INTEGRATED SCIENCE

STUDENT BOOK

FOR TTC

YEAR

3

OPTIONS:

Early Childhood
& Lower Primary Education (ECLPE)

FOREWORD

Dear Student,

Rwanda Education Board is honoured to present to you this Integrated Science textbook for Year Three of TTC ECLPE Option which serves as a guide to competence-based teaching and learning to ensure consistency and coherence in the learning of Integrated Science subject. The Rwandan educational philosophy is to ensure that you achieve full potential at every level of education which will prepare you to be well integrated in society and exploit employment opportunities.

The government of Rwanda emphasizes the importance of aligning teaching and learning materials with the syllabus to facilitate your learning process. Many factors influence what you learn, how well you learn and the competences you acquire. Those factors include the instructional materials available among others. Special attention was paid to the activities that facilitate the learning process in which you can develop your ideas and make new discoveries during concrete activities carried out individually or with peers.

In competence-based curriculum, learning is considered as a process of active building and developing knowledge and meanings by the learner where concepts are mainly introduced by an activity, a situation or a scenario that helps the learner to construct knowledge, develop skills and acquire positive attitudes and values. For effective use of this textbook, your role is to:

- Work on given activities including laboratory experiments which lead to the development of skills;
- Share relevant information with other learners through presentations, discussions, group work and other active learning techniques such as role play, case studies, investigation and research in the library, from the internet or from your community;
- Participate and take responsibility for your own learning;
- Draw conclusions based on the findings from the learning activities.

I wish to sincerely extend my appreciation to the people who contributed towards the development of this book, particularly REB staff who organized the whole process from its inception. Special gratitude goes to teachers, illustrators and designers who diligently worked to successful completion of this book.

Dr. NDAYAMBAJE Irénée

Director General of Rwanda Education Board

ACKNOWLEDGEMENT

I wish to express my appreciation to all the people who played a major role in development of this Integrated Science textbook for Year Three of TTC, ECLPE Option. It would not have been successful without active participation of different education stakeholders.

I owe gratitude to different Universities and schools in Rwanda that allowed their staff to work with REB in the in-house textbooks production project. I wish to extend my sincere gratitude to lecturers, teachers, tutors, illustrators, designers and all other individuals whose efforts in one way or the other contributed to the success of writing of this textbook.

Finally, my word of gratitude goes to the Rwanda Education Board staff particularly those from the Curriculum, Teaching and Learning Resources Department who were involved in the whole process of in-house textbook writing.

Joan MURUNGI

Head of Curriculum, Teaching and Learning Resources Department

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UNIT 1

HUMAN REPRODUCTIVE SYSTEM AND GAMETOGENESIS

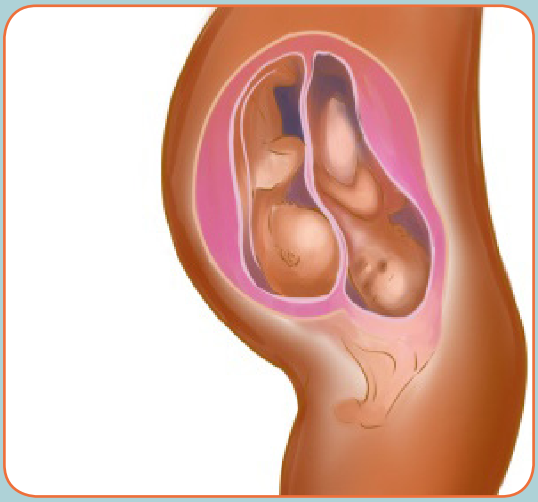
Key Unit Competence:

Relate the structures of the human reproductive system to their functions and describe gamete formation.

Introductory activity 1

Observe the figures below and answer related questions:

A



B

a) What do you see on figure A and figure B?

b) Outline the contribution of each parent (male and female) in formation of a child

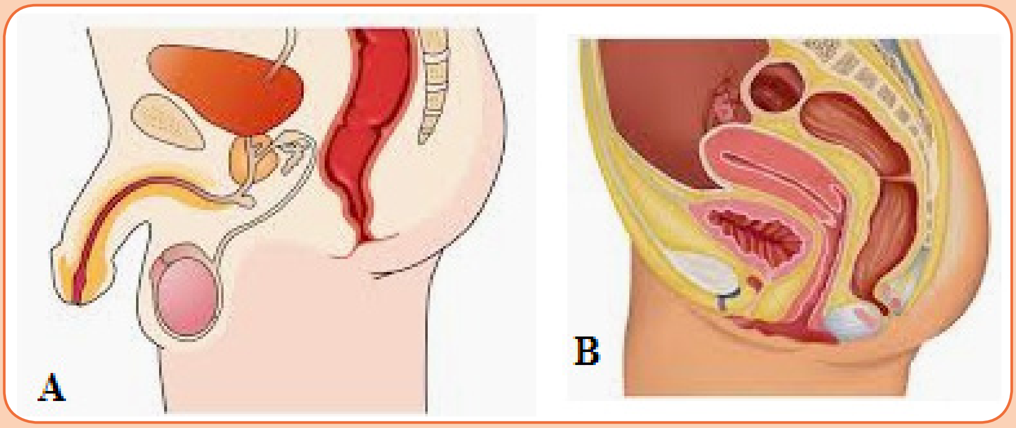
c) Are there any physical and physiological (hormonal) changes observed during pregnancy differently from non-pregnant women? If yes, explain those changes.

d) Which circumstances do you think can lead to having twins?

1.1. Male and female reproductive systems

Activity 1.1

Observe and answer the questions below:



a) What represent those illustrations above?
b) Using search engine or library textbook, identify the main parts of the above illustrations.

1.1.1. Male reproductive systems

The main visible differences between boys and girls at birth are their reproductive organs. The sex of a child is determined at the time of fertilization of the ovum by the spermatozoon. The differences between a male and a female are genetically determined by the chromosomes that each possesses in the nuclei of the cells. Human reproductive system generally involves the fusion of specialized sex cells (gametes), derived from two different individuals.

A. Parts and functions of male human reproductive system

The male reproductive system is a series of organs located outside the body and around the pelvis region of a male that contribute towards the reproduction process. The primary direct function of the male reproductive system is to provide the male sperm for fertilization of the ovum.

The following figure **1.1** represents all parts of male reproductive system.

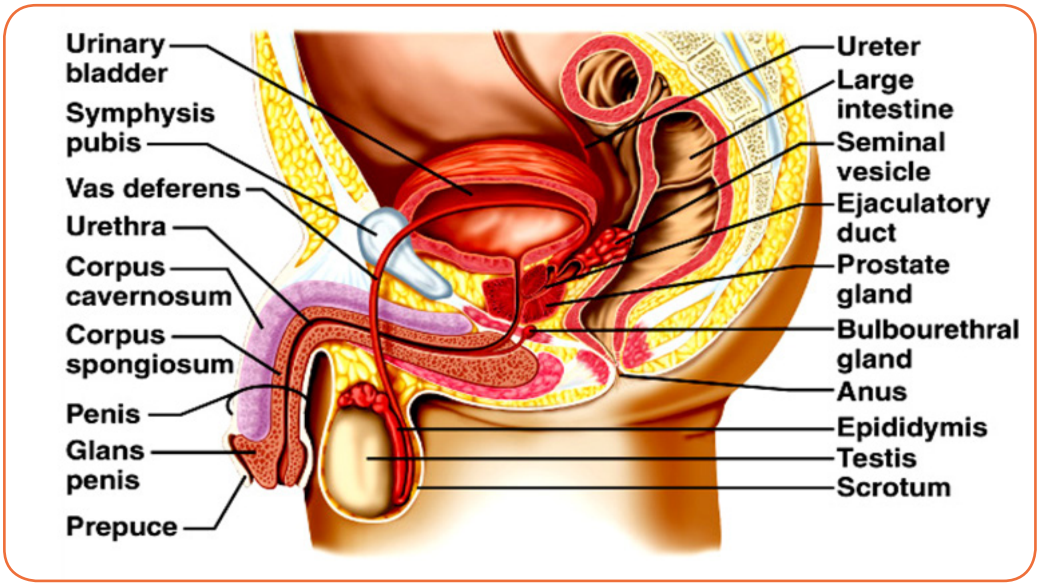


Figure 1.1: Parts of male reproductive system

Male reproductive system comprises the following main parts and their roles:

- The **testis or testicles** is where the male reproductive cells (spermatozoa) are manufactured and the **epididymis** is where the sperms are stored after being released from the testis (it is a coiled tube on the outside of testis; it provides a conducive environment for maturation of sperms).
- The **vas deferens**, **ejaculatory duct** and **urethra** are the tubes used to conduct the sperm cells from the testis to outside (vas deferens is also called the sperm duct, conducts the spermatozoa to the seminal vesicle where spermatozoa are mixed with semen).

In normal healthy semen there are hundreds of millions of sperm. The lowest number of sperm counted as normal is 20 million sperms per 1 cm^3 of semen and an average ejaculate contains 3 cm^3 of semen.

- The **accessory gland** (**seminal vesicles**, the **prostate gland** and **Cowper's gland**) are used to produce a fluid (semen) in which the sperms can live until they are introduced into the female reproductive tract. Semen increases the motility of sperms and also makes them survive longer.
- The **penis** acts as an intromittent organ because it is used to introduce sperms into the female reproductive tract during the act of **copulation** (**sexual intercourse**). The head of penis is **glans** which is covered by the skin called **prepuce**. This prepuce is often removed (**circumcise**) at birth or at puberty for cultural reasons.

The testes develop within the body of the foetus near the kidneys and descend into the scrotum after birth. The testes are maintained at temperature 1 or 2 degrees below the internal body temperature.

This seems to be essential for the proper development of the sperm cells. The people with undescended testes are usually infertile.

- The **urethra** conducts the sperms and urine.

The testes are mixed glands because they produce exocrine secretion and endocrine secretion.

- Exocrine secretion is semen in which sperm cells are kept.

In one ejaculation (semen of 5 ml): the 60% comes from seminal vesicle, the 30% comes from prostate gland, 5% comes from epididymis gland,5% comes from Cowper's gland (bulbourethral gland).

- Endocrine secretion is **testosterone**; the hormone that controls the secondary characteristics such as: Growth of facial hair, growth of pubic hair, growth of axillary hair, and increase in muscle mass and deepening of voice.

Testosterone activates sertoli cells to release male reproductive cells.

- **Seminal vesicles** secrete semen which increases the motility of sperms and also makes them survive longer.
- **Prostate** increases the pH of the semen which enables sperms to survive the acidic nature of the vagina.

Table 1.1: Parts of the male reproductive system and their functions

Structure	Function
Testes	Produce sperm cells and sex hormone **"testosterone".**
Epididymis	Sites of maturation and storage of sperm.
Vas deferens	Carries sperm from the epididymis to its junction with the urethra.
Seminal vesicle	Secretes fructose into the semen, which provides energy for the sperm.
Prostate gland	Secretes an alkaline buffer into the semen to protect the sperm from the acidic environment of the vagina.
Cowper's gland	Secretes mucus-rich fluids into the semen that may protect the sperm from acids in the urethra.
Urethra	Carries semen during ejaculation and urine from the bladder to the exterior of the body.
Penis	Deposits sperm into the vagina during ejaculation

B. Categories of major male reproductive organs.

The major reproductive organs of the male can be grouped into three categories:

The first category produces and stores sperm (spermatozoa). These are produced in the testes, which are housed in the temperature-regulating scrotum; immature sperm then travel to the epididymis for development and storage.

The second category are the ejaculatory fluid producing glands which include the Cowper's gland (also called bulbo-urethral gland), seminal vesicles, prostate, and vas deferens.

The final categories are those used for copulation and deposition of the sperm within the female; these include the penis, urethra, and vas deferens.

Major secondary sexual characteristics include: larger, more muscular stature, deepened voice, facial and body hair, broad shoulders, and development of an Adam's apple. An important sexual hormone of males is androgen, and particularly testosterone.

The testes release a hormone that controls the development of sperm. This hormone is also responsible for the development of physical characteristics in men such as facial hair and a deep voice.

In males, infertility may be due to:

- Absence of sperms in the semen (Azoospermia).
- Low sperm count e.g. when ones ejaculate less than 1cm^3 of semen.
- Abnormal sperm e.g. sperms with 2 tails, or without tail, or without acrosomes,
- Auto-immunity e.g. antibodies attack one's sperms
- Premature ejaculation: the man has orgasm before copulation
- Impotence i.e. inability to achieve or maintain an erection of the penis.

The common signs of infertility in men are: Changes in sexual desire, testicle pain or swelling, problems maintaining erection, issues with ejaculation, small firm testicles.

1.1.2. Female reproductive systems

The human female reproductive system is a series of organs primarily located inside the body and around the pelvic region of a female that contribute towards the reproductive process.

Parts and functions of female human reproductive system

The figure1.2 represents all parts of female human reproductive system.

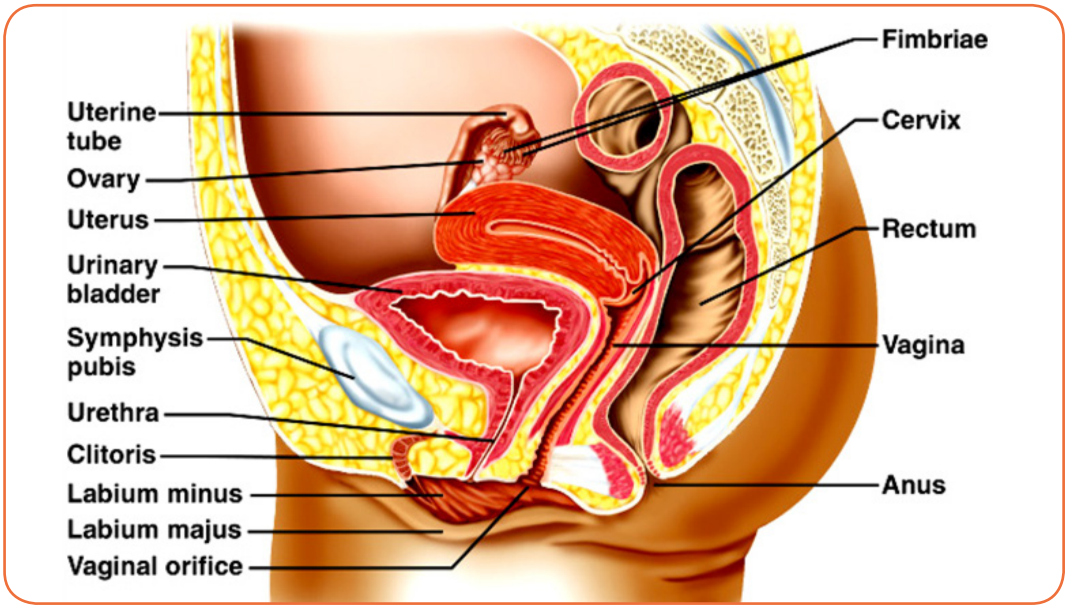


Figure 1.2: Parts of female reproductive system

The female reproductive system is made up of the internal and external sex organs that function in reproduction of new offspring. In human, the female reproductive system is immature at birth and develops to maturity at puberty to be able to produce gametes and to carry out fetus to full term.

The vagina meets the outside at the vulva, which also includes the labia, clitoris and urethra; during intercourse this area is lubricated by mucus secreted by the Bartholin's glands. The vagina is attached to the uterus through the cervix, while the uterus is attached to the ovaries via the Fallopian tubes. Each ovary contains hundreds of egg cells or ova.

The role of a woman in human reproduction is to produce a relatively small number of large gametes or ova, to provide the developing embryo with food and oxygen, to remove its wastes products and after to deliver a baby into the world, to provide it with a continued supply of food for a period of time. Female reproductive system comprises the following main parts and their roles:

- **Ovaries**: the female has 2 ovaries and they are where ova or eggs are produced. They are located on either side of the pelvic girdle. Their functions are to produce the hormones that control egg development and pregnancy and in the formation of eggs by the process of oogenesis.

Functions of ovaries:

- Production of hormones that control egg development and pregnancy
- Formation of eggs by a process called oogenesis

Note: The cells that form eggs are called the graafian follicles. The number of cells from where eggs mature must have formed by puberty. That is to say, the process of oogenesis starts from infant stage up to puberty.

Formation of eggs is by meiosis (one cell divides by mitosis followed by meiosis) but the number of eggs from one cell is one while the others form small cell unable to unite called polar bodies. This explains why females produce few eggs in their lifetime. This differs from spermatogenesis where four sperms are formed from one cell.

- **Oviducts**: are the fallopian tubes, uterine tube. They collect eggs, they are the place where the fertilization takes place and they conduct the zygote to the uterus.

These tubes perform the following functions:

  - To receive the egg after ovulation
  - To act as an area for fertilization
  - To transport the fertilized egg to the uterus for implantation

Special way in which the oviduct is made to carry out its functions include

  - It is funnel shaped for easy reception of the egg and its content at -ovulation.
  - It can carry out peristaltic contractions that push the egg/ fertilized egg towards the uterus.
  - It has cilia that beat so pushing the egg forward.

- **Uterus**: is the place where early embryo undergoes all further development. The uterus is adapted to its functions in the following ways:
  - It has muscular walls able to contract and relax at birth to expel the baby (labour pain)
  - It has a dense network of blood vessels to supply oxygen and food to the growing embryo in the early stages of development
  - It is able to proliferate (thicken) and fill with blood vessels to supply oxygen and foods to the growing embryo in the later stages or development
  - The cervix has a muscle that dilates and allows the passage of a baby during birth
- **Vagina**: is the receptacle for male intromittent organ (**penis**). Vagina is the deposition place of sperms during copulation. It is the opening through which the baby passes during birth.

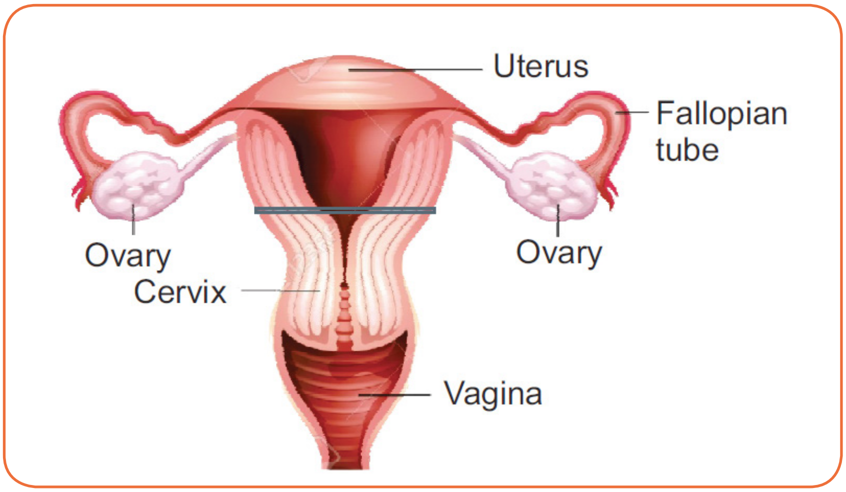


Figure 1.3: Human female reproductive system

Table 1.2: Parts of the female reproductive system and their functions

Structure	Function
Ovaries	Produce eggs and sex hormone **"estrogen and progesterone".**
Oviducts (fallopian tubes)	Carry the ovum from the ovary to the uterus and is a site of fertilization.
Fimbria	Sweep the ovum into the oviduct following ovulation.
Uterus (womb)	– Pear-shaped organ in which the embryo and fetus develop. – Involved in menstruation.
Cervix	– Separates the vagina from the uterus. – Holds the fetus in place during pregnancy. – Dilates during birth to allow the fetus to leave the uterus.
Vagina	– Receives penis during copulation and serves as birth canal. – Provides a passageway for the sperm and menstruation flow.

In females, infertility may be due to:

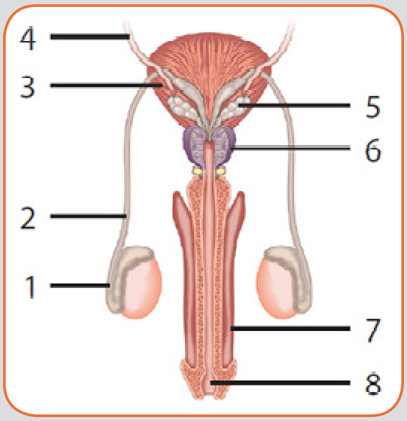
- Failure to ovulate due to the lack of some hormones.
- Damage of the Fallopian tubes / oviducts, for example the tubes may be completely blocked by nature or after an infection.
- Damage on the uterus; for example, the endometrium can be destroyed.
- Damage on the cervix, for example the cervix may be narrow or too wide or may stop producing cervical mucus needed for the sperm to reach uterus.

- Antibodies against sperms, for example, the cervix, the uterus or the oviduct of a woman can produce antibodies against her husband's sperms.

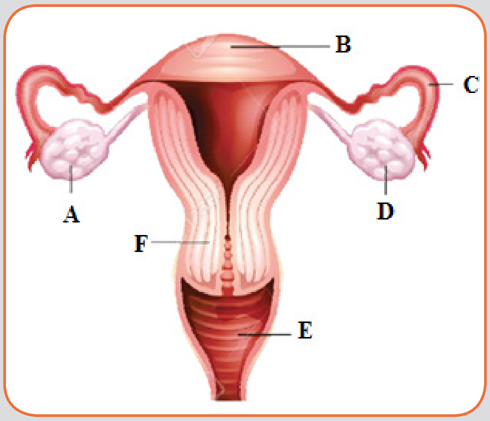
The main symptom of infertility in female is when a menstrual cycle that's too long (35 days or more), too short (less than 21 days), irregular or absent can mean that she's not ovulating. There may be no other outward signs or symptoms.

Application activity 1.1

1. The figures below shows the parts of male and female reproductive systems.



A



B

Complete the labels of the both diagrams A and B and suggest the function of each labelled part.

2. Enclose the 12 parts of male and female reproductive system from the puzzle below:

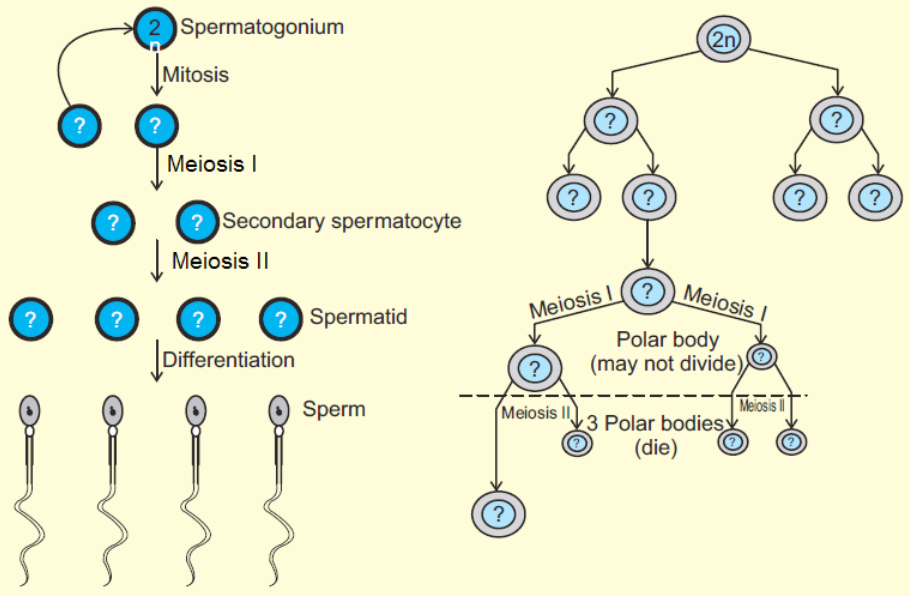
W	A	V	C	L	I	T	O	R	I	S	U	K	E	P
P	H	A	R	N	X	M	O	U	T	H	Y	I	Y	Y
H	U	G	E	C	E	R	V	I	X	T	V	G	E	U
O	V	I	D	U	C	G	T	F	S	D	A	L	X	R
T	I	N	I	L	J	L	L	O	V	E	S	I	F	E
E	J	A	C	U	L	A	T	O	R	Y	D	U	C	T
L	U	N	G	H	P	N	E	V	U	E	E	G	N	H
M	K	P	E	N	I	S	S	A	B	S	F	A	O	R
H	E	A	R	T	T	D	T	R	E	U	E	C	S	A
H	O	R	M	O	N	E	E	Y	N	E	R	A	E	Q
T	G	U	T	E	R	U	S	H	G	C	E	C	Y	D
O	V	I	D	U	C	T	O	N	E	E	N	A	J	A
S	T	O	M	A	C	H	K	A	R	U	S	H	A	U

1.2. Gametogenesis

Activity 1.2: Gametogenesis process

Gametes are haploid cells formed from mother cell (diploid) through gametogenesis process.

Observe the diagram below thereafter answer the related questions



1. From your search engine or library, complete and explain the charts of the gametogenesis above.
2. Compare spermatogenesis with oogenesis processes using the above illustrations.

In humans, meiosis occurs as gametes are formed inside the testes and ovaries. The formation of male gametes is known as **spermatogenesis** and the formation of female gametes as **Oogenesis**.

That formation of gametes takes place in the **gonads (**testis and ovaries). In other words; Spermatogenesis is the process of formation of haploid spermatozoa (sperms) from diploid spermatogonia inside the testes of the male. It occurs in the seminiferous tubules of the testes. Oogenesis is the process of formation of functional haploid ova from the diploid germinal cells in the ovary.

1.2.1. Spermatogenesis

The process of formation of haploid male gametes or spermatozoa from diploid reproductive cells in males is called spermatogenesis. The complete process is broadly divided into two parts:

- Formation of spermatids and
- Spermiogenesis or spermatoleosis.

(a) Formation of Spermatids

The process of formation of spermatids is divided into three stages as follows:

i) **Multiplication phase:** The primordial germ cells or sperm mother cells differentiate from germinal epithelium of testis and increase in size with prominent nuclei. These cells divide repeatedly by mitosis (i.e. equational division) and produce a number of diploid daughter cells, known as spermatogonia. Thus, in this stage, multiplication of germ cells takes place mitotically.

ii) **Growth phase:** In this phase, spermatogonia increase in size by accumulating food reserves and are now called primary spermatocytes.

iii) **Maturation phase:** The primary spermatocytes (which are diploid) undergo first maturation division which is **meiotic division** (or **reductional division**) to produce two haploid secondary spermatocytes. These haploid secondary spermatocytes divide further by mitosis to give rise to four haploid spermatids. This mitotic division is called second maturation division.

(b) Spermiogenesis

A series of changes in spermiogenesis that transform a non-motile spermatid into motile, functional spermatozoa are listed below:

- The nucleus shrinks and flattens by losing water. Only DNA is left in the nucleus, making cells very light that aids to its motility.
- The two **centrioles** of a centrosome form proximal and distal centrioles. The proximal centriole lies at the posterior end of nucleus and the distal centriole gives rise to axial filament of the flagellum and acts as a basal granule.
- The **mitochondria** gather around axial filament and gradually unite to form spiral sheath or nebenkern. It acts as power house of the sperm and provides energy.
- The **golgi bodies** form the covering over nucleus called acrosome. During acrosome formation, one or more vacuoles start enlarging with a small, dense body called pro-acrosomal granule which further enlarges to form acrosomal granule.

The vacuole loses its liquid content and forms the cap of spermatozoan. The remaining part of golgi apparatus is reduced and discarded from sperm.

During all these steps, head of the developing sperm remains embedded in sertoli cells for nourishment. At the end, fully formed spermatozoan shows distinct head, middle piece and tail region.

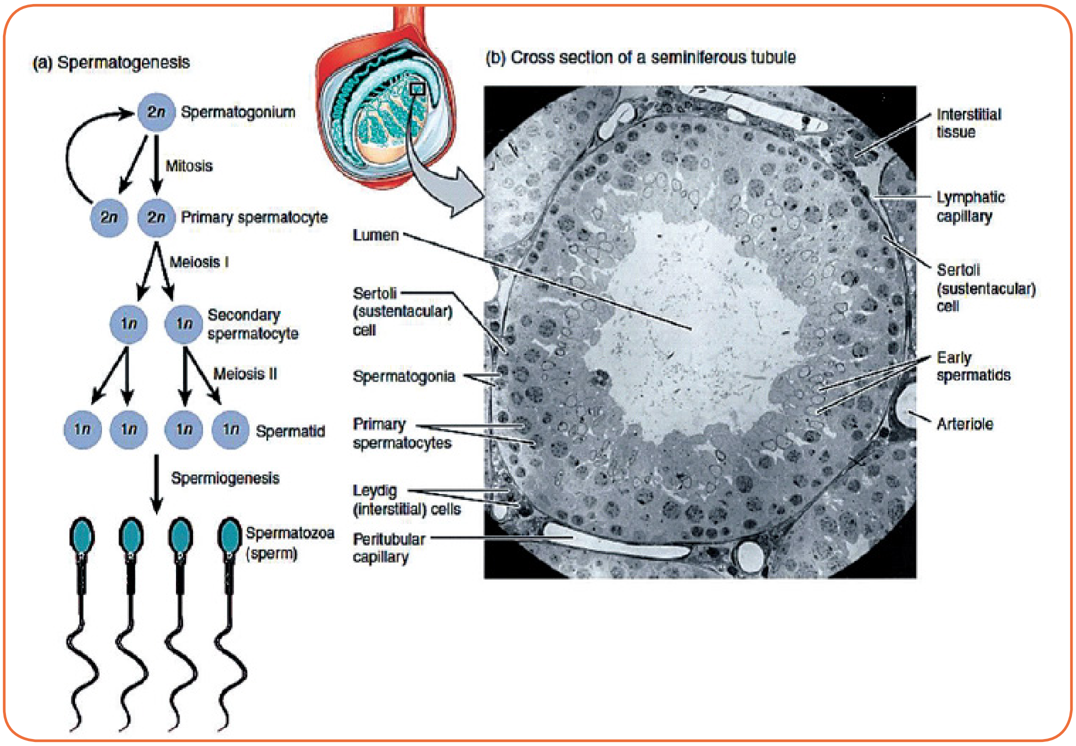


Figure 1.4: (a) Process of spermatogenesis showing chromosome numbers at various stages and the cross-section of a seminiferous tubule showing histological arrangement of various cell types (b) Stages in the formation of spermatozoan from spermatid and acrosome formation from Golgi apparatus during spermiogenesis.

Sperms are produced in the **seminiferous tubules** of the testes. Here, diploid cells divide by mitosis to produce numerous diploid spermatogonia, which grow to form diploid primary spermatocytes.

Adaptive features of sperm

- The sperms are lined in germinal epithelium, when they are mature they are released and pass into epididymis.
- The interstitial cells (Leydig cells) develop between the tubules, they produce hormone called testosterone. The sperm cells take their development within the sertoli cells.
- At their maturation, they are released by the sertoli cells into the lumen of the seminiferous tubule and they pass into the epididymis.

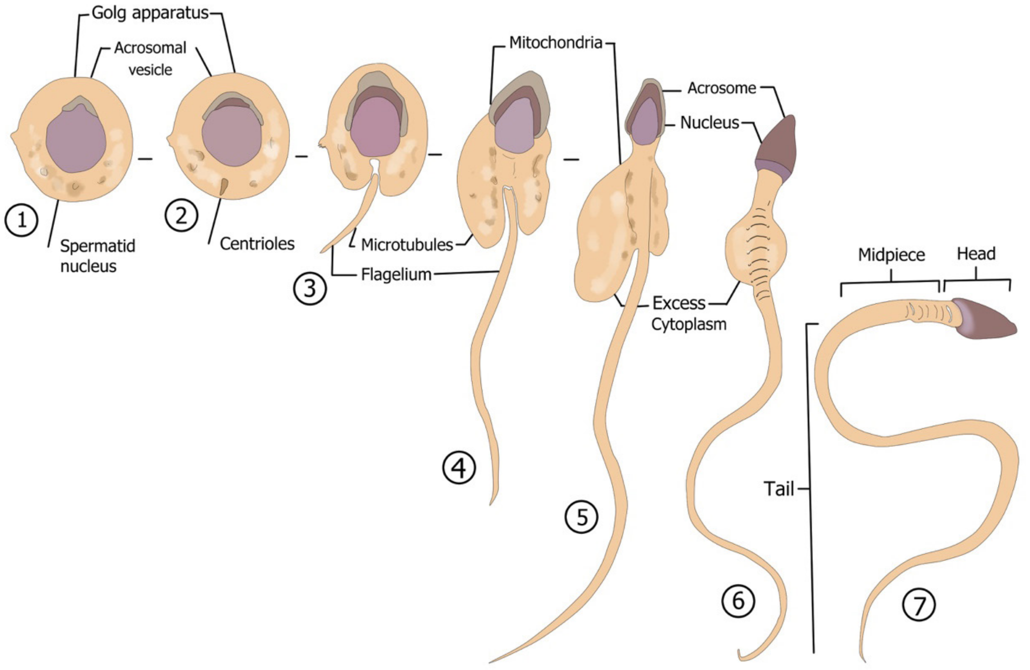


Figure 1.5: Growth of human sperm

Emission: is the process of semen from prostate gland to the prostatic urethra.

Ejaculation: is the movement of semen from prostatic urethra to the outside of penis.

Ejaculation is accompanied by a pleasant sensation (orgasm). Ejaculation and emission are controlled by symphatic nervous system.

Erection: is a hydraulic process in human involving pumping a large amount of blood into the penis and maintaining them there.

Human sperm growth

The role of sperm: to find and penetrate an egg in fertilization. The mature consists of a head, a middle piece and tail.

a) Head: contains 23 chromosomes and its end is called acrosome. Acrosome has enzymes which can break the cells and membranes around the egg and allow sperm to enter.
b) Middle-piece: contains mitochondria which produce energy for movement.
c) Tail: plays a big role in movement of sperm

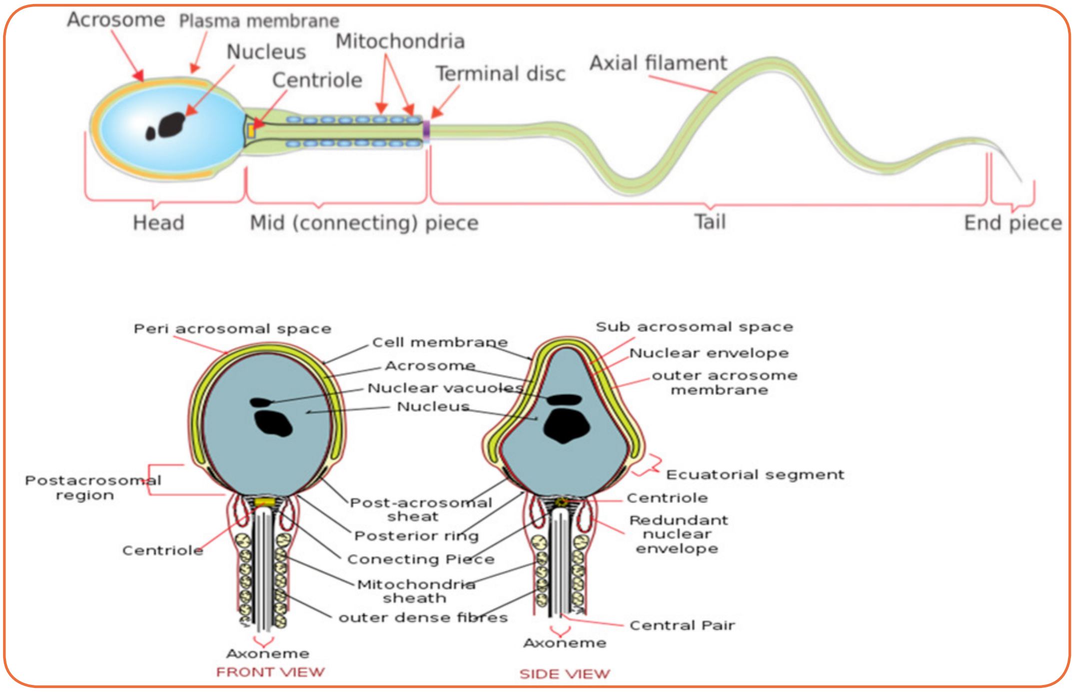


Figure1.6: Different parts of human sperm

1.2.2. Oogenesis

The process of oogenesis occurs in the ovaries. The three phases of proliferation, growth and maturation occur in discontinuous steps.

a) **Proliferative or multiplication phase:** During early foetal development, certain cells within the germinal epithelium of the ovary become enlarged. These cells proliferate by mitosis, producing undifferentiated germ cells called egg mother cells or oogonia (2n). The oogonia divide mitotically to produce groups of oogonia, termed follicles.

b) **Growth and differentiation phase:** During this long phase, which may last upto years, one cell in a follicle prepares for the formation of ovum. It starts meiotic division but gets arrested at prophase-I stage and is called primary oocyte. The remaining cells of the follicle lose the potential to become primary oocyte and are known as the follicular cells or granulosa cells. These follicular cells serve to protect and nourish the primary oocyte. The complete follicle with a primary oocyte surrounded by a layer of follicular cells is called the primary or the ovarian follicle.

c) **Maturation phase:** At puberty, only one of the primary oocytes resumes division per menstrual cycle, alternately in each ovary. The tertiary follicle matures into a Graafian follicle, within which the primary oocyte divides to form two very unequal cells - a large secondary oocyte (n) and a very small 1st polar body or polocyte (n). The 1st polar body may further be divided into two polar bodies.

However, the secondary oocyte again gets arrested at metaphase stage of meiosis-II and is released from the ovary during ovulation. It waits in the oviduct for the sperm to arrive. If fertilization occurs, sperm entry into the secondary oocyte marks the resumption of meiosis. The 2nd maturation division (meiosis-II) again divides the secondary oocyte into two unequal daughter cells a large ootid and a very small 2nd polar body. The ootid undergoes maturation into a functional haploid ovum. A thin vitelline membrane develops outside the plasma membrane of the ovum that protects and nourishes the latter.

Structure of Ovum

An ovum is a spherical, non-motile cell, in the secondary oocyte stage of oogenesis, where the second maturation division is yet to occur. Human ovum is extremely small in size i.e. 0.15 mm in diameter, polar and microlecithal. The large nucleus is called germinal vesicle or later the female pronucleus. The nucleolus is called the germinal spot and cytoplasm is known as ooplasm. The peripheral layer of ooplasm, known as cortex, is more viscous and contains cytoskeletal structures like microtubules and microfilaments, pigment granules and cortical granules of mucopolysaccharides.

The inner part of cytoplasm, called the endoplasm is with cell-organelles, informosomes, tRNAs, histones, enzymes etc. The ovum is covered over by a thin, transparent vitelline membrane which is further covered over by zona pellucida. There is a narrow space between these two membranes known as perivitelline space. During discharge of ovum from the Graafian follicle, several layers of follicular cells adhere to the outer surface of zona pellucida and are arranged radially forming corona radiata.

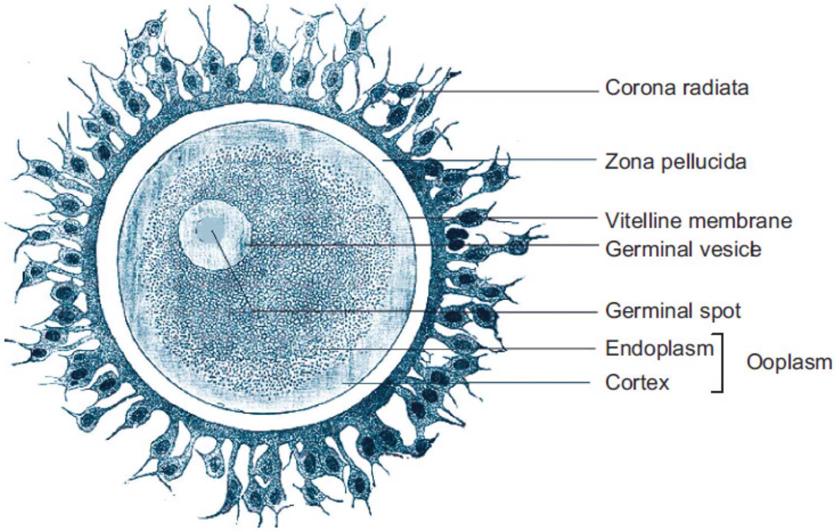


Figure 1.7: Structure of a mature human ovum with corona radiata surrounding it.

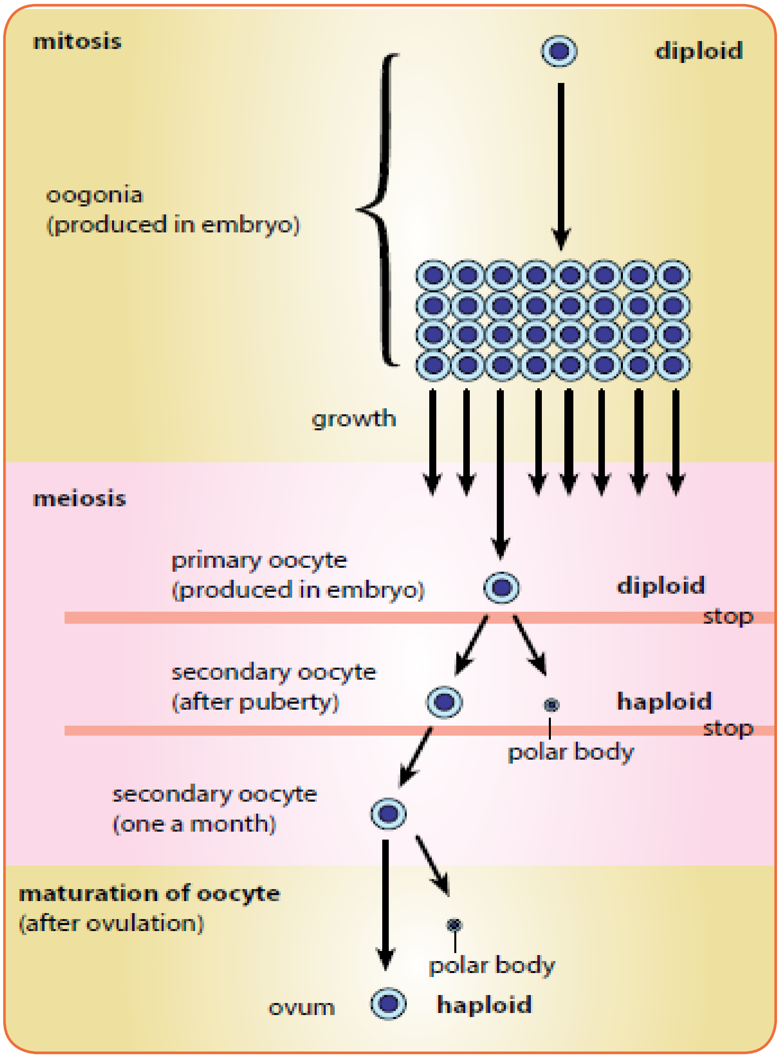


Figure 1.8: Oogenesis in human

The first division of meiosis then takes place, forming two haploid secondary spermatocytes. The second division of meiosis then produces haploid spermatids, which mature into spermatozoa. Oogenesis follows a similar pattern, but many fewer gametes are made than during spermatogenesis, and the process takes much longer, with long ‘waiting stages›. It takes place inside the ovaries, where diploid cells divide by mitosis to produce many oogonia. These begin to divide by meiosis, but stop when they reach prophase I. At this stage, they are called primary oocytes, and they are, of course, still diploid. All of this happens before a baby girl is born, and at birth she has around 400 000 primary oocytes in her ovaries.

