes

Candidates should be able to:

define a gene as a unit of inheritance and distinguish clearly between the terms gene and allele

explain the terms dominant, recessive, codominant, homozygous, heterozygous, phenotype and genotype

predict the results of simple crosses with expected ratios of 3:1 and 1:1, using the terms homozygous, heterozygous, F1 generation and F2 generation

explain why observed ratios often differ from expected ratios, especially when there are small numbers of progeny

use genetic diagrams to solve problems involving monohybrid inheritance (genetic diagrams involving autosomal linkage or epistasis are not required)

explain co-dominance and multiple alleles with reference to the inheritance of the ABO blood group phenotypes (A, B, AB and O) and the gene alleles (I^A, I^B and I^o)

describe the determination of sex in humans – XX and XY chromosomes

describe mutation as a change in the structure of a gene such as in sickle cell anaemia, or in the chromosome number, such as the 47 chromosomes in the condition known as Down syndrome

name radiation and chemicals as factors which may increase the rate of mutation

describe the difference between continuous and discontinuous variation and give examples of each

state that variation and competition lead to differential survival of, and reproduction by, those organisms best fitted to the environment

give examples of environmental factors that act as forces of natural selection

explain the role of natural selection as a possible mechanism for evolution

give examples of artificial selection such as in the production of economically important plants and animals

19.1 Heredity

- A hereditary trait is a characteristic that can be passed on from one generation to another.
- Genetics is the study of the inheritance of characteristics, or traits, by transmission of genetic material from one generation to another.
- Monohybrid inheritance refers to the inheritance of one characteristic or trait that has two contrasting forms. (*dihybrid inheritance not in syllabus)*

19.2 Basic Knowledge for Studying Heredity

Chromosome, Gene and Alleles

- A **chromosome** is a highly coiled and condensed structure visible during cell division. It is made up of the molecule DNA (deoxyribonucleic acid).
- A **gene locus** (plural: loci) is the position on the chromosome where a gene is located.
- A **gene** is a basic unit of inheritance, born on a particular locus of a chromosome. It is a segment of DNA in a chromosome in which specific genetic information is stored and controls a particular characteristic or protein in an organism.
- **Alleles** are different forms of the same gene. They occupy the same relative position (gene locus) on a pair of homologous chromosomes.

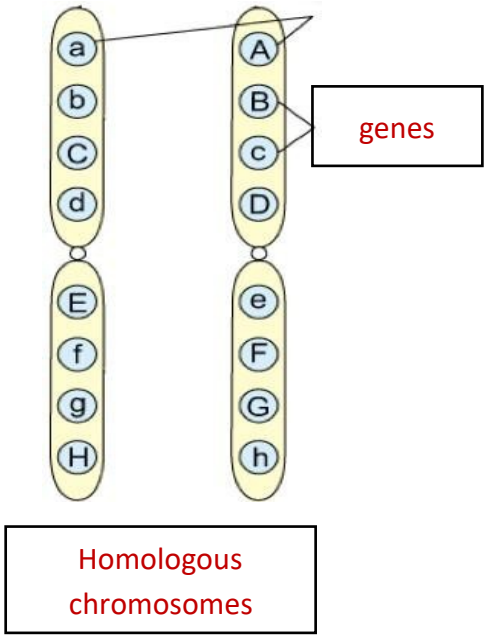
alleles

N2020/P2/A3(d)
Distinguish between the terms *gene* and *allele* with an illustrated example.

State:
A gene is a segment of DNA in a chromosome while
alleles are different forms of the same gene.

Elaborate:
An individual can possess two alleles of one gene.

Exemplify:
The gene for the height of the pea plant has two alleles, short and tall.



Phenotype and Genotype

- The **phenotype** of an organism refers to its observable traits. (e.g. blue eye color, black hair)
- The **genotype** is the genetic make-up of an organism, that is, the combination of genes in an organism which is inherited from its parents.
  - Genotypes are written in the form of letter coding, for which each letter represents one of the two alleles.
- The phenotype of an organism is influenced by its genotype and the environment.

Dominant and Recessive allele

- Alleles can exist in dominant or recessive forms.

T	tt

- A dominant allele expresses itself in both homozygous dominant and heterozygous conditions.
- A recessive allele will only express itself in a homozygous recessive genotype.

Example: T represents dominant allele for tallness while t represents recessive allele for dwarfism

- A genotype of TT and Tt will both produce tall plants
- Only a genotype of tt will produce dwarf plants.