When she reaches puberty, some of the primary oocytes get a little further with their division by meiosis. They proceed from prophase I to the end of the first meiotic division, forming two haploid cells.

However, the division is uneven; one cell gets most of the cytoplasm, and becomes a secondary oocyte, while the other is little more than a nucleus, and is called a polar body. The polar body can be thought of as simply a way of getting rid of half of the chromosomes, and has no further role to play in reproduction.

Ovum (egg) production and ovulation

The ova (eggs) are released by the ovaries whereas producing hormones as their functions. The length of human **gestation** is about 9 months (280 days). **Gestation** is the development of zygote from fertilization to the birth. The newborn girl has about 2 millions of primary oocytes in her ovaries, but only about 400 survived until puberty. After puberty the ovaries produce one per month. The release of egg is called **ovulation,** that egg is the second oocyte.

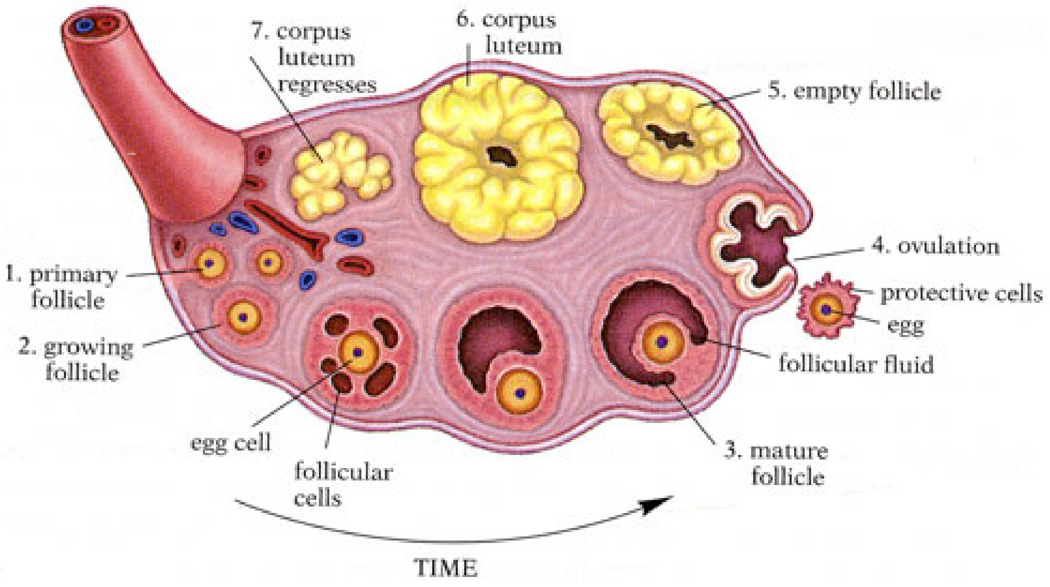


Figure 1.9: Formation of follicles

Each oocyte is enclosed within a cluster of cells that forms a follicle (1). The oocyte fills most of the space in the small, immature follicle. As the follicle matures, it grows bigger relative to the oocyte and develops a large fluid-filled cavity (2, 3). The oocyte, with its follicular cells, protrudes into the cavity.

The outer wall ruptures and both the liquid and the detached oocyte with its surrounding cells are expelled during ovulation (4). The empty follicle is converted into a corpus luteum, which regresses at the end of the cycle (5-7).

1.2.3. Differences and similarities between spermatogenesis and oogenesis

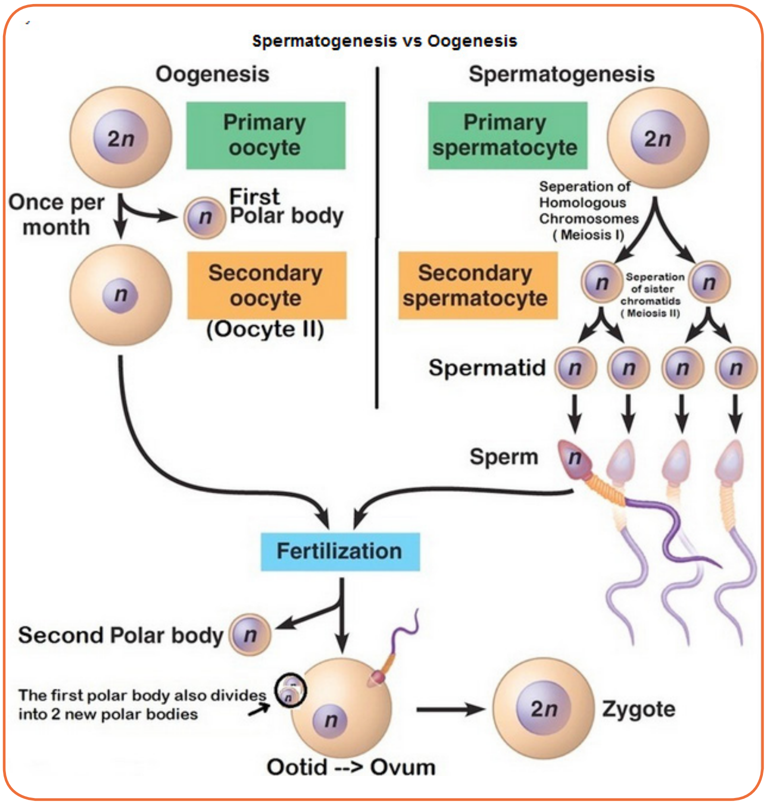


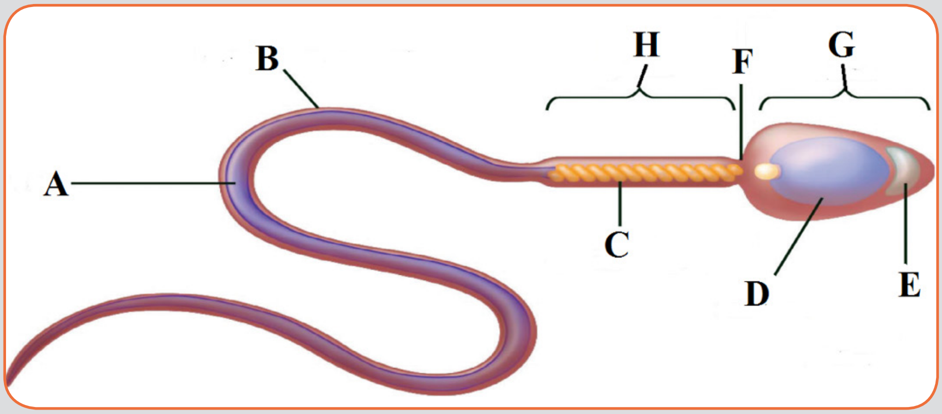
Figure 1.10: Comparison of Spermatogenesis and oogenesis

- Both occur in gonads resulting in production of gametes
- Both involve the same stages i.e. multiplication phase, growth phase and maturation phase.

Spermatogenesis	Oogenesis
1. All four products become functional spermatozoids	1. Only 1 of the four products of meiosis become a functional egg
2. All spermatogonia develop into primary spermatocytes	2. Only 1 oogonium develops into a primary oocyte
3. The amount spermatocyte more than that of a primary oocyte	3. The amount of growth to form a primary oocyte is greater than that of formation of a primary spermatocyte
4. Meiotic divisions are equal resulting into the formation of the equal sperm	4. Meiotic divisions are unequal resulting into the formation of small polar bodies and a big ovum
5. Human males produce 200.000.000 sperms per day	5. The female produces 1 egg at each menstrual cycle

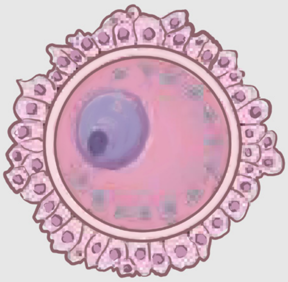
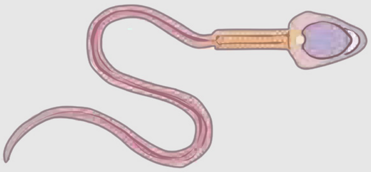
Application activity 1.2

1. Suppose that four hundred sperm mother cells undergo a process of spermatogenesis in a testis of human. How many sperms are produced at the end of spermatogenesis? How many chromosomes each sperm have?
2. (a) Label the following parts of the human sperm



(b) In case the length of the labeled part A is not enough, what do you think can affect individual fertility in natural condition?

3. On the basis of your observations, use the drawn structure of a human spermatozoan and an ovum and label their respective parts along with the functions of each:

Human Egg (Ovum) 	Human Sperm (Spermatozoa) 
Egg	Sperm
Zona pellucida	Nucleus
Vitelline membrane	Middle piece
Corona radiata	Acrosome

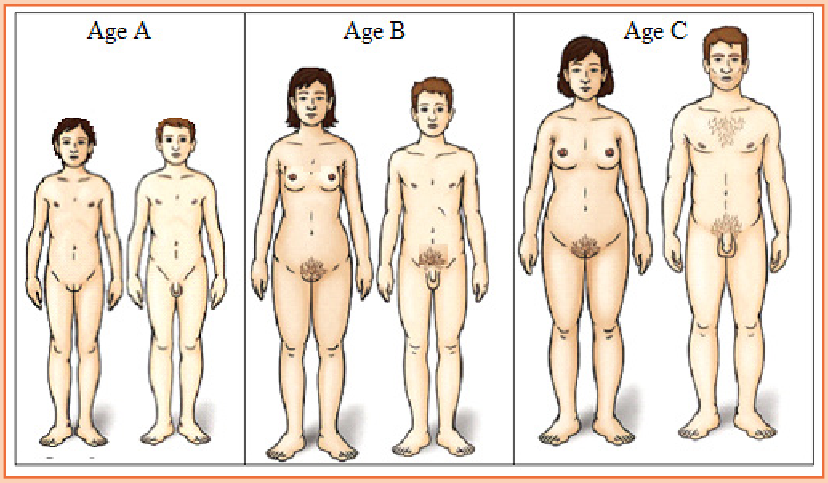
4. Complete the crossword referring to the questions

			2												
1										P	H	A	S	E	
	3										P	H	A	S	E
4											P	H	A	S	E
			P												
			H												
			A												
			S												
			E												

1.3. Puberty

Activity 1.3

Analyze the diagrams below and march further research to answer questions that follow.



1. What could the probable ages of individuals in A, B and C respectively?
2. Age B is known as puberty. What are the signs of the puberty?
3. Can individuals in age B reproduce? Give reasons
4. What hormones trigger changes in puberty?

Puberty is the time in life when a boy or girl becomes sexually mature. It is a process that usually happens between ages 10 and 14 for girls and ages 12 and 16 for boys. It causes physical changes, and affects boys and girls differently.

1.3.1 Secondary sexual characteristics

Human beings produce new human beings by a process of sexual reproduction. We use a process of internal fertilization, and the embryo develops inside the body of the mother in a special organ called the uterus. The gametes are produced in special sex organs. In the sexually mature male, sperms are produced in the testes. In females, the ova are produced in ovaries. This happens during the development of the baby girl in the mother's uterus in a process called oogenesis

When the girl becomes sexually mature, some of the ova ripen and mature in the ovaries each month and one is released in each menstrual cycle.

When an early embryo is developing in the uterus, it is very difficult to tell whether it is male or female. But the time the baby is born, the external genetalia of the two sexes are quite obviously different, although otherwise the appearance of baby boys and girls is very similar

The big physical changes that make boys and girls to appear very different take place at the puberty time when the immature body changes and develops. At puberty, the sex organs become active and the body takes on its adult form. These changes come about in response to hormones released by the brain and by the sex organs themselves.

In girls:
- The first sign of puberty is usually breast development.
- Then hair grows in the pubic area and armpits.
- Menstruation (or a period) usually happens last.

In boys:
- Puberty usually begins with the testicles and penis getting bigger.
- Then hair grows in the pubic area and armpits.
- Muscles grow, the voice deepens, and facial hair develops as puberty continues.

Both boys and girls may get acne. They also usually have a growth spurt (a rapid increase in height) that lasts for about 2 or 3 years. This brings them closer to their adult height, which they reach after puberty.

Guys and girls will also notice other body changes as they enter puberty, and they're all normal changes. Girls might see and feel a white, mucous-like discharge from the vagina. This doesn't mean anything is wrong it is just another sign of your changing body and hormones.

Guys will start to get erections (when the penis fills with blood and becomes hard). Erections happen when guys fantasize and think about sexual things or sometimes for no reason at all. They may experience something called nocturnal emissions (or wet dreams), when the penis becomes erect while a guy is sleeping and he ejaculates. When a guy ejaculates, semen comes out of the penis semen is a fluid that contains sperm. That's why they are called wet dreams they happen when sleeping and their underwear or the bed might be a little wet when they wake up.

1.3.2 Hormonal determinants of pubertal growth

When your body reaches a certain age, your brain releases a special hormone that starts the changes of puberty. It's called gonadotropin - releasing hormone or GnRH for short. When GnRH reaches the pituitary gland , this gland releases into the bloodstream two more puberty hormones: luteinizing hormone (LH for short) and follicle-stimulating hormone (FSH for short). Guys and girls have both of these hormones in their bodies. And depending on whether you're a guy or a girl, these hormones go to work on different parts of the body.

For guys, these hormones travel through the blood and give the testes the signal to begin the production of testosterone and sperm. Testosterone is the hormone that causes most of the changes in a guy's body during puberty. Sperm cells must be produced for men to reproduce.

In girls, FSH and LH target the ovaries, which contain eggs that have been there since birth. The hormones stimulate the ovaries to begin producing another hormone called estrogen. Estrogen, along with FSH and LH, causes a girl's body to mature and prepares her for pregnancy.

So that's what's really happening during puberty it's all these new chemicals moving around inside your body, turning you from a teen into an adult with adult levels of hormones.

Pubertal growth results from increased sex steroid and growth hormone (GH) secretion. Estrogens appear to play an important role in the regulation of pubertal growth in both girls and boys. In girls, however, estrogens cannot be the only sex steroids responsible for pubertal growth, as exogenous estrogens do not initiate a complete growth spurt. We therefore investigated the levels of the different sex steroids and GH, and related them to pubertal growth.

In addition, we studied the process of bone maturation and mineralization during this period. Levels of both estrogens and androgens were found to increase at the start of the female pubertal growth spurt, and it was demonstrated that height velocity is related to levels of GH, estradiol and androstenedione, but not dehydroepiandrosterone sulfate. In boys, GH, testosterone and estradiol increased at the time of peak height velocity. Bone mineralization increased as puberty began, and was associated with the increase in height velocity.

Osteocalcin, a marker of bone formation, declined when height velocity decreased, although bone maturation progressed at a steady rate. We conclude, therefore, that in girls, the concerted actions of estradiol, GH and androstenedione play a role in the pubertal growth spurt, whereas in boys this role is fulfilled by testosterone, GH and estradiol.

Application activity 1.3

1. Can a girl have a growth spurt at 16? Explain your reason
2. What age is considered delayed puberty? Explain
3. Do you think that a diet can affect puberty? Give your opinion

1.4. The menstrual cycle in humans

Activity 1.4

Watch the video on the human menstrual cycle or open the link https://youtu.be/3Lt9I5LrWZw Then, answer the following questions:

1. Why do women have menstruation?
2. State main hormones involved in the regulation of menstrual cycle. For each give the origin and the functions.
3. Describe the four main stages in the menstrual cycle.

1.4.1. Sites of production and roles of hormones related to menstrual cycle

The menstrual cycle is a sequence of events that takes place approximately every four weeks throughout the fertile life of a woman, from the age of puberty to around 50 years of age.

At the onset of puberty, the cycle begins and repeats after 28 days unless interrupted by pregnancy. The changes are stimulated by the gonadotrophic hormone such as; follicle stimulating hormone (FSH) and luteinizing hormone (LH). These hormones stimulate ovaries to secrete; oestrogen (steroid) and progesterone hormones. These four hormones are involved in menstrual cycle.

Two of them including; FSH and LH are produced by pituitary gland and the other two are released by ovaries respectively. The most obvious sign of the cycle is the monthly discharge of blood a process called menstruation. The first day of menstruation is regarded as the first day of the cycle.

A baby girl has ovaries full of immature ova, but they do nothing until after puberty. Then, once a month, a surge of the hormone FSH from the pituitary gland in the brain starts a few of the ova developing

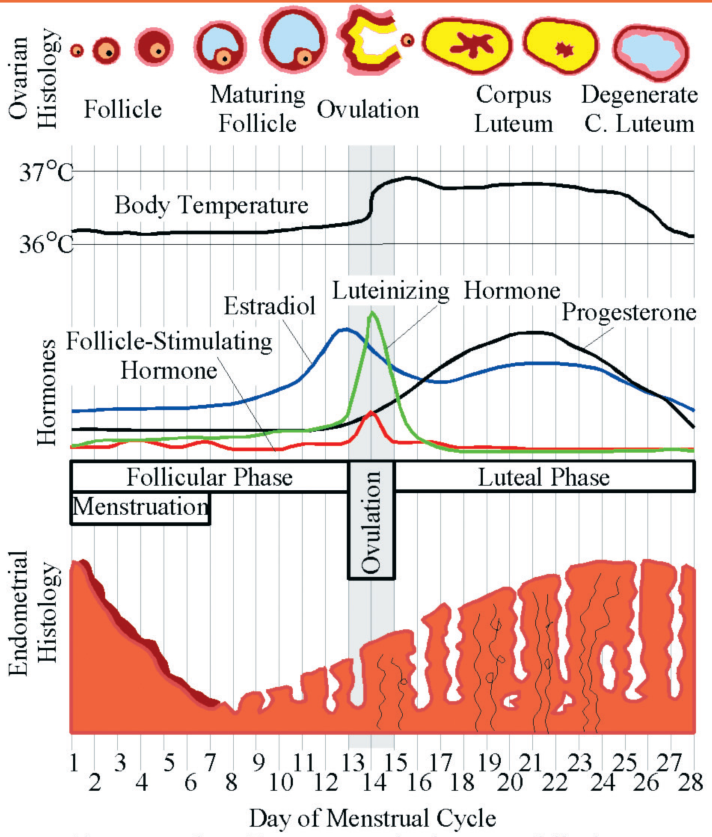
FSH also affects the ovary itself, which starts making the female hormone oestrogen. This in turn stimulates the uterus to build up a thick, spongy lining with a lot of bold vessels, ready to support a pregnancy. About 14 days after ova start ripening; one of them bursts out of its follicle. This is called ovulation and when it happens, the hormone levels from the pituitary begin to drop dramatically.

After ovulation, the remaining of the follicle forms the corpus luteun (which mean s yellow body because it is filled with a yellowish fat) and this secretes a different hormone, progesterone.

Progesterone makes sure that for some days the uterus lining stays thick and spongy and stimulates the growth of more blood vessels, ready to receive a fertilized ovum. If the pregnancy occurs, the embryo will immediately receive a rich supply of food and oxygen. About 10 days after ovulation, when no pregnancy has occurred, the ovary reduces the levels of both oestrogen and progesterone. As the chemical messages change again, the blood vessels supplying the thick spongy lining of the uterus close down. The lining detaches from the wall of the uterus and is lost throughout the vagina as the monthly period or bleeding (**menstruation**)

However, if the ovum has been fertilized, it will reach the uterus and sink into the thick, spongy lining, attach itself (implantation) and start to develop.

An average girl loses around 50 cm^3 of blood in each menstrual period, and will have approximately 450 periods during her fertile life time. This means she will lose around 22.5 liters of blood before she goes through the menopause.



(Average values. Durations and values may differ between different females or different cycles.)

Figure 1.11: The menstrual cycle

1.4.2. Phases or events of menstrual cycle

Menstrual cycle is divided into three phases or events:

a) Follicular phase

Menstrual cycle usually begins when blood is first discharged from the uterus during the first to fifth day (1-5 days).

Following the reduction of progesterone, the hypothalamus releases gonadotropin releasing hormone (GnRH) which stimulates anterior pituitary gland to secrete follicle stimulating hormone (FSH). FSH brings about the following effects:

- Stimulates the development of a primary follicle
- Contributes to the shedding of uterine wall
- Causes production of oestrogen by uterine cells. The oestrogen produced promotes healing, repair and growth of uterine lining, inhibits further secretion of FSH. Oestrogen levels keep on raising until day 13 where they stimulate secretion of luteinizing hormone (LH) by anterior pituitary gland.

b) Ovulatory phase

Around the 14th day, the high levels of oestrogen cause release of luteinizing hormone (LH) the

release of LH brings about ovulation (release of mature egg from the ovary). Immediately after and slightly before ovulation, a woman is fertile and can conceive a baby if she has sexual intercourse or if sperm is present in her oviduct.

c) Luteal phase

After ovulation, the remains of ovarian follicle form corpus luteum also known as **Yellow body**, which secrete large amounts of progesterone hormone and smaller oestrogen. These two hormones; stimulate further development of mammary glands, inhibit release of FSH and thickening wall of uterus in anticipation of pregnancy. If oocyte (ovum) is not fertilized with in about 36 hours of being shed into oviduct, it dies and corpus luteum gets smaller. Thus levels of progesterone and oestrogen keep on reducing until day 28 days i.e. 14 days after ovulation. Low levels of progesterone remove the inhibitory effect on FSH, causing its release thus menstruation and the cycle starts again.

Notice:

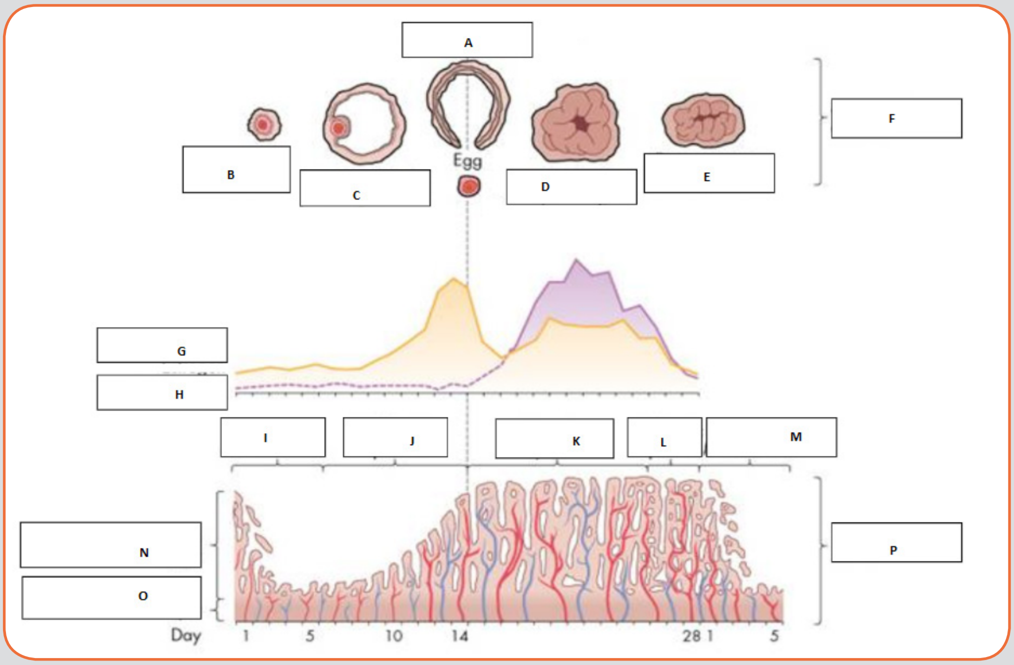
- At menopause there are no more fertile follicle so follicular development and ovulation is ceased.
- The menstrual cycle is controlled by hormones from both brain and the ovary.
- The natural cycle repeats until there is either a pregnancy or the woman reaches menopause.

The uterine cycle also has three phases (events):

1. **Proliferative phase**: It stimulates the thickening of endometrium of the uterus. This thickness of endometrium is stimulated by oestrogen from follicles before ovulation. This results the development of ovary. It acts like follicular phase.
2. **Secretory phase**: it occurs after ovulation for describes further thickening of endometrium (endometrium tissue become more complex) in preparation for implantation. This is stimulated by progesterone which is secreted by corpus luteum and this occurs when corpus luteum is functioning. It acts like lacteal phase.
3. **Menstrual phase**: when endometrium tissue is discharged and vaginal bleeding occurs at the end of ovulatory cycle if pregnancy has not occurred. It is called menstruation. It describes the shedding of endometrium when implantation does not occur.

When pregnancy does not occur the level of progesterone falls and this results shedding of endometrium. Menstrual bleeding lasts between 3 and 5 days. The first day of the period is the first day of the cycle.

Application activity 1.4



1. Label the components and events below on above diagram that occurs during the ovarian and uterine cycles:

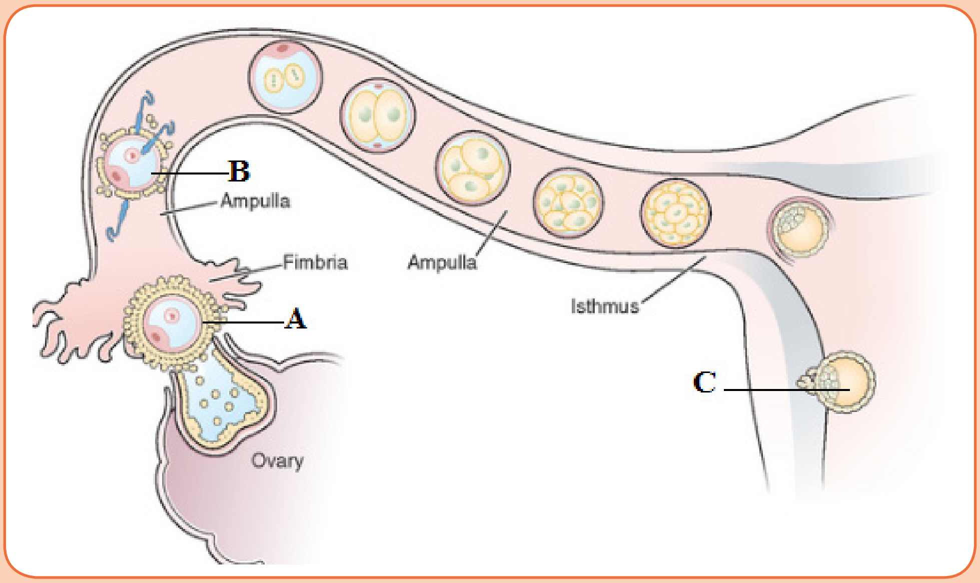
Progesterone; uterine cycle; estrogen; ovulation; graafian (mature) follicle; proliferative phase; endometrium; Early corpus luteum; primary follicle; degraded corpus luteum; myometrium; menstruation; secretory phase; ischemic phase; Ovarian events.

2. Provide the causes for irregular menstruation periods?
3. How long does each phase of the menstrual cycle last?
4. Predict any four hormones that control the menstrual cycle? Explain for each

1.5. Fertilization and fetal development

Activity 1.5

1. The following diagram represents different stages that happen before fetal development. Use it to answer related questions.



   i) Suggest the name of the cell labeled A.
   ii) Name the process which is happening on the cell labeled B. What are the conditions required for the process to happen? Justify your answer.
   iii) Describe the process which is happening in C and what happens after?

2. After watching the two simulations (https://www.youtube.com/watch?v=5OvgQW6FG4); and (https://www.youtube.com/watch?v=hJLZLvKxJFU) from internet; suggest where fertilization is taking place.

Fertilization is the fusion of male and female nuclei to form zygote. Copulation results in the ejection of spermatozoa into vagina. The spermatozoa swim in the watery mucus of vagina and uterus up into the oviduct where the fertilization takes place at the top of oviduct, and it takes about six days for the fertilized egg (zygote) to reach the uterus. The zygote begins to divide and form an **embryo**. This embryo is at the **blustra stage** and it embeds (fixes) itself to the wall of the uterus to continue its development. This is called Implantation. The extra-embryonic membranes are formed (**chorio, amnion, allantois and yolk sac**).

If the ovum and sperm meet in the fallopian tube at the right time, the sperm cluster around the ovum and try to break through its protective layers. They use enzymes to break down these barriers until finally one sperm penetrates the ovum. This is the moment of fertilization, which in humans is also known as conception. At this point the nucleus from sperm (containing chromosomes from the father) fuses with the nucleus from the ovum (containing chromosomes from the mother) and a potential new life begins.

A tough fertilization membrane forms around the fertilized ovum, which prevents any other sperm from penetrating it. The new cell (zygote) has a unique set of chromosomes. If no problems arise, it will develop into a baby.

Sometimes two ripe ova will be released during the same monthly cycle. If they are both fertilized by sperms, two babies may develop in the uterus and the mother will deliver non identical twins. The babies may be the same or different sex, and are really normal siblings born at the same time.

More rarely, the fertilized ovum splits completely in two as the early embryo forms. Again, two babies develop but these are identical twins. Because they come from the same fertilized egg, they are genetically identical. Identical twins are actually human clones.

If ovulation has already taken place, the egg and sperm meet in the upper part of oviduct and once they come into contact, acrosome raptures and release lytic enzyme which dissolve corona radiata of the egg and soften zona pellucida and vetelline membrane. The following processes take place:

a) Capacitation

This is a stage where by sperm undergoes essential changes while passing through female genital trackand this takes about 7 hours. These changes include the removal of a layer of glycoprotein from outer surface of sperm, by enzyme in uterus. Cholesterol also is removed to weaken the membrane.

b) Acrosome reaction

This involves the releasing of enzyme found in acrosome such as hyaluronidases and protease. These enzymes digest **corona radiata** (narrow path in the follicle cells) and the **zona pellucida** (a protective glycoprotein surrounding the plasma membrane of the egg).

c) Fusion

In this stage the head of sperm will fuse with the microvilli surrounding the secondary oocyte and penetrate its cytoplasm.

d) Cortical reaction

This stage involves the releasing of enzymes by lysosomes in cortical granules (outer region of the secondary oocytes); the enzymes cause the zona pellucida to thicken and harden forming a fertilization membrane. This cortical reaction prevents the entry of other sperm inside ovum (polyspermy).

e) Zygote formation

The secondary oocyte is stimulated to complete meiosis II, during this time of stimulation the nucleus of sperm and secondary oocyte are called pro-nuclei and then the two nuclei fuse to form the zygote (2n).

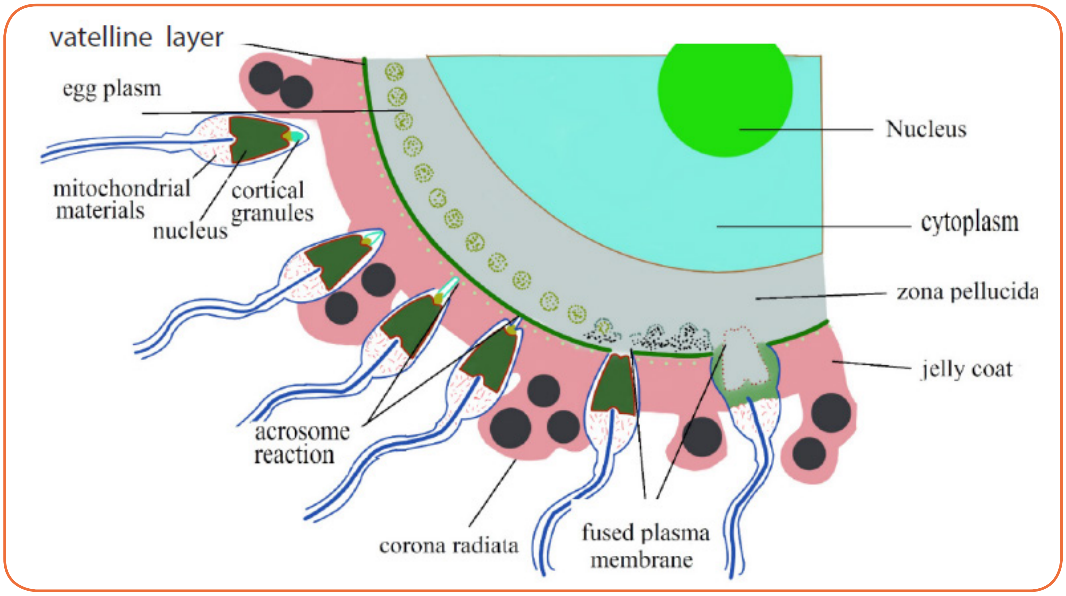


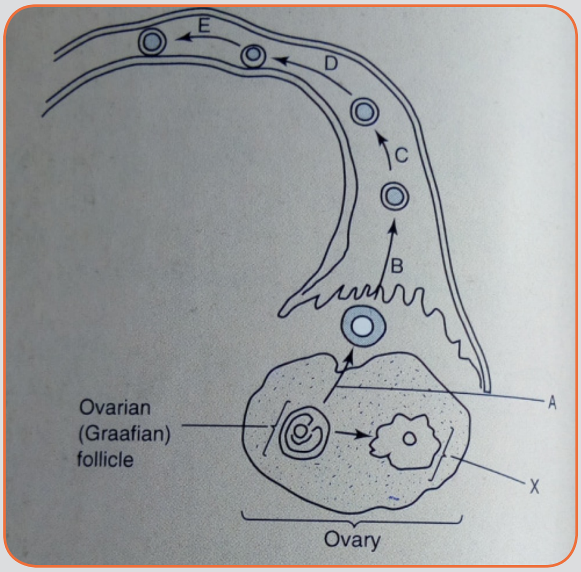
Figure 1.12: Process of fertilization

The cell formed at fertilization divides rapidly to form a hollow sphere made up of a large number of small cells. This occurs as the zygote is moved along the fallopian tube towards the uterus, which in humans takes about one week. By the time it arrives, it is known as an embryo.

After several days in the uterus, the tiny embryo must embed itself into the lining of the uterus if the pregnancy is to continue. Finger like projections grow out and embed themselves into the lining of the uterus, usually at the top end of the uterus; this is known as implantation. It is usually completed about 11 or 12 days after fertilization, and from this time onwards the woman is considered to be pregnant. The implanted embryo sends out chemical signals so the corpus luteum keeps producing progesterone. This keeps the lining of the uterus thick and well supplied with blood vessels until the placenta takes over.

Application activity 1.5

The diagram below shows some of the events which take place in the ovary and oviduct (Fallopian tube) around the time of fertilization.



a) Name the following:
   - i) The process labelled A.
   - ii) The type of nuclear division taking place at D and E.
   - iii) The structure labelled X.
   - iv) One hormone produced by structure X.

b) On the above diagram, use the letter F to label the region where fertilization took place.

1.6. Development of embryo

Activity 1.6

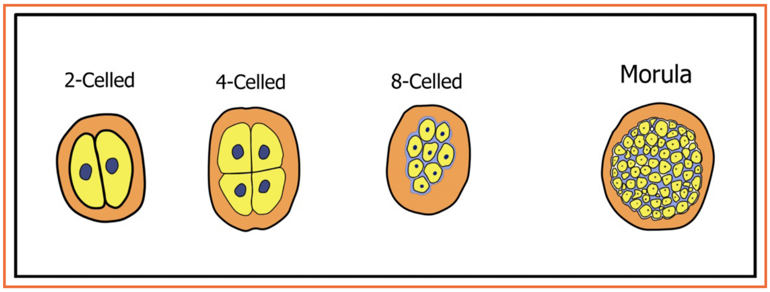
1. Through your research on internet or library, suggest the first things that developed in an embryo?
2. What do you understand about this statement "Does an embryo have a heartbeat"?
3. Predict where the embryo develops in the part of female reproductive system?

The embryonic development is normally triggered by the act of fertilization. This development of an embryo falls into 3 stages: **Cleavage, Gastrulation and Organogeny.**

i) Cleavage:

Development starts with cleavage where the zygote divides repeatedly by mitosis into progressively smaller cells or blastomeres. This stage is also called **Morula. Morula**: morus= **mulberry**: from the very moment of fusion, the egg begins to divide into two cells; cells divide yet again. The successive subdivisions happen, they come to form a small cellular congeometerate (berry) from where it gets name "morula" and the egg hardly increases in size.

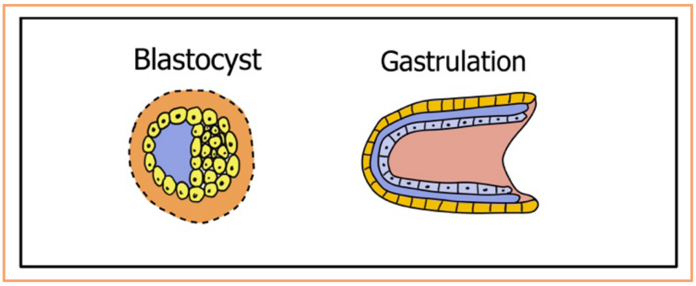
This stage consists of the division of zygote without increase in mass into a ball of consisting of many daughter cells.



ii) Gastrulation

It is the development of different layers of cells in the embryo. It generally occurs during the second week after fertilization. During gastrulation, cells of the embryo migrate to form three distinct cell layers: the ectoderm, mesoderm, and endoderm. Each layer will eventually develop into certain types of tissues and cells in the body of vertebrates.

- **Ectoderm:** it forms tissues that cover the outer body; develops into cells such as nerves skin, hair, and nails.
- **Mesoderm:** it forms tissues that provide movement and support; develops into cells such as muscles, bones, teeth, and blood.
- **Endoderm:** it forms tissues involved in digestion and breathing; develop into organs such as lungs, liver, pancreas, and gall bladder.



iii) Organogeny

Differentiation of cells leads to the development of specific organs and tissues within the three cell layers. This is called organogenesis. All the major organs and systems begin to form during the remaining weeks of embryonic development.

During the second week after fertilization, cells in the embryo migrate to form three distinct cell layers, called the **ectoderm, mesoderm**, and **endoderm**. Each layer will soon develop into different types of cells and tissues

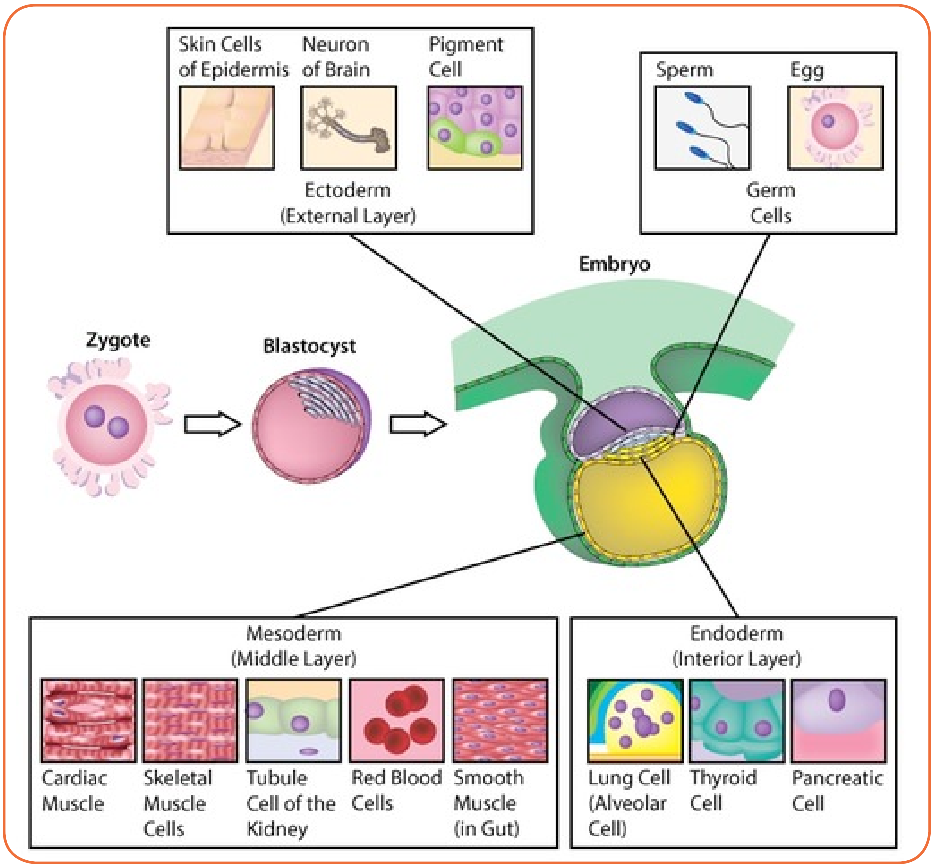


Figure 1.13: Cell Layers of the Embryo

Extra-embryonic membranes

These membranes are part of placenta. The outer cells of the blastocyst, the trophoblast grow and develop into an outer layer or membrane called the **chorion**. This plays a major role in nourishing and removing waste products from the developing embryo.

The **amnion** is a thin membrane covering the embryo like an umbrella and has a protective function. Between the embryo and the amnion is the amniotic fluid. The amniotic fluid supports the embryo and protects it from mechanical shocks.

The **yolk sac** has no significant function in humans but is important in reptiles and birds, where it absorbs food from the separate yolk and transfers food to the gut of the developing embryo.

Note:

The first trimester of the development or the embryo is critical. There is high risk of spontaneous abortion or miscarriage due to alcohol, infection, radiations (X-rays), nutritional deficiencies, genetic mistakes or abnormalities in the developing embryo. From the 8th week until birth (around 38 weeks), the developing organism is called a foetus. The foetus is not as sensitive to damage from environmental exposures as the embryo, and toxic exposures often cause physiological abnormalities or minor congenital malformation. All major structures are already formed in the foetus, but they continue to grow and develop.

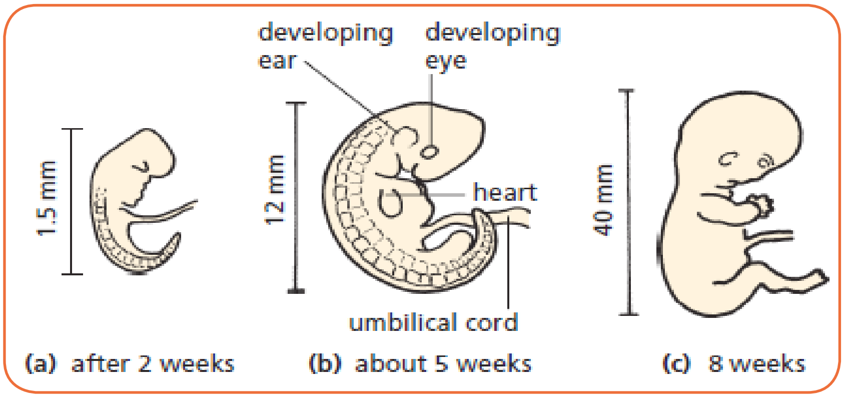


Figure 1.14: Human embryo: The first 8 weeks

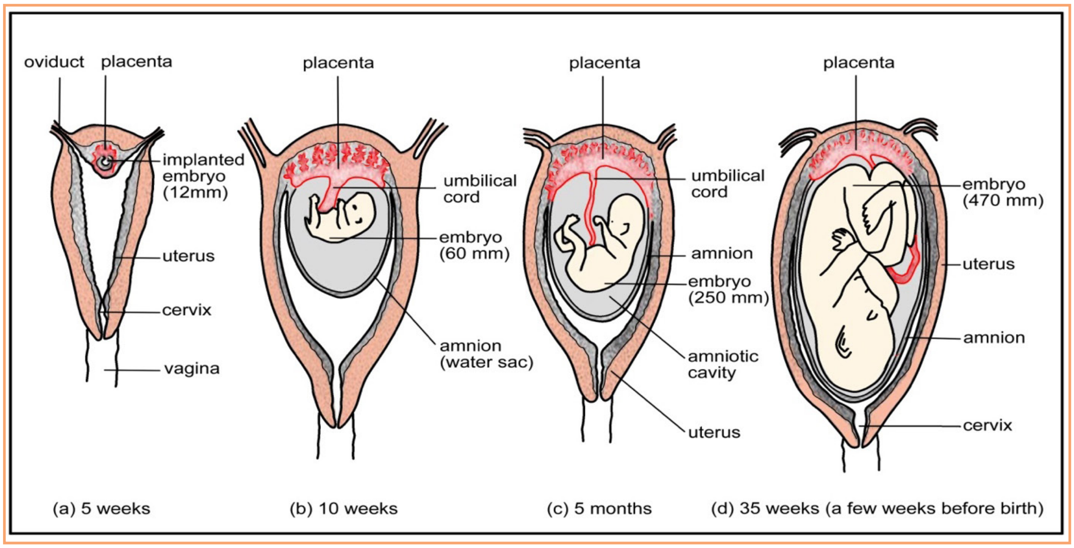
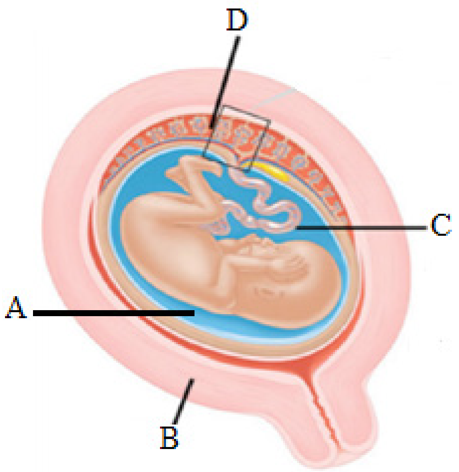


Figure 1.15: Growth and development in the uterus

Application activity 1.6

1. The drawing below shows a developing human fetus inside the uterus.



a) Name the parts marked A to D.

b) Name four substances which pass from the mother to the embryo.

c) Name one substance which passes from the embryo to the mother.

2. What do you think about this statement “Is an embryo a baby”? Explain.

1.7. Physiological changes in females during pregnancy

Activity 1.7

Observe the following images thereafter answer the related questions

1. (a) Suggest the physical changes that can be observed to the pregnant women.

   (b) What physiological and behavioral changes that can happen when women get pregnant.

2. Predict any change occur in uterus during pregnancy?
3. From what you predict in (2) what do you think could cause that change?
4. Suggest any physiological changes cause nausea and vomiting in pregnancy?

During pregnancy, the body goes through many emotional and physiological changes, these changes are a natural part of pregnancy. Pregnancy is more than just the growth of the uterus and the embryo. Fertilization and early embryo formation cause significant changes in all of the body's systems. This is how the body prepares and helps the pregnancy develop into successful childbirth. Each woman is affected differently. Understanding the changes and effects on the various body systems helps the burden during pregnancy, reduces anxiety and unnecessary tensions. Some of the symptoms go away immediately after birth and most of them disappear within six weeks of delivery.

As the uterus grows it presses against the woman's abdominal organs. The uterus presses against the bladder, stomach and lungs, the arteries, veins and nerves and stretches the abdominal skin. These results in frequent urination, heartburn, congestion in the veins, difficulty breathing and other conditions that will pass after birth as the uterus returns to its pre-pregnancy size.

1.7.1. Common physiological symptoms during Pregnancy

- **Frequent urination:** In order to prevent urinary tract infections make sure you drink plenty of water and juice. Perform exercises to strengthen the pelvic floor to control unwanted urination. The pregnant women must also be careful to maintain proper hygiene to prevent infection. Perform periodic urine tests during pregnancy to avoid infections.
- **Heartburn:** The growing uterus puts pressure on the sphincter of the stomach. Eating small, frequent meals, avoiding spicy foods, fried foods, oils, and eating ginger can help ease heartburn. Drinking a lot of water , lying on the left side supported by pillows or in a half sitting position also are helpful in controlling the heartburn. The pregnant women should try to take walk after meals. Avoid lying down immediately after eating to relieve and prevent the onset of heartburn.
- **Nausea/Vomiting:** Nausea and/or vomiting is caused by hormonal and chemical changes during pregnancy. An empty stomach may increase the feeling of nausea. Try eating dry snacks, rich in carbohydrates such as, biscuits before bed and prior to getting out of bed in the morning.

- **Fatigue:** This is caused by progesterone disturbances. It is a sign that your body needs to rest.
- **Sleep disturbances:** This can be caused by frequent urination, the inability to find a comfortable sleeping position in bed, fetal movements or stress and worry.
- **Constipation:** Constipation happened when there is a decrease in intestinal function. The colon absorbs excess fluid as a result of the rise in progesterone. This can be alleviated through proper nutrition. The pregnant women should drink 2-3 liters of liquid per day. In the morning before a meal drink a glass of hot water. Include a variety of fiber rich foods in the diet such as fruits, vegetables, whole wheat bread, prunes. It is recommended to keep up physical activity like walking and exercising daily.
- **Back Pain :** Back pain is caused by a change in the center of gravity, weight gain and muscle tension, due to the need to maintain stability of the body. The relaxin and progesterone hormones sometimes cause softening of the ligaments, joint laxity and instability in the ankles. Back pain can be reduced by exercise such as the rolling basin, correct posture, walking, wearing comfortable shoes, back rubs and pressure applied to the painful area. The pregnant women try to maintain a straight back when lifting objects.
- **Swelling of the Hands and Feet:** Swelling is caused by the accumulation of fluids during pregnancy. Tight jewelry should be removed (such as rings). Elevate the legs when resting and wear comfortable shoes.

1.7.2. Hormonal Changes

Pregnant women experience adjustments in their endocrine system. Levels of progesterone and estrogens rise continuously throughout pregnancy to suppress the hypothalamic axis and, subsequently, the menstrual cycle.

Estrogen produced by the placenta is associated with fetal well being. Women also experience an increase in human chorionic gonadotropin (HCG), which is produced by the placenta and maintains progesterone production by the corpus luteum. The increase in progesterone production primarily functions to relax smooth muscles. Prolactin levels increase due to maternal pituitary gland enlargement that mediates a change in the structure of the mammary gland from ductal to lobular-alveolar.

Parathyroid hormone increases and leads to increased calcium uptake in the gut and reabsorption by the kidney. Adrenal hormones such as cortisol and aldosterone also increase.

Application activity 1.7

1. Copy and complete the table to show, for each hormone, the precise site of its secretion, and its effects on the ovary or on the endometrium of the uterus.

Hormone	Site of secretion	Effect(s) of hormone	
		Ovary	Endometrium
FSH			None
LH			None
Estrogens		None	
Progesterone		None	

2. Suggest the function of human chorionic gonadotrophin during the women pregnancy
3. Do girls have more estrogen when pregnant? Explain your reason
4. Predict what will happen if estrogen levels are low during pregnancy?

Skills Lab 1

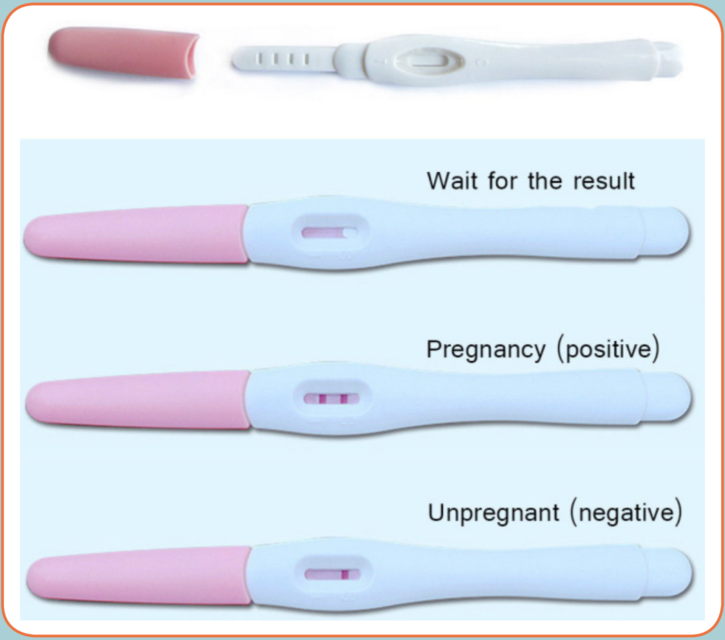
1. Pregnancy test

All pregnancy tests detect the hormone human chorionic gonadotrophin (HCG), which starts to be produced around 6 days after fertilization, by checking your urine. Your body only makes this hormone if you are pregnant. HCG is released when a fertilized egg attaches to the lining of your uterus when pregnancy begins.

Most pregnancy tests come in a box that contains 1 or 2 long sticks. You pee on the stick and the result appears on the stick after a few minutes. All tests are slightly different, so always check the instructions. A positive test result is almost certainly correct. A negative result is less reliable. If you get a negative result and still think you're pregnant, wait a few days and try again.

You'll either urinate on a pregnancy dipstick, or urinate in a cup and then put the dipstick in the urine. You'll wait a few minutes for the results. At home pregnancy tests claim to be about 99 percent accurate. But they can sometimes result in a false positive or a false negative. A false negative might occur if you take the pregnancy test too early, or if your urine is too diluted. For this reason, you should hold off testing until at least 1 week after a missed period.

Also, it's more reliable to take a pregnancy test first thing in the morning when your urine is likely to have the highest level of the pregnancy hormone.



Why is it necessary to use urine in pregnancy testing for women?

2. Determining the fertile period

Count the number of days of your menstrual cycles and count the number of days for 10 consecutive cycles. Choose the cycle with the highest number of days and the cycle with the lowest number of days. Subtract 18 from the lowest cycle and 11 from the highest cycle.

Example: Mary has 27 days as her shortest cycle and 36 as her longest cycle. She has had her menstruation on 09August, 2019. What will be her fertile period?

First fertile period 27-18=9 (August 9+9=August 17)

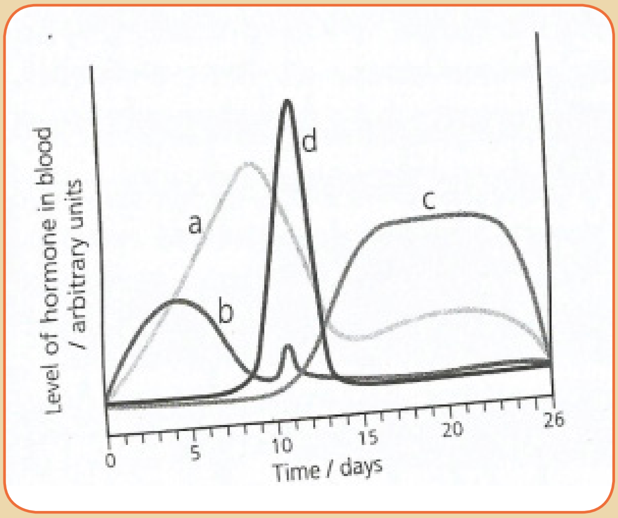
Last fertile period 36-11=25 (August 9+25=September 3)

The fertile period of Mary will be from 17th August to 3rd September, 2019

Think about your shortest cycle and your longest cycles thereafter find out your fertile period.

End Unit Assessment 1

1. Which testicle carries the sperm?
2. What is the difference between sperm and eggs?
3. Explain the following statement: Can one follicle release two eggs? Explain your reason
4. What is the last organ to develop in a fetus? Explain your answer
5. The graph below shows the level of reproductive hormones in the blood of an un-named mammal during its reproductive cycle.



   a) Name the hormones labelled (a) to (d)
   b) Give the likely day of the cycle on which ovulation takes place and give reasons for your answer.

6. When is a menstrual cycle too short?
7. What causes hormonal imbalance in females?
8. Explain why during oogenesis each diploid primary oocyte produces one functional egg and three polar bodies?
9. (a) In the table, identify the function(s) of the male reproductive organs mentioned.

   (b) In the last column, suggest how you think the structure of the organ is adapted to perf

Reproductive Organ	Function	Adaptation
Penis		
Testes and scrotum		

10. Based on the information you have on gametogenesis respond to the following questions:
    a) What does Oogenesis produce?
    b) When a female ovulates, in what phase of division is the oocyte? Explain
    c) What hormones are involved in Gametogenesis?
11. Explain why the chance of fertilization in humans is restricted to only a few days each month?
12. What are 3 main functions of the male reproductive system?
13. Can a man with one testicle have babies? Explain your reason
14. How are the sperm and egg adapted to their function?
15. From your own research, what is the normal size of human egg?
16. After making your own research, what is the function of the lytic enzyme released by sperm?
17. Use the information you have about menstruation periods to answer the following questions:
    a) Is it normal to have menstruation periods twice a month? Explain
    b) What is the role of progesterone in menstrual cycle?
    c) Which two glands secrete hormones that control the menstrual cycle?
    d) What is the main hormone that helps primordial follicles develop into primary follicles?
18. With a clear explanation answer the following questions:
    a) How many days after ovulation is implantation?
    b) A woman can get pregnant if she wipes sperm inside her? Explain why
    c) How many sperm do women need to get pregnant? Explain
    d) How can you differentiate an embryo with a fetus
    e) What is an 8 cell embryo called?
    f) At what point does a fetus become a baby? Explain your reasoning
    g) Where is the site of fetal development?
19. Which of the following is TRUE regarding the physiology of pregnancy?
    a) Increased estrogen reduces uterine vascular resistance and increases blood flow to the uterus and placenta.

b) An expansion of blood volume results in a slight increase in blood pressure.
c) Increased growth hormone leads to insulin resistance and hyperglycemia.
d) Increased prolactin leads to increased milk production.
e) All of the above

20. What happens to the corpus luteum if pregnancy does not occur?
    a) It remains to bring on menopause.
    b) It degenerates.
    c) It remains and continues to secrete progesterone and estrogen.
21. Which of the following is the first change that occurs to the zygote after fertilization?
    a) It begins to migrate toward the uterine lumen.
    b) It initiates the formation of a placenta.
    c) It begins to secrete hormones.
    d) It contacts the endometrial wall of the uterus and becomes buried inside it.
    e) It divides to form a hollow ball of cells, called the blastocyst.
22. How is the menstrual cycle controlled by hormones and negative feedback?
23. What can affect the development of a fetus? Explain your answer
24. What pituitary hormone stimulates the process of Gametogenesis?

UNIT 2

METHODS OF BIRTH CONTROL

Key Unit Competence:

Apply the methods of birth control in the life situation.

Introductory activity 2

The looming problem of insufficient food is largely caused by rapid population growth. Population growth and economic growth are also the primary drivers of climate change, through increased greenhouse gas emissions and deforestation. Population growth simultaneously increases the number of consumers while threatening food output through climate change, ocean acidification, and other global ecological issues. To deal with these problems, Rwanda has put into place different measures such as family planning.

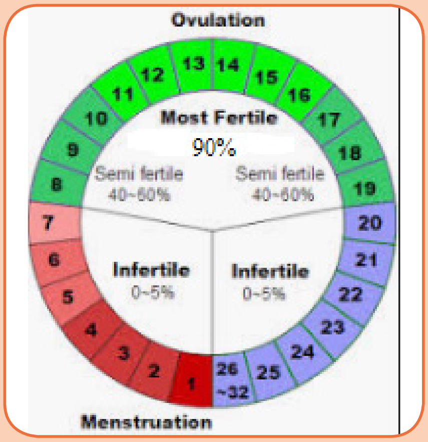
a) What do you understand by family planning?
b) How family planning can solve the problem of rapid population growth?
c) Taking into consideration to your rural village, which methods are being implemented by people to respond to family planning?
d) Among the methods mentioned in (c) above which are they natural or artificial?

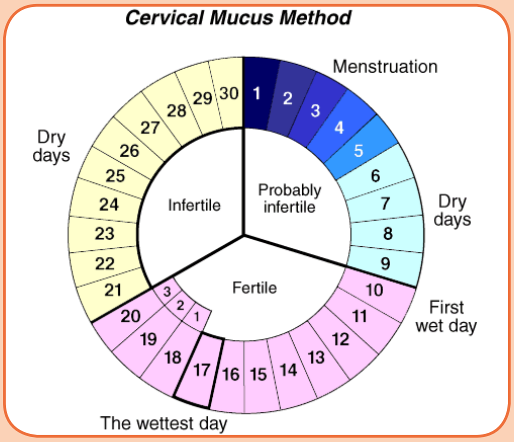
Contraception has allowed people to have control over their own fertility. Therefore, people are able to make an attempt to avoid pregnancy at times when they do not plan to have children; or to plan and choose the number of children they wish to have. There are many different techniques encompassed by the term **contraception**.

2.1. Natural contraceptive methods

Activity 2.1

The diagrams below represent some examples of natural contraceptive methods.





a) Referring to the diagram, suggest the meaning of natural contraceptive methods.

b) What are the names of natural contraceptive methods presented on the diagram?

c) Suggest other natural contraceptive methods which are not represented on the diagram.

Natural family planning methods relies on knowledge of the menstrual cycle of the woman. This knowledge enables couples to avoid having sex when the woman is fertile. Natural birth control methods teach women to determine the fertile phase of their menstrual cycle. To avoid pregnancy, women avoid intercourse on their fertile days. In order to effectively use the method, a woman needs to accept responsibility for charting and interpreting her fertility on a day-to-day basis.

(a) Abstinence

Sexual abstinence is the avoidance of vaginal intercourse. It is very effective for preventing unwanted pregnancy and sexually transmitted diseases. It allows couples to engage in other forms of sexual expression.

Advantages of abstinence

- Minimal risk of misuse.
- Prevents transmission of STIs including HIV and AIDS.

- No physical side effects.
- No need to visit a health care provider.
- No cost involved.

There are no disadvantages of abstinence so long as a couple is able to maintain a fulfilling relationship without the need for penetrative sex.

(b) The calendar rhythm method

The calendar rhythm method to avoid pregnancy relies upon calculating a woman's fertile period on the calendar. Based upon her 12 previous menstrual cycles, a woman subtracts l8 days from her shortest menstrual cycle to determine her first fertile day, and 11 days from her longest menstrual cycle to determine her last fertile day. She can then calculate the total number of days during which she may ovulate. If a woman's menstrual cycles are quite irregular from month to month, there will be a greater number of days during which she might become pregnant.

The calendar method is only about 80% effective in preventing pregnancy and when used alone, it is considered outdated and ineffective.

(c) Basal body temperature method

The basal body temperature (BBT) method is based upon the fact that a woman's temperature drops 12 to 24 hours before an egg is released from her ovary and then increases again once the egg has been released. Unfortunately, this temperature difference is not very large. It is less than one degree F (about a half degree C) when the body is at rest.

The basal body temperature method requires that a woman take her temperature every morning before she gets out of bed. A special thermometer that is more accurate and sensitive than a typical oral thermometer must be used, and the daily temperature variations carefully noted. This must be done every month. Online calculators are available to help a woman chart her basal body temperature.

To use the basal body temperature as a birth control method, a woman should refrain from having sexual intercourse from the time her temperature drops until at least 48 to72 hours after her temperature increases again.

(d) Mucus inspection method

The mucus inspection method depends on the presence or absence of a particular type of cervical mucus that a woman produces in response to estrogen. A woman will generate larger amounts of more watery mucus than usual (like raw egg white) just before release of an egg from her ovary. This so-called egg-white cervical mucus stretches for up to an inch when pulled apart.

A woman can learn to recognize differences in the quantity and quality of her cervical mucus by examining its appearance on her underwear, pads, and toilet tissue; or she may gently remove a sample of mucus from the vaginal opening using two fingers. She may choose to have intercourse between the time of her last menstrual period and the time of change in the cervical mucus. During this period, it is recommended that she have sexual intercourse only every other day because the presence of seminal fluid makes it more difficult to determine the nature of her cervical mucus. If the woman does not wish to become pregnant, she should not have sexual intercourse at all for 3 to 4 days after she notices the change in her cervical mucus.

(e) Withdrawal method

Withdrawal is a behavioural action where a man pulls his penis out of the vagina before he ejaculates. The withdrawal method also relies on complete self-control. You must have an exact sense of timing to withdraw your penis in time.

Because this can be difficult for the man to complete successfully, the withdrawal method is only about 75%-80% effective in preventing pregnancy.

(f) Lactation Amenorrhea Method

Lactation Amenorrhea method can postpone ovulation for up to 6 months after giving birth. This natural birth control method works because the hormone required to stimulate milk production prevents the release of the hormone that triggers ovulation. This method is highly effective for the first six months after childbirth. The mother has to breastfeed the baby at least every four hours during the day and every six hours through the night. She also has to be aware of her menstrual period. After six months, fertility may return at any time.

Advantages of natural contraception

- Effective method of birth control.
- Have no negative health side effects.
- An alternative for women who cannot or do not want to use hormonal methods.
- Promotes positive body awareness.
- Consistent with many religious beliefs and lifestyles.
- Alerts women to reproductive health and fertility concerns.
- Fosters communication between partners and encourages male involvement.

Disadvantages of natural contraception

- Provides no protection from sexually transmitted infections.

- Often difficult to find trained instructors.
- Requires time to learn (usually 3 to 6 cycles).

Application activity 2.1

Counting the number of days of the menstrual cycles is a method that aims to determine the fertile period and it is done at least in 10 consecutive cycles. There are cycles with the highest number of days and the cycle with the lowest number of days. To determine the fertile period, Subtracts 18 from the lowest cycle and 11 from the highest cycle. Use the given example and calculate the fertile period of Mary.

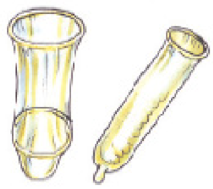
Mary has 27 days as her shortest cycle and 36 as her longest cycle. She has had her menstruation on 09/08/2019. What will be her fertile period?

2.2. Artificial contraceptive methods

Activity 2.2

The following diagrams represent the commonly used artificial contraceptive methods.


A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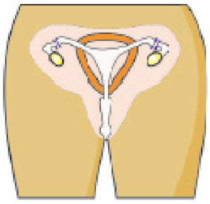
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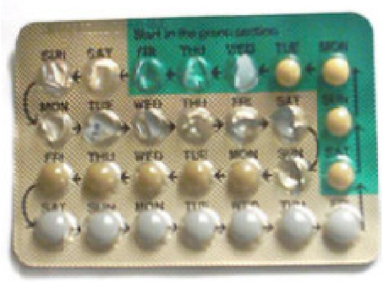
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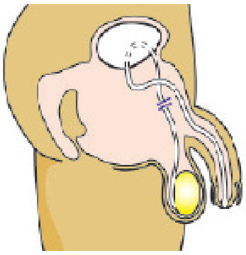
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a) Observe the diagrams and suggest the name of artificial contraceptive methods labeled by letters.

b) Which letters are representing permanent artificial contraceptive methods? Why are they permanent?

Artificial birth control is any product, procedure or practice that uses artificial or unnatural means to prevent pregnancy. Barrier methods such as condoms and diaphragms, hormonal methods such as the pill and IUDs (Intrauterine devices), and surgical sterilisation procedures such as vasectomy or hysterectomy are all artificial birth control methods. Most types of artificial contraceptives work by:

- Preventing an egg from being released every month (hormones).
- Preventing sperms from reaching the egg (barrier and some IUD methods).
- Blocking the reproductive function in men or women (sterilisation).
- Preventing a fertilised egg from implanting in the uterus (hormones).

2.2.1. Barrier methods

a) The male condom

This is a thin rubber sheath worn by a man over an erect penis. It collects semen at its tip so that they are not released into the vagina. It is composed of a thin barrier of latex this is placed over the erect penis and captures semen on ejaculation. This is also a good barrier to prevent the transmission of sexual diseases.

Figure 2.1: How to put on a male condom

b) The female condom

This is a loose rubber fitting with two flexible plastic rings on either ends. It is inserted into the vagina before sexual intercourse.

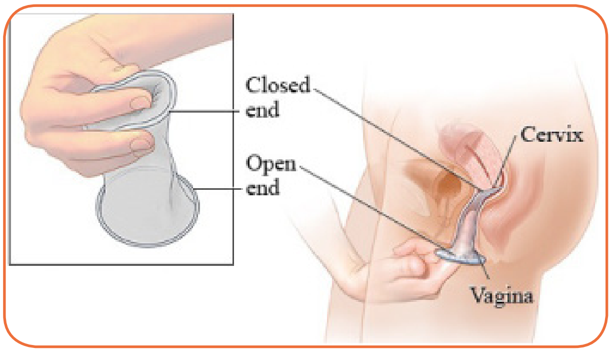


Figure 2.2: How to put on a female condom

It offers 95% effective protection against pregnancy, as well as some protection against STIs. Female condoms are generally more expensive than the male ones but they are less likely to burst. They can be inserted up to eight hours before sex.

c) Spermicide

Spermicide is a birth control method that contains chemicals that stop sperms from fertilising the ova. Spermicides are available in different forms, including creams, film, foams and gels. Spermicide can be used alone, or it can be used with other birth control methods such as diaphragm, to make them more effective. Spermicide does not always offer the best protection against pregnancy. It has very few associated side-effects, but it does not protect against STIs.

d) The Diaphragm

The cap is placed over the cervix to prevent the entry of sperm in semen. This technique requires that the cap is put in position in advance of sexual intercourse and that it is used in combination with a spermicidal cream. When used correctly this is an effective contraceptive however this is not a barrier against the transmission of sexual diseases. It is inserted at least six hours before sex and it needs to be removed after 24 hours for cleaning. Depending on the material and type of the diaphragm, it can be reused many times.

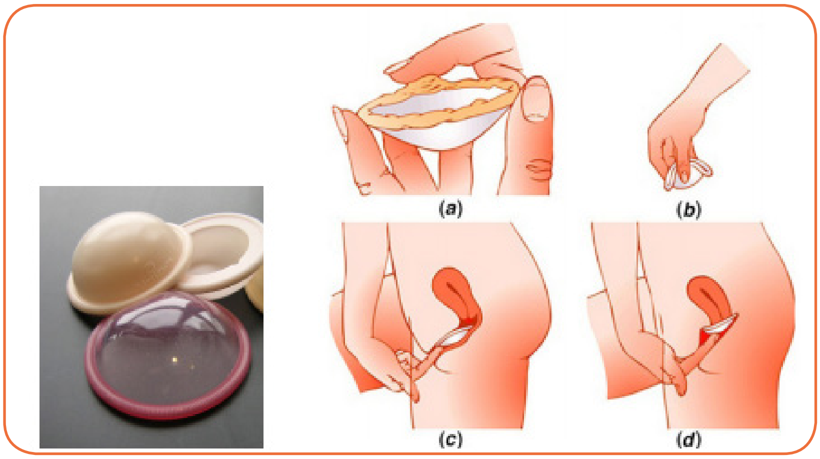


Figure 2.3: Diaphragms and how to put on it.

2.2.2. Hormonal based contraceptives

This is the use of a mixture of artificial hormones resembling oestrogen and progesterone. They are administered in three ways:

- Orally (oral contraceptives).
- Through injections.
- Administration of implants.

a) The Pill

It is the most popular form of female contraception. It is taken orally in form of a tablet, every day at almost the same time. It uses a combination of progesterone and oestrogen that inhibits ovulation.

The contraceptive pill will prevent pregnancy 95%. It comes close to providing 99% protection if one pill is taken every day as prescribed. The pill does not provide any protection against STIs and a doctor's prescription is required to buy it.

Figure 2.4: *Oral contraception (birth control pills)*

b) Contraceptive Injections

Contraceptive injections contain a progestogen hormone which is similar to the natural progesterone produced by the ovaries. There are three types of injection. Depo- Provera and Sayana Press protect you from pregnancy for 13 weeks. Noristerat protects you for eight weeks and has the same effect as the pill.

Injections are about 99% effective. It fails if the user forgets to renew the contraceptive shot in time. However, once the shot is given, it cannot be reversed. One becomes effectively infertile for the next three months. Just like the pill, contraceptive injections do not protect against STIs.

c) The contraceptive implant

The implant offers long term protection. It lasts for about three years on average. The contraceptive implant contains progestin (progesterone), the same hormone as the contraceptive pill.

The hormone is released into the body at a steady, slow pace for three years, producing the same effects as the pill. The implant is inserted in the arm by a doctor and must be removed after three years. Since the risk of human mistake is ruled out, the implant has a much higher effectiveness rate than the pill around 99.99%. The implant does not protect against STIs.

d) The vaginal ring

The vaginal contraceptive ring is a small, transparent plastic ring that is inserted in the vagina and kept for three weeks. It is removed during monthly periods and replaced with a new one after that.

The ring contains the same hormones as the contraceptive pill (progesterone and oestrogen), therefore providing the same kind of effective protection. A doctor's prescription is required and just like other hormonal contraception, the vaginal ring does not protect from STIs.

e) The contraceptive patch

The contraceptive patch is exactly the same thing as the contraceptive pill but in the form of a patch. It provides the same effective protection against pregnancy. It does not protect from STIs. There is however a risk of skin irritation, and a (rare) chance that the patch accidentally comes off.

f) Emergency contraception

Emergency contraception refers to methods of contraception that can be used to prevent pregnancy after sexual intercourse or cases of eventualities such as rape or unprotected sex. These are recommended for use within 3 days but are more effective the sooner they are used after the act of intercourse. After 72 hours (3 days) the effectiveness drops to below 50%.

2.2.3. Non – hormonal based contraception methods

a) The Intrauterine Device (IUD)

An intrauterine device (IUD or coil) is a small contraceptive device, often 'T'-shaped. It often contains either copper or hormones. It is inserted into the uterus. It offers long-acting reversible contraception. Therefore, it is the most effective type of reversible birth control. It is kept inside the vagina for up to five or ten years. IUDs does not prevent fertilization but only implantation of the zygote in the endometrium.

The effectiveness rate for IUDs is above 99%. However, it provides no protection against STIs.

It requires a doctor to properly insert it and to make periodic follow ups.

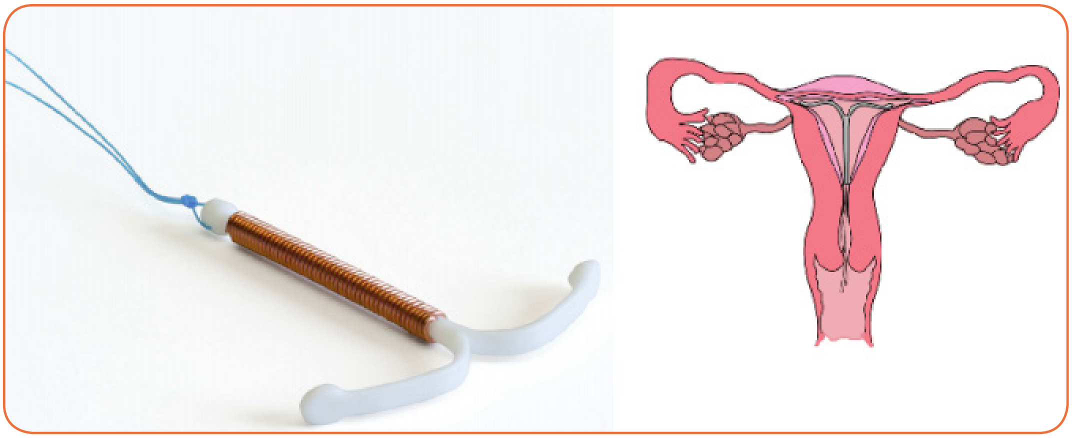


Figure 2.5: IUD and Intrauterine device placement

b) Permanent contraception methods

Sterilisation

Sterilisation is a procedure that closes or blocks fallopian tubes in women and sperm duct in men. This prevents movement of the ova and sperm respectively. Sterilisation is an option available to both men and women.

i) Vasectomy

This involves tying off and cutting the tubes that carry sperms; the vas deferens. It provides no protection against STIs and the effects are permanent. In very rare cases (less than 1%), the tubes can grow back, making pregnancy a risk.

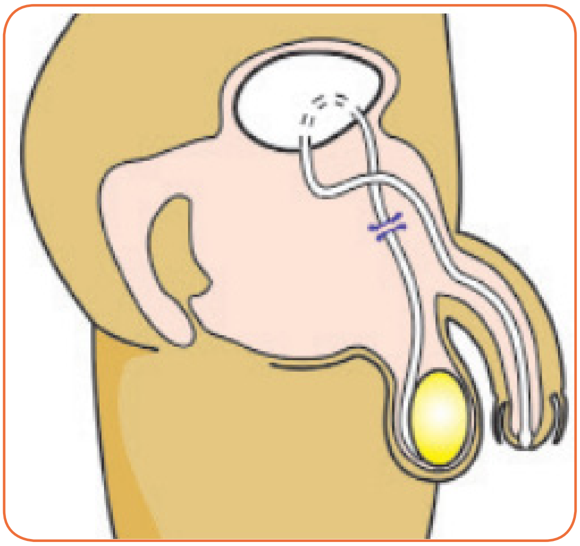


Figure 2.6: Vasectomy

ii) Tubal ligation

– **Surgical sterilisation:** This involves cutting and tying the fallopian tubes so that they cannot link the ovaries with the uterus any more. The effects are permanent.

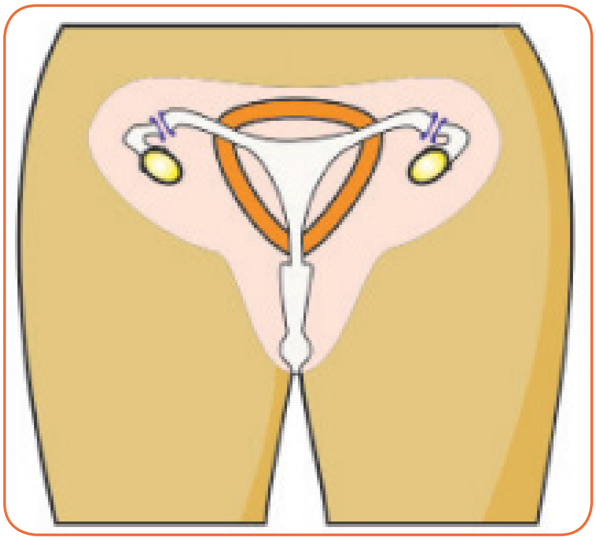


Figure 2.7: Tubal ligation

– **Non-surgical sterilisation:** This involves placing a coil in each fallopian tube through the vagina and uterus. Scars appear and eventually block each tube completely. The scars may take up to 3 months to completely block the tubes, so you need to use another method of contraception in the meantime.

Both options also offer more than 99% of protection against pregnancy. In rare cases the blocked tubes can grow back and reconnect. However, the method offers no protection against STIs.

Advantages of artificial contraceptive methods

- Gives great protection against unplanned pregnancy if one follows instructions.
- Condoms to some extent protect against pregnancy and STDS.
- Combinations of pills reduce/prevent cysts in breasts and ovaries.
- Improved family wellbeing.
- Improved maternal and infant health.

Disadvantages of artificial contraceptive methods

- Necessity of taking medication continually.
- High cost of medication.
- Hormonal contraceptive does not protect against STDS.

- Eggs may fail to mature in the ovary for a woman who uses hormonal contraceptives.
- Woman must remember to take them regularly.
- Woman must begin using hormonal contraceptive in advance before they become effective.

Some women experience several; headaches, breast tenderness, chest pain, discharge from vagina, leg cramps and swelling or pain.

Social implications of contraception and fertility treatments

Though reproductive choice is basically a personal decision, it is not totally so. This is because reproduction is a process which involves not only the person who makes the choice, but it also involves the other partner, the family, society and the world at large. It is therefore not surprising that reproductive choice is affected by the diverse contexts, sexual morals, cultures and religions, as well as the official position of different societies.

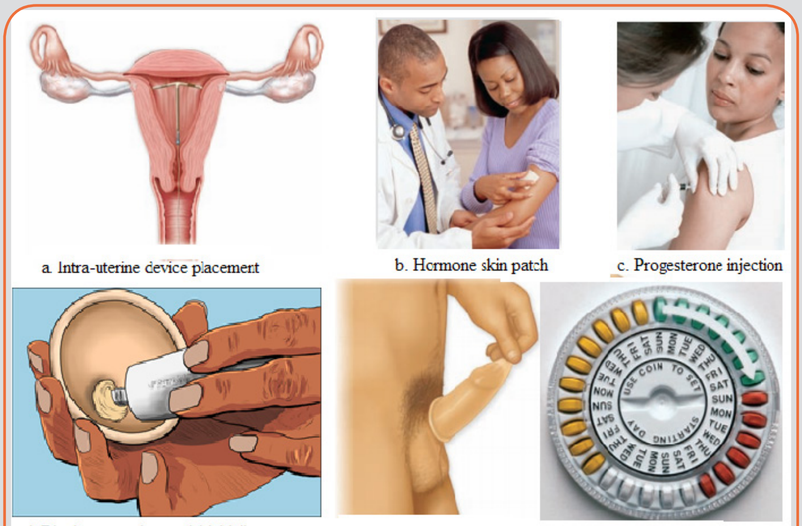
Some religions are against any artificial forms of contraception and actively discourage the use of contraceptives such as the sheath and femidom. However, these are important in the prevention of transmission of STDs in addition to their role as contraceptives.

Fertility treatments such as in vitro fertilization are controversial because of the ‘spare’ embryos that are created and not returned to the uterus. Some people believe that since these embryos are potential human beings, they should not be destroyed or used for research. In some cases the ‘spare’ embryos have been frozen and used later of the first transplant did not work.

The use of reproduction technologies is surrounded with controversy over the social implications involved. In the case of developing countries, some fear allowing access to these societies would lead to increased population growth in already overpopulated environments. A potential consequence of this would include further inequality to resource access, increased risk for the spread of disease, and subsequent extrapolation of financial costs.

Application activity 2.2

The diagrams below represent different artificial contraceptive methods.



a. Intra-uterine device placement

b. Hormone skin patch

c. Progesterone injection

d. Diaphragm and spermicidal jelly

e. Male condom placement

f. Oral contraception pills

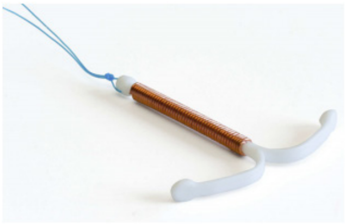
a) Use the diagrams to state contraceptive method that can prevent both STDs and pregnancy. Justify your answer.

b) Suppose you are married, which contraceptive method do you prefer to use and why?

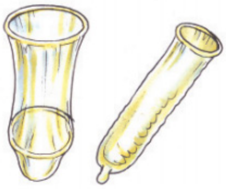
2.3. STIs and HIV prevention

Activity 2.3

Assuming that you have a friend who engages in bad sexual activities, which are some of the risks that face them? How can they avoid such risks? Look at the pictures below.



A



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D

Which diagram is used to prevent the risks mentioned above? Justify your answer.

2.2.1. Acquired Immune Deficiency Syndrome (AIDS)

It is a serious disease which suppresses body defense. It is characterised by suppression of immune system leading to development of a number of rare infectious diseases. It is caused by virus known as Human Immunodeficiency Virus (HIV). This virus can be transmitted from sick/infected person to healthy one in a number of ways:

- None protected sexual intercourse either homosexually or heterosexually. It passes from infected semen or vagina fluid to blood of health person through damaged tissue in the vagina, penis or rectum.
- From sick mother to her baby during birth or through breast milk during suckling.
- Through transfusion blood by contaminated needles.
- Through sharing contaminated sharp instruments.