Homozygous and Heterozygous

- An organism is homozygous for a trait if the two alleles controlling the trait are the same.
- An organism is heterozygous for a trait if the two alleles controlling the trait are the different.

Genetic diagrams

- Genetic diagrams can be used to explain how alleles are passed on to offspring or predict the traits that will be displayed by an offspring.

In a breeding experiment, Mendel crossed a **pure-bred tall** pea plant with a **pure-bred dwarf** pea plant. All the F_1 offspring were tall.

Explain this information by means of a **genetic diagram**.

Let T represent the dominant allele for tall pea plants and

t represent the recessive allele for dwarf pea plants.

If the F_1 offspring were crossed amongst themselves, what proportion of the F_2 generation would be expected to be heterozygous?

In a breeding experiment, Mendel crossed a **pure-bred black** guinea pig with a **pure-bred white** guinea pig. All the F_1 offspring were black.

Explain this information by means of a **genetic diagram**.

If the F_1 offspring were crossed amongst themselves, what proportion of the F_2 generation would be expected to be heterozygous?

Punnett square

- **Punnett square** is a simpler method to determine or explain genetic crosses.
- The diagrams below are Punnett squares for Mendel's monohybrid experiment.

Parents

TT X tt

Gametes	t	t
T	Tt	Tt
T	Tt	Tt

F1 hybrid self-cross

Tt X Tt

Gametes	T	t
T	TT	Tt
t	Tt	tt

19.3 Determining Genotypes

- Breeding experiments are used to identify genotype of an organism.
- To identify the genotype of an organism showing the dominant trait, a test-cross is performed. This involves crossing the organism with a homozygous recessive organism.
  - If all the offspring should show the dominant trait, the organism is homozygous dominant.
  - If half the number of offspring show the dominant trait, the organism is heterozygous.

1c. If you were given a tall pea plant (w.r.t example on page 4), how would you attempt to find out whether it is heterozygous? Explain your answer using a Punnett square.

Gametes	t	t
T	Tt	Tt
T	Tt	Tt

Gametes	t	t
T	Tt	Tt
t	tt	tt

2c. If you were given a black guinea pig (w.r.t example on page 5), how would you attempt to find out whether it is heterozygous? Explain your answer using a Punnett square.

Gametes	b	b
B	Bb	Bb

Gametes	b	b
B	Bb	Bb

	B	Bb	Bb		b	bb	bb

Codominance

- Codominance occurs when both alleles controlling a trait are equally expressed in the heterozygous condition. (i.e. neither allele is completely dominant over the other)
- Examples of codominance:
  - Coat colour in short-horned cattle
    - homozygous (C^RC^R) - red
    - homozygous (C^WC^W) - white
    - heterozygous (C^RC^W) - mixture of red and white hairs
  - The ABO blood group in humans

Sex determination in humans

- Sex chromosomes are chromosomes that determine the sex of an organism.
- Autosomes are chromosomes in cells other than the sex chromosome.
- There are two types of sex chromosomes — the X and Y chromosome.
- Sex cells are also known as gametes and they are produced by meiosis. They contain haploid number of chromosomes.
- The other non-sex cells in the body are known as somatic cells.
- Humans have 22 pairs of autosomes and one pair of sex chromosomes (XY - male or XX - female) in each cell.
- Male gametes (sperm) contain either the X chromosome or Y chromosome.
- Female gametes (egg) contain only the X chromosome.
- Whether an X-carrying sperm or a Y-carrying sperm fertilises the ovum determines the genetic composition of the zygote, which eventually determines the sex of the offspring.
- When male and female gametes fuse during fertilisation, there is an equal chance that the offspring could be a male or a female.

Practice Question

The figure below shows a karyotype of an unknown organism.

(a) Circle and label the sex chromosomes.

(b) What is the gender of this individual? Explain.

Male. Sex chromosomes are not identical, indicating an X and a Y chromosome.

(c) How many autosomes are there? 19 pairs

(d) Is this a somatic cell or sex cell? Explain.

Somatic cell. It has 20 pairs of chromosomes.

19.4 Multiple Alleles

- Multiple alleles is a term used for a gene that exists in more than two alleles.
- Human blood group is determined by three alleles — I^A, I^B and I^O.
- I^A and I^B are both codominant, while I^O is recessive to both I^A and I^B.