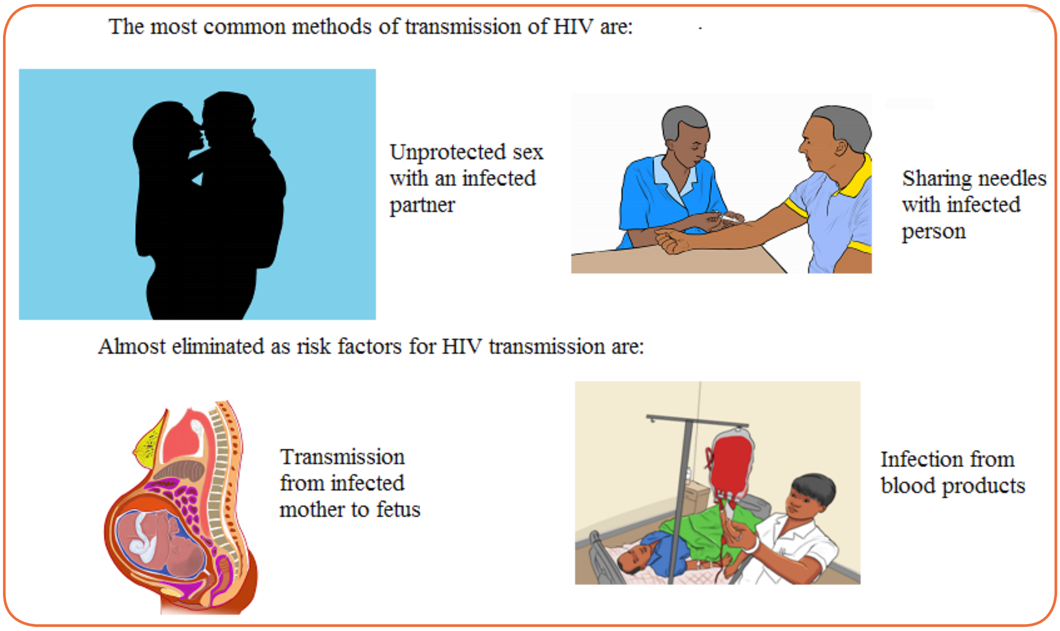


Figure 2.8: Modes of HIV transmission

HIV attaches white blood cells (helper T cells) which is essential component of the body's immune system. HIV is retrovirus invades its genetic materials into the host's body and therefore its DNA remains dormant in host cells and being replicated leading host cells to divide.

When HIV uses host cells to manufacture new viruses. New viruses burst out of host cells and eventually kill it and attack new host cells to infect and suppress immune system thus HIV develop into AIDS and show number of diseases such as: tuberculosis, skin cancer, pneumonia and thrush. Infected person may show some symptoms such as: swelling of lymph glands, fever, sweating and fatigue, coughing, diarrhoea and unexplained loss of weight. The death may result as there is no known cure for AIDS but drugs reduce its progress but cannot stop it. Other symptoms include:

- Headache
- Vomiting, and upset stomach
- Mouth, genital, or anal sores
- Rash or flaky skin
- Short-term memory loss

No specific treatment for AIDS but some drugs may be used to treat various infections that come about as result of AIDS.

HIV infection is not easy to treat. Some reasons why HIV is difficult to treat are as follow:

- HIV remains inactive in host cells for years and it cannot be targeted and destroyed.
- Since its symptoms are not easily evident, the infected person may continue spreading the virus consciously or unknowingly.
- HIV is extraordinary variable therefore cells of immune system identify infective agents by shapes of antigen on their protein coats means that HIV cannot be detected easily by changing shape of its antigens.
- HIV destroys helper T cells which help in body defense thus difficult to control it.

There are many precautions which can be followed in trying to prevent the disease:

- Abstinence
- Fidelity or restriction to one sex partner and the absence of promiscuity will also clearly reduce the risk of infection.
- Use of a sheath or condom during intercourse can prevent the virus from infecting through blood or semen.
- A reduction in the spread of HIV can be brought about by the use of clean needles and syringes by drugs addicts.
- The blood donated should be tested for the presence of antibodies to HIV which indicates whether or not the donor is infected. Blood containing these antibodies is not used.
- Educating the people about the disease.
- Taking antiretroviral during pregnancy and delivery.
- To avoid breastfeeding and to administer antiretroviral drugs to the newborn.

2.2.2. Sexually transmissible infections (STIs)

(a) Syphilis

It is serious sexually transmitted disease caused by bacteria **Treponema pallidum**. The symptoms of syphilis occurred in three stages if not cured.

- **Stage I**: it appears between 10 days to 3 months after the time between contact and appearance of first symptom (incubation period). The disease begins with painless sore which appear on sex organs and it heals itself.
- **Stage II**: it appears between 2 to 6 months after contact with disease such as: headache, fever, pain in bones and joints and sore throat.
- **Stage III**: it appears about 10 years after contact with disease such as: nervous system, heart and aorta therefore the result is serious damage to affected organs.

Syphilis can be transmitted through sexual intercourse.

Syphilis can be cured completely by antibiotics such as penicillin.

(b) Gonorrhoea

It is a common sexually transmitted disease caused by bacteria Neisseria gonorrhoea. It can be transmitted through sexual intercourse or from mother to baby during birth. The first symptoms appear from 3 to 5 days after sexual contact with infected individual and discharges from genital thus burning sensation during urination but in female there is no symptoms:

- Pain or burning when urinating.
- Yellowish and sometimes bloody vaginal discharge.
- Bleeding between periods.
- Pain during sex.

It can be cured by antibiotics but if untreated it may lead sterility, heart disease and blindness.

(c) Genital herpes (simplex)

It is a sexually transmitted disease caused by **herpes simplex virus**. It is transmitted through unprotected sexual intercourse. Its signs include small red bumps, blisters, or open sores where the virus entered the body, such as on the penis, vagina, or mouth. Other symptoms may be: vaginal discharge, fever, headache, muscle aches, pain when urinating, itching, burning, or swollen glands in genital area, pain in legs, buttocks, or genital area and symptoms may go away and then come back. Sores heal after 2 to 4 weeks.

No specific cure for the disease but number of drugs may be used to reduce pain and even further attach.

(d) Trichomoniasis

It is caused by protozoan **Trichomonas vaginalis**, transmitted through sexual contact, underwear and toilet seats. Its symptoms are: itching of urethra or vaginal in females, yellow discharge and smelly.

It can be prevented through avoiding indiscriminate sex, avoiding sharing underwear and personal hygiene.

(e) Hepatitis

It is caused by virus **hepatitis B** through unprotected sexual contact, contaminated needles, blood transfusion and syringes. Its symptoms include: Fever, jaundice, nausea (sickness, vomiting), loss of appetite and yellow urine.

It can be prevented through avoiding indiscriminate sex, use disposable needles and syringes and strict personal hygiene.

(f) Candidiasis or Thrush

It is caused by fungus **Candida albicans** through unprotected sexual contact, sharing linen and towels. Its symptoms include; Itching and burning sensation and white discharge from genitals. It is prevented through: avoiding indiscriminate sex and treat both partners.

The control of STIs / STDs may include:

- Abstaining from sexual intercourse in order to avoid STDS.
- Using of condoms during sexual intercourse.
- Going for blood check-up before engaging in sexual activities.
- Not engaging in homosexuality/lesbianism reduces the risk of STDS.
- avoiding multiple sexual partners
- Getting medical attention as soon as possible in case of getting infections.

Application activity 2.3

Read the scenario and answer the questions.

You are informed by a national surveillance officer about the detection of an infectious disease outbreak of unknown origin in your school on both girls and boys. The frequent symptoms include: pain or burning when urinating, yellowish and sometimes bloody vaginal discharge, bleeding between periods and pain during sex. One patient who got to the hospital, get tested positive for STIs. A team of infectious disease epidemiologists is currently in the field for investigation. Blood samples have been sent to the National Laboratory for confirmation but results are still pending.

a) Referring to signs and symptoms, suggest the infectious disease that is affecting people.

b) Suggest preventive measures to avoid the spread of diseases in whole area.

Skills Lab 2

A condom is a sheath-shaped barrier device, used during sexual intercourse to reduce the probability of pregnancy and sexually transmitted infections.

Materials: Male condom, 50 mL- syringes, tap water

Procedure:

- Select at least two different types of male condoms made from different industries.
- Carefully open the package so that the condom does not tear.
- Unroll all condoms and stretch them to find which one is more flexible and resistant.
- Using the syringe, fill each condom with 50 mL of water, then tie the top end.

- Squeeze the tip of condom downwards to increase the pressure in each until it bursts.
- Note your observations. Which one can you advise people to use? Give reasons.

End Unit Assessment 2

1. The male sterilisation operation known as vasectomy is carried out by
   a) Blocking the ureter
   b) Removing the testis
   c) Cutting the scrotum
   d) Tying the vas deferens
2. Which hormones are present in implants?
   a) Testosterone
   b) progesterone
   c) FHS
   d) LH
3. Which means of birth control is most effective in preventing sexually transmitted diseases?
   a) Condom
   b) Spermicidal jelly
   c) Pill
   d) Vasectomy
   e) Diaphragm
4. Which of these is a sexually transmitted disease caused by a bacterium?
   a) Gonorrhea
   b) Genital herpes
   c) Hepatitis B
   d) HIV
5. Compare natural methods of family planning and artificial methods.
6. MUSABYIMANA has been using contraceptives to prevent unwanted pregnancy. She was shocked recently to discover she was pregnant. What could have gone wrong?
7. Describe the general limitations of natural contraceptive methods.
8. Discus the main ways by which HIV is transmitted?
9. What is difference between AIDS and HIV?
10. Discuss the advantages and disadvantages of birth control methods.

UNIT 3

ALKANES

Key Unit Competence:

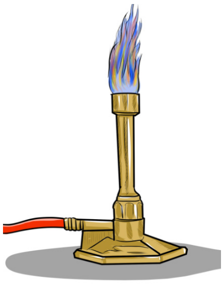
Relate the physical and chemical properties of the alkanes to the preparation methods, uses and isomerism.

Introductory activity 3

Observe the following pictures and answer the questions below:

A

B



C

D

1. In Rwanda, natural gas has been discovered in Lake Kivu and the government is under its exploitation.
   a) Suggest the name and formula of the gas extracted by Kivu watt power station?
   b) Outline all possible uses of the chemical compound extracted in Kivu watt power station.
2. The cosmetic in picture B is made of which chemicals and what is the main source of these chemicals?
3. Suggest the names and structures of the chemical compounds used to produce energy in the picture C.
4. What is the source of the fumes produced as shown by the picture D?
5. Analyse the environmental problems caused by the fumes observed in the picture D and suggest different ways to solve it.

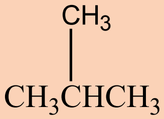
3.1. Nomenclature of straight and branched chain hydrocarbon alkanes

Activity 3.1

Given the following organic compounds, suggest the answers of the questions below:

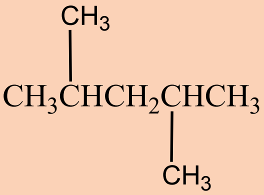
a) CH_4
b) $CH_3CH_2CH_3$
c) $CH_3CH_2CH_2CH_3$

d)



$CH_3\overset{\overset{CH_3}{|}}{C}HCH_3$

e)



$CH_3\overset{\overset{CH_3}{|}}{C}HCH_2\underset{\underset{CH_3}{|}}{C}HCH_3$

Questions:

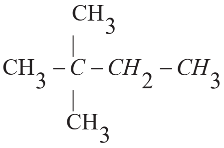
1. All the five compounds given above are made of only two elements. Identify these two elements and find out other characteristics all the five compounds have in common.
2. Identify the particular similarity between compound (d) and (e).
3. Explain how compounds (d) and (e) differ from (b) and (c).
4. Suggest the names of the above five organic compounds.

Alkanes are the simplest class of organic compounds. They are made of carbon and hydrogen atoms only and contain two types of bonds, carbon-hydrogen (C-H) and carbon-carbon (C-C) single covalent bonds. They do not have functional groups.

Alkanes form a homologous series with the general formula $\mathbf{C_nH_{2n+2}}$ where n is the number of carbon atoms in the molecule. The first member of the family has the molecular formula $\mathbf{CH_4}$ (n=1) and is commonly known as methane and the second member with molecular formula is $\mathbf{C_2H_6}$ (n=2) is called ethane.

The alkanes are **saturated hydrocarbons.** "Saturated" means that they contain the maximum content of hydrogen possible, with no double or triple bonds between carbon atoms. It is possible to have alkanes with straight or with branched chains, for example:

$CH_3CH_2CH_2CH_2CH_3$ **straight chain**



$$CH_3-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH_2-CH_3$$

branched chain

Alkanes are the simplest compounds to name. All alkanes end their names with the suffix **–ane.**

When naming a molecule from its structure, you just need to follow some simple steps:

a) Find and name the longest unbranched chain (parent chain) in the molecule.

b) Identify and name groups (radicals or substituents) attached to this chain.

c) Number the chain consecutively, starting at the end nearest a substituent group.

d) Designate the location of each substituent by an appropriate number and name.

e) Assemble the name, listing groups in alphabetical order.

The first four members are known by their common names, from C_5 and above the Roman prefixes indicating the number of carbon atoms is written followed by the ending "**ane**" of the alkanes.

Note: Alkyl groups are obtained when one hydrogen atom is removed from alkanes; therefore, their names are deduced from the corresponding alkanes by replacing "**ane**" ending with "**yl**".

Table 3.1. Examples of naming alkanes

n	Formula of Alkanes	Name of alkanes	Alkyl group formulae	Name of alkyl groups
1	CH_4	Methane	CH_3-	Methyl
2	CH_3CH_3	Ethane	CH_3CH_2-	Ethyl
3	$CH_3CH_2CH_3$	Propane	$CH_3CH_2CH_2$-	Propyl
4	$CH_3(CH_2)_2CH_3$	Butane	$CH_3(CH_2)_2CH_2$-	Butyl
5	$CH_3(CH_2)_3CH_3$	Pentane	$CH_3(CH_2)_3CH_2$-	Pentyl
6	$CH_3(CH_2)_4CH_3$	Hexane	$CH_3(CH_2)_4CH_2$-	Hexyl

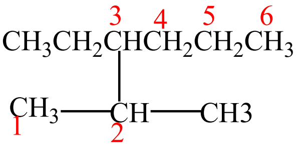
7	$CH_3(CH_2)_5CH_3$	Heptane	$CH_3(CH_2)_5CH_2$-	Heptyl
8	$CH_3(CH_2)_6CH_3$	Octane	$CH_3(CH_2)_6CH_2$-	Octyl
9	$CH_3(CH_2)_7CH_3$	Nonane	$CH_3(CH_2)_7CH_2$-	Nonyl
10	$CH_3(CH_2)_8CH_3$	Decane	$CH_3(CH_2)_8CH_2$-	Decyl

Note: **n** is the number of carbon atoms

Prefixes **di, tri, tetra, sec, tert**, are not considered when alphabetizing.

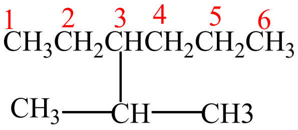
a) In case of chains of the same length, the priority is given for part where many branches of alkyl groups appear.

Examples:



$CH_3CH_2CHCH_2CH_2CH_3$ with $CH_3-CH-CH3$ attached at C-3

3-ethyl-2-methylhexane
(two substituents)

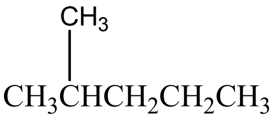


$CH_3CH_2CHCH_2CH_2CH_3$ with $CH_3-CH-CH3$ attached at C-3

not
3-isopropylhexane
(one substituent)

The prefix "**iso**" is used when all carbons, except one, form a continuous chain. This one carbon is part of an iso group at the end of the chain.

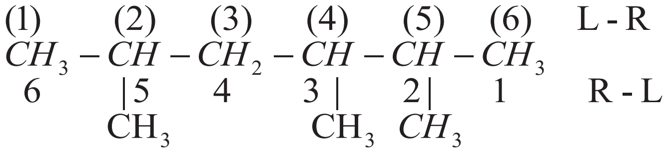
Example:



$$\overset{\displaystyle CH_3}{\overset{|}{CH_3CHCH_2CH_2CH_3}}$$

Isopentane

b) If there are more than one substituent, the numbering is done so that the sum of the numbers used to locate the locants is minimum. This is the lowest sum rule.



$$\begin{array}{ccccccc} (1) & (2) & (3) & (4) & (5) & (6) & \text{L - R} \\ CH_3 - & CH - & CH_2 - & CH - & CH - & CH_3 & \\ 6 & |5 & 4 & 3\,| & 2| & 1 & \text{R - L} \\ & CH_3 & & CH_3 & CH_3 & & \end{array}$$

The longest chain has 6 carbons; it is hexane chain. The sum of locants:

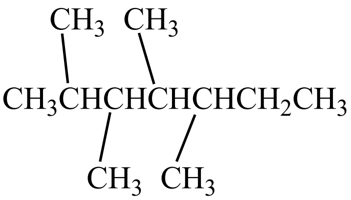
i) L-R (left to right) = 2+4+5 = 11

ii) R-L (right to left) = 2+3+5 = 10

Since the sum of the locants for R-L numbering is minimum, then it is preferred.

The name of alkane is given by the numbers of the locants (2,3,5-) followed by the prefixed substituent (trimethyl), followed by the name of the long chain (hexane): 2,3,5-trimethylhexane.

Example:

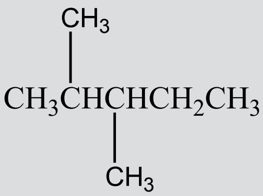


2,3,4,5-tetramethylheptane
not 3,4,4,6-tetramethylheptane

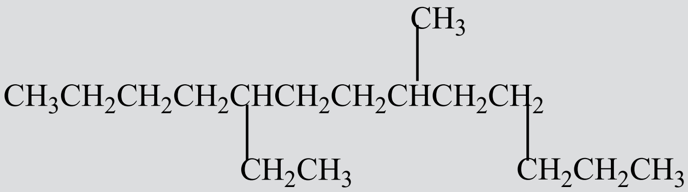
The system of nomenclature described above is called the **IUPAC system (IUPAC** stands for **I**nternational **U**nion of **P**ure and **A**pplied **C**hemistry**).**

Application activity 3.1

1. Name each of the following alkanes according to the IUPAC system:

a) 

$CH_3\overset{CH_3}{\overset{|}{C}}H\underset{CH_3}{\underset{|}{C}}HCH_2CH_3$

b) 

$CH_3CH_2CH_2CH_2\underset{CH_2CH_3}{\underset{|}{C}}HCH_2CH_2\overset{CH_3}{\overset{|}{C}}HCH_2\underset{CH_2CH_2CH_3}{\underset{|}{CH_2}}$

2. Draw the structure of the following compounds:
   a) 3-ethyl-4-propyloctane
   b) 4-ethyl-2-methylhexane
   c) 2,2-dimethylpentane

3.2. Physical properties of straight and branched alkanes

Activity 3.2

Observe the following pictures and answer the questions below:

(A) Gas containers (B) Gasoline

(C) Candle waxes

1.
   a) Nowadays, the gas is used in cooking in some of Rwandan homes. The gas used is a mixture of some alkanes.
      ii) Suggest the alkanes in that mixture for figure (A)
      iii) The mixture is in which physical state at room temperature.
   b) The commonly used fuel (gasoline) in vehicles is an alkane. Suggest one alkane which can be used as fuel in vehicles and state the physical state of this fuel at room temperature.
   c) Candle wax is made using alkanes. Suggest the alkane used to make it and indicate its physical state at room temperature.
2. Between candle wax and gasoline, which one can be easily converted into vapours? Suggest a reason to your answer.
3. When you mix gasoline and water what do you observe? Explain your observations.

The values of melting, boiling points, density and physical state of some alkanes are summarized in the table below.

Table 3.2. Physical parameters of alkanes

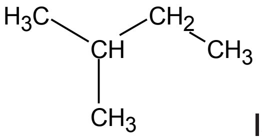
Alkanes	Melting Point ^{0}C	Boiling Point ^{0}C	Density	Physical state
CH_4	-182.6	-162.0	0.4240	Gas
C_2H_6	-172.0	-89.0	0.5463	
C_3H_8	-157.1	-44.0	0.5824	
C_4H_{10}	-135.0	-0,5	0.5933	
C_5H_{12}	-129.7	36.2	0.6264	Liquid
C_6H_{14}	-94.5	69.0	0.6594	
C_7H_{16}	-90.5	98.4	0.6837	
C_8H_{18}	-57.0	125.6	0.7028	
C_9H_{20}	-53.7	150.7	0.7179	
$C_{10}H_{22}$	-29.7	174.0	0.7298	
….	….	….	….	
….	….	….	….	
$C_{17}H_{36}$	16.0	300.0	0.769	
$C_{18}H_{38}$	28.0	309.0	0.7767	Solid and elsewhere as n increases

The above table shows that the boiling and melting points of homologue alkanes increase with the number of carbon i.e. molecular mass.

The boiling and melting points depend on the magnitude of the Van Der Waal's forces that exist between the molecules. These forces increase in magnitude with molecular mass.

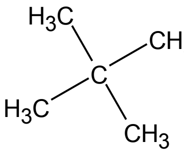
Note: Branched chain isomers have lower boiling and melting points than their straight chain isomers, because straight chain isomers are closer packed than the branched chain isomers.

Examples: n-pentane: CH_3-CH_2-CH_2-CH_2-CH_3 Boiling point is 36 °C



Isopentane: Boiling point is 28 °C

(2-methylbutane)



Neopentane: Boiling point is 9.5°C

(2,2-dimethylpropane)

Boiling points decrease with increase in branching because increased branching gives the molecule a more nearly spherical shape and this reduces the extent of contact between neighbouring molecules, in other words the branched isomers are less packed than straight chain isomers, and hence the attractive force between the molecules are reduced hence decrease in the boiling points.

Alkanes are not soluble in water, because of their low polarity and also because of their inability to form hydrogen bonds. They are, however soluble in non-polar solvents, like CCl_4, CS_2, benzene, and are miscible with one another.

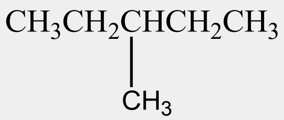
Notice that; when you mix gasoline and water, due to the differing densities of water and gas, mixing cannot occur. As soon as you add water to a tank of gasoline, all of the water will settle to the bottom of the tank. The lighter gasoline will float on top. You get the same effect as you would get when you mix oil with water.

Application activity 3.2

1. a) Put 5 ml of hexane in a test tube; add 5ml of water and shake. Record your observations.
   b) Repeat the above procedure using heptane instead of hexane.
   c) Repeat the steps (a) and (b) using carbon tetrachloride instead of water and record your observations.

Question: Interpret all your observations.

2. Predict which one of the following compounds has higher boiling point (which one is less volatile) and explain why.

a) 

$CH_3CH_2CHCH_2CH_3$ with CH_3 below the third carbon

b) CH_3-CH_2-CH_2-CH_2-CH_2-CH_3

3.3. Preparation of the alkanes

Activity 3.3

Laboratory preparation of an alkane

Requirements:

1. Stand and accessories
   a) Delivery tube
   b) Sodium hydroxide solid (NaOH)
   c) Sodium acetate solid (CH_3COONa)
   d) Calcium oxide solid (CaO)

Procedure:

Set up the apparatus as shown on the diagram below

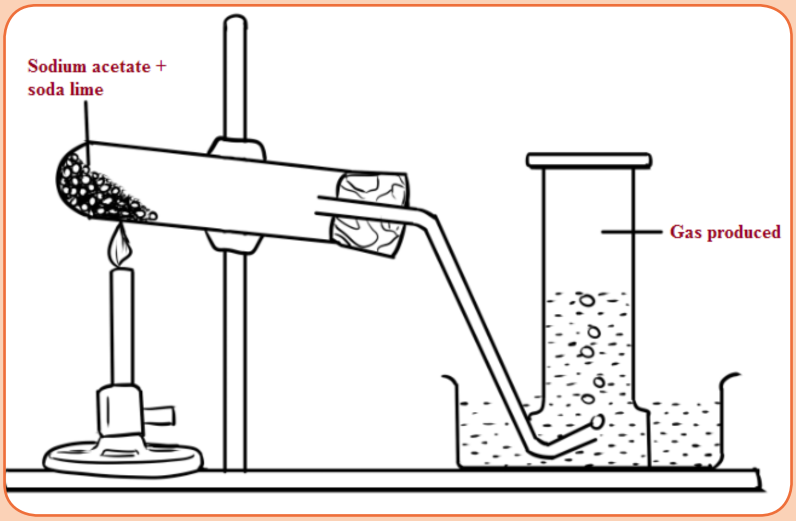


Figure 3.1: Laboratory preparation of an alkane

i) Prepare a mixture of the reagents in ratio 1:1. Weigh about 3 grams of sodium acetate and the same quantity as soda lime. Mix them thoroughly in a beaker.

ii) Place about 4 grams of the mixture into a boiling tube. Seal the boiling tube with a stopper with a gas-delivery tube. The gas-delivery tube should look upwards.

iii) Fix the boiling tube on a stand.

iv) Heat the test-tube gently. After a while the gas starts liberating.

v) Prepare an empty test-tube or measuring cylinder. Collect some gas keeping this test-tube on top of the gas delivery tube.

Question: Suggest the name and formula of the gas produced.

Methane can be prepared by the reaction between sodium acetate and sodium hydroxide solid according to the equation:

$$CH_3COONa(s) + NaOH(s) \xrightarrow[\text{heat}]{CaO(s)} CH_4(g) + Na_2CO_3(s)$$

Other gaseous alkanes can be prepared in the same way according to the general equation.

$$RCOONa(s) + NaOH(s) \xrightarrow[\text{heat}]{CaO(s)} RH(g) + Na_2CO_3(s)$$

Note: The reaction is practically used to reduce by one carbon the length of carbon chain. It is referred as decarboxylation of sodium carboxylates.

Other reactions used for the preparation of alkanes are the following:

(1) Addition reaction of hydrogen to alkenes and alkynes in the presence of catalyst like nickel, palladium or platinum produces alkanes: this reaction is called hydrogenation reaction of alkenes and alkynes; it is also called a reduction reaction of alkenes and alkynes.

$$\underset{\text{alkene}}{R\text{-}CH{=}CH\,R'} + H_2 \xrightarrow[150^{0C}]{Ni} \underset{\text{Alkane}}{R\text{-}CH_2\text{-}CH_2\text{-}R'}$$

Example:

$$\underset{\text{But-1-ene}}{CH_3CH_2\text{-}CH{=}CH_2} + H_2 \xrightarrow[150^{0}C]{Ni} \underset{\text{Butane}}{CH_3CH_2\text{-}CH_2\text{-}CH_3}$$

(2) From halogenoalkanes or Alkyl halides

a) $2RX + Zn \xrightarrow{H^+} 2RH + Zn^{2+} + 2X^-$

b) $R - X + H_2 \xrightarrow{Pd} RH + HX$

Example: $CH_3 - Cl + H_2 \xrightarrow{Pd} CH_4 + HCl$

c) $RX + Mg \xrightarrow{Ether/sec} RMgX \xrightarrow{H_2O/NH_3/CH_3OH} RH + \begin{Bmatrix} MgXOH \\ MgNH_2X \\ Mg(CH_3O)X \end{Bmatrix}$

Example: $CH_3Br + Mg \rightarrow CH_3MgBr \xrightarrow{CH_3Br} CH_3 - CH_3 + MgBr_2$

d) Alkyl halides when heated with sodium metal in ether solution give higher alkanes (alkanes with more carbon atoms) (**Wurtz reaction**).

Example: $2CH_3CH_2Br + 2Na \xrightarrow{ether/heat} CH_3 - CH_2 - CH_2 - CH_3 + 2NaBr$

Note: This reaction is practically useful in organic synthesis to increase the length of carbon chain.

e) When Alkyl halides are treated with Zn-Cu couple, in the presence of ethanol, alkanes are formed.

Note: Zn-Cu couple is obtained by adding Zinc granules in aqueous copper (II) sulphate solution where copper is deposited on the Zn pieces.

Example:

$$CH_3CH_2Cl \xrightarrow{\text{Ethanol/Zn-Cu}} CH_3CH_3$$

3) From carbonyl compounds (aldehydes or ketones)

Reduction of carbonyl compounds, with amalgamated Zinc (alloy made of zinc and mercury) and HCl. This is the Clemmensen reduction).

Example: $CH_3CH_2COCH_3 \xrightarrow{Zn(Hg)/HClconc} CH_3 - CH_2 - CH_2 - CH_3 + H_2O$

Application activity 3.3

Complete the following reactions:

a) $CH_3CH_2COONa(s) + NaOH(s) \xrightarrow[\text{heat}]{CaO(s)}$

b) $CH_3CH_2Br + H_2 \xrightarrow{Pd}$

c) $CH_3CH{=}CHCH_2CH_3 + H_2 \xrightarrow[150^0C]{Ni}$

d) $CH_3CH_2CH_2Cl \xrightarrow{Ethanol/Zn\text{-}Cu}$

3.4. Uses of the alkanes

Activity 3.4

Observe the following pictures and outline some of the uses of alkanes

A

B

C

Alkanes have a number of industrial applications beyond fuels, including uses in cosmetics and plastics, alkanes are generally less reactive than alkenes and alkynes because they lack the more reactive double and triple bonds.

Alkanes are very versatile and are being used as solvents, heating oils, fuels, in fat synthesis, in the synthesis of fatty acids by air oxidation, in the manufacture of albumen, in the transformation to olefins. Here below there are some uses of alkanes:

(1) Methane (CH_4)

Methane finds many uses:

- It is used as a **fue**l at homes, ovens, water heaters, kilns and automobiles as it combusts with oxygen to produce heat.
- Highly refined liquid methane is used as **rocket fuel**.
- Methane is used as fuel for electricity generation.
- It is used as a vehicle fuel in the form of liquefied natural gas (LNG).
- Methane can be used as raw material in the production of urea, a fertilizer.

In general, methane is more environmental friendly than gasoline/petrol and diesel.

(2) Ethane (C_2H_6)

- Ethane is used in the preparation of ethene and certain heavier hydrocarbons.
- Ethane can be used as a refrigerant in cryogenic refrigeration systems.

(3) Propane (C_3H_8)

- Propane is used as a **propellant** for aerosol sprays such as shaving creams and air fresheners.
- Propane is also used as fuel for home heat and back up electrical generation in sparsely populated areas that do not have natural gas pipelines.
- Propane is commonly used in movies for explosions

(4) Butane (C_4H_{10})

- Butane is a key ingredient of synthetic rubber.
- It is used as fuel in cigarette lighters.
- When blended with propane and other hydrocarbons, it may be referred to commercially as LPG, for liquefied petroleum gas.
- Butane gas cylinders are used in cooking.
- Also used in aerosol spray cans.

(5) Pentane (C_5H_{12})

- Pentane is used in the production of polystyrene **foams** and other foams.
- Used in laboratories as **solvents**.
- It is also an active ingredient of **pesticides**.
- Used as solvent in **liquid chromatography (LC)**

(6) Hexane (C_6H_{14})

- It is used in the formulation of glues for shoes, leather products, and roofing.
- It is also used to extract cooking oils such as canola oil or soy oil from seeds.
- Hexane is generally used in extraction of non-polar and slightly polar compounds such as natural products from various sources including plants and animal tissues.

For example, hexane is used in extraction of pyrethrin from pyrethrum; e.g. Horizon SOPYRWA (a pyrethrum factory in Musanze District).

- Also for cleansing and degreasing a variety of items, and in textile manufacturing.

(7) Heptane (C_7H_{16})

- Heptane is used as solvent in paints and coatings.
- Pure n-heptane is used for research, development and pharmaceutical manufacturing
- Also as a minor component of **gasoline.**
- It is used in laboratories as a **non-polar solvent**.

Application activity 3.4

1. Provide the major use of alkanes?
2. Within an example suggest where alkanes used for in everyday life
3. From the information you have about hydrocarbons, do you think that alkanes are soluble in water?
4. a) Knowing that branching affects the boiling points for alkanes, how this happens to alkanes?

   b) After give your view on (a), which alkanes has the highest boiling point?

3.5. Chemical properties of the alkanes

Activity 3.5

Observe the following pictures and answer the questions below:

A

B

Question: Suggest the name of the reaction that takes place in the above two pictures and the possible equations.

Generally, alkanes are quite inert towards common reagents because:

- The C-C bond and C-H bonds are strong and do not break easily.
- Carbon and hydrogen have nearly the same electronegativity value hence C-H bond is slightly polarized; generally, C-H bond is considered as covalent.

They, however, undergo the following reactions:

(1) Reaction with oxygen

Alkanes react with oxygen to produce carbon dioxide and water (if oxygen is enough to burn all quantity of hydrocarbons). If oxygen is insufficient, carbon monoxide and water or carbon and water are produced. This reaction is called "**combustion**".

$$C_nH_{2n+2} + \frac{(3n+1)}{2}O_2\,(g) \longrightarrow nCO_2\,(g) + (n+1)\,H_2O\,(g) + heat$$

$$C_nH_{2n+2} + \frac{(2n+1)}{2}O_2\,(g) \longrightarrow nCO\,(g) + (n+1)\,H_2O\,(g) + heat$$

$$C_nH_{2n+2} + \frac{(n+1)}{2}O_2\,(g) \longrightarrow nC\,(g) + (n+1)\,H_2O\,(g) + heat$$

Examples:

a) $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

b) $2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$

(2) Reaction with halogens (halogenation)

$R\text{-}H + X_2 \rightarrow RX + HX$ where X = Cl, Br, I

Example: Reaction of methane with bromine

$$CH_4 + Br_2 \rightarrow CH_3Br + HBr$$

Notice: (i) Br_2 reacts as Cl_2 but slowly while iodine reacts hardly or does not. Fluorine, the most electronegative element of the periodic table reacts with alkanes to give coke, i.e. a decomposition reaction:

$$C_nH_{2n+2} + (n+1)F_2 \xrightarrow{\text{Light(hv)}} nC_{(S)} + (2n+2)\,HF$$

Example:

$$CH_4 + 2F_2 \xrightarrow{\text{light}} C + 4HF$$

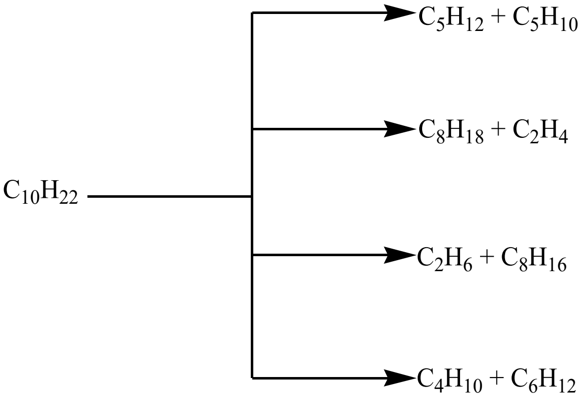
(3) Dehydrogenation of alkanes gives alkenes under heat and a catalyst like V_2O_5.

$$CH_3CH_2CH_2CH_3 \xrightarrow[500^oC]{V_2O_5} CH_3CH_2CH{=}CH_2$$

(4) Cracking

On heating or in the presence of a catalyst, large molecules of alkanes are decomposed into smaller alkanes and alkenes. If the cracking is performed on heating, it is referred as **thermocracking**.

If the cracking is performed using a catalyst; it is referred as **catalytic cracking** and many products result from one reactant as shown below.



Application activity 3.5

1. In Rwanda, methane gas has been discovered in Lake kivu and the government is under its exploitation. Outline all possible uses of methane gas.
2. The hydrocarbon C_5H_{12} burns to form carbon dioxide and water. Write the balanced equation for the reaction.
3. Name the environmental problem that is caused by the formation of carbon dioxide during the combustion of hydrocarbon.

Skills Lab 3

Preparation of Beeswax Candles

Beeswax is the major component of honeycomb and it consists of at least 284 different compounds, mainly a variety of long-chain alkanes such as hentriacontane ($CH_3(CH_2)_{29}CH_3$).

Beeswax is the natural, non-toxic waxy substance secreted by bees after they consume honey. Bees use this wax to construct their honeycombs, and when cleaned and filtered, it can be used for beautiful and beneficial candles.

Beeswax candles are reputed to have several health benefits, including:

- Light
- Lower Toxicity
- Neutralizing Pollutants
- Relaxation

a) Describe how you can make beeswax candles

b) Collect all the requirements for making beeswax then make them.

End Unit Assessment 3

1. Answer by **True** or **False**
   a) 2,2-dimethylbutane is an isomer of hexane
   b) Boiling point of alkanes increases with increasing the length of the chain.
   c) Alkanes are polar molecules
2. Draw the structures of the following formulas:
   a) Octane
   b) 2,3,5-trimethyl-4-propylheptane
   c) 2,2-dimethylpropane
   d) Isobutane
   e) 4-ethyl-2,3-dimethyloctane
3. (a) What do you understand by the term hydrocarbon?

   (b) What is the relationship between the number of carbon atoms in a hydrocarbon and its boiling point?

4. Consider the alkane with the formula CH_3-CH_2-CH_2-CH_2-CH_2-CH_3
   a) Write down the balanced chemical equation of combustion of the compound,
   b) Name the environmental problem that is caused by the performance of the reaction in a) and suggest different ways to solve that environmental problem.
5. Show how each of the following conversions can be accomplished with a good yield
   a) CH_3-Br to CH_3-CH_2-CH_3
   b) CH_3-CH=CH-CH_3 to CH_3-CH_2-CH_2-CH_3

UNIT 4

ALKENES AND ALKYNES

Key Unit Competence:

Relate the physical and chemical properties of the alkenes and alkynes to their reactivity and uses.

Introductory activity 4

Observe the following pictures and answer the questions below after making a research:

(A): Plastics

(B): Yellow banana

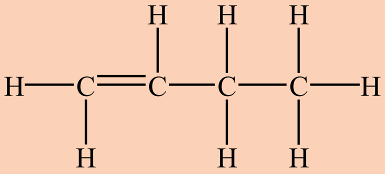
Questions:

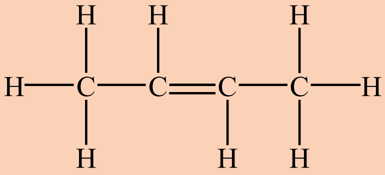
1. In everyday life people use different materials made in plastics
   a) The plastic materials are manufactured from which organic compounds?
   b) Give some examples of chemical reactions which are used to produce plastics.
   c) The items which appear in the picture A above are very useful in our daily life but they also present some disadvantages. Describe these advantages and suggest solutions to these disadvantages.
   d) What will happen to the above plastics when heated?
2. Sometimes we eat different ripen fruits at our home. Suggest the name and structure of a plant hormone involved in the ripening of fruits.

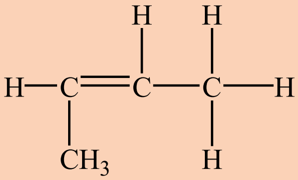
4.1. Nomenclature and structure of the alkenes

Activity 4.1

1. Refer to the functional groups you have seen in unit 3, what is the general name of the homologous series containing a carbon-carbon double bond?
2. Refer to the general rules of naming organic compounds point out rules that can be applied to name compounds with a double bond.
3. From the molecular isomers below, identify their similarities and their differences between them.

a)

$\mathrm{H-C=C-C-C-H}$

b)

$\mathrm{H-C-C=C-C-H}$

c)

$\mathrm{H-C=C-C-H}$

Alkenes are a homologous series of hydrocarbons which contain at least one carbon-carbon double bond. Since their skeleton can add more hydrogen atoms, they are referred as unsaturated hydrocarbons.

The general formula of alkenes is C_nH_{2n}.

Example: Ethene (C_2H_4)

The double bond in alkenes is made of one sigma bond and one pi bond. This gives rise to the impossibility of rotation around the double bond. The hybridization state in alkenes is sp^2 and the structure around each carbon doubly bonded is trigonal planar with a bond angle value of 120°.

IUPAC names of alkenes are based on the longest chain of carbon atoms that contains the double bond.

The name given to the chain is obtained from the name of the corresponding alkane by changing the suffix from –**ane** to –**ene**.

If the double bond is equidistant from each end, number the first substituent that has the lowest number. If there is more than one double bond in an alkene, all of the bonds should be numbered in the name of the molecule, even terminal double bonds. The numbers should go from lowest to highest, and be separated from one another by a comma.

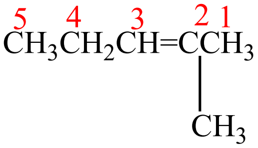
The chain is always numbered from the end that gives the smallest number for the location of the double bond.

If a compound contains two or more double bonds, its location is identified by a prefix number. The ending is modified to show the number of double bonds:

- **a diene** for two double bonds,
- **a triene** for three bonds,
- **a tetraene** for four double bonds.

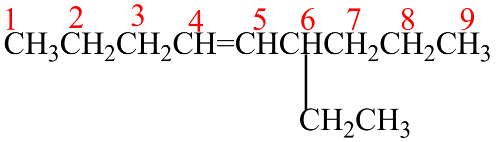
Examples:

a) $H_2\overset{1}{C}=\overset{2}{C}H\overset{3}{C}H_2\overset{4}{C}H_2\overset{5}{C}H_2\overset{6}{C}H_3$ hex-1-ene

b) 

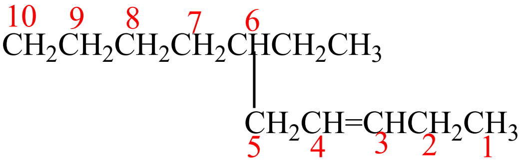
$\overset{5}{C}H_3\overset{4}{C}H_2\overset{3}{C}H=\underset{\underset{CH_3}{|}}{\overset{2}{C}}\overset{1}{C}H_3$

2-methylpent-2-ene

c) 

$\overset{1}{C}H_3\overset{2}{C}H_2\overset{3}{C}H_2\overset{4}{C}H=\overset{5}{C}H\underset{\underset{CH_2CH_3}{|}}{\overset{6}{C}H}\overset{7}{C}H_2\overset{8}{C}H_2\overset{9}{C}H_3$

6-ethylnon-4-ene

d) 

$\overset{10}{C}H_2\overset{9}{C}H_2\overset{8}{C}H_2\overset{7}{C}H_2\underset{\underset{\underset{5}{C}H_2\underset{4}{C}H=\underset{3}{C}H\underset{2}{C}H_2\underset{1}{C}H_3}{|}}{\overset{6}{C}H}CH_2CH_3$

6-ethyldec-3-ene

e) $\overset{6}{C}H_3\overset{5}{C}H=\overset{4}{C}H\overset{3}{C}H_2\overset{2}{C}H=\overset{1}{C}H_2$ 1,4-hexadiene or hexa-1,4-diene

4.1.1. Structural isomerism in the alkenes

Alkenes can also demonstrate structural isomerism, there are multiple structural isomers based on where in the chain the double bond occurs. Alkenes show as well position isomerism and chain isomerism.

- In position isomerism, the position of the double bond changes but the length of the chain remains the same.

Example:

$CH_2{=}CHCH_2CH_2CH_3$ and $CH_3CH{=}CHCH_2CH_3$

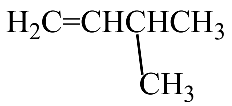
Pent-1-ene or 1-pentene pent-2-ene or 2-pentene

The number in the name of the alkene refers to the lowest numbered carbon in the chain that is part of the double bond.

- The chain isomerism arises due to difference in the length of the chains.

Example:

$H_2C{=}CHCH_2CH_2CH_3$ and



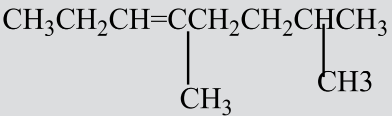
$H_2C{=}CH\underset{\displaystyle CH_3}{\underset{|}{C}}HCH_3$

pent-1-ene 3-methylbut-1-ene **or 3-methyl-1-butene**

Application activity 4.1

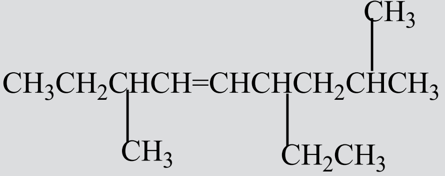
1. Write the structural formula of:
   a) 4-ethylhept-3-ene
   b) 3-ethyl-2,4,6-trimethyloct-2-ene
   c) Buta-1,2-diene
2. Name each of the following compounds according to the IUPAC system
   a) $CH_3HC{=}CHCH_2CH_2CH_2CH_3$

   b)



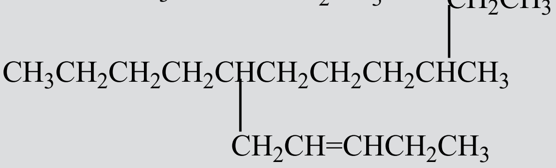
$CH_3CH_2CH{=}\underset{\displaystyle CH_3}{\underset{|}{C}}CH_2CH_2\underset{\displaystyle CH3}{\underset{|}{C}}HCH_3$

   c)



$CH_3CH_2\underset{\displaystyle CH_3}{\underset{|}{C}}HCH{=}CH\underset{\displaystyle CH_2CH_3}{\underset{|}{C}}HCH_2\overset{\displaystyle CH_3}{\overset{|}{C}}HCH_3$

   d)



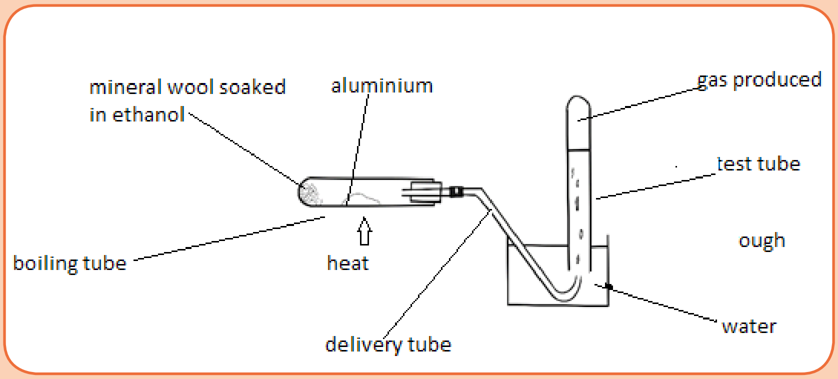
$CH_3CH_2CH_2CH_2\underset{\displaystyle CH_2CH{=}CHCH_2CH_3}{\underset{|}{C}}HCH_2CH_2CH_2\overset{\displaystyle CH_2CH_3}{\overset{|}{C}}HCH_3$

3. Write any three structural isomers and their names of the following compounds:
   a) C_6H_{12}
   b) C_7H_{14}

4.2. Preparation and Chemical test of ethene

Activity 4.2

1. Set up the apparatus for *laboratory preparation of an alkene as bellow* and follow the instructions to perform the experiment on the preparation of ethene.



Requirements:

Chemicals: Ethanol, aluminium oxide, lime water**,** mineral wool.

Apparatus: Boiling tube, Rubber stopper with hole, Delivery tube, Test-tube rack, test tubes, Spatula, Bunsen burner, Glass rod, Matches.

Procedure and setting:

- Pour some ethanol into the boiling tube to a 3 cm depth
- Add some glass wool to soak up the ethanol, using a glass rod to push the wool down the tube.
- Clamp the boiling tube in a horizontal position using a retort stand.
- Put a small amount of aluminium oxide about half way along the boiling tube.
- Complete the setup of the apparatus as shown in the diagram above.
- Light the Bunsen burner, adjust it to a blue flame and heat the aluminium oxide. (Make sure the test tube is filled with water when you start to collect the gas produced.)
- As the aluminium oxide gets hot the heat reaches the ethanol at the end of the tube. The ethanol then changes to vapour, passes over the hot aluminium oxide and is dehydrated to produce alkene gas.
- Collect the gas and close the test tube with a stopper.

Questions:

1. a) Name the gas produced during this experiment.
   b) Test the gas produced in the above experiment using bromine or potassium permanganate and interpret your observations.
2. From your own research, provide the test for unsaturation for organic compounds?

4.2.1. Laboratory preparation of Alkene

Different methods are used for the preparation of alkenes. Most of them are elimination reactions.

(a) Dehydration of alcohols

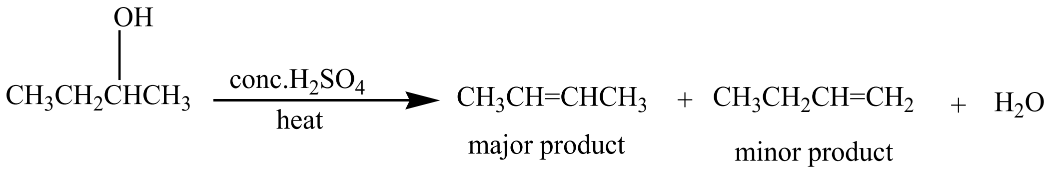
An alkene may be obtained by dehydration of an alcohol. The reaction involves the loss of H and OH (water) from adjacent carbons of an alcohol to form an alkene. The dehydrogenation is carried out by heating an alcohol with concentrated sulphuric acid or 85% phosphoric acid.

$$CH_3CH_2OH \xrightarrow[180^oC]{\text{conc. } H_2SO_4} H_2C{=}CH_2 + H_2O \qquad \text{or}$$

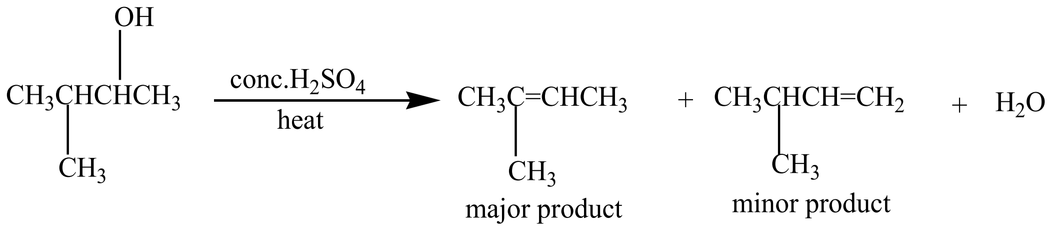
$$CH_3CH_2OH \xrightarrow[100^oC]{85\%\ H_3PO_4} H_2C{=}CH_2 + H_2O$$

If two or more alkenes may be obtained, the one having more substituents on the double bond generally predominates. This is the **Zaitsev's rule.**

Example:



$$CH_3CH_2\overset{OH}{\overset{|}{C}}HCH_3 \xrightarrow[\text{heat}]{conc.H_2SO_4} \underset{\text{major product}}{CH_3CH{=}CHCH_3} + \underset{\text{minor product}}{CH_3CH_2CH{=}CH_2} + H_2O$$



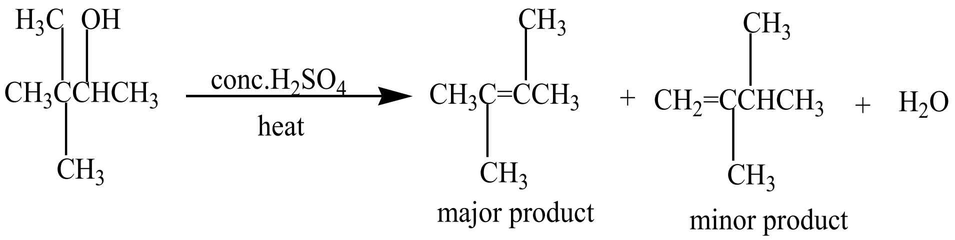
$$CH_3\underset{\underset{CH_3}{|}}{C}H\overset{OH}{\overset{|}{C}}HCH_3 \xrightarrow[\text{heat}]{conc.H_2SO_4} \underset{\text{major product}}{CH_3\underset{\underset{CH_3}{|}}{C}{=}CHCH_3} + \underset{\text{minor product}}{CH_3\underset{\underset{CH_3}{|}}{C}HCH{=}CH_2} + H_2O$$

This is due to the stability of the intermediate carbocation. The carbocation produced in step 2 may undergo a transposition (rearrangement) of a hydride ion or a methyl group giving a more stable carbocation and therefore a more stable alkene.

Example 1:

$$CH_3CH_2CH_2CH_2OH \xrightarrow[\text{heat}]{\text{conc.}H_2SO_4} \underset{\text{major product}}{CH_3CH{=}CHCH_3} + \underset{\text{minor product}}{CH_3CH_2CH{=}CH_2} + H_2O$$

Example 2:



$$CH_3\overset{H_3C\ \ OH}{\underset{CH_3}{C}}CHCH_3 \xrightarrow[\text{heat}]{\text{conc.}H_2SO_4} \underset{\text{major product}}{CH_3\underset{CH_3}{C}{=}\overset{CH_3}{C}CH_3} + \underset{\text{minor product}}{CH_2{=}\overset{CH_3}{\underset{CH_3}{C}}CHCH_3} + H_2O$$

The dehydration of alcohols leading to alkenes may also be effected by heating alcohols in the presence of alumina.

Example:

$$CH_3CH_2OH \xrightarrow[\text{heat}]{Al_2O_3} H_2C{=}CH_2 + H_2O$$

(b) Dehalogenation of dihalogenoalkanes

When a compound containing two halogen atoms on the adjacent carbon atoms is treated with magnesium or zinc it transforms to an alkene.

Example 1:

$$(CH_3)_3CCH_2CHBrCH_2Br + Zn \longrightarrow (CH_3)_3CCH_2CH{=}CH_2 + ZnBr_2$$

Example 2:

CH_3-CH_2- CH_2Cl+KOH $\quad$ CH_3-CH= CH_2+KCl+H_2O

4.2.2. Chemical test for ethene

When ethanol is heated in the presence of aluminium oxide, a gas is produced. This gas does not react with lime water. This means that the produced gas is not carbon dioxide, this gas is ethene.

The equation of the reaction is:

$$CH_3CH_2OH \xrightarrow[\text{heat}]{Al_2O_3} H_2C{=}CH_2 + H_2O$$

The gas decolourises bromine water. Bromine water is used to identify the presence of a carbon-carbon double bond or triple bond. The bromine adds across the double bond and a dibromoalkane is formed. The reaction between alkene and bromine water is shown below:

$$H_2C{=}CH_2 + Br_2 \longrightarrow CH_2BrCH_2Br$$

If you shake an alkene with bromine water (or bubble a gaseous alkene through bromine water), the solution becomes colourless. Alkenes decolourise bromine water.

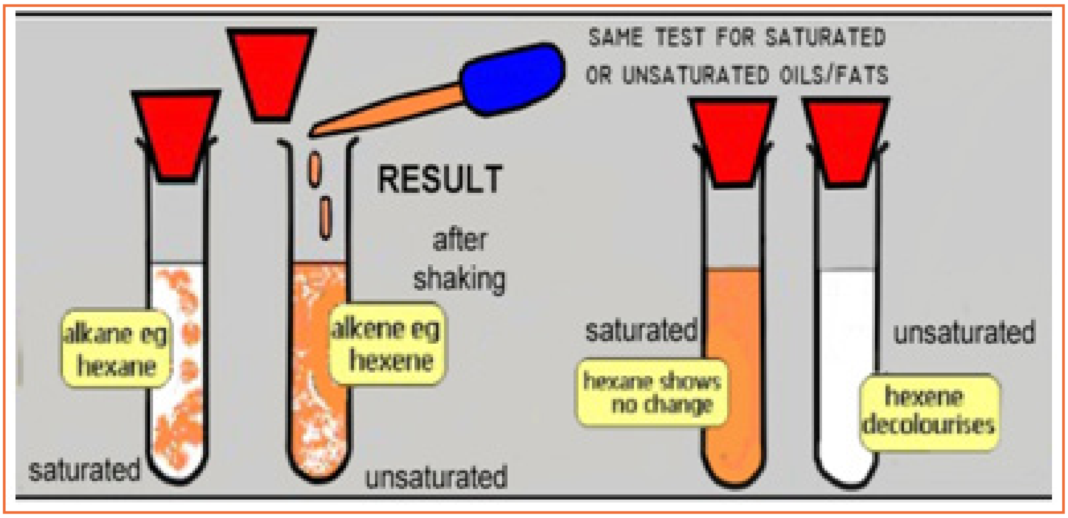


Figure 4.1: Chemical test for ethene

When ethene reacts with acidified potassium manganate (VII), the purple colour of the permanganate solution turned to colourless or light pink indicating the presence of the carbon – carbon double bond. The reaction is the following:

$$5H_2C{=}CH_2 + 2MnO_4^- + 6H^+ \rightarrow 5CH_2OHCH_2OH + 2Mn^{2+}$$

The ethene gas burns with a smoky flame producing carbon dioxide and heat energy. The carbon dioxide produced turns into milky lime water.

$$H_2C{=}CH_2 + 3O_2 \rightarrow 2CO_2 + 2H_2O + \text{heat}$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Application activity 4.2

1. Refer to the IUPAC system, name the alkenes formed when the following alcohols are dehydrated in the presence of sulphuric acid.
    a) 2-methylpropan-1-ol
    b) 2,3-dimethylbutan-2-ol
    c) 2-methylbutan-2-ol
2. What are the products of the dehydrohalogenation of the following compounds? Show the major product.
    a) 1-bromo-2-methylpropane
    b) 2-bromo-3-methylpentane
    c) 3-chloro-3-ethylpentane
3. Establish the formula of the compounds formed when each of the following dihalogenoalkanes react with magnesium.
    a) $(CH_3)_2CHCHClCHClCH_3$
    b) $CH_3CH_2C(Br)(CH_3)CH(Br)CH_2CH_3$
4. Describe the chemical test used to identify the presence of a carbon-carbon double bond in an organic compound.

4.3. Physical properties and uses of the alkenes

Activity 4.3

1. Put in a test tube 5ml of cyclohexene, add 5ml of water and mix. Record your observations and interpret them.
2. Put in a test tube 5ml of cyclohexene, add 5ml of tetrachloromethane and mix. Record your observations and interpret them.
3. An alkene containing 25 atoms of carbon and 50 atoms of hydrogen is in the nature. Predict its physical state at room temperature.

4.3.1. Physical properties of the alkenes

Many of the physical properties of alkenes and alkanes are similar they are colourless, non- polar, and combustible.

- Alkenes which have less than 5 carbon atoms are gaseous at ordinary temperature, the other are liquid up to 18 while others are solids as the number of carbon atoms increases.

- Boiling points and melting points of alkenes are less than those of alkanes but also increase as the molecular weight increase.
- Alkenes are insoluble in water but soluble in most organic solvents.
- Alkene isomers that can achieve more regular packing have higher melting and **boiling points** than molecules with the same molecular formula but weaker dispersion forces. Alkenes are non-polar, and they are both immiscible in water and less dense than water.

4.3.2. Uses of the alkenes

Alkenes find many diverse applications in industry; they are used as starting materials in the syntheses of alcohols, plastics, liquors, detergents, and fuels. The most important alkenes for the chemical industry are ethene, propene and 1,3-butadiene. Ethene is produced from natural gas and crude oil by cracking. Some of their uses are as follows:

- Alkenes are extremely important in the manufacture of plastics which have many applications such as: packaging, wrapping, clothing, making clothes, artificial flowers, pipes, cups, windows,...
- Ethene (ethylene) is a plant hormone involved in the ripening of fruits, seed germination, bud opening; etc
- Ethene derivatives are also used in the making of polymers such as polyvinylchloride (PVC), Teflon...
- Alkenes are used as raw materials in industry for the manufacture of alcohols, aldehydes, etc.
- Many alkenes can be polymerized, forming plastics.
- The various forms of vitamin A (including beta-carotene) are alkenes, as is lycopene, an antioxidant found in tomatoes.
- Some alkenes such as alpha-pinene and limonene smell good (and aren’t too toxic), so they are used to give aromas to such things as candles and cleaning products.

Other alkenes that occur in nature include 1-octene, a constituent of lemon oil, and octadecene ($C_{18}H_{36}$) found in fish liver. Dienes (two double bonds) and polyenes (three or more double bonds) are also common. Butadiene ($CH_2{=}CHCH{=}CH_2$) is found in coffee. Lycopene and the carotenes are isomeric polyenes ($C_{40}H_{56}$) that give the attractive red, orange, and yellow colour to watermelons, tomatoes, carrots, and other fruits and vegetables. Vitamin A, essential to good vision, is derived from a carotene.

Application activity 4.3

1. Propene and butene are in the same homologous series of alkenes, which one has higher boiling point? Explain.
2. Pentane which is an alkane is insoluble in water; predict what will happen when pentene, which is an alkene, is mixed with water.

4.4. Chemical properties of alkenes

Activity 4.4

1. To the test tube containing ethene add about 1ml of bromine. Interpret your observations and suggest the balanced reaction that takes place.
2. To the test tube containing again ethene, add about 1ml of very dilute potassium permanganate solution and shake the tube a few times. For this one also interpret your observations and suggest the balanced reaction that takes place.
3. Into another closed test tube containing ethene remove the stopper and apply a light to the mouth of the test tube using a lighted splint. Allow the gas to burn and when it has stopped burning add a small amount of lime water to the test tube, stopper it and shake the tube a few times. Interpret your observations and suggest the balanced reaction that takes place.

4.4.1. Addition reactions

Alkenes are far more reactive than alkanes due to the carbon-carbon double bond. These compounds are unsaturated and they can easily undergo addition reactions to yield saturated products.

The double bond in alkenes is a region of high density of electrons. Therefore, this region is readily attacked by electrophiles. An **electrophile** is an atom, a molecule or an ion which is electron-deficient; i.e. it is a Lewis acid or an electron pair acceptor.

a) Addition of hydrogen halides

Hydrogen halides (HCl, HBr, HI) react with alkenes to yield halogenoalkanes. The reaction is carried out either with reagents in the gaseous state or in inert solvent such as tetrachloromathane.

Example:

$$CH_2{=}CH_2 + HCl \longrightarrow CH_3CH_2Cl$$

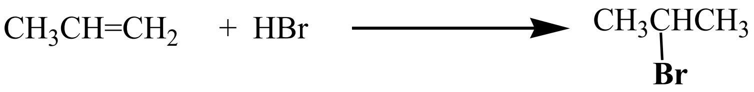
When hydrogen halides add to unsymmetrical alkenes, the reaction leads to the formation of two products in two steps. The first step leads to the formation of two different carbocations with the major product formed from the more stable carbocation. This is the **Markownikov's rule.**

That is "The electrophilic addition of an unsymmetric reagent to an unsymmetric double bond proceeds by involving the most stable carbocation".

The order of stability of the carbocations is:

$$\xrightarrow[\textit{Increasing order of stability}]{\textit{Methyl} < \textit{Primary carbocation} < \textit{Secondary carbocation} < \textit{Tertiary carbocation}}$$

Example: Reaction of propene with hydrogen bromide



$$CH_3CH{=}CH_2 + HBr \longrightarrow CH_3\underset{\displaystyle\mathbf{Br}}{\underset{|}{C}}HCH_3$$

In the presence of peroxide, the reaction follows a free radical mechanism and it does not follow the Markonikov's rule.

Example:

$$CH_3CH{=}CH_2 + HBr \longrightarrow CH_3CH_2CH_2\mathbf{Br}$$

b) Addition of water

The hydration of alkenes catalysed by an acid is an electrophilic addition. Ethene can be transformed into ethanol. The first step consists of adding concentrated sulphuric acid. The second step consists of the hydrolysis of the product of the first step.

In industry the reaction is carried out at approximately 300 °C in the presence of phosphoric acid as a catalyst.

Example: Hydration of 2-methylbut-2-ene

c) Addition of cold concentrated sulphuric acid

When cold concentrated sulphuric acid reacts with alkene, an alkyl hydrogen sulphate is obtained. If the starting alkene is unsymmetrical, two different alkyl hydrogen sulphates are obtained. If the alkyl hydrogen sulphate is warmed in the presence of water, an alcohol is obtained.

Example: Reaction of propene with H_2SO_4

d) Addition of halogens

The addition of halogens (halogenation) on alkenes yields vicinal dihalogenoalkanes. The reaction takes place with pure reagents or by mixing reagents in an inert organic solvent.

When a chlorine or bromine molecule approaches an alkene, the pi electrons cloud interact with the halogen molecule causing its polarisation.

Example: Reaction of ethene with bromine in an inert organic solvent gives:

$H_2C{=}CH_2 + Br_2 \rightarrow CH_2Br\text{-}CH_2Br$

The reaction with bromine is a useful test for alkenes. The brown red colour of bromine is discharged in alkenes.

e) Hydrogenation

In the presence of a catalyst (Pt, Ni, Pd), alkenes react with hydrogen to give alkanes.

Example: $CH_3CH_2CH = CH_2 + H_2 \xrightarrow{Ni} CH_3CH_2CH_2CH_3$

This reaction is very useful when transforming vegetable oils into fats such as margarine by hydrogenation. The process is referred as **hardening**.

Figure 4.2: Unsaturated oils

4.4.2. Combustion

Alkenes burn in oxygen to give carbon dioxide, water and energy

$$C_nH_{2n} + 3n/2\ O_2 \longrightarrow nCO_2 + nH_2O$$

Example: $CH_3CH{=}CHCH_2CH_3 + O_2 \longrightarrow 5CO_2 + H_2O + Energy$

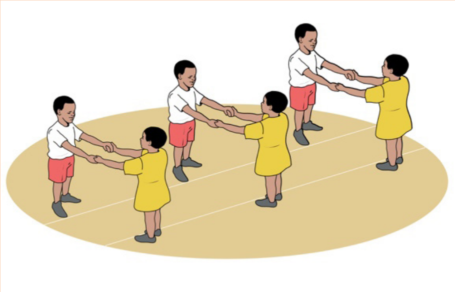
Note: An alkane does not react with $KMnO_4$ but an alkene reacts with $KMnO_4$ producing a dark brown precipitate of MnO_2.

Application activity 4.4

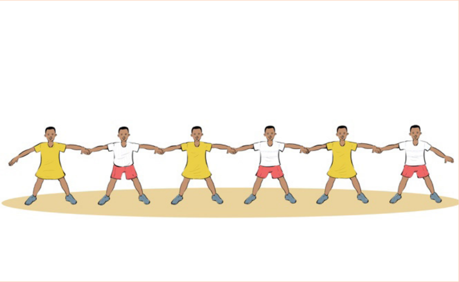
1. Write the equations of the reaction between 3-methylpent-2-ene with:
   a) Oxygen in the presence of silver catalyst.
   b) Cold dilute potassium permanganate solution
2. Describe the observations when butane and but-2-ene react separately with potassium manganate (VII) solution.

4.5. Polymerization of ethene and chloroethene

Activity 4.5



A



B

a) From your observation of the above photos, illustrate the difference and similarities between the pictures A and B.

b) From the information you have on alkenes, illustrate the molecule which can behave like the above photos.

Alkenes undergo addition polymerisation reaction to form long chain polymers. i.e a polymer is a large molecule containing a repeating unit derived from small unit called monomers. A polymerisation reaction involves joining together a large number of small molecules to form a large molecule.

Many different addition polymers can be made from substituted ethene compounds.

Each polymer has its physical properties and therefore many polymers have wide range of uses.

If Z is monomer unit them on combination, so many repeated units of Z will be in the product called the polymer.

$$\underset{\text{monomer unit}}{n\,Z} \longrightarrow \underbrace{\text{Z-Z-Z--Z-Z-Z-Z-Z-Z-Z-Z-..........Z}}_{\text{polymer chain}}$$

Polymer, substance consisting of large molecules that are made of many small, repeating units called monomers. The number of repeating units in one large molecule is called the degree of polymerization. Materials with a very high degree of polymerization are called high polymers. Polymers consisting of only one kind of repeating unit are called homopolymers. Copolymers are formed from several different repeating units.

The C=C double bond in ethene is involved in the polymerization reaction. It allows ethene molecules to join together to form a single product, so it is an example of an addition reaction. Poly (ethene) is an addition polymer.

High density poly(ethene) or High density polyethylene (HDPE); Two types of catalyst are used principally in the manufacture of HDPE: A Ziegler-Natta organometallic catalyst (titanium compounds with an aluminium alkyl). The **Ziegler-Natta catalysts** include many mixtures of halides of transition metals, especially titanium, chromium, vanadium, and zirconium, with organic derivatives of non-transition metals, particularly alkyl aluminum compounds.

Table 4.1: Polymers of alkenes

Polymers	Monomers	Uses
Polyethylene(PE) $-(CH_2-CH_2-)_n-$	$CH_2=CH_2$	Films, bags, pipe, insulating gloves, bottle stoppers, lids and plastic wraps
Polypropylene (PP) $-(CH_3-CH-CH_2)_n-$	$CH_3-CH=CH_2$	Household items, plastic wraps, automobile parts, batteries, garden furniture, syringes, bottle appliance.
Polystyrene (PS) $(C_6H_5-CH-CH_2)_n$	$C_6H_5-CH=CH_2$	Plastic wraps, kitchen utensils, furniture covers, thermal insulation, toys and office supplies, disposal razors.

Polyvinyl chloride $-(CH_2-CHCl)_n-$	$CH_2=CHCl$	Household items, electrical wire insulation, water pipes, floor, coverings, window and door covers, items for chemicals and industry sports.
Polytetrafluoro Ethylene(PTFE) $-(CF_2-CF_2)_n-$	$CF_2=CF_2$	Orthopedic and prosthetic appliances, hearing aids, corrosion resistant and mechanical parts, upholstery, joints, flying pan coatings, electric insulation.
Poly(acrylonitrile) $(-CH2-\underset{C\equiv N}{\underset{\mid}{CH}}-)n$	$(CH_2=CH)_n-C\equiv N$	Lugs, brankets, yarn, apparel, simulated fur

The above table is the summary of most alkene polymers obtained from alkenes as monomers and their uses.

Disposal of poly(alkene) plastics

Plastics are widely used in many aspects of everyday life. However, the large-scale use of poly(alkene)s has created a problem when we come to dispose of them. During their useful life, one of the poly(alkene)s' useful properties is their lack of reactivity. As they are effectively huge alkane molecules, they are resistant to chemical attack. So they can take hundreds of years to decompose when dumped in landfill sites, taking up valuable space. They are non-biodegradable.

Therefore, throwing away poly(alkenes) creates rubbish that will pollute the environment for centuries.

Figure 4.3: Poly (alkene) plastic waste.

One way to solve this problem would be to burn the poly(alkene)s and use the energy released to generate electricity. If hydrocarbons burn in excess oxygen the products are carbon dioxide and water. So this solution would not help combat global warming, but would help to conserve our supplies of fossil fuels that currently generate most of our electricity.

However, we have also seen that toxic carbon monoxide is produced from incomplete combustion of hydrocarbons. Another problem is the difficulty recycling plants have in separating other plastic waste from the poly(alkene)s when objects have just been thrown away without being sorted according to their recycling code. Then if poly(chloroethene) is burnt, acidic hydrogen chloride gas will be given off, as well as toxic compounds called dioxins. Acidic gases would have to be neutralised before releasing the waste gas into the atmosphere and very high temperatures used in incinerators to break down any toxins.

The disposal of poly(alkene) plastic waste is difficult, as much of it is chemically inert and non-biodegradable. When burnt, waste plastics may produce toxic products, such as hydrogen chloride from PVC (poly(chloroethene)).

Chemists have been able to design ways of removing toxic waste products such as HCl before they get into the atmosphere. A base or carbonate is put into the incineration chimney, and this reacts with the HCl gas, neutralising it before it is released (eg $CaO + 2HCl \rightarrow CaCl_2 + H_2O$).

There are three sustainable ways to dispose of polymers (i.e not just burying them or incinerating them):

- Separate them into different types of polymer and recycle them
- Incinerate them in a power station and use the energy released to generate electricity
- Crack them in order to turn them into smaller molecules, which can be used to make other materials or more plastics.

Halogenated plastics (plastics which contain Cl, Br or I atoms) such as PVC pose an additional environmental hazard; when incinerated, they produce the toxic gas HCl.

Application activity 4.5

1. What happens when ethene is allowed to polymerization? Provide the answer within an example.
2. Provide a way for removal of toxic waste products, i.e removal of HCl formed during disposal by combustion of halogenated plastics (ie PVC)?

4.6. Structure and nomenclature of straight and branched alkynes

Activity 4.6

1. Write the names and structural formulae of the first three members of the homologous series of alkenes.
2. Suggest the names and structural formulae of the first three members of the homologous series of alkynes.

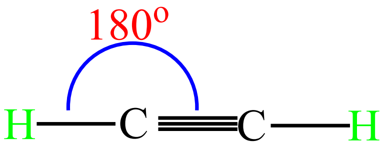
Alkynes are aliphatic hydrocarbons with at least one carbon-carbon triple bond. A triple bond consists of one sigma bond and two pi bonds.

The general formula of this homologous series is C_nH_{2n-2}. Some members of this homologous series are:

$HC\equiv CH$	Ethyne or acetylene
$CH_3C\equiv CH$	Propyne
$CH_3CH_2C\equiv CH$	But-1-yne
$CH_3C\equiv CCH_3$	But-2-yne

According to the VSEPR model, the molecular geometry in alkynes include bond angle of 180° around each carbon triply bonded. Thus, the shape around the triple bond is linear.

Example: Structure of ethyne.



There are two types of alkynes: terminal alkynes and non-terminal (internal) alkynes

A terminal alkyne has a triple bond at the end of the chain e.g.: $R-C\equiv C-H$

A non-terminal alkyne has a triple bond in the middle of the chain: $R-C\equiv C-R'$

Examples:

$HC\equiv CHCH_2CH_2CH_3$, a terminal alkyne

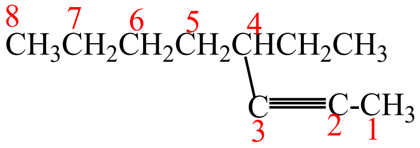
$CH_3C\equiv CCH_2CH_3$, a non-terminal alkyne

Alkynes are named by identifying the longest chain containing the triple bond and changing the ending **–ane** from the corresponding alkane to **–yne**.

Examples:

H-C≡C-H: ethyne

$HC\equiv C\text{-}CH_2CH_2CH_3$: pent-1-yne or 1-pentyne



$$CH_3CH_2CH_2CH_2\underset{\overset{|}{C\equiv C\text{-}CH_3}}{CH}CH_2CH_3$$

, 4-ethyloct-2-yne

or 4-ethyl-2-octyne

Alkynes with four or more carbon atoms have structural isomers.

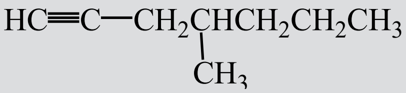
Example:

$HC\equiv CCH_2CH_2CH_3$ and $CH_3C\equiv CCH_2CH_3$ are isomers of C_5H_8

Application activity 4.6

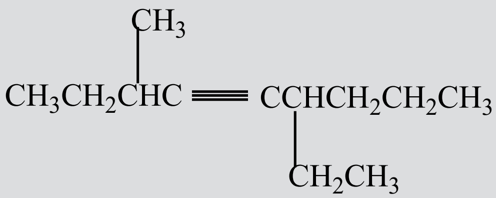
1. Name according to the IUPAC system, each of the following compounds.

a)



$$HC\equiv C-CH_2\underset{\overset{|}{CH_3}}{C}HCH_2CH_2CH_3$$

b)



$$CH_3CH_2\overset{\underset{|}{CH_3}}{C}HC\equiv C\underset{\overset{|}{CH_2CH_3}}{C}HCH_2CH_2CH_3$$

2. Write structural formula for:
   a) 2, 5-dimethylhex-3-yne
   b) 4- ethyl-5-methyloct-1-yne

4.7. Physical properties and uses of the alkynes

Activity 4.7

Set up the apparatus as shown in the diagram below.

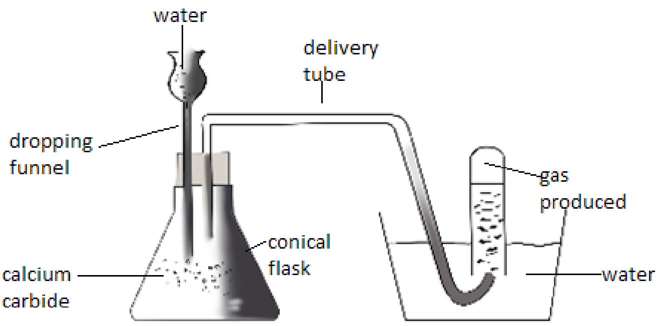


Figure 4.4: Laboratory preparation of an alkyne

Procedure:

- Place 2g of calcium carbide in a conical flask
- Using the dropping funnel, add water dropwise.
- Collect the gas produced in the test tube.
- Remove the first tube and connect a second test tube.

Questions:

1. To the first test tube add two drops of bromine water. Record your observations and interpret them.
2. To the second test tube add two drops of potassium manganate (VII). Record your observations and interpret them.
3. Suggest the name and formula of the alkyne produced during this experiment.
4. The gas produced is it soluble in water or not? Explain your answer.

4.7.1. Physical properties of alkynes

Alkynes are non-polar compounds with physical properties similar to those of alkenes with the same number of carbon atoms. Their linear structure gives them greater intermolecular forces than alkenes.

Examples: Table 4.2: Boiling and melting points

Compound	Melting point/°C	Boiling point/°C
Propene	-185	-47
Propyne	-101	-23
Pent-1-ene	-138	30
Pent-1-yne	-90	40

– **Physical state and odour of alkynes:**

The first three members of alkyne family: ethyne, propyne and butyne are colourless gases, the next eight members are liquids and the higher ones are solids. Except for ethyne, which has characteristic smell, all members are odourless.

- It is a gas at room temperature, it is a foul(dirty) smelling gas
- It burns in air with a yellow sooty flame. (Sooty: a black powder separated from fuel during combustion, residue from smoking, ash). When the flame is supplied with pure oxygen, however the colour turns to light blue and flame temperature increases dramatically

– **Boiling points of alkynes:**

The boiling point of alkynes increases with molar mass. Among hydrocarbons, alkynes have higher boiling point than alkenes and alkanes because of the presence of triple bond in alkynes.

– **Solubility of alkynes:** Alkynes like alkanes and alkenes are non-polar solvents; therefore, they are insoluble in water but readily dissolve in organic solvents such as ether, carbon tetrachloride and benzene.

– **Density of alkynes:** The density of alkynes increases with mass. All alkynes are lighter than water

4.7.2. Use of alkynes

a) Uses of acetylene

- Acetylene is the most important commercial alkynes. It is used as the fuel for the oxyacetylene welding torch. It is used for welding.
- Acetylene produces, when burned, a high temperature flame. For example the oxyacetylene flame reaches temperatures as high as 2800°C
- Acetylene is safely stored and handled in cylinders that are filled with crushed firebrick with acetone.
- Acetylene is also used in chemical synthesis, particularly in the manufacture of vinyl chloride for plastics, acetaldehyde, acetic acid acetone and the neoprene type of synthetic rubber.

Manufacture of acetylene

Acetylene is one of the cheapest organic chemicals. It is made from coal or from natural gas

See the reactions below from coal

(a) Here calcium oxide obtained by heating calcium carbonate is heated together with coke to a temperature of about 2000⁰C in an electric furnace.

$$3C + CaO \xrightarrow{2000^0 C} CaC_2 + CO + 112kCal$$

The calcium dicarbide is then hydrolyzed: $CaC_2 + 2H_2O \rightarrow C_2H_2{}^{\uparrow} + Ca(OH)_2$

From natural gas

(b) Ethyne is also prepared (industrially) by heating (for a short period of time) methane to 1500⁰C

$$2CH_4 \xrightarrow{1000°C} C_2H_2 + 3H_2$$

Other uses of alkynes

- Alkynes are used in the preparation of many other compounds. For example ethyne is used in the making of ethanal, ethanoic acid, vinyl chloride, trichloroethane, ...
- Ethyne (acetylene) is used as a fuel in welding and cutting metals.
- Propyne is used as substitute for acetylene as fuel for welding.

Application activity 4.7

1. Which of 3, 4,4-trimethylpent-1-yne and oct-3-yne has a high volatility? Explain
2. Table salt (NaCl) is water soluble but hex-2-yne is not. Explain why.
3. The plastics produced from alkenes, alkynes and their derivatives are very useful but they have some disadvantages. Describe these disadvantages and outline different ways of solving this problem.

4.8. Chemical properties of alkynes

Activity 4.8

1. Interpret your observations and suggest the balanced reaction that takes place of the following:
    a) The test tube containing ethyne add about two drops of bromine.
    b) The test tube containing again ethyne, add about two drops of very dilute potassium permanganate solution.

As unsaturated hydrocarbons, alkynes are very reactive. Because they are unsaturated hydrocarbons, alkynes undergo addition reactions. Alkynes can add two moles of reagents.

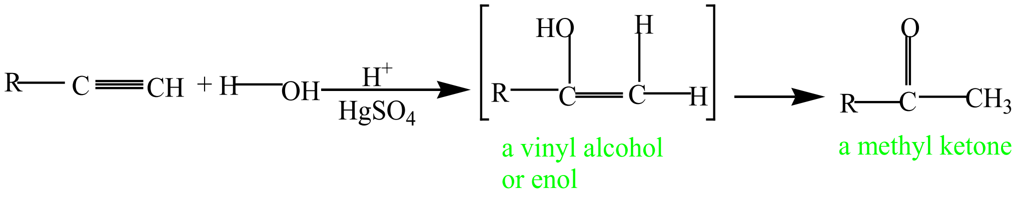
Even though they have a higher electron density than alkenes, they are in general less reactive because the triple bond is shorter and therefore the electron cloud is less accessible.

a) Addition of hydrogen halides

Alkynes react with hydrogen halides to yield dihalogenoalkanes; the reaction follows the Markovnikov's rule.

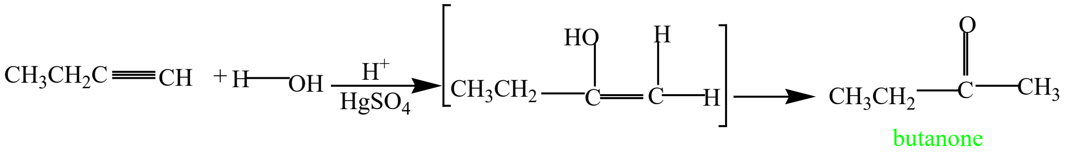
b) Addition of water

Alkynes react with water in the presence of sulphuric acid and mercury sulphate at 60°C to give carbonyl compounds.



$$R-C\equiv CH + H-OH \xrightarrow[HgSO_4]{H^+} \left[R-C(OH)=CH-H\right] \longrightarrow R-C(=O)-CH_3$$

Example:



$$CH_3CH_2C\equiv CH + H-OH \xrightarrow[HgSO_4]{H^+} \left[CH_3CH_2-C(OH)=CH-H\right] \longrightarrow CH_3CH_2-C(=O)-CH_3$$

c) Hydrogenation

The hydrogenation of alkynes in the presence of palladium catalyst gives alkanes

The reaction requires two moles of hydrogen for a complete saturation.

Example: $CH_3CH_2C\equiv CH + 2H_2 \rightarrow CH_3CH_2CH_2CH_3$

In the presence of Lindlar catalyst, the alkynes are partially hydrogenated giving alkenes

Example:

$$CH_3CH_2C\equiv CH + H_2 \xrightarrow{\text{Lindlar catalyst}} CH_3CH_2CH{=}CH_2$$

A Lindlar catalyst is a heterogeneous catalyst that consists of palladium deposited on calcium carbonate and poisoned with different lead derivatives such as lead oxide or lead acetate. A heterogeneous catalyst is the one which is in the phase different from that of the reactants.

d) Reaction with metals

Terminal alkynes react with active metals to yield alkynides and hydrogen gas. Internal alkynes do not react as they do not have an acidic hydrogen atom.

Example:

$$CH_3CH_2C\equiv CH + Na \rightarrow CH_3CH_2C\equiv C^-Na^+ + \tfrac{1}{2} H_2$$

e) Reaction with metal salts

When a terminal alkyne is passed through a solution of ammoniacal silver nitrate, a white precipitate of silver carbide is formed.

$$CH_3C\equiv CH\ (g) + 2AgNO_3\ (aq) + 2NH_3\ (aq) \rightarrow CH_3C\equiv C^-Ag^+(s) + NH_4NO_3\ (aq)$$

When a terminal alkyne is passed through a solution of ammoniacal copper (I) chloride, a red precipitate of copper (I) carbide is formed.

$$2CH_3CH_2C\equiv CH\ (g) + 2CuCl\ (aq) + 2NH_3\ (aq) \rightarrow 2CH_3C\equiv C^-Cu^+(s) + 2NH_4Cl\ (aq)$$

The reactions above are used to:

- Differentiate between terminal and non-terminal alkynes.
- Differentiate ethene and ethyne

The reaction shows that hydrogen atoms of ethyne are slightly acidic, unlike those of ethene.