Blood group	Genotype
A	$I^A I^A$ (homozygous dominant) or $I^A I^O$ (heterozygous)
B	$I^B I^B$ (homozygous dominant) or $I^B I^O$ (heterozygous)
AB	$I^A I^B$ (codominant)
O	$I^O I^O$ (homozygous recessive)

Practice question

A woman whose blood group was O married a man of blood group A. Their first child has blood group O.

(a) Explain how it is possible for the couple to have a child with blood group O.[2]

For the child to have a blood type O, he must have received an **I^O allele from the father** and an **I^O allele from the mother** since the allele **I^O is recessive to dominant I^A**. This is possible if the father's blood type A is attributed to the **heterozygous $I^A I^O$**.

(b) What is the chance of their second child having blood group A? [2]

Father I^AI^O × Mother I^OI^O

Gametes	I^O	I^O
I^A	I^AI^O	I^AI^O
I^O	I^OI^O	I^OI^O

50% chance

(c) Another couple has two children. Both of blood group B. The father was of blood group O and the mother, group B. The mother concluded that she must be homozygous, I^BI^B, because if she was heterozygous, half her children would be of group O. Do you think her conclusion was justifiable? [1]

No. The couple had only two children. Genetic ratios are unreliable with small numbers.

N2020/P2/A3(b)

The inheritance of blood groups demonstrates both codominance and multiple alleles. Explain with reference to human blood groups, what is meant by codominance and multiple alleles.

Codominance

In codominance, alleles **express themselves equally** in the heterozygous condition. [1] As such, neither allele is dominant over the other. For example, if an individual has **both I^A and I^B alleles**, they will have the **AB blood type**.

multiple alleles

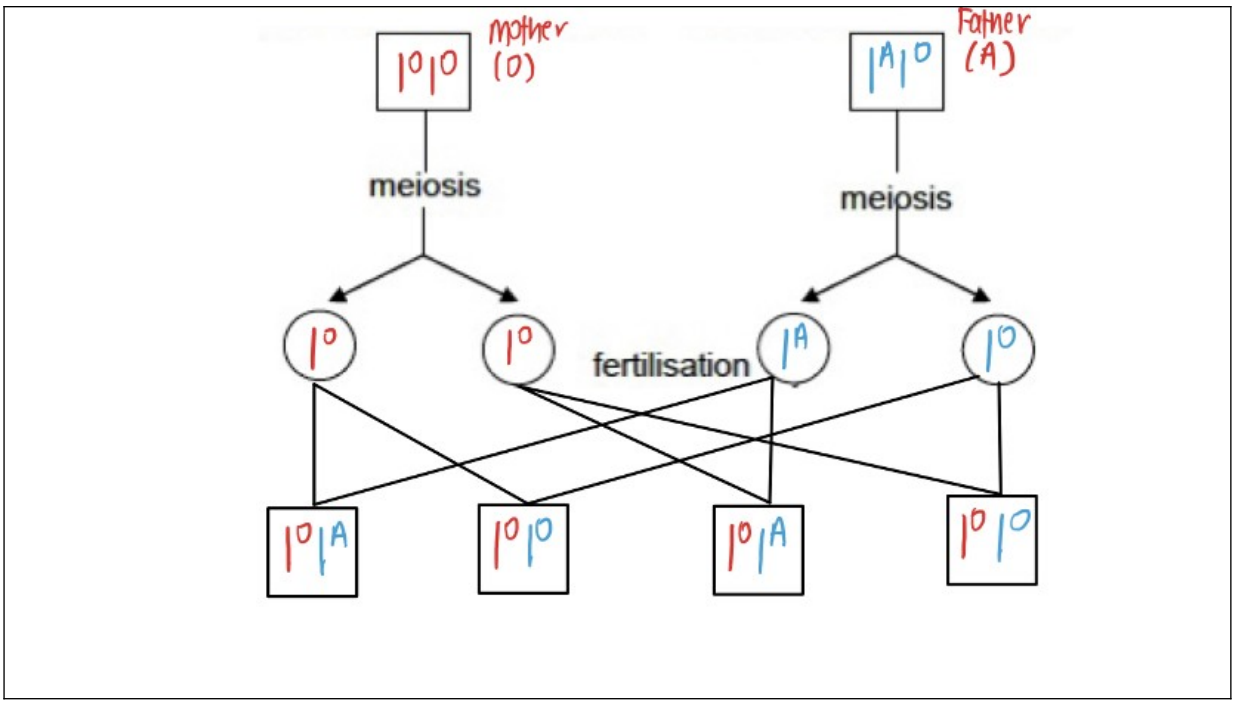
Multiple alleles occur when there are **more than two alleles** for a particular gene. [1] As such, the trait will occur in more than two phenotypes. For example, the human blood group has **three alleles: I°, I^A and I^B**, which resulted in the blood groups A, B, AB and O.