Application activity 4.8

1. Write the formula(s) and the name (s) of the products of the reaction of pent-1-yne with:
   a) Water
   b) Hydrogen chloride
2. From your own research, do alkynes react with KMnO4? Explain what you find out.
3. Within an example, how does alkyne react with water?

Skills Lab 4

Although plastics have many uses, the majority of them are non-biodegradable reason why they have side effects and therefore some of them are being replaced by more eco-friendly plastics (biodegradable plastics).

1. Design a project of making plastics which are biodegradable.
2. Design a project of recycling plastics especially non-biodegradable.

End Unit Assessment 4

I. Multiple choice questions:

1. Which of the following is given off during ripening of fruits and vegetables?
   a) Ethane
   b) Ethene
   c) Ethyne
   d) Methane
2. Loss of hydrogen halide is called:
   a) Halogenation
   b) Dehydration
   c) Dehydrohalogenation
   d) Hydrogenation
3. Alkenes can be oxidized using which powerful oxidizing agent in acidified medium?
   a) Potassium manganate (VII)

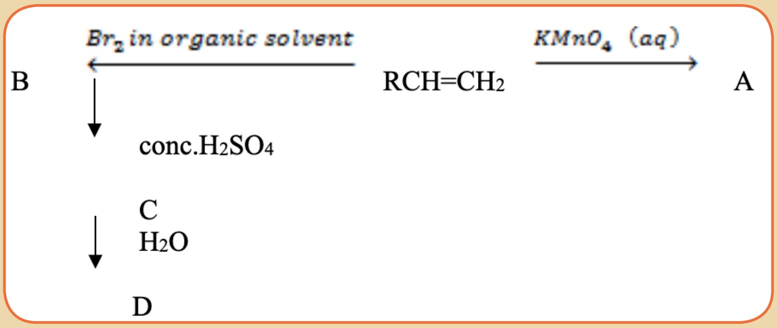
b) Sodium manganate (VI)
c) Calcium manganate (VI)
d) All of them

4. The molecular formula of-------- fit the general formula (C_nH_{2n-2}).
   a) Alkanes
   b) Alkynes
   c) Alcohols
   d) Alkenes
5. Acetylene is also called:
   a) Ethyne
   b) Ethene
   c) Ethane
   d) Methane

II. Open questions

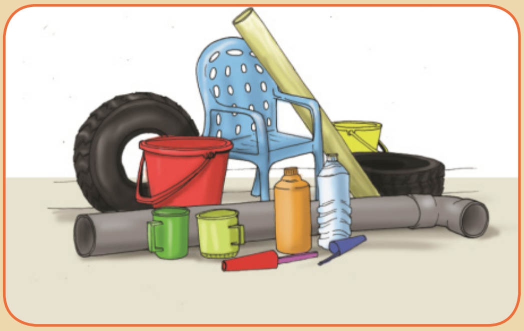
6. Give five possible isomers of C_5H_{10}.
7. Show how the following conversion may be accomplished CH_3-$CH=CH_2$ to Propyne
8. a) Alkenes such as ethene and propene have been described as the building blocks of the organic chemical industry. Within examples discuss this statement.

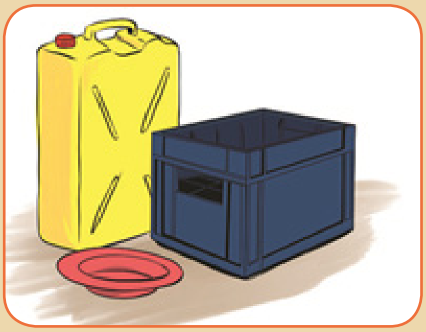
   b) What particular features of the chemistry of alkenes make them suitable for this role and why are alkanes less suitable.
9. How will you distinguish between ethene and ethyne by a suitable chemical test?
10. The chart below shows some reaction of alkene, study the chart and answer the question follow.

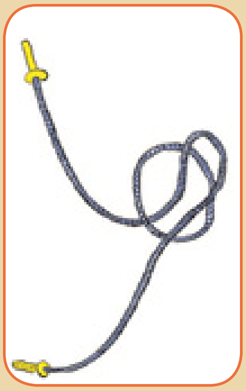


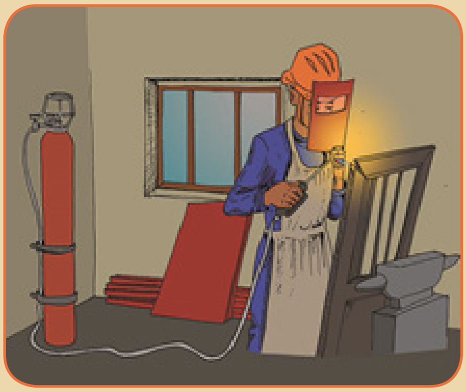
Give formula A, B, C and D

11. Look at the pictures below and suggest the importance of alkenes and alkynes.









UNIT 5

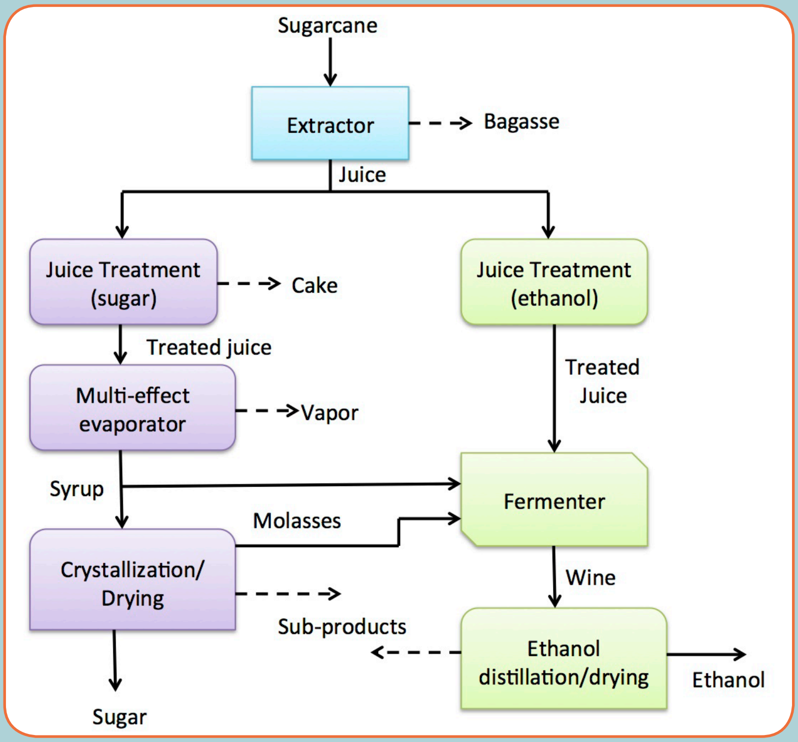
ALCOHOLS

Key Unit Competence:

Compare the physical and chemical properties of alcohols to their preparation methods, reactivity and uses.

Introductory activity 5

Study the flow chart below related to preparation of ethanol from Sugar cane and answer the questions which follow.

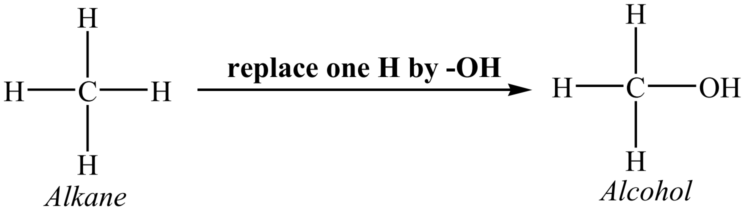


1. There are seven stages of the sugar cane process as shown in the diagram above. Explain each step of the seven stages beginning with Sugar Cane.

2. Describe how the wine is obtained locally from the juice (here, focus on the banana juice).
3. The ethanol obtained can be used in different domains. In laboratory, different compounds can be prepared from it but also ethanol finds many applications in many daily works.
   a) State at least two compounds that can be prepared from ethanol in laboratory. It will be better if you suggest the way each one is obtained.
   b) Ethanol is a very common alcohol; in many activities, it is referred to as “alcohol”! State different fields in which “alcohol” is used; and, for each, show the purpose of using it.
4. Relate the properties of alcohols with their given uses.

Alcohols are organic compounds that are derivatives of hydrocarbons where one or more hydrogen atoms of hydrocarbon is or are replaced by hydroxyl (-OH) group. They are represented by the general formula: **C_nH_{2n+1}–OH** or **R-OH** where **R** is a radical: *alkyl* or *aryl* (phenyl).

When one, two or more hydrogen atoms of a hydrocarbon are replaced by a corresponding number of hydroxyl groups (-OH), alcohols can be obtained.



Alcohols are called *monohydric* if only one hydroxyl group is present (example: CH_3CH_2-OH). *Dihydric* alcohols are those with two hydroxyl group (diols), *trihydric* (triols) and *polyhydric* are those with many – C-OH groups. The functional group attached is –OH group to any atom of carbon.

5.1. Nomenclature, isomerism and the classification of alcohols

Activity 5.1

Given the following organic compounds,

A: CH_3CH_3 **B:** $CH_3CH=CH_2$ **C:** CH_3CH_2Cl **D:** CH_3CH_2OH
E: $CH_3CH_2CH_2CH_2OH$

1. Name all compounds given above.

2. Identify the ones which are in the same homologous series and suggest the name of this homologous series.
3. Show a structure of any isomer of **E**.

5.1.1. Nomenclature

In the ***common system***, alcohols are named as *alkyl alcohols*. The word alcohol is added after the name of the alkyl group to which the hydroxyl group is attached. For example, CH_3OH is methyl alcohol and CH_3-CH_2-CH_2-OH is n-propyl alcohol where **n** stands for “normal”.

In ***the IUPAC system***, alcohols are named by replacing the final “**e**” of the parent hydrocarbon (like alkane or alkene) with “**ol**”, then specify the position of **-OH** group before ending by -**ol** using a number. Some examples of IUPAC names are shown below.

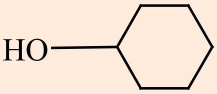
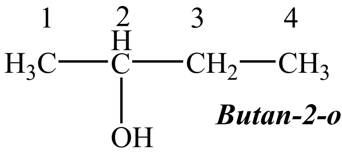
Alcohol structure	IUPAC Name
CH_3-CH_2-OH	Ethanol
CH_3-CH_2-CH_2-OH	Propan-1-ol
CH_3-CH_2-CH_2-CH_2-OH	Butan-1-ol
CH_2=CH-CH_2-OH	Prop-2-en-1-ol
	Cyclohexanol

Table 5.1(a): Nomenclature of alcohols

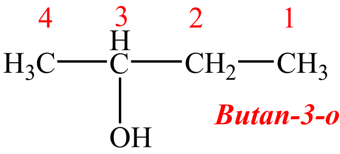
The numbering is done such that the carbon atom attached to the -OH group gets the lowest number.


$\overset{1}{H_3C}-\underset{OH}{\overset{2}{\overset{H}{C}}}-\overset{3}{CH_2}-\overset{4}{CH_3}$

Butan-2-ol

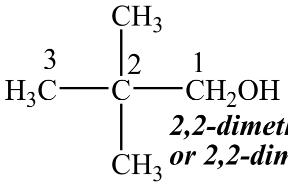
Or 2-butanol

not


$\overset{4}{H_3C}-\underset{OH}{\overset{3}{\overset{H}{C}}}-\overset{2}{CH_2}-\overset{1}{CH_3}$

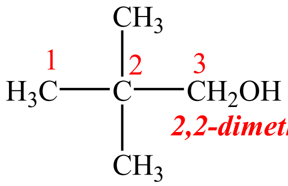
Butan-3-ol

or 3-butanol


$\overset{3}{H_3C}-\underset{CH_3}{\overset{CH_3}{\overset{2}{C}}}-\overset{1}{CH_2OH}$

2,2-dimethylpropan-1-ol
or 2,2-dimethyl-1-propanol

not


$\overset{1}{H_3C}-\underset{CH_3}{\overset{CH_3}{\overset{2}{C}}}-\overset{3}{CH_2OH}$

2,2-dimethylpropan-3-ol

or 2,2- dimethyl -3-propanol

Alcohols are found in different groups according to the number of OH groups they possess. They may be:

- **Monohydric alcohols:** Alcohols with one hydroxyl group.
  Ex: $CH_2OH\text{-}CH_2CH_2CH_2CH_2CH_2CH_3$: heptan-1-ol or 1-heptanol
- **Dihydric alcohols:** Alcohols with two hydroxyl groups.
  Ex:$CH_2OH\text{-}CH_2CHOHCH_2CH_2CH_2CH_3$: heptane-1,3-diol or 1,3-heptanediol
- **Trihydric alcohols:** Alcohols with three hydroxyl groups.
  Ex: $CH_2OH\text{-}CH_2CHOHCH_2CHOHCH_2CH_3$: heptane-1,3,5-triol or 1,3,5-heptanetriol
- **Polyhydric alcohols:** Alcohols with four or more hydroxyl groups.
  Ex: $CH_2OHCHOHCHOHCH_2CHOHCH_2CH_{3:}$ heptane-1,2,3,5-tetraol or 1,2,3,5-heptanetetraol

For naming polyhydric alcohols, the name of the alkane is retained and the ending **-e** is not dropped. Thus *dihydric* alcohols are named as ***alkane diols*** and ***trihydric alcohols*** are named as ***alkane triols***. The position of carbon atoms carrying -OH groups are indicated by locants written after the name of alkane.

The number of hydroxyl groups is indicated by adding the multiplicative prefix **di, tri**, **tetra**, etc., before the suffix**-ol** and in the case there are more than one locants; they are separated by a comma.

Structure	IUPAC name	Common name
$HOCH_2\text{-}CH_2OH$:	Ethane-1,2-diol	Ethylene glycol
$HOCH_2\text{-}CHOH\text{-}CH_2OH$	Propane-1,2,3-triol	Glycerin or glycerol

Table 5.1(b): Nomenclature of alcohols

OH group takes priority over alkyl substituents, double or triple bonds and even halides.

$CH_3\text{-}CH{=}CH\text{-}CHOH\text{-}CH_2\text{-}CHCl\text{-}CH_3$: ***6-chloro hept-2-en-3-ol***

$(CH_3)_2CH\text{-}CHOH\text{-}C{\equiv}CH$: ***4-methyl pent-1-yn-3-ol***

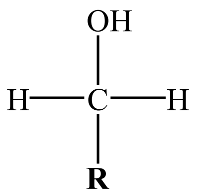
5.1.2. Classification of alcohols

The **saturated monohydric alcohols** have the general formula $\mathbf{C_nH_{2n+1}OH}$ or **ROH.** These may be classified into three important types:

1. **Primary Alcohol:** The carbon atom bearing the hydroxyl group is attached to just one other carbon atom. Example: $\mathbf{CH_3CH_2OH}$

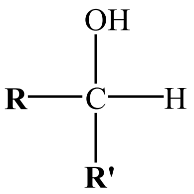
2. **Secondary Alcohol:** The carbon atom bearing the hydroxyl group is attached to two other carbon atoms. Example: $\mathbf{CH_3CH(CH_3)OH}$

3. **Tertiary Alcohol:** The carbon atom bearing the hydroxyl group is attached to three other carbon atoms. Example: $\mathbf{C(CH_3)_3OH}$



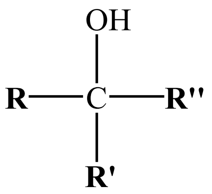
$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{H-C-H} \\ | \\ \mathbf{R} \end{array}$$

Primary alcohol



$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathbf{R}\mathrm{-C-H} \\ | \\ \mathbf{R'} \end{array}$$

Secondary alcohol



$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathbf{R}\mathrm{-C-}\mathbf{R''} \\ | \\ \mathbf{R'} \end{array}$$

Tertiary alcohol

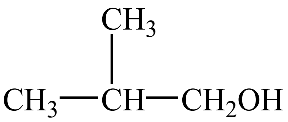
5.1.3. Isomerism in alcohols

Alcohols containing at least three carbon atoms exhibit different types of isomerism.

(a) Chain isomerism: Alcohols with four or more carbon atoms exhibit this type of isomerism in which the carbon skeleton is different.

$CH_3-CH_2-CH_2-CH_2OH$ and

Butan-1-ol



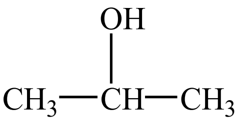
$$\begin{array}{c} \quad\ \mathrm{CH_3} \\ \quad | \\ \mathrm{CH_3-CH-CH_2OH} \end{array}$$

2-methylbutan-1-ol

(b) Position isomerism: Alcohols with three or more carbon atoms can exhibit position isomerism. In this type of isomerism, the position of the functional group i.e., the –OH group varies. In other words, the carbon atoms to which the -OH group is attached is different.

$CH_3-CH_2-CH_2OH$ and

Propan-1-ol



$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{CH_3-CH-CH_3} \end{array}$$

Propan-2-ol

(c) Functional isomerism: Alcohols with two or more carbon atoms can exhibit functional isomerism with ***ethers*** (a class of organic compounds that contain an ether group which is an oxygen atom connected to two alkyl groups and thus having the general formula **R–O–R′,** where **R** and **R′** represent the alkyl groups).

Thus ethers and alcohols have the same molecular formula but have different functional groups; hence they are called functional isomers.

$CH_3-CH_2-CH_2-CH_2OH$ and $CH_3CH_2-O-CH_2CH_3$

Butan-1-ol *Ethoxyethane*

Application activity 5.1

Give the names and structures of all eight alcohols with the formula $C_5H_{12}O$. State, in each case, whether they are primary, secondary or tertiary alcohols.

5.2. Physical properties and uses of alcohols

Activity 5.2

1. Describe different areas in which alcohols are used.
2. Analyze the following data and answer the questions below:

Carbon number	Alcohol Name	Boiling Point/K	Alkane Name	Boiling point/K
1	Methanol	337	Methane	111.3
2	Ethanol	351	Ethane	184.4
3	Propan-1-ol	371	Propane	231
4	Butan-1-ol	396	Butane	272.5

Table 5.2: Boiling points of some alcohols and corresponding alkanes

a) Explain the trends in the boiling point of the molecules (alcohols and alkanes of the same number of carbons) given in the table.

b) Compare and explain the differences in the boiling point of alkanes and alcohols.

5.2.1. Physical properties of alcohols

Alcohols consist of two parts, an *alkyl group* and a *hydroxyl group*. The properties of alcohols are due to the **-OH** group and the alkyl group modifies these properties.

a) Physical state, colour and smell

The lower members of alcohols are colourless, volatile **liquids** with a characteristic alcoholic smell and burning taste whereas higher alcohols are odourless, tasteless and colourless **waxy solids.**

b) Solubility of alcohols

The first three members are completely miscible with water. The solubility rapidly decreases with increase in molecular mass.

The higher members are almost insoluble in water but are soluble in organic solvents like benzene, ether etc.

The solubility of lower alcohols is *due to the existence of hydrogen bonds* between water and polar -OH group of alcohol molecules. The -OH group in alcohols contain a hydrogen atom bonded to an electronegative oxygen atom. Thus they form hydrogen bonds with water molecules.

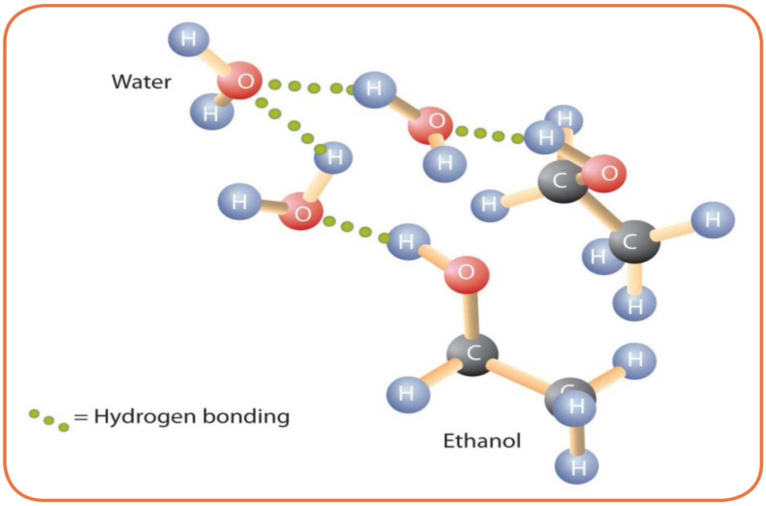


Figure 5.1: Hydrogen bonding

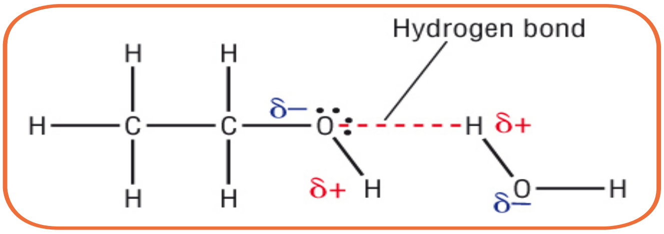


Figure 5.2: Hydrogen bonding

As the length of the hydrocarbon chain increases (i.e. as the molecular mass increases), the solubility in water decreases; this is because the non-polar alkyl group becomes predominant and masks the effect of polar -OH group.

In addition, among the isomeric alcohols, the solubility increases with branching of chain. As the surface area of the non-polar part in the molecule decreases, the solubility increases.

c) Boiling points and volatility

Volatility is the state of being volatile; this means that it is the state of having a low boiling point, and thus, evaporating readily.

Alcohols are less volatile than hydrocarbons of approximately the same molecular mass and the same carbon number ***because of formation of hydrogen bonds*** which is not possible with hydrocarbons and this leads to high intermolecular forces which require high energy to be broken down and hence the boiling point increases as the number of -OH increases.

The boiling point of alcohols with branches is lower than that of unbranched alcohols with the same number of carbon atoms. This is because increased branching gives molecules a nearly spherical shape and the surface area of contact between molecules in the liquid. This results in weakened intermolecular forces and therefore in lower boiling points.

Tertiary alcohols exhibit the lowest boiling point than secondary and primary alcohols:

Primary alcohol > **Secondary alcohol** > **Tertiary alcohol**

↑ *Highest boiling point* (Primary alcohol)

↑ *Lowest boiling point* (Tertiary alcohol)

5.2.2. Uses of alcohols

There exist different alcohols with different uses. Let us take ethanol as a typical example.

a) As Drinks

The “alcohol” in alcoholic drinks is simply ethanol.

Ethanol is usually sold as industrial methylated spirits which is ethanol with a small quantity of methanol added and possibly some colour. Methanol is poisonous, and so the industrial methylated spirits is unfit to drink.

Drinking alcohol (ethanol) is a normal social activity; but excess of it is dangerous for our health. Hence excess of alcoholic consumption must be avoided. For non-adult youth, consumption of alcohol in any form is illegal in Rwanda and in many other countries.

b) As a solvent

Ethanol is widely used as a solvent. It is relatively safe, and can be used to dissolve many organic compounds which are insoluble in water. It is used, for example, in many perfumes and cosmetics. It is also used to prepare various solvent systems of desired polarities in chemistry research laboratories.

c) As a fuel

Ethanol burns to give carbon dioxide and water and can be used as a fuel in its own right, or in mixtures with petrol (gasoline). “Gasohol” is a petrol/ethanol mixture containing about 10 - 20% ethanol. Because ethanol can be produced by fermentation, this is a useful way for countries without an oil industry to reduce imports of petrol.

$$CH_3CH_2OH + 3\ O_2 \longrightarrow 2\ CO_2 + 3\ H_2O$$

d) As cleaning and antiseptic agent

Rubbing alcohol is a liquid for cleaning medical equipment or a person's skin so that it is free from bacteria or any other harmful microorganism. It contains approximately 70% ***denatured ethanol*** or ***isopropanol***. It is undrinkable even though it may be composed by high percentage of ethanol.

After shaving your beards and after your hair cut, razor bumps or a rash may occur. You can remove the razor bumps by applying rubbing alcohol on your face and your head. The rubbing alcohol acts as an *antiseptic for your skin*. It cleans any small cuts and prevents ingrown hairs from forming.

Application activity 5.2

1. Ethanol with a molecular mass of 46 and butane with a molecular mass of 58 have the boiling point of 78°C and -0.5°C, respectively. Explain these differences.
2. Explain why alcohols dissolve easily in water than alkanes.
3. Leaning on the ethanol as a typical example, explain 3 uses of alcohols.
4. You are provided with two alcohols: Propan-2-ol and nonan-2-ol. Compare with explanations these alcohols in terms of:
   a) Solubility in water.
   b) Volatility

5.3. Preparation of alcohols

Activity 5.3

Complete and name the organic products formed from the following chemical reactions.

a) $CH_3CH_2CH_2CH_2Cl + KOH \xrightarrow{\text{water}}$

(b) $CH_2{=}CH_2 + H_2O \xrightarrow{H_2SO_4}$

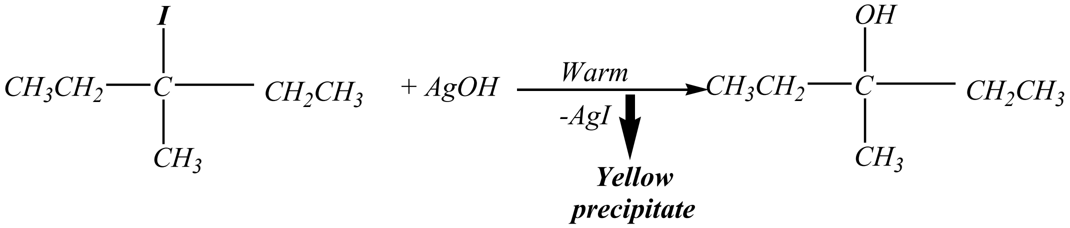
Alcohols are prepared with different methods:

a) From alkyl halides (halogenoalkanes)

Alkyl halides, when refluxed with aqueous alkali (NaOH or KOH) or moist silver hydroxide (AgOH), produce alcohols. The hydrolysis occurs by a nucleophilic substitution reaction.

$$R-X+KOH\xrightarrow{warm}R-OH+KX$$

$$CH_3CH_2CH_2Cl+KOH\rightarrow CH_3CH_2CH_2OH+KCl$$

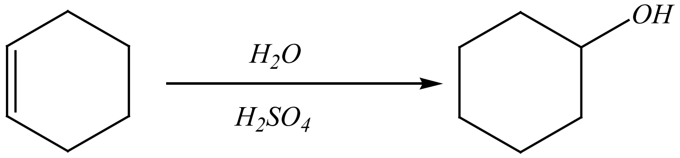


b) From alkenes

Alkenes react with water (hydration) in the presence of concentrated sulphuric acid to yield alcohols.

$$R\text{-}CH{=}CH_2\ \xrightarrow[H_2SO_4]{H_2O}\ R\text{-}CHOH\text{-}CH_3$$

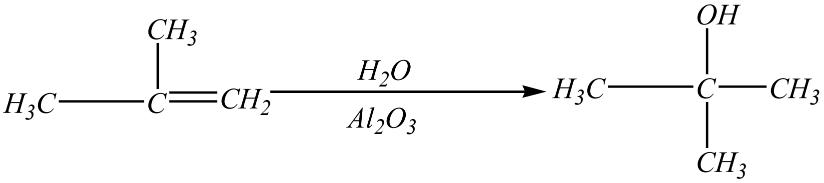
$$CH_3CH{=}CH_2\ \xrightarrow[H_2SO_4]{H_2O}\ CH_3CHOH\text{-}CH_3$$



Note:

- Alkenes, in the presence of aluminium oxide (Al_2O_3), react with water to form alcohols in vapour phase and then condense to give liquid alcohols.

Example:



- The manufacture of ethanol from ethene

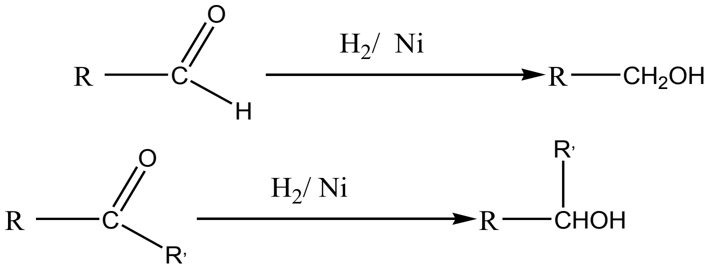
Ethanol is manufactured by reacting ethene with steam. The catalyst used is solid silicon dioxide coated with phosphoric (V) acid. The reaction is reversible.

$$CH_2{=}CH_{2(g)}+H_2O_{(g)}\overset{H_3PO_4}{\rightleftharpoons}CH_3CH_2OH_{(g)}$$

Only 5% of the ethene is converted into ethanol at each pass through the reactor. By removing the ethanol from the equilibrium mixture and recycling the ethene, it is possible to achieve an overall 95% conversion.

c) From carbonyl compounds

When aldehydes and ketones are reduced by a suitable reducing agent, they form primary and secondary alcohols respectively. The reducing agent commonly used is hydrogen in the presence of a suitable catalyst like Pt, Ni or Pd (known as ***catalytic hydrogenation***), but also lithium tetrahydridoaluminate ($LiAlH_4$) can be used even though it is not strong enough to reduce the double bond.



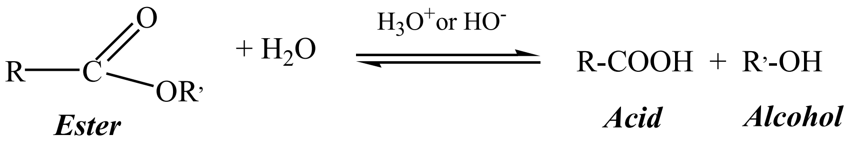
Examples:

$$CH_3CH_2CHO + H_2 \xrightarrow{Ni} CH_3CH_2CH_2OH$$

$$CH_3COCH_2CH_3 + H_2 \xrightarrow{Ni/Heat} CH_3CHOHCH_2CH_3$$

d) From esters

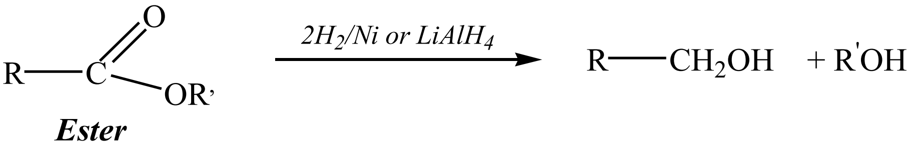
- Esters, on hydrolysis in the presence of mineral acid or alkalis, produce alcohols and carboxylic acids.



Example:

$$CH_3COOCH_2CH_3 + H_2O \xrightleftharpoons{H_3O^+} CH_3COOH + CH_3CH_2OH$$

- Reduction of esters also yields two similar or different alcohol molecules.



Example:

$$CH_3\text{-}COOCH_2CH_3 \xrightarrow{2H_2/Ni \text{ or } LiAlH_4} CH_3\text{-}CH_2OH + CH_3CH_2OH$$

e) From primary amine to give primary alcohol

Primary amines react with nitrous acid to produce primary alcohols.

$$R{-}NH_2 \xrightarrow{NaNO_2/HCl} R\text{-}OH + N_2 + H_2O + NaCl$$

Example:

$$CH_3CH_2CH_2NH_2 \xrightarrow{NaNO_2\ /\ HCl} CH_3CH_2CH_2OH + N_2 + H_2O + NaCl$$

Application activity 5.3

1. Using chemical equations, explain five methods by which Butan-2-ol can be prepared:
    a) From primary amine
    b) From ester
    c) From ketone
    d) From alkene
    e) From halogenoalkane
2. Complete the following reactions:

a) $CH_3CH_2CH_2CH{=}CHCH_3 + H_2O \xrightarrow{H_2SO_4}$

b) $(CH_3)_2C{=}CHCH_3 + HCl \longrightarrow \mathbf{A} \xrightarrow{NaOH_{(aq)}} \mathbf{B}$

5.4. Local preparation of ethanol by fermentation

Activity 5.4

Observe each image carefully to answer the questions below:

Sorghum

Banana

(1)

(2)

(3)

(4)

(5)

(6)

(7)

(8)

1. Describe how sorghum beer and how banana wine are prepared.
2. In both banana wine and sorghum beer, there is an alcohol; suggest the name and chemical formula of this alcohol.
3. The alcohol prepared from banana or sorghum can be used to prepare other organic compounds; using chemical equations show how these other compounds can be produced from alcohol.
4. Recall other uses of alcohols.

The preparation of “urwagwa” and “ikigage” is done locally using “beer” bananas collected from rural areas in Rwanda, and the sorghum cultivated on Rwandan land.

The process of the preparation of “Urwagwa”, consisting mainly by the ripening of the bananas, juice extraction and fermentation, was even done traditionally as practiced by the rural people of Rwanda. Like the preparation of Urwagwa which is done locally, it is the same case for ‘Ikigage”.

In the preparation of Ikigage, well dried s*orghum is soaked in water, and begins to germinate. It is* immersed completely in a large container filled with water where it stays for three days. It is then removed and, after these few days, it begins to ferment. This process gives the sorghum a good flavour. The sorghum is then placed under the sun for three or four days, before it is ground in a mortar to obtain the flour.

The water is boiled and is mixed with the flour until it forms a concentrate (ikivuge) that will then be diluted with water. The mixture is left to cool, and is then poured into a large container. Malt is then added to help this fermentation process.

Scientifically describing the way ethanol is prepared, ethanol is prepared from **starch** (found in maize, cassava, millet, sorghum, etc) and **sugar molasses** (or simply banana juice) by fermentation process.

- **Fermentation** is any of many anaerobic biochemical reactions in which an enzyme (or several enzymes produced by a microorganism) catalyses the conversion of one substance into another, especially the conversion (using yeast) of sugars to alcohol or acetic acid with the evolution of carbon dioxide.
- **Alcoholic fermentation** is the process in which enzymes act on carbohydrates to give simpler compounds like ethanol (alcohol) and carbon dioxide (CO_2).

a) From Starch

Malt obtained either from maize grain, millet, or cassava contains an enzyme called **diastase** which catalyzes the hydrolysis of ***starch to maltose***.

$$2(C_6H_{10}O_5)_n + nH_2O \xrightarrow{\text{Diastase}} nC_{12}H_{22}O_{11} \text{ (maltose)}$$

At room temperature, yeast is added and one of its enzymes called **maltase** catalyzes the hydrolysis of ***maltose to simple*** sugar so called glucose.

$$\underset{\text{Maltose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{Maltase}} \underset{\text{Glucose}}{2\ C_6H_{12}O_6}$$

Finally, another enzyme of yeast called ***zymase*** catalyzes the decomposition ***of glucose to ethanol.***

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2\ CH_3CH_2OH + 2CO_2$$

b) From Molasses

Molasses containing sugars are mixed with water and yeast and then allowed to ferment for several days after which ethanol are obtained during fermentation process.

- One enzyme of the yeast called **sucrase** catalyzes the hydrolysis of ***sucrose*** present in the molasses to ***glucose and fructose***.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{Sucrase}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}$$

- Thus, another enzyme of yeast called **zymase** catalyzes the decomposition of ***glucose to ethanol***.

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2\ CH_3CH_2OH + 2\ CO_2$$

The ethanol obtained by fermentation process is only about **11%**. This is made concentrated by distillation which converts it to about ***95% ethanol***.

Table 5.3: A comparison of fermentation with the direct hydration of ethene

	Fermentation	**Hydration of ethene**
Type of process	A batch process. Everything is put into a container and then left until fermentation is complete. That batch is then cleared out and a new reaction set up. This is inefficient.	A continuous flow process. A stream of reactants is passed continuously over a catalyst. This is a more efficient way of doing things.

Rate of reaction	Very slow.	Very rapid.
Reaction conditions	Uses gentle temperatures and atmospheric pressure.	Uses high temperatures and pressures, needing lots of energy input.
Use of resources	Uses renewable resources based on plant material.	

Application activity 5.4

1. Answer the following questions about the preparation of ethanol
    a) Write equations to show the production of ethanol by:
        i) Fermentation of glucose
        ii) Hydration of ethene
    b) Give the conditions needed for each process and state the relative advantages and disadvantages of each process.
    c) State **one** advantage and **one** disadvantage of the production of ethanol by the hydration of ethene compared to the fermentation of glucose.
2. Many naturally-occurring organic compounds can be converted into other useful products. Glucose, $C_6H_{12}O_6$, can be fermented to make ethanol, which can then be dehydrated to make the unsaturated compound, ethene.
    a) Write an equation for the fermentation of glucose to form ethanol.
    b) Identify a catalyst for the dehydration of ethanol to form ethene. Write an equation for this reaction.

5.5. Chemical properties of alcohols

Activity 5.5(a)

To investigate the oxidation reaction of an alcohol

– **Requirements:**

Methanol, ethanol, 2M sulphuric acid, potassium dichromate solution, test tubes, burner, droppers, propan-2-ol and 2-methylpropan-2-ol

– **Procedure:**

- Put 5 drops of methanol in test tube

- Add 10 drops of dilute sulphuric acid followed by 5 drops of potassium dichromate solution.
- Warm the mixture gently
- Repeat the experiment with ethanol, propan-2-ol and 2-methylpropan-2-ol.

– **Questions:**

1. What happens to the colour of the solution in each case?
2. Explain the observations
3. Write the equations for the reactions that take place.

In alcohols, -**OH** group is the functional group. Thus the chemical properties of alcohols generally involve the reactions of **-OH** group. They can undergo substitution as well as elimination reaction.

The molecule of an alcohol consists of an alkyl group and functional –OH group. The C-O bond and O-H are both polarized with oxygen atom carrying a partially charge and yet it has unshared pair of electrons.

The reactions of alcohols therefore consist of;

- The cleavage of C-O resulting in either nucleophilic substitution or elimination.
- Cleavage of O-H bond resulting in substitution of hydrogen.
- Oxidation of carbon atom carrying O-H group for primary and secondary alcohol to give carbonyl derivatives.

5.5.1. Action of electropositive metals on alcohols

Electropositive metals like Na or K, reacts with alcohols forming *alkoxide* with evolution of hydrogen gas (the gas that produces *pop-motion*).

Equation:

$$2\ R\text{-}OH + 2\ Na \longrightarrow \underset{\textit{Alkoxide}}{2\ R\text{-}O\text{-}Na} + H_{2(g)}$$

Example:

$$2\ CH_3CH_2\text{-}OH + 2\ Na \longrightarrow \underset{\textit{Alkoxide}}{2\ CH_3CH_2\text{-}O\text{-}Na} + H_{2(g)}$$

Note:

In this reaction, alcohols are behaving as *weak acids* since they do not easily release the proton from O-H because oxygen is more electronegative than

H of OH, thus it attracts strongly hydrogen, and therefore H cannot be freely liberated.

$$R\text{-}OH + Na \rightarrow R\text{-}O^-Na^+ + ½\ H_2$$

Alcohols also behave as weak bases by reaction with mineral acids because they are able to accept hydrogen ion (the proton).

$$R\text{-}OH + H^+ \rightarrow R\text{-}O^+H_2$$

Hence, alcohols are *amphoteric* species since they behave as acid (losing a proton) and as base (accepting a proton). Alcohols are neither acidic nor basic enough to affect litmus paper reason why more generally they are described as *neutral*.

Alcohols are not enough acidic to react with metal hydroxides such as sodium hydroxide or potassium hydroxide.

$$R\text{-}OH + NaOH \longrightarrow \text{No reaction}$$

5.5.2. Action of hydrohalic acids (HX)

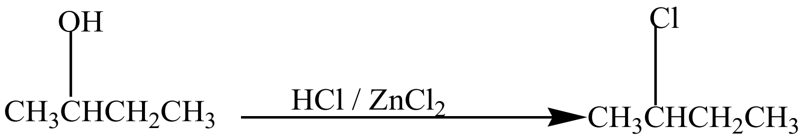
Alcohols react with hydrohalic acids to give alkyl halides (halogenoalkanes).

Examples:

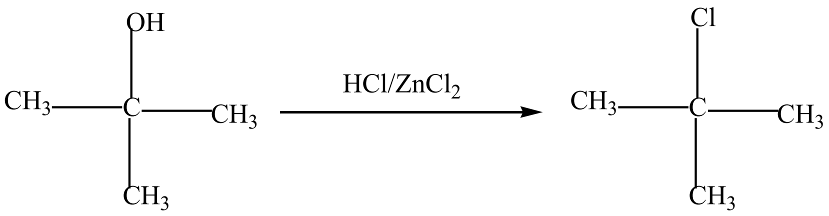
$$CH_3CH_2CH_2OH + HBr \rightarrow CH_3CH_2CH_2Br + H_2O$$

$$CH_3CH_2CH_2OH + HI \rightarrow CH_3CH_2CH_2I + H_2O$$

$$CH_3CH_2CH_2CH_2OH + HCl \xrightarrow{HCl / ZnCl_2} CH_3CH_2CH_2CH_2Cl + H_2O$$



$$CH_3\overset{OH}{\overset{|}{C}}HCH_2CH_3 \xrightarrow{HCl / ZnCl_2} CH_3\overset{Cl}{\overset{|}{C}}HCH_2CH_3$$



$$CH_3-\underset{CH_3}{\overset{OH}{C}}-CH_3 \xrightarrow{HCl/ZnCl_2} CH_3-\underset{CH_3}{\overset{Cl}{C}}-CH_3$$

Note:

The reaction with ***concentrated hydrochloric acid*** is catalyzed by ***anhydrous zinc chloride***. This reaction is called **LUCAS** test and is used to distinguish between *simple primary, secondary* or *tertiary alcohols*.

In this reaction, the alcohol is shaken with a solution of zinc chloride in concentrated hydrochloric acid.

Observations:

- Immediate cloudiness indicates presence of a tertiary alcohol.
- If the solution becomes cloudy within 5 minutes, then the alcohol is a secondary one.
- Primary alcohol would show no cloudiness at room temperature since the reaction is very slow.

For example, alcohols which are in different classes and are isomers of $\mathbf{C_4H_{10}O}$ can be distinguished by the **LUCAS** test.

Activity 5.5(b)

Experiment: Lucas Test

Aim: Determine the class of alcohol by determining their reactivity

Chemicals: 1-Butanol, 2-Butanol, t-Butyl alcohol.

Procedures

- To 0.2 mL or 0.2 g of the unknown in a test tube add 2 mL of the Lucas reagent at room temperature.
- Stopper the tube and shake vigorously, then allow the mixture to stand.
- Note the time required for the formation of the alkyl chloride, which appears as an insoluble layer or emulsion. The Lucas reagent is already prepared for you.

Positive test

Appearance of a cloudy second layer or emulsion

- 3° alcohols: Immediate to 2-3 minutes
- 2° alcohols: 5 -10 minutes
- 1° alcohols: No reaction

5.5.3. Esterification

Alcohols react with organic acids in the presence of mineral acids like sulphuric acid (as catalysts) with elimination of water, under 100 °C, to produce an ester which gives off a perfume smell. This reaction is also possible using carboxylic acid derivatives and is called ***esterification*** because it produces esters.

$$R'\text{-}OH + R\text{-}COOH \xrightleftharpoons[100^{o}C]{H_2SO_4} \underset{\textit{Ester}}{R\text{-}COOR'} + H_2O$$

$$R'\text{-}OH + R\text{-}COCl \rightleftharpoons R\text{-}COOR' + HCl$$

$$R'\text{-}OH + R\text{-}COOR'' \longrightarrow R\text{-}COOR' + R''\text{-}COOH$$

Examples:

$$CH_3CH_2\text{-}OH + CH_3\text{-}COOH \xrightleftharpoons[100^{o}C]{H_2SO_4} CH_3\text{-}COOCH_2CH_3 + H_2O$$

$$CH_3CH_2\text{-}OH + CH_3\text{-}COCl \rightleftharpoons CH_3\text{-}COOCH_2CH_3 + HCl$$

$$CH_3CH_2\text{-}OH + CH_3\text{-}COOCH_3 \longrightarrow CH_3\text{-}COOCH_2CH_3 + CH_3CH_2CH_2\text{-}COOH$$

5.5.4. Action of phosphorus halides and thionyl halide

Alcohols react with phosphorus tri- and pentachlorides to form chloroalkanes (alkyl halides).

$$3\ R\text{-}OH + PCl_3 \longrightarrow 3\ R\text{-}Cl + H_3PO_3$$

$$R\text{-}OH + PCl_5 \longrightarrow R\text{-}Cl + O{=}PCl_3 + HCl$$

Example:

$$3\ CH_3CH_2\text{-}OH + PCl_3 \longrightarrow 3\ CH_3CH_2\text{-}Cl + H_3PO_3$$

$$CH_3CH_2\text{-}OH + PCl_5 \longrightarrow CH_3CH_2\text{-}Cl + O{=}PCl_3 + HCl$$

Similar reactions occur with other phosphorus halides (PBr_3, PBr_5, PI_3 and PI_5).

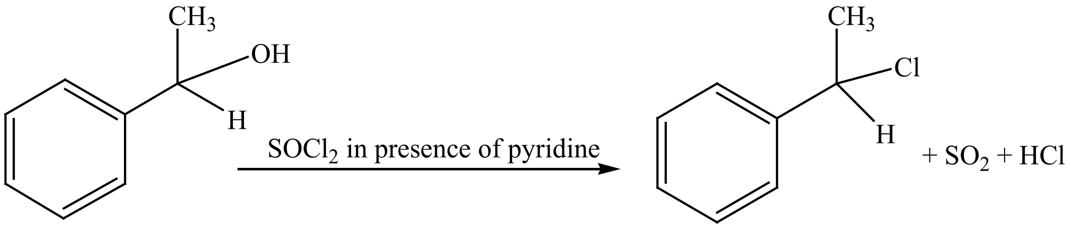
Note: In these reactions, HCl gas evolved suggests the ***presence of –O-H group***.

Alcohols also react with thionyl chloride or bromide to form alkyl halide (chloride or bromide) respectively.

$$R\text{-}OH + SOCl_2 \longrightarrow R\text{-}Cl + SO_2 + HCl$$

Examples:

$$CH_3CH_2\text{-}OH + SOCl_2 \longrightarrow CH_3CH_2\text{-}Cl + SO_2 + HCl$$



Note: This reaction generates the greenhouse gas SO_2 which is confirmed by the acidified dichromate paper which turns from orange to green colour.

5.5.5. Reaction with sulphuric acid

Alcohols react with concentrated mineral acid to give products depending on the nature of the alcohol and conditions of reactions.

- At ***about 0 °C***, primary alcohols react with sulphuric acid (in equimolar amounts) to produce alkyl hydrogen sulphates.

$$R\text{-}OH \xrightarrow[Cold\ (0\ ^{o}C)]{Conc.\ H_2SO_4} R\text{-}OSO_3H + H_2O$$

Example:

$$CH_3CH_2\text{-}OH \xrightarrow[Cold\ (0\ ^{o}C)]{Conc.\ H_2SO_4} CH_3CH_2\text{-}OSO_3H + H_2O$$

- At ***about 140 °C***, in the presence of excess primary alcohol and concentrated sulfuric acid, ether is formed.

$$2R\text{-}CH_2OH \xrightarrow{H_2SO_4/140\ ^{o}C} R\text{-}CH_2\text{-}O\text{-}CH_2\text{-}R + H_2O$$

Example:

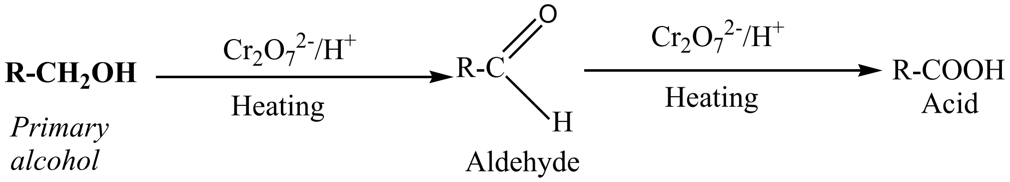
$$2CH_3CH_2\text{-}CH_2OH \xrightarrow{H_2SO_4/140\ ^{o}C} CH_3\text{-}CH_2\text{-}CH_2\text{-}O\text{-}CH_2\text{-}CH_2\text{-}CH_3 + H_2O$$

- At ***about 170 °C***, alcohols are dehydrated by heating with concentrated sulphuric acid or phosphoric acid to alkenes. The ease of dehydration is in the order: **Tertiary>secondary>primary.** This is the elimination reaction

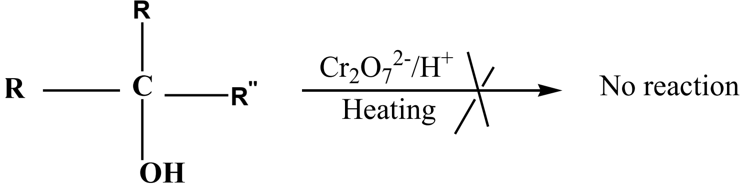
$$CH_3\text{-}CH_2\text{-}CH_2\text{-}OH \xrightarrow[170\ ^{o}C]{H_2SO_4} CH_3\text{-}CH{=}CH_2 + H_2O$$

5.5.6. Reaction of oxidation

Primary and secondary alcohols are oxidized to aldehydes and ketones respectively by use of acidified $K_2Cr_2O_7$, CrO_3, $KMnO_4$ acidified, nitric acid once concentrated.

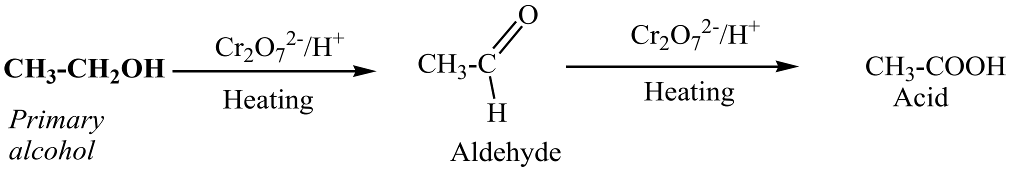


$$\underset{\text{Secondary alcohol}}{\textbf{R-CHOH-R}} \xrightarrow[\text{Heating}]{Cr_2O_7^{2-}/H^+} \underset{\text{Ketone}}{\text{R-CO-R}'}$$

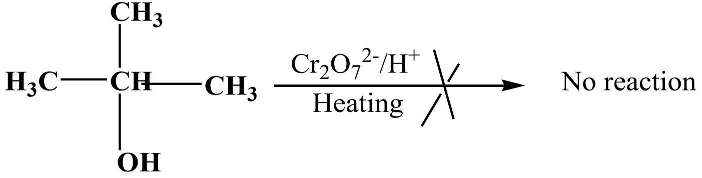


Tertiary alcohols

Examples:



$$\underset{\text{Secondary alcohol}}{\mathbf{CH_3\text{-}CHOH\text{-}CH_3}} \xrightarrow[\text{Heating}]{Cr_2O_7^{2-}/H^+} \underset{\text{Ketone}}{CH_3\text{-}CO\text{-}CH_3}$$



Tertiary alcohols

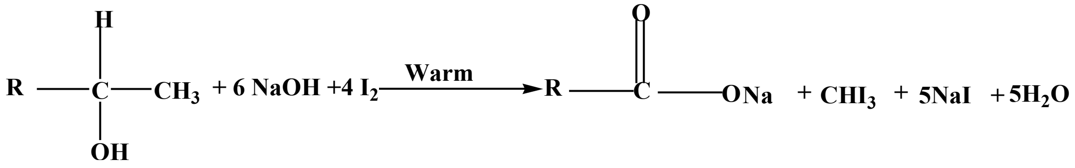
This reaction ***allows us to distinguish primary, secondary alcohols with tertiary alcohols*** because a primary and secondary alcohol turns **colourless** the solution of $KMnO_4$ from **violet** while the acidified potassium dichromate is turned from **orange** to **green.**

This is the general principle of **breathalyzer** (a trademark for an apparatus that measures a person's blood alcohol concentration from his or her breath) **used by the police to test whether the driver is drunkard or not.**

Note:

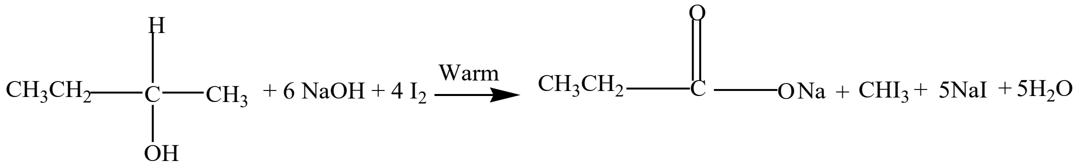
- Tertiary alcohols resist to oxidation.
- Oxidation also occurs when the alcohol is in gaseous phases by use of **silver** or **copper** catalyst under 500 °C and 300 °C respectively; here, the vapour of the alcohol is passed with air (oxygen) over heated silver or copper.
- Secondary alcohols having the structure **R-CHOH-CH_3** only undergo oxidation on treatment with iodine solution in the presence of sodium hydroxide to give ***yellow precipitate of tri-iodomethane*.**

This is a reaction which is characteristic of methyl ketones, **CH_3-CO-R'**; but iodine here acting as an oxidizing agent first oxidizes the CH_3-CHOH-R'to CH_3-CO-R'; then the methyl ketone formed gives the yellow precipitate of **CHI_3** (iodoform). From the reaction involved, we have the **iodoform test.**



$$R-\underset{OH}{\overset{H}{C}}-CH_3 + 6\,NaOH + 4\,I_2 \xrightarrow{\text{Warm}} R-\overset{O}{\overset{\|}{C}}-ONa + CHI_3 + 5NaI + 5H_2O$$

Example:



$$CH_3CH_2-\underset{OH}{\overset{H}{C}}-CH_3 + 6\,NaOH + 4\,I_2 \xrightarrow{\text{Warm}} CH_3CH_2-\overset{O}{\overset{\|}{C}}-ONa + CHI_3 + 5NaI + 5H_2O$$

Application activity 5.5

1. Complete the following chemical reactions and name the organic products obtained:
   a) Propan-2-ol + Na →
   b) Propan-2-ol + HBr→
   c) Methanol + CH_3CH_2COOH →
   d) Butan-1-ol + PCl_5 →
   e) Butan-1-ol + $SOCl_2$ →
   f) 2-methylpentan-3-ol + PBr_3 →
2. A compound **A**, $C_4H_{10}O$, is found to give the positive test on Lucas reagent immediately. **A** does not react with potassium permanganate. When **A** is heated with hydroiodic acid, it is converted into single alkyl iodide. Suggest the structure of **A.**
3. Identify the organic product or products formed by the dehydration of
   a) Ethanol
   b) Butan-1-ol
   c) Butan-2-ol
4. Equations for the processes given
   a) Mild oxidation of propan-1-ol
   b) Oxidation of propan-2-ol

5. Butan-1-ol can be oxidised by acidified potassium dichromate (VI) using two different methods.
   a) In the first method, butan-1-ol is added dropwise to acidified potassium dichromate (VI) and the product is distilled off immediately.
      i) Using the symbol [O] for the oxidising agent, write an equation for this oxidation of butan-1-ol, showing clearly the structure of the product.
      ii) State what colour change you would observe.
   b) In a second method, the mixture of butan-1-ol and acidified potassium dichromate (VI) is heated under reflux.
      i) Identify the product which is obtained by this reaction.
      ii) Give the structures and names of two branched chain alcohols which are both isomers of butan-1-ol. Only isomer 1 is oxidised when warmed with acidified potassium dichromate (VI).

Skills Lab 5

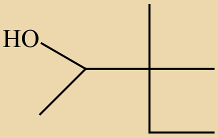
Figure 5.2: Modern brewery of alcoholic beverages

1. Visit breweries to assess the industrial production of ethanol by fermentation and write an appropriate field report.
2. Debate the uses of alcohols and dangers associated with unsafe use of different types of alcohols on our health, family and society. Write a summary.

End Unit Assessment 5

(A) MULTIPLE CHOICE QUESTIONS

1. What is the correct name of the molecule with the skeletal formula shown?



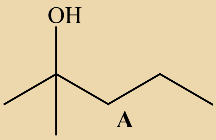
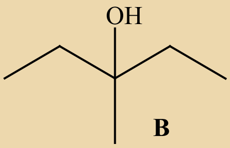
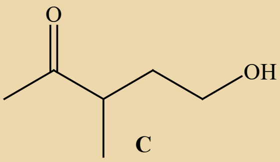
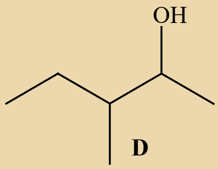
a) 1,2, 2-trimethylbutan-3-ol
b) 2-ethyl-2-methylbutan-2-ol
c) 3,3-dimethylpentan-2-ol
d) 4-hydroxy-3,3-dimethylpentane

2. An unknown organic compound reacts with sodium to give a combustible gas as one product but does not give a yellow precipitate with alkaline aqueous iodine. What is a possible identity of the unknown organic compound?

a) Propanal
b) Propan-1-ol
c) Propan-2-ol
d) Propanone

3. The boiling point of butan-1-ol is 118 °C. The boiling point of 2-methylpropan-2-ol is 82 °C. Why is the boiling point of butan-1-ol higher than that of 2-methylpropan-2-ol?
   a) Butan-1-ol has stronger induced dipole–dipole interactions because it has more electrons
   b) Butan-1-ol has stronger induced dipole–dipole interactions because it has a straight-chain structure
   c) Butan-1-ol can form hydrogen bonds while 2-methylpropan-2-ol cannot
   d) Butan-1-ol is more stable because it is a primary alcohol

4. Which compound can be oxidised by acidified potassium manganate (VII) to give 3-methylpentan-2-one?

 **A**	 **B**	 **C**	 **D**

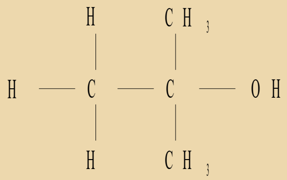
5. Ethane-1,2-diol, $HOCH_2CH_2OH$, reacts with an excess of ethanoic acid, CH_3CO_2H, in the presence of an acid catalyst. A compound is formed with the molecular formula $C_6H_{10}O_4$. What is the structure of this compound?
   a) $CH_3OCOCH_2CH_2CO_2CH_3$
   b) $CH_3CO_2CH_2CH_2CO_2CH_3$
   c) $CH_3CO_2CH_2CH_2OCOCH_3$
   d) $HOCH_2CH_2COCH_2OCOCH_3$

(B) OPEN QUESTIONS

6. This question is about a compound **X** which has the structure: $CH_3CH_2CH_2CH_2CH_2$-OH
   a) Give the systematic name of compound **X**.
   b) Is **X** a primary, secondary or tertiary alcohol?
   c) What name is given to the intermolecular forces in compound **X**?
   d) Give the structural formulae for two organic compounds which could be obtained by reacting **X** with a hot mixture of potassium dichromate and sulphuric acid.

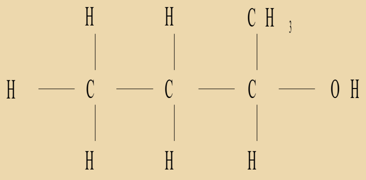
7. There are four structurally isomeric alcohols of molecular formula $C_4H_{10}O$. Graphical formulae of these isomers, labelled **A**, **B**, **C** and **D**, are shown below.

8.



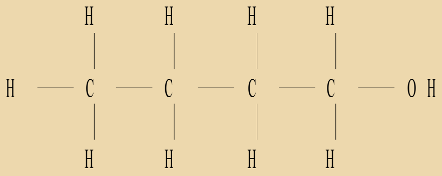
$$\begin{array}{ccccccc} & & H & & CH_3 & & \\ & & | & & | & & \\ H & - & C & - & C & - & OH \\ & & | & & | & & \\ & & H & & CH_3 & & \end{array}$$

A



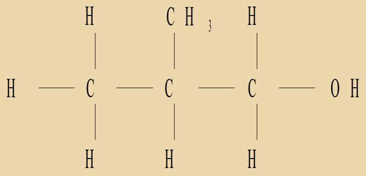
$$\begin{array}{ccccccccc} & & H & & H & & CH_3 & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & OH \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

B



$$\begin{array}{ccccccccccc} & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & OH \\ & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & \end{array}$$

C



$$\begin{array}{ccccccccc} & & H & & CH_3 & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & OH \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

D

a) Identify the type of alcohol represented by **A** and by **B**.

b) Give the name of alcohol **A**.

c) Select one of the alcohols **A**, **B**, **C** or **D** which will, on oxidation, produce an aldehyde.

   i) Give the structural formula of the aldehyde produced by this reaction.

   ii) State the reagents and conditions required for the aldehyde to be the main product of the oxidation reaction.

d) All the alcohols **A**, **B**, **C** and **D** may be readily dehydrated.

   i) Explain what is meant by the term *dehydration.*

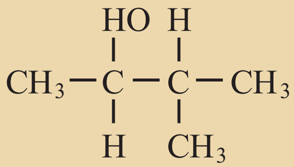
   ii) State the type of compound formed by dehydration of alcohols.

   iii) Suggest suitable reagent(s) and condition(s) for the dehydration of alcohols.

   iv) Select one of the alcohols **A**, **B**, **C** or **D** which, on dehydration, would give a single product. Draw the structural formula of this product.

   v) Select one of the alcohols **A**, **B**, **C** or **D** which, on dehydration, would give two products which are structurally isomeric. Draw structural formulae for these two structural isomers and explain why the formation of two structural isomers is possible in this case.

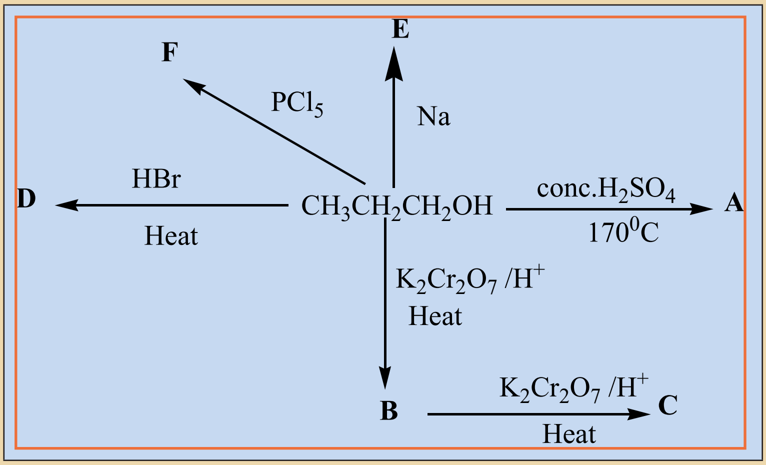
9. In the presence of reagent **X**, the alcohol shown below undergoes a reaction to form two isomeric alkenes.



$$CH_3-\overset{HO}{\underset{H}{C}}-\overset{H}{\underset{CH_3}{C}}-CH_3$$

a) Name this alcohol.
b) Give the name of the type of reaction involved in the formation of the two alkenes.
c) Suggest the identity of reagent **X**.

10. Some reactions of propan-1-ol are shown in the scheme below:



Give the structural formulae of the organic compounds **A**, **B**, **C**, **D**, **E** and **F**.

11. Glucose can be used as a source of ethanol. Ethanol can be burned as a fuel or can be converted into ethene.

$$\underset{\textit{Glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{Ethanol}}{CH_3CH_2OH} \rightarrow \underset{\text{Ethene}}{H_2C{=}CH_2}$$

a) Name the types of reactions illustrated by the two reactions above.
b) State what must be added to an aqueous solution of glucose so that ethanol is formed
c) Identify a suitable catalyst for the conversion of ethanol into ethene.
d) State the class of alcohols to which ethanol belongs.
e) Give one advantage of using ethanol as a fuel compared with using a petroleum fraction.

UNIT 6

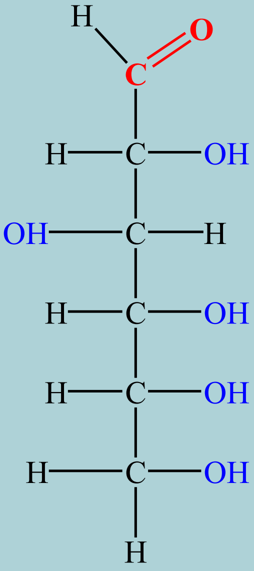
CARBONYL COMPOUNDS

Key Unit Competence:

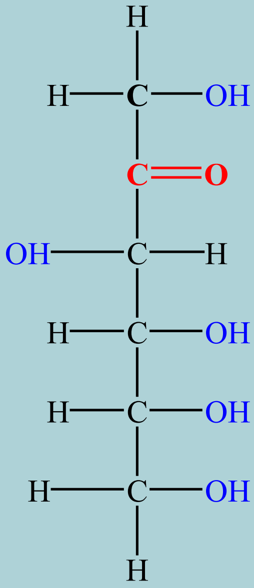
Compare the chemical nature of carbonyl compounds to their reactivity and uses.

Introductory activity 6

Honey, mangoes and other fruits contain some sugars like glucose and fructose. The following figures represent foods (honey and mangoes) and the sugars they contain.



Glucose



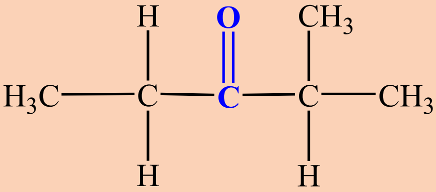
Fructose

1. State the functional groups found in each sugar; fructose and glucose.
2. State examples of other foods that contain sugars.
3. Describe similarities and differences between the two sugars in term of structural formulae.
4. Explain similarities and differences in terms of reactivity of fructose and glucose
5. What is the role of glucose meter?

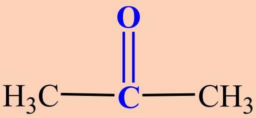
6.1. Nomenclature and isomerism of carbonyl compounds

Activity 6.1

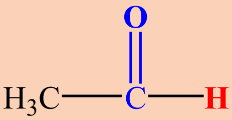
Look at the molecules below and answer the following questions.



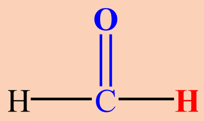
A



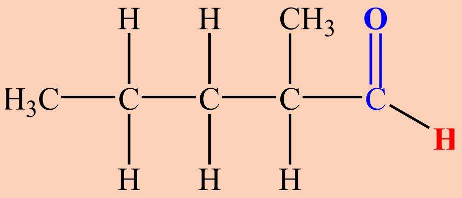
B



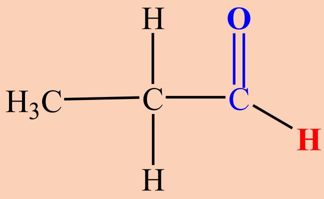
C



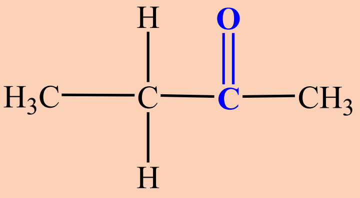
D



E



F



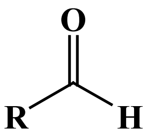
G

1. Try to organize those molecules into categories
2. What criteria have you used to categorize?
3. Give a name to those categories
4. Suggest the names of the individual molecules

Carbonyl compounds are compounds that contain carbon-oxygen double bond (C=O). Carbonyl compounds are classified into two general categories based on the kinds of chemistry they undergo. In one category there are ***aldehydes and ketones***; in the other category there are ***carboxylic acids and their derivatives***.

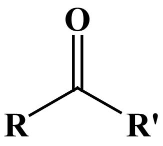
Aldehydes and Ketones compounds belong to a class of reactive organic compounds resulting from a simple replacement of methylene (-CH_2-) group by *carbonyl group* (>C=O) so called *carbonyl compounds*.

From the above definition, *two classes* of carbonyl compound are known:



Aldehyde

and



Ketone,

where **R** and **R'** can be *alkyl* or *aryl groups*, but for aldehydes **R** can be *hydrogen atom* (formaldehyde) or *different to hydrogen* while for ketones, **R** and **R'** should be *different to hydrogen atom* even though they can be the same or different.

6.1.1. Nomenclature

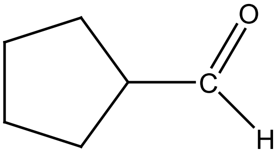
In naming aldehydes and ketones, the terminal **–e** of the corresponding alkane is replaced by ***–al*** or ***–one***, respectively.

A. Aldehydes

For aldehydes, the parent chain should contain the **–CHO group**. If the aldehyde functional group is the functional group of highest priority, the carbonyl carbon is assigned as carbon **1**.

For example, in the case of *propane*, when two of the hydrogen atoms on the terminal carbon are replaced by an oxygen atom double bonded to the carbon atom, the name of the aldehyde described is *propanal*.

A cyclic aldehyde is a compound where an aldehyde group is directly attached to a ring. In naming these types of compounds, the suffix ***–carbaldehyde*** is added to the name of the cyclic compound. For example, a *cyclopentane* with an aldehyde group attached to it will be named *cyclopentanecarbaldehyde*.



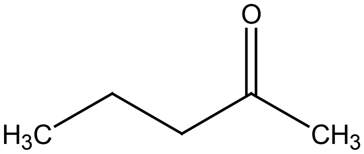
Cyclopentanecarbaldehyde

B. Ketones

Ketones are named by replacing the terminal **–e** of the parent hydrocarbon with **–one**. For compounds containing ketone as the functional group of highest priority, the parent chain is the longest chain containing the ketone functional group.

The assignment of carbon numbers proceeds in the direction giving the carbonyl carbon the lowest possible number; and the locant number is placed before the suffix.

For example, when the parent compound is *pentane* as it is a 5-carbon alkane, the lowest possible number for the carbonyl carbon is 2 when counting is started from the rightmost carbon atom. In this case, the name of the compound will be ***pent-2-one****or* ***2-pentanone.***

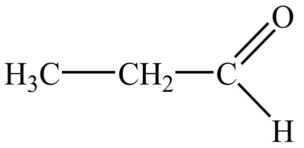


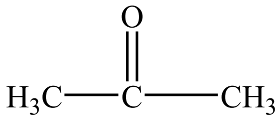
Pent-2-one

6.1.2. Isomerism

Aldehydes show *chain isomerism* (for aldehydes with 4 or more carbon atoms and ketones with five or more carbon atoms) and *positional isomerism* (for aromatic aldehydes and ketones with five or more carbon atoms) among themselves, and *functional isomerism* with ketones, cyclic ether, and unsaturated alcohols (enol) that may provide geometric isomers (cis and trans or of E-Z convention).

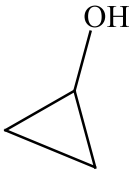
***Example:* C_3H_6O** has many isomers like the following:

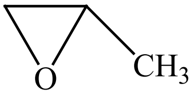


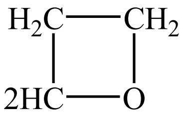


$$H_3C-\overset{\overset{O}{\|}}{C}-CH_3$$

$$CH_3-O-\underset{H}{C}=CH_2$$



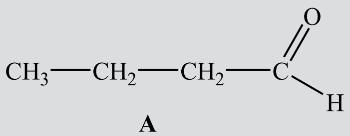




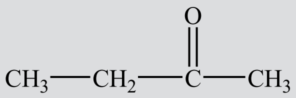
$HO\text{-}CH_2\text{-}CH\text{=}CH_2$

Application activity 6.1

1. Write the names of the following compounds:

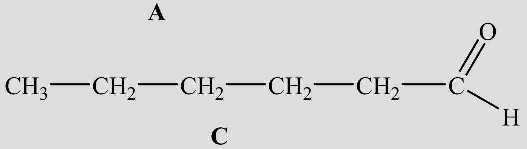


A

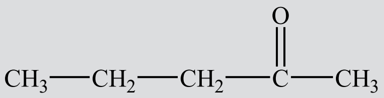


$$CH_3-CH_2-\overset{\overset{O}{\|}}{C}-CH_3$$

B



C



$$CH_3-CH_2-CH_2-\overset{\overset{O}{\|}}{C}-CH_3$$

D

2. Draw the structural formula of hexan-3-one and write the name and formula of its isomer which is an aldehyde.
3. Draw the structural formula of 2-methylpropanal and write the name and formula of its isomer which is a ketone.

6.2. Physical properties and uses of aldehydes and ketones

Activity 6.2 (a)

To investigate some physical properties of aldehydes and ketones

Procedure:

- Take 50 mL for each substance: ethanal, butanal and propanone.
- Mix ethanal (or formaldehyde) with 50 mL of water in beaker.
- Mix butanal with 50 mL of water in beaker.
- Mix propanone (or acetone) with 50 mL of water in beaker

Questions

1. Compare the solubility of ethanal, butanal and propanone in water.
2. State the intermolecular forces present in each substance.
3. Explain what happens in terms of intermolecular forces during mixing each of the above substances with water.
4. Explain why some substances have high solubility in water than others.
5. Explain how the intermolecular forces present in ethanal, butanal and propanone affect other physical properties like boiling and melting point of these substances.
6. Suggest any uses of the substances given.

6.2.1. Physical properties of aldehydes and ketones

a) Physical state and smell

Lower members of aldehydes and ketones (for **$n<5$**) are ***liquids***, except methanal which is a *gas* at room temperature. Methanal and liquid aldehydes have a ***distinguishing smell*** (pungent smell) while liquid ketones have ***pleasant odour*** due to carbonyl group, and are sweet like bonbons (for example, the solid ketones like fructose which is a ketose and propanone which is liquid has a mild, pleasant odour).

b) Boiling point

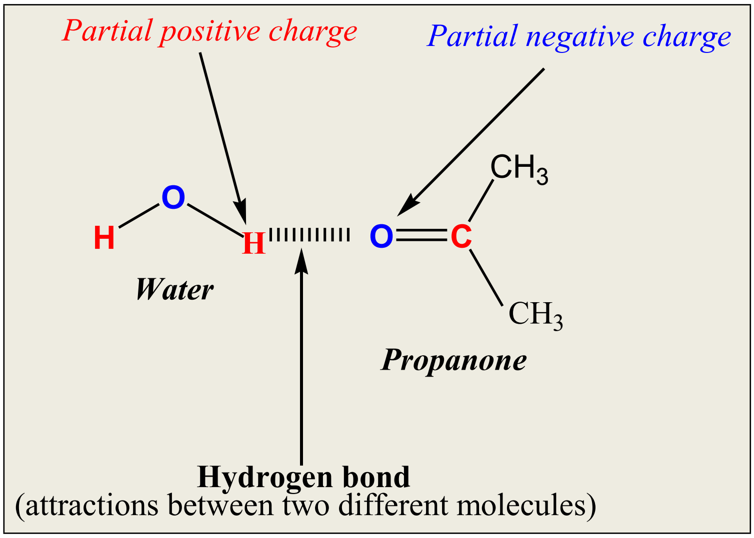
The boiling point of methanal is -19°C and for ethanal it is +21°C. From this we can say that the boiling point of ethanal is close to room temperature. Generally, the boiling point of aldehydes and ketones increases with increase in molecular weight. Boiling point depends upon the strength of the intermolecular forces.

- *Vander Waals dispersion* forces: As the molecules get longer and the number of electrons increases, the attraction between them also increases. For both aldehydes as well as ketones the boiling point increases with the increase in number of carbon atoms.
- *Vander Waals dipole-dipole attraction*: Because of the presence of carbon-oxygen double bond, both aldehydes as well as ketones are polar in nature. There will be attraction between permanent dipoles as well as the molecules which are near to it. This is the reason for aldehydes and ketones having boiling point higher than the similar sized hydrocarbons.

c) Solubility

Aldehydes and ketones are soluble in water but their solubility decreases with increase in the length of the chain. Methanal, ethanal and propanone are those aldehydes and ketones which are of small size and are miscible with water in almost all proportions.

Aldehydes and ketones cannot form hydrogen bonds with themselves but they can have hydrogen bonds with water molecules and this forms the basis for good solubility of aldehydes and ketones in water. This is also because of dispersion forces and dipole-dipole interactions.



6.2.2. Uses of aldehydes and ketones

Activity 6.2 (b)

Observe the following materials made by *bakelite polymers* and answer the questions below:


Questions:

1. The Bakelite polymer is made from phenol and methanal. Basing on the objects represented in the pictures above, give some uses of formaldehyde.
2. Outline the uses of other carbonyl compounds.

- **Methanal** (formaldehyde) is mainly found in *formalin* (trade name for solution containing 40% formaldehyde and 60% water or water and methanol); it is employed as a disinfectant, insecticide, fungicide, and deodorant. Formaldehyde is used extensively in the chemical industry in the synthesis of organic compounds such as *Bakelite* (a polymer made from methanal and phenol). It is also used in embalming and in tanning.

- **Propanone** (acetone) is a colourless, flammable liquid, completely soluble in water and organic solvents; acetone is itself an important solvent and is used both in the laboratory and in industry. Enormous quantities are used as solvents for cellulose acetate in the production of rayon (a textile fibre or fabric made from regenerated cellulose) and as a gelatinizing agent for explosives. Acetone is also used as an ingredient in lacquer solvent and to dissolve gums and resins. It is the solvent in rubber cement and in some cleaning fluids.

- **Ethanal** (acetaldehyde) is a colourless volatile flammable liquid manufactured by catalytic oxidation of ethanol or catalytic hydration of ethene. It is used in the breathalyser test and to silver mirrors.

- **Butanal** (n-butyraldehyde) is an organic compound which appears as a clear liquid. It is used mainly as an intermediate in the production of synthetic resins, rubber vulcanization accelerators, solvents, and plasticizers.

Application activity 6.2

1. The boiling point of ethanal is around 20°C (MW = 44 $gmol^{-1}$) and that of ethanol is around 78°C (MW = 46 $gmol^{-1}$).
   a) Explain the cause of this difference in their boiling points even though they have nearer molecular weights.
   b) No hydrogen bonding is formed between ethanal molecules but ethanal readily dissolves in water. Why?
2. Appreciate the existence of carbonyl compounds in our daily life.
3. Explain the reasons of the following observations:
   a) Unlike the similar-sized alkanes, the small aldehydes and ketones are soluble in water.
   b) The solubility of aldehydes and ketones falls as the molecules get bigger.

6.3. Preparation methods of ketones and aldehydes

Activity 6.3 (a)

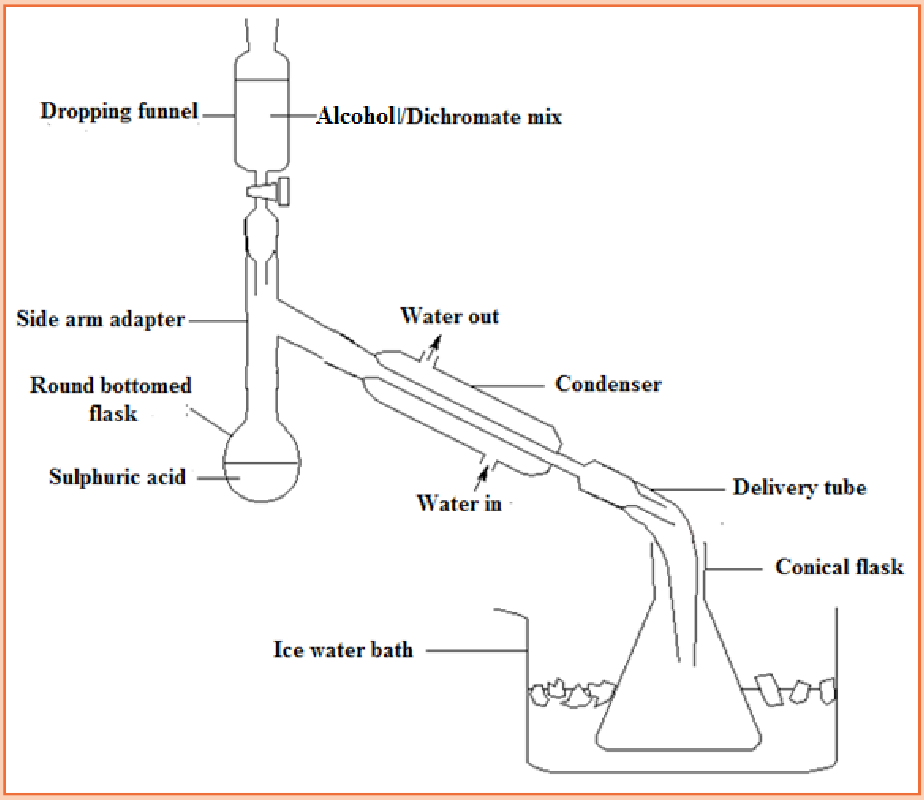
Aim: To prepare ethanal from ethanol using acidified potassium dichromate.

Ethanal and ethanoic acid can both be prepared by the oxidation of ethanol using the same oxidising agent – acidified potassium dichromate. The product formed during this oxidation reaction depends on the conditions and apparatus used.

Procedure

1. Place about 20 cm^3 of dilute sulphuric acid into a round-bottomed flask, and add two anti-bumping granules.
2. Add 10 g of potassium dichromate and shake the mixture until the solid has dissolved. It may be necessary to warm the mixture gently.
3. Cool the mixture down and add 8 cm^3 of ethanol dropwise, shaking the flask between additions.

4. Set up the distillation apparatus as shown below:



5. Heat the product gently until a few cm^3 of liquid has boiled over.

Analysis

1. Write equation, using [O] to represent the oxidising agent, to show the oxidation of ethanol to ethanal.
2. What happens to the ethanal during distillation and why is this important?
3. What does ethanal smell like?

Activity 6.3 (b)

Aim: Preparation of Propanone (Acetone) from Propan-2-ol

Procedure:

1. Prepare an ice/water bath; this may be conveniently done in a large (i.e., > 500 mL) beaker.
2. Place 20 mL of 70% propan-2-ol in a 250 mL beaker, and add 20 mL of distilled H_2O.

3. Stir to mix, and cool the beaker in an ice bath to about 10°C.
4. With the solution still in the ice bath, add, all at once, 100 mL of "acidic dichromate" solution.
5. In a few seconds, the mixture will turn dark, followed by a rather sudden rise in temperature to 50-60°C.
6. Stir the mixture (still in the ice bath) until its temperature has fallen to below 50°C. Do not use the thermometer as a stirring rod.
7. Pour the mixture into a 250 mL distilling flask using a funnel to prevent spilling any.
8. Assemble a distillation apparatus (see apparatus in activity 6.3 (a)). Use a graduated cylinder as the receiver.
9. Heat *gently*. After 10-15 minutes, the liquid should begin to boil and drops of acetone begin to collect in the receiver.
10. Record the temperature when the first drop appears.
11. Continue the distillation until at least 5 mL of acetone has collected.
12. Record the temperature again, and then stop the distillation.
13. Measure the volume of acetone obtained.

Questions

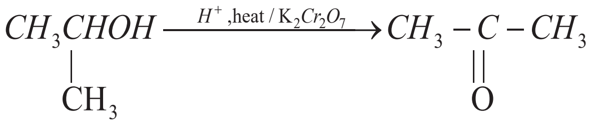
1. Write the equation of the reaction which takes place in this experiment.
2. What is the colour change observed during the experiment?

Aldehydes and ketones can be formed by similar methods (especially oxidation of alcohols) or different methods. The following section outlines different methods of how carbonyl compounds can be prepared.

6.3.1. Preparation of aldehydes and ketones from alcohols

(a) In liquid phase

Primary and secondary alcohols in ***liquid phase*** can be oxidized by use of acidified $K_2Cr_2O_7$, $KMnO_4$, or CrO_3 to aldehydes and ketones respectively.