[note – 1m for reference to human blood groups]

[3]

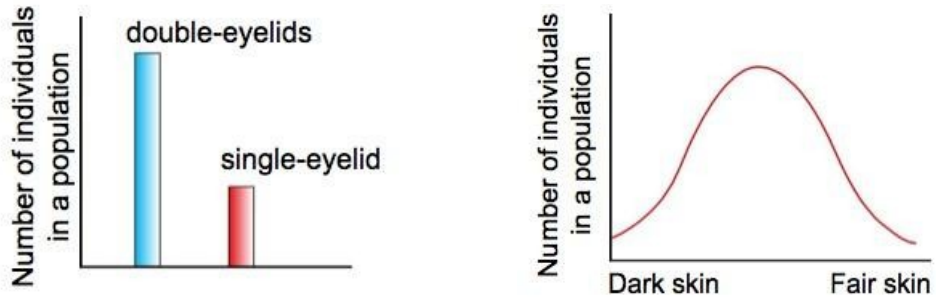
N2020/P2/A3(a) – *extra practice [hint: you need to work backwards]*

A father and mother have four children. The mother is an individual with blood type O. Two children have blood group A and two have blood group O. Use the relevant symbols for alleles (I^A, I^B and I^O) to draw the genetic diagram.



19.5 Discontinuous and Continuous Variation

- **Variations** are differences in traits that occur between individuals of the same species.



discontinuous variation continuous variation

- Traits of an individual are dependent on genes and its' interactions with the environment. Genetic variation is heritable, but variations due to the environment are not.
- Comparison between discontinuous variation and continuous variation.

Discontinuous variation	Continuous variation
Deals with a few clear-cut phenotypes with no intermediate forms.	Deals with a range of phenotypes
Controlled by one or a few genes	Controlled by many genes
Genes do not show additive effect	Genes show additive effect
Not affected by environmental conditions	Affected by environmental conditions
E.g. eye colour and blood group	E.g. height and skin colour

N2020/P2/A3(c)
Blood groups show discontinuous variation. Explain what is meant by discontinuous variation.
Discontinuous variation refers to differences in traits that show clear-cut phenotypes with no intermediate forms. These traits are controlled by one or a few genes, and genes controlling them do not show an additive effect. These traits are also not affected by environmental conditions. (note that if the qn awards more marks, you should bring in examples) [3]

19.6 Mutations

- Mutation is a sudden random change in the structure of a gene or in the chromosome number.
- Mutations can be harmful or beneficial.
  - Individuals with harmful mutation will be eliminated.
  - Individuals with beneficial mutation on the other hand may leave more offspring than normal individuals as nature 'selects' organisms with more favourable characteristics to survive and reproduce.

Inheriting mutations

- Somatic mutations, mutations that take place in body cells other than gametes, are not inherited by the next generation.
- If a mutation occurs during gamete production, the resulting genetic change can be inherited by the offspring.
- Dominant mutations are easily detected unlike recessive mutations, which may not be detectable for generations.

Types of mutations

- **Chromosome mutation**: mutations that change the number of chromosomes
  - **Example: Down syndrome (trisomy 21)**

- Humans normally have 46 chromosomes in their body cells.
- People with Down's syndrome have 47 chromosomes.
- Extra copy of chromosome number 21 is usually caused by the chromosome not separating during gamete formation in female.

- **Gene mutations**: mutations that change the structure of the gene
  - **Example: sickle cell anemia**
    - Caused by mutation in recessive allele, hence only expressed in homozygous recessive condition.
    - Mutation occurs in gene controlling haemoglobin production
    - Sickle-shaped red blood cells have low oxygen carrying capacity and tend to clump together. This disease is fatal and sufferers usually die young.
    - However, individuals who are heterozygous for the sickle-cell allele are more resistant to malaria. Hence, heterozygous individuals are common in area such as West Africa where malaria is prevalent.
  - **Example: albinism**
    - Caused by mutation in recessive allele.
    - Mutation occurs in gene controlling haemoglobin production. Absence of the pigment results in reddish-white skin, white hair and pink eyes.

Mutagens

- Rate of spontaneous mutation is usually very low.
- However, in the presence of certain agents called mutagens, the rate of mutations can greatly increase.
- Mutagens include ultraviolet light, X-rays, alpha, beta and gamma radiation and some chemicals.

19.7 Selection

- Variations in organisms may arise due to:
  - Two main events in meiosis: crossing over and independent assortment of homologous chromosomes
  - mutation in genetic material

Natural Selection

- **Genetic variations provide different alleles to the gene pool for natural selection to act on.**
- Natural selection: process that ensure the best adapted organisms in a population survive to reproduce and pass on their genes to the next generation.
- Nature selects varieties of organisms that are:
  - more resistant to diseases
  - better adapted to changes in the environment

Evolution by natural selection

- **Natural selection over time gives rise to evolution.**
- **Evolution:** process by which present complex forms of living organisms have arisen from simpler ancestral forms.
- The flow chart below describes the mechanism of evolution by natural selection.

Organisms reproduce rapidly as food supply is abundant.

↓

Organisms migrate to different environments.

↓

Spontaneous mutation takes place, resulting in variation in the organisms.

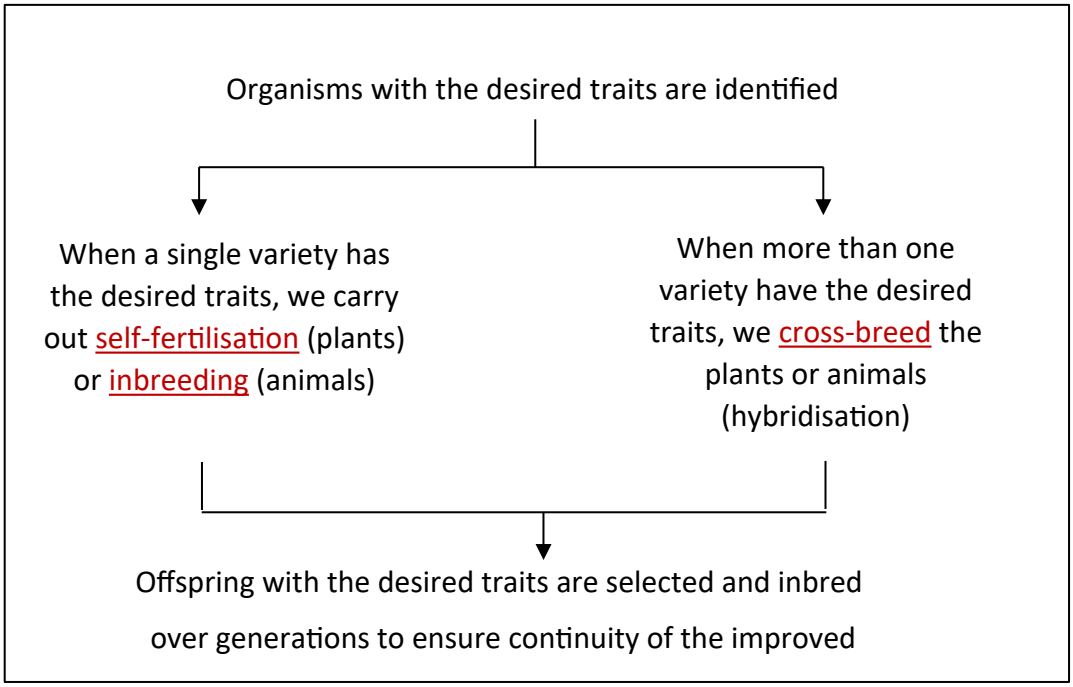
↓

Competition occurs. Organisms with favourable traits will survive, reproduce and pass on the favourable genes to their offspring.

These organisms become the predominant species in the environment.

Artificial Selection

- Plants and animals with desirable traits can be artificially selected through selective breeding.
- The flow chart below illustrates the selective breeding process.



Comparison between natural and artificial selections

Natural selection	Artificial selection
Results from mutations in genes	Results from manipulation by humans
Brought about by changes in environmental conditions	Humans select organisms with desired traits to reproduce
Very slow process	Relatively faster process
May be advantageous or harmful to man	Advantageous to man

N2020/P2/A8(a)

In one part of the world, eucalyptus trees have evolved to resist fires. Explain how these trees have evolved to resist fires. [5]

Variations exist in the eucalyptus trees population due to crossing over and