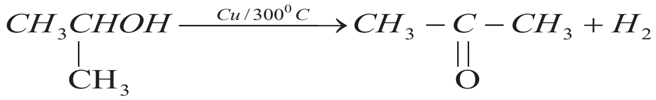
$$CH_3\underset{\substack{|\\ CH_3}}{CH}OH \xrightarrow{H^+,\text{heat}/K_2Cr_2O_7} CH_3-\underset{\substack{||\\ O}}{C}-CH_3$$

$$3CH_3CHOHCH_3 + Cr_2O_7^{2-} + 8H^+ \longrightarrow 3CH_3COCH_3 + 2Cr^{3+} + 7H_2O$$

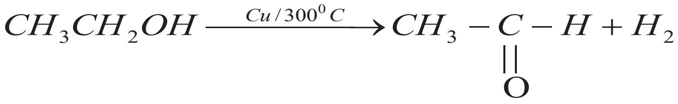
Note: One *major disadvantage* of this method for preparing aldehydes is that the aldehydes produced are further oxidized to carboxylic acids. Further oxidation of the aldehydes produced *can however be avoided by carrying out the reaction under heat so that aldehydes which have lower boiling points than corresponding alcohol are removed from the reaction mixture as soon as they are formed*. Therefore, the alcohol must be added to the hot oxidizing agent.

(b) In vapor phase

In ***vapor phase*** both the primary and secondary alcohols can be dehydrated by passing their vapour over heated copper at 300 °C to give aldehydes and ketones respectively.



$$CH_3\underset{\underset{CH_3}{|}}{CH}OH \xrightarrow{Cu/300^0C} CH_3-\underset{\underset{O}{||}}{C}-CH_3+H_2$$



$$CH_3CH_2OH \xrightarrow{Cu/300^0C} CH_3-\underset{\underset{O}{||}}{C}-H+H_2$$

Note: Also by passing the vapors of the above alcohols together with air over heated silver catalyst, aldehydes or ketones are produced.

$$R-CH_2-OH+\frac{1}{2}O_2 \xrightarrow{Ag/500^0C} RCHO+H_2O$$

$$CH_3-CH(CH_3)-OH+\frac{1}{2}O_2 \xrightarrow{Ag/500^0C} CH_3CO-CH_3+H_2O$$

6.3.2. Preparation of aldehydes and ketones from carboxylic acid

This is done by heating calcium salts of carboxylic acids. When calcium methanoate is heated alone, methanal is produced.

$$(HCOO)_2Ca \xrightarrow{heat} CaCO_3+H_2CO$$

Other aldehydes are produced by heating calcium salt of carboxylic acid with calcium methanoate.

$$(HCOO)_2Ca+(RCOO)_2Ca \xrightarrow{heat} 2CaCO_3+2RCHO$$

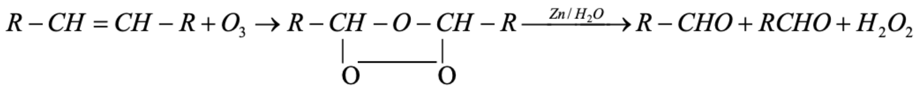
$$(HCOO)_2Ca+(CH_3CH_2COO)_2Ca \xrightarrow{heat} 2CaCO_3+2CH_3CH_2CHO$$

When calcium salts of carboxylic acids other than that of methanoic acid are heated alone ketones are produced.

$$(CH_3CH_2COO)_2Ca \xrightarrow{heat} CaCO_3+CH_3CH_2-CO-CH_2CH_3$$

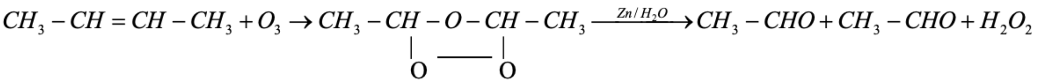
6.3.3. Preparation of aldehydes and ketones from alkenes

In this method, alkenes are ozonized and diluted with water in the presence of Zn.



$$R-CH=CH-R+O_3 \rightarrow R-\underset{|}{CH}-O-\underset{|}{CH}-R \xrightarrow{Zn/H_2O} R-CHO+RCHO+H_2O_2$$

Example:



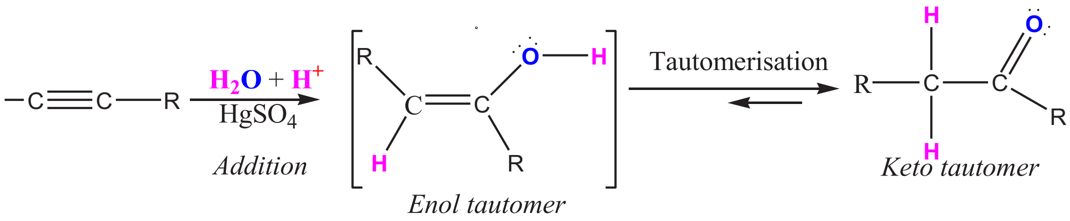
$$CH_3-CH=CH-CH_3+O_3 \rightarrow CH_3-\underset{|}{CH}-O-\underset{|}{CH}-CH_3 \xrightarrow{Zn/H_2O} CH_3-CHO+CH_3-CHO+H_2O_2$$

Note:

- In case a mixture of ketones and aldehydes is produced, here they can be separated by *fractional distillation* even though it is not easy to achieve it except retaking again several times.
- Zn dust is used so as to decompose H_2O_2 which would otherwise oxidize aldehydes produced.

6.3.4. Preparation of aldehydes and ketones from alkynes

When alkynes are passed through hot dilute sulphuric acid in the presence of mercuric sulphate, carbonyl compounds are produced.



Example:

$$CH_3-CH_2-C\equiv CH+H_2O \xrightarrow{H_2SO_4/Hg^{2+}} CH_3-CH_2-CH(OH)=CH_2$$

$$\xleftrightarrow{Tautomerism} CH_3-CH_2-CO-CH_3$$

6.3.5. Preparation of aldehydes and ketones from acid chlorides

In this method, acid chlorides are reduced by hydrogen in the presence of a suitable catalyst (like palladium or platinum) to aldehydes.

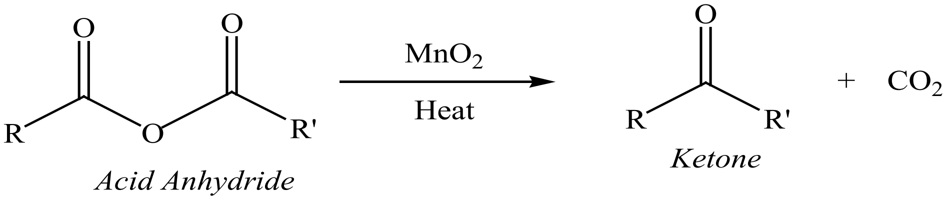
$$R-CO-Cl+H_2 \xrightarrow{Pd} R-CHO+HCl$$

$$CH_3-CO-Cl+H_2 \xrightarrow{Pd} CH_3-CHO+HCl$$

6.3.6. Preparation of aldehydes and ketones from acid anhydrides

Passing the vapour of acid anhydride on manganese dioxide, MnO_2, the *decarboxylation* occurs with the evolution of carbon dioxide where MnO_2 acts as a catalyst.

This process is *specific to ketones only.*



Application activity 6.3

1. Write a balanced equation of the reaction between propan-2-ol and $K_2Cr_2O_7/H^+$
2. Draw the structure of the carbonyl compound that would be formed if each of the following alcohols is oxidized. You can assume that conditions are fulfilled to avoid further oxidation of the aldehyde to a carboxylic acid.
   (i) $CH_3CH_2CH_2OH$
   (ii) $CH_3CH_2CH(CH_3)CH_2OH$
   (iii) $CH_3CH_2CHOHCH_3$
3. Draw the structure of the alcohol you would oxidize in order to obtain each of the following compounds.
   (i) Pentan-2-one
   (ii) Butanal
4. Outline five different ways by which you can prepare butan-2-one.

6.4. Chemical reactions of carbonyl compounds

Activity 6.4 (a)

To separate carbonyl compounds from other compounds basing on their chemical properties

2,4-dinitrophenylhydrazine (Brady's reagent) is a substance that reacts with all carbonyl compounds. The occurrence of this reaction is easily observed because the orange/yellow precipitate forms. You are provided with the following substances: propanal, propanone, ethanol, glucose solution and Brady's reagent.

Procedure

- Take about 2 mL of each solution; propanal, propanone, ethanol and glucose solution in test tubes.
- Add 6 drops of the 2,4-dinitrophenylhydrazine to each of the test tubes containing: propanal, propanone, ethanol or glucose solution. If no precipitate forms immediately, warm for 5 minutes in the water bath.
- Record your observations in the table below.

Substance	Observations	Deductions
Aldehyde (propanal)		
Ketone (propanone)		
Alcohol (ethanol)		
Sugar (glucose)		

Both aldehydes and ketones have a common functional group >C=O in which oxygen atom being *more electronegative* than carbon attracts more towards itself thus acquiring a *partial negative charge* while the carbon carries a *partial positive charge.* Hence carbon oxygen bond is polarized, therefore nucleophilic reagents and bases will attack the electron deficient carbon with the result that its electrons are shifted towards the oxygen atom. The anion formed then takes up a proton to give the end product.

The ***carbonyl group in aldehydes will be more reactive than in ketones***. This is because in ketone, due to presence of two alkyl groups which have ***positive inductive effect***, the charge on carbonyl carbon will be highly neutralized with the result that any attacking nucleophile is less attracted. Because of this, methanal without any alkyl group, will be more reactive than any ***aldehyde*** and all ***ketones****.*

6.4.1. Some reactions undergone by both aldehydes and ketones

(a) Reduction reactions

Both aldehydes and ketones are reduced by hydrogen in the presence of catalyst, like *Ni, Pt* or *Pd,* to primary and secondary alcohols respectively.

$$R-COH+H_2 \xrightarrow{Ni/heat} RCH_2OH \text{(primary alcohol)}$$

$$R-CO-R'+H_2 \xrightarrow{Ni/heat} RCHOH-R' \text{(secondary alcohol)}$$

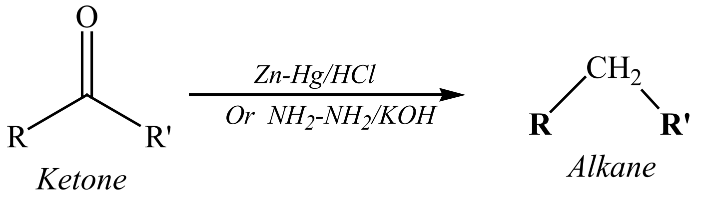
Note:

- Reduction also can be effected by use of *$LiAlH_4$, $NaBH_4$* or *Na /Alcohol*.

$$CH_3CH_2-CHO+H_2 \xrightarrow{NaBH_4} CH_3CH_2CH_2OH$$

$$CH_3CH_2-CO-CH_3+H_2 \xrightarrow{LiAlH_4} CH_3CH_2CHOH-CH_3$$

- The reduction can be enhanced only for **ketones to alkanes** in the presence of **concentrated hydrochloric acid and zinc amalgam powder** as a catalyst through **Clemmensen reduction**; or, using **hydrazine in the presence of alkali (KOH)** by a special reduction called **Wolf Kishner reduction.**

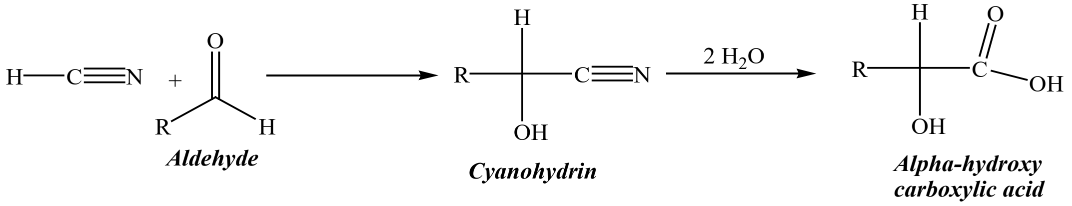


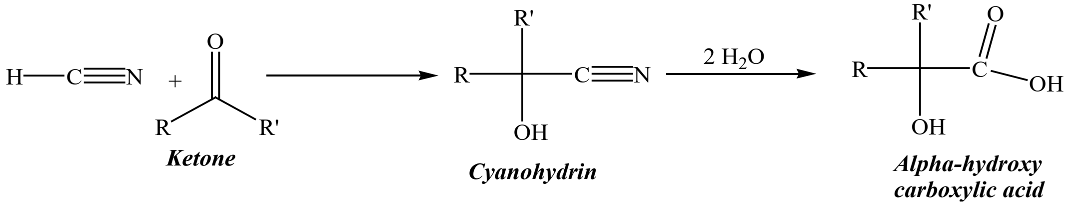
(b) Addition reaction of Hydrogen Cyanide

Both aldehydes and ketones react with KCN in the presence of H_2SO_4 (or H-CN) to produce ***2-hydroxyl nitriles*** (known as ***cyanohydrins***).

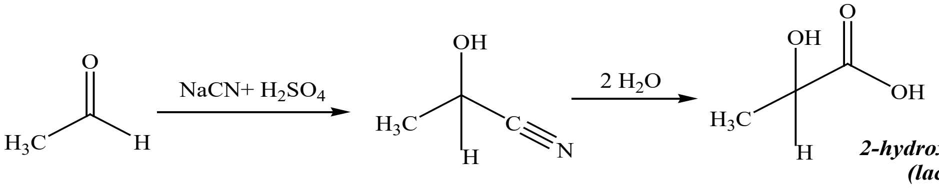
Note that, once this water is added to this cyanohydrin, the ***alpha-hydroxy carboxylic acid*** is produced.

Hydrogen cyanide, HCN, is a nucleophile; it donates electrons to the electron deficient carbon of the carbonyl group.

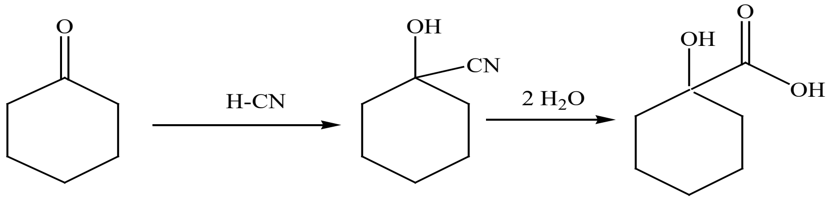




Examples:



2-hydroxy propanoic (lactic acid)



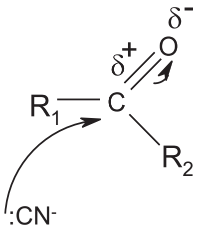
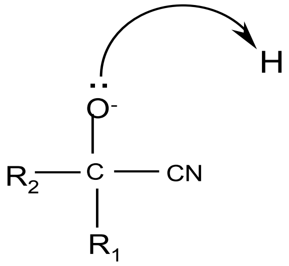
Note:

HCN is a very toxic gas, that is why it is preferable to generate it in situ by the reaction between KCN or NaCN with sulphuric acid (or HCl).

$$H_2SO_4 + KCN \rightarrow KHSO_4 + HCN$$

$$KCN(s) + HCl(aq) \rightarrow HCN(g) + KCl(aq)$$

The mechanism consists of three steps:

***Step 1**:* The HCN is a weak acid and dissociates: $HCN \rightarrow H^+ + CN^-$ The CN^- behaves as a nucleophile. ***Step 2**:* The nucleophile attacks the carbonyl:  	***Step 3:*** The O atom picks up the H^+ ion: 

(c) Reaction with Phosphorous pentachloride

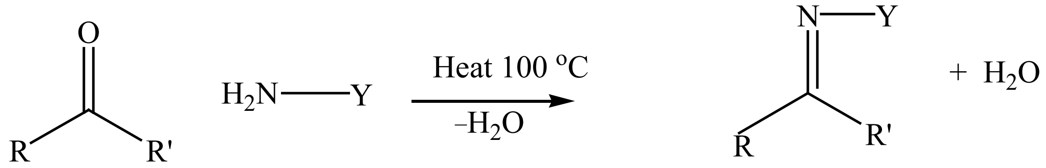
Both aldehydes and ketones react with PCl_5 to give gem dihalides (*dihalides with halogen atoms are attached to the same carbon*).

$$CH_3CH_2CHO + PCl_5 \rightarrow CH_3CH_2CHCl_2 + O = PCl_3$$

$CH_3COCH_3 + PCl_5 \rightarrow CH_3CCl_2CH_3 + O = PCl_3$

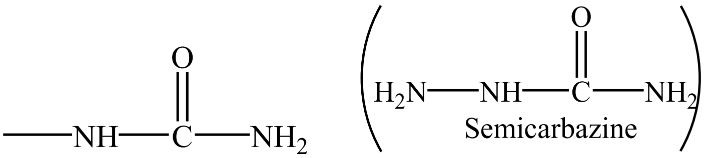
(d) Condensation reactions

Both aldehydes and ketones react with compounds containing **$-NH_2$** with loss of water molecule. The products of these condensation reactions are ***brightly coloured (yellow or orange) crystalline solids with sharp melting points*** which are used for identifying them.



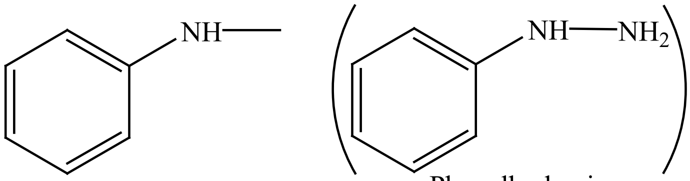
Note: Y can be one of the following atoms or groups:

- H (H-NH_2: Ammonia) to give ***imines*** from the intermediate unstable form which is ***iminol***
- OH (NH_2OH: Hydroxylamine) to produce ***oxime***
- NH_2 (NH_2-NH_2: Hydrazine) to produce ***hydrazones***



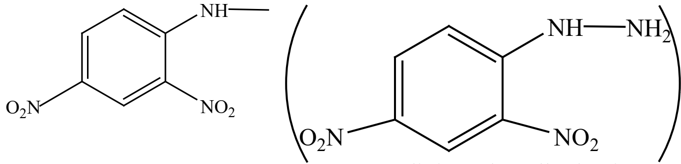
Semicarbazine

to give ***semi-carbazone***



Phenylhydrazine

to give ***phenylhydrazone***



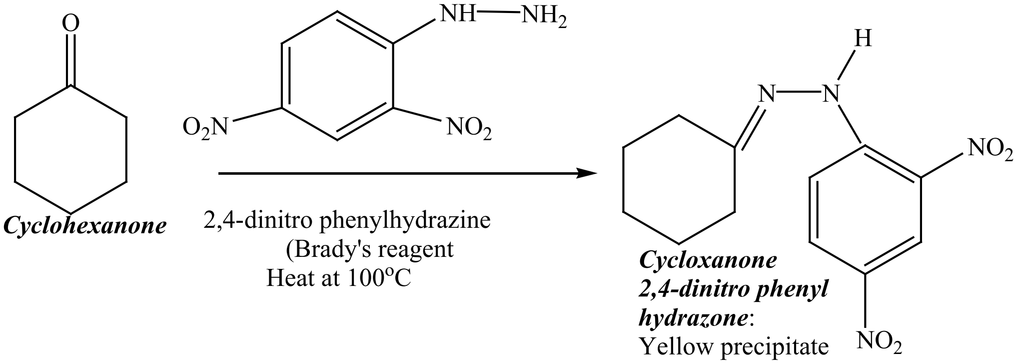
2,4-dinitro phenylhydrazine

(Brady's reagent)

to give ***2,4-dinitrophenylhydrazones***

(A **yellow precipitate** with tendency to **yellow orange** on the sunlight)

Note: This reaction **is used to test carbonyl group**, i.e. aldehydes and ketones, with a positive test when a ***yellow precipitate*** is formed.



Note: These reactions take place *not at lower values of* pH (between 4.5 - 6.5) since protons that accelerate the rate of dehydration but at lower values of pH , the molecule **Y-NH$_2$** will be protonated by **H$^+$** and give **Y-NH$_3^+$** and cannot undergo nucleophilic attack against carbonyl group.

6.4.2. Difference in reactions for aldehydes and ketones

(a) Oxidation reactions of carbonyl compounds

Activity 6.4 (b)

You are provided with the following: propanal, propanone and potassium dichromate (VI) solution acidified with dilute sulphuric acid.

- Take about 2 mL of each solution; propanal and propanone;
- Add 6 drops of the potassium dichromate (VI) solution acidified with dilute H_2SO_4.
- Record your observations in the table below and give your deductions.

Substance	Observations	Deductions
Aldehydes (propanal)		
Ketones (propanone)		

Aldehydes and not ketones are oxidized to carboxylic acids. Oxidizing agents can be acidified $Cr_2O_7^{2-}$, CrO_3, H_2O_2, acidified $KMnO_4$ and O_2 from air.

Oxidation of aldehyde by $K_2Cr_2O_7/H^+$ solution

Add few drops of the aldehyde or ketone to a solute of potassium dichromate (VI) acidified with dilute sulphuric acid. If the colour does not change in the cold, the mixture is warmed gently in a beaker containing hot water.

Tested substances	Observations
Aldehydes	Orange colour of $K_2Cr_2O_7$ solution turns green of Cr^{3+}solution.
Ketones	Orange colour of $K_2Cr_2O_7$ solution does not change.

The dichromate (VI) ion, $Cr_2O_7^{2}$, is an oxidizing agent, it oxidizes aldehyde to carboxylic acid, and it is reduced to Cr^{3+}:

$$3RCHO + Cr_2O_7^{2-} + 8H^+ \rightarrow 3RCOOH + 2Cr^{3+} + 4H_2O$$

Oxidation of aldehyde by acidified $KMnO_4$ solution

When aldehydes are treated with acidified potassium permanganate, the purple solution becomes colourless due to the formation of manganese (II) ions.

Tested substances	Observations
Aldehydes	Purple colour of $KMnO_4$ solution turns colourless of Mn^{2+} solution.
Ketones	Purple colour of $KMnO_4$ solution does not change.

The manganate (VII) ion, MnO_4^-, is an oxidizing agent, it oxidizes aldehyde to carboxylic acid, and it is reduced to Mn^{2+}:

$$RCHO + MnO_4^- + H^+ \xrightarrow[Warm]{} RCOOH + Mn^{2+}$$

Oxidation of aldehyde by Fehling's solution, Benedict's solution or Tollen's reagent

Oxidizing agents like ***Fehling's solution***, ***Benedict's solution*** or ***Tollens reagent*** are also used especially with the purpose of distinguishing ketones from aldehydes since their (oxidation) reactions lead to clear observations.

Activity 6.4 (c)

You are provided with the following: ethanal, propanone, Fehling's solution and Benedict's solution.

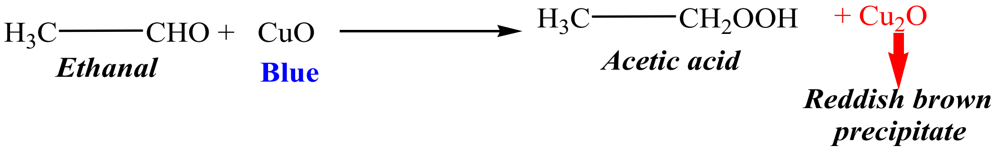
- Put about 2 mL of ethanol in the first test tube and about 2 mL of propanone in the second test tube.
- Add 6 drops of the Fehling's solution or Benedict's solution to each of the tubes containing 2 ml of ethanal or propanone to be tested.
- Warm gently the mixture in a hot water bath for a few minutes.

- Record your observations and give deductions in the table below.

Substance	Observations	Deductions
Ketones (propanone)		
Aldehydes (propanal)		

When aldehydes are heated with ***Fehling's solution***, a reddish brown precipitate of copper (I) oxide is obtained. Fehling's solution is a mixture of $CuSO_4.5H_2O$ and sodium potassium tartrate: KOOC-CHOH-CHOH-COONa in a stronger alkali.

Simplified reaction with ethanal is given as the example here below:



$$H_3C{-}CHO + CuO \longrightarrow H_3C{-}CH_2OOH + Cu_2O$$

When aldehydes are heated with ***Benedict's solution***, a reddish brown precipitate of copper (I) oxide (Cu_2O) is also obtained.

A few drops of Fehling's solution or Benedict's solution are added to the aldehyde or ketone and the mixture is warmed gently in a hot water bath for a few minutes.

Tested substances	Observations
Aldehydes	Blue solution produces a reddish brown precipitate of Cu_2O.
Ketones	The blue colour of Cu^{2+} solution does not change. Reaction does not occur.

Fehling's solution and Benedict's solution are oxidizing agent; they oxidize aldehydes to carboxylic acid.

Remember that reaction takes place in basic solutions, acid formed is neutralized by base, and hence the products area salt of carboxylic acid instead of carboxylic acid. Equation of reaction:

$$RCHO(l) + 2\,Cu^{2+}\text{ (in complex)} + 5OH^-(aq) \longrightarrow RCOO^-\,(aq) + Cu_2O\,(s) + 3H_2O\,(l)$$

Note: Fehling's solution and Benedict's solution react with aldehyde in the same way; both solutions contain Cu^{2+} and OH^-. The only difference is in their structures; in Fehling's solution Cu^{2+} is ***complexed with tartrate ligand*** but in Benedict's solution Cu^{2+} is ***complexed with citrate ligand***.

Activity 6.4 (d)

You are provided with the following: propanal, propanone and Tollens' reagent.

- Take about 2 mL of each solution; propanal and propanone.
- Add 6 drops of the Tollens' reagent to each of the following in the test tubes; propanal or propanone.
- Warm gently the mixture in a hot water bath for a few minutes.
- Record your observations and deductions in the table below.

Substance	Observations	Deductions
Aldehydes (propanal)		
Ketones (propanone)		
Sugar (glucose)		

When aldehydes are warmed with **Tollens reagent**, metallic silver deposits on the wall of the test tube, giving silver mirror: This is the **silver mirror test** for aldehydes.

$$RCHO + 2Ag(NH_3)_2NO_3 + H_2O \rightarrow RCOO^- NH_4^+ + NH_3 + 2Ag_{(s)}$$

Therefore, $CH_3CH_2CH_2CHO$ and $CH_3CH_2COCH_2CH_3$ can be distinguished by this test.

Tollens' reagent is a solution of ***diamminesilver (I) ion, $[Ag(NH_3)_2]^+$ and OH^-.*** In order to identify if a substance is aldehyde or ketone, add few drops of Tollens' reagent to test tubes containing aldehyde or ketone and warm gently in a hot water bath for a few minutes. The formations of sliver mirror or grey precipitate is an indication of the presence of aldehyde.

Tested substances	Observations
Aldehydes	The colourless solution produces a grey precipitate of silver, or a silver mirror on the test tube.
Ketones	Colourless solution does not change: No reaction.

Equation of reaction:

$$2\ Ag(NH_3)_2{}^+{}_{(aq)} + RCHO_{(l)} + 3\ OH^-_{(aq)} \longrightarrow 2\ Ag_{(s)} + ROO^-_{(aq)} + 4\ NH_{3(aq)} + 2\ H_2O_{(l)}$$

Note: Oxidation of aldehydes is so easy that even atmospheric oxygen can bring about. That is the reason why most samples of aldehydes are found contaminated with variable amounts of corresponding acids; which is the case during the oxidation of ethanol from fermentation to be oxidized fast to acetic acid (vinegar), therefore ***the wine becomes sour***.

(b) Iodoform reaction

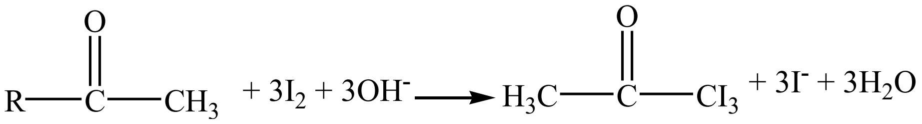
Only methyl ketones (R-CO-CH_3) not aldehydes (*excluding ethanal*) undergo this reaction. This reaction can be used to distinguish a methyl ketone from any other ketones.

In this reaction, the methyl ketone is heated with a mixture of iodine solution and sodium hydroxide solution. A ***yellow precipitate of triiodomethane***, **CHI_3**, (iodoform) is formed.

This reaction takes place into two main steps:

First step:

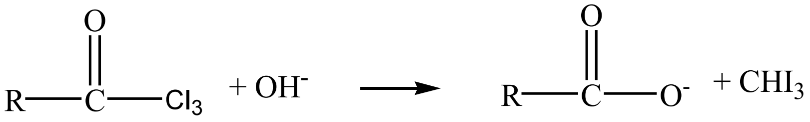
Three hydroxides, OH^-, remove three hydrogens from methyl group and the place of hydrogen is taken by iodide.



$$R-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3 + 3I_2 + 3OH^- \longrightarrow H_3C-\overset{\overset{\displaystyle O}{\|}}{C}-CI_3 + 3I^- + 3H_2O$$

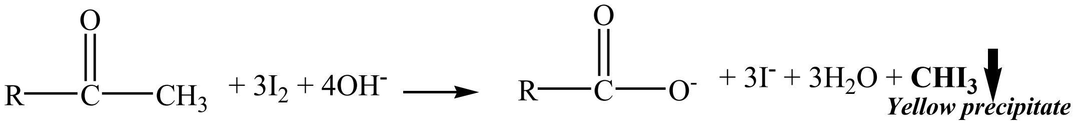
Second step:

CI_3^- group is a good leaving group; CI_3^- is replaced by OH^- to form carboxylic acid, because CI_3^- is a base according to Brønsted-Lowry, it reacts with acid to form the following product:



$$R-\overset{\overset{\displaystyle O}{\|}}{C}-CI_3 + OH^- \longrightarrow R-\overset{\overset{\displaystyle O}{\|}}{C}-O^- + CHI_3$$

Overall equation of the reaction



$$R-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3 + 3I_2 + 4OH^- \longrightarrow R-\overset{\overset{\displaystyle O}{\|}}{C}-O^- + 3I^- + 3H_2O + \underset{\textit{Yellow precipitate}}{\mathbf{CHI_3}\downarrow}$$

Note that the same reaction takes place for other halogen elements in the same way.

Note: Ketones also can be oxidized strongly and are splitted into 2 carboxylic acids according to the ***Poppof's rule***. This rule states that "*if ketone undergoes oxidation by some powerful oxidising agent, carbonyl group remains with the alkyl group which is smaller in size and forms carboxylic acids with less number of carbon atoms*". Let us use [O] to show that powerful oxidizing agent (like hot concentrated HNO_3) to illustrate what is meant by the rule.

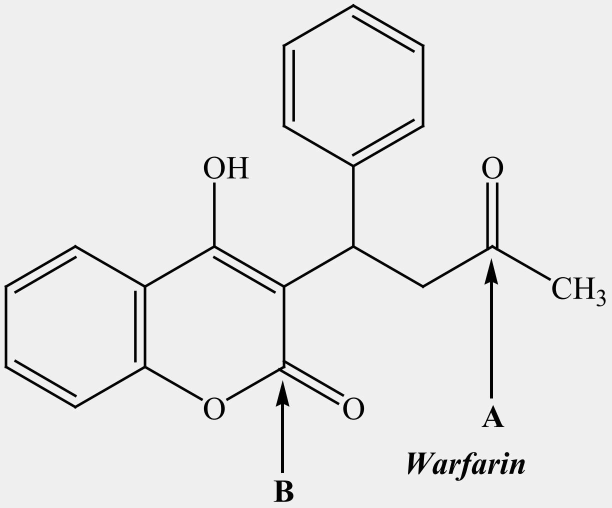
$$CH_3COCH_3 \xrightarrow{[O]} CH_3COOH + HCOOH$$

$$CH_3COC_2H_5 \xrightarrow{[O]} CH_3COOH + CH_3COOH$$

$$CH_3COC_3H_7 \xrightarrow{[O]} CH_3COOH + CH_3CH_2COOH$$

Application activity 6.4

1. Using chemical reactions if possible, give the reagents and the observation that can be used to distinguish the all isomers of C_3H_6O.
2. **A** has the formula $C_5H_{12}O$. Its oxidation gives **B** with the formula $C_5H_{10}O$. **B** reacts with 2,4-dinitrophenylhydrazine to give a positive test but **B** does not give a positive test with Tollens reagent. **A** is dehydrated by concentrated H_2SO_4 to **C**. Identify the compound **A** and draw the formula of **B** and **C**.
3. Brady's reagent is a solution of 2,4-dinitrophenylhydrazine in a mixture of methanol and sulphuric acid. What do you observe when a Brady's reagent is added to an aldehyde or ketone?
4. An aliphatic aldehyde **A** has the general formula RCHO.
   - **a)** **A** reacts with 2,4-dinitrophenylhydrazine. Explain what happens and name the type of reaction. Say how the product of reaction could be used to identify **A**.
   - b) When **A** is treated with warm, acidified $K_2Cr_2O_7$ solution, **B** is formed. Give the general structural formula of **B**.
   - c) When **A** is treated with lithium tetrahydridoaluminate (reducing agent) in ethoxyethane solution **C** is formed. Give the structural formula of **C**.
   - **d)** **A** is warmed gently with ammoniacal silver nitrate. Explain what happens, and say what is observed.
   - **e)** **B** and **C** react to form **D**. Write the structural formula of **D**.
5. Warfarin is an oral anticoagulant, a drug that inhibits the clotting of blood. It prevents the formation of blood clots by reducing the production of factors by the liver that promote clotting, factors II, VII, IX and X, and the anticoagulant proteins C and S.



Warfarin

a) Name any three different functional groups present in the *Warfarin* molecule.

b) State what would be expected to be observed if *Warfarin* is treated under appropriate conditions with Iodine and aqueous solutions of NaOH. Give a reason.

c) The structure of *Warfarin* shows two carbonyls (>C=O) groups, the carbon atoms of which are labeled **A** and **B**. State how many molecules of 2,4-dinitrophenylhydrazine would react with one molecule of *Warfarin*. Give a reason for your answer.

Skills Lab 6

We are surrounded by objects, most of which, some way or the other have a polymer associated with them. The ease of molding polymers into different shapes and their relatively low cost of production has been the main *reason for their universal usage. As such, Bakelite is one of the commercially manufactured polymers that we witness in our daily lives. This is one of the oldest polymers that were synthesized by man.*

1. *Collect different objects/materials available in your surroundings that are made in Bakelite and dedicate their uses in our daily life to Bakelite.*
2. *Observe and carry out experiments on these obtained materials where necessary to reveal, at least, three physical properties of Bakelite.*
3. *Describe and carry out the experiment to prepare Bakelite. Compare the (physical) properties of the prepared Bakelite with those of their materials.*

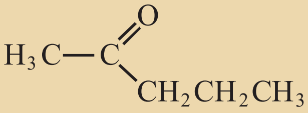
End Unit Assessment 6

1. Answer the following questions by choosing the best alternative represented by letters from A, B, C and D:
   a) The compound ($CH_3COCH_2CH_3$) belongs to which class of organic compound?
   A) Alcohols B) Alkenes C) Ketones D) Aldehydes
   b) The compound CH_3CHO belongs to which class of compounds?
   A) Alkenes B) Aldehydes C) Ketones D) alcohols
2. One of the compounds responsible for the flavour of butter is butane-2,3-dione. Give its structural formula.
3. Three compounds **E**, **F**, and **G** all have the molecular formula C_3H_6O. **E** is an alcohol, **F** is ketone and **G** is aldehyde. Draw the structural formulae of **E**, **F** and **G**.
4. Carbonyl compound **X** undergoes the following reactions
   - **X** gives an orange precipitate with 2,4-dinitrophenylhydrazine.
   - **X** gives pale yellow precipitate with mixture of potassium iodide and sodium iodate (I)
   - **X** does not react with warm acidified $K_2Cr_2O_7$ solution.
   - **X** does not react with aqueous bromine.
   - **X** is reduced by hydrogen in the presence of catalyst to a mixture of isomers **Y** and **Z** of formula $C_4H_{10}O$.

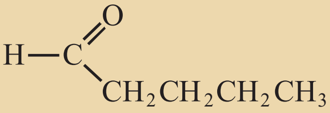
   Identify **X**, and give the structural formulae of **X, Y** and **Z**.
5. The three compounds $CH_3CH_2CH_2CH_2OH$, $(CH_3)_3COH$ and $CH_3CH_2CH_2CHO$ can be distinguished by use of the following reagents:
   - Potassium dichromate (VI) acidified with dilute sulphuric acid
   - Tollens' reagent

   a) Identify which of these three organic compounds would reduce acidified potassium dichromate (VI). Give the structures of the organic products formed. Write a half-equation for the reduction of dichromate (VI) ions in acidic solution.
   b) Identify which one of these three organic compounds would reduce Tollens' reagent. Give the structure of the organic product formed. Write a half-equation for the reduction of Tollens' reagent.

6. Consider the following pair of isomers.

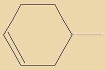


E



F

   a) Name compound **E**.
   b) Identify a reagent which could be used in a test-tube reaction to distinguish between **E** and **F**. In each case, state what you would observe.
   c) Draw the structure of the chain isomer of **F** which shows optical isomerism.

7. The two functional groups in compound **A**,  CHO, behave independently.
   a) State what would be observed if a few drops of compound **A** were added to Fehling's solution and heated. Give the structure of the organic reaction product.
   b) Using RCHO to represent compound **A**, write an equation for the reaction between RCHO and hydrogen cyanide. State the type of reaction taking place and outline a mechanism.

8. Write equations to show how each of the following compounds can be synthesized. Indicate the reagent used and the conditions of reactions.
   a) Diethyl ether from ethanal
   b) Propanone from propane
   c) Propane from propanone
   d) Pentane from pentanal
   e) Formaldehyde from inorganic compound via industrial process

UNIT 7

CARBOXYLIC ACIDS

Key Unit Competence:

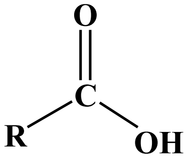
Analyze the chemical nature of the carboxylic acids to their reactivity

Introductory activity 7

1. You have certainly drunk and tasted fresh milk and fresh banana juice or any other fruit juice. What happens if the milk or juice stays for long time (five days, for example)? How does it taste before and after that time? Can you explain the change?

2. After an ant's stings, you feel a prolonged pain and sometimes the part of the body that was stung swells.
    a) Explain the reasons of these observations and sensations
    b) Is there any other substance that accompanies the ant's stings?
3. Both lemon juice and vinegar have a sour test and they can be used in treatment of salad before they are eaten.
    a) Why are they used for this purpose?
    b) Which chemical substance do they have in common that is responsible for this sour taste?
    c) Identify the part that is common in the structures of the main chemical responsible for their sour taste.

Carboxylic acid is a class of organic compounds that are characterized by the presence of carboxyl group in their chemical formula. The general formula for carboxylic acids is **R-COOH** where **R**- refers the alkyl group of the molecule.



Carboxylic acids naturally occur in different substances that we normally encounter in our daily life and are also used to make various useful materials. For instance, lemons taste sour because they contain citric acid and ant sings are painful because they are followed by an injection of formic acid in the stung part of the body.

7.1. Nomenclature and isomers of carboxylic acids

Activity 7.1

1. With help of the general rules of naming organic compounds studied in previous units, suggest the IUPAC names of the following compounds.
    a) CH_3-COOH
    b) CH_3-CH(CH_3)-COOH
    c) HCOOH
    d) HOOC-CH_2-COOH
    e) CH_3-CH_2-CH(CH_3)-COOH

2. Find the structures that correspond to the systematic names below
    a) 2,2-dimethylpropanoic acid
    b) 3-methylbutanoic acid
3. You are provided with molecular formulae of different organic compounds: $C_2H_4O_2$ and $C_3H_6O_2$. Identify all possible isomers of these compounds.
4. A student was given two samples of enantiomers; L-lactic acid and D-lactic acid, which are both colourless liquids.
    a) How are these two isomers related?
    b) Briefly describe how the two samples can be distinguished so that they can be properly labeled.

7.1.1. Nomenclature of carboxylic acids

Carboxylic acids are named by following the general rules of naming organic compounds, where the suffix '**oic acid'** is added to the stem name of the longest carbon chain that contains the acid functional group. The side branches are also positioned by starting from the carbon with carboxylic functional group.

The carboxylic group takes priority to other functional group when numbering carbons in the case of substituted chain.

Table 7.1: Nomenclature of carboxylic acids

Formula	Systematic name	Common name
HCOOH	Methanoic acid	Formic acid
CH_3COOH	Ethanoic acid	Acetic acid
CH_3-CH_2-COOH	Propanoic acid	Propionic acid
CH_3-$(CH_2)_2$ –COOH	Butanoic acid	Butyric acid
CH_3-$(CH_2)_{10}$ –COOH	Dodecanoicacid	Lauric acid
CH_3-$(CH_2)_{12}$ –COOH	Tetradecanoic acid	Myristic acid
CH_3-$(CH_2)_{14}$ –COOH	Hexadecanoic acid	Palmitic acid
CH_3-$(CH_2)_{16}$ –COOH	Octadecanoic acid	Stearic acid

For diacids, the suffix of the IUPAC name becomes **'dioic acid'.** They have a general formula of **HOO-C_nH_{2n}-COOH**.

Table 7.2: Nomenclature of carboxylic acids with two carboxyl groups

Formula	Systematic name	Common name
HOOC-COOH	Ethanedioic acid	Oxalic acid
$HOOC-CH_2-COOH$	Propanedioic acid	Malonic acid
$HOOC-CH_2-CH_2-COOH$	Butanedioic acid	Succinic acid
$HOOC-(CH_2)_4-COOH$	Hexanedioic acid	Caproic acid or adipic acid
$HOOC-(CH_2)_8-COOH$	Decanedioic acid	Sebacic acid

Unsaturated acids (alkenoic acids) are systematically named by changing the stem suffix **'-an'** to**'-en'.**

Table 7.3: Nomenclature of unsaturated carboxylic acids

Formula	Systematic name	Common name
$CH_2=CH-COOH$	Prop-2-enoic acid	Acrylic acid
$CH_3-CH=CH-COOH$	But-2-enoic acid	Crotonic acid
$CH_2=C(CH_3)-COOH$	2-methylprop-2-enoic acid	Metacrylic acid
$CH_3-(CH_2)_7-CH=CH-(CH_2)_7-COOH$	Octadec-9-enoic acid	Oleic acid

Hydroxy-acids are named by considering -hydroxyl group as a substituent on the longest carbon chain that contains carboxylic functional group.

Table 7.4: Nomenclature of hydroxy-acids

Formula	Systematic name	Common name
$HOCH_2-CH_2-COOH$	3-hydroxy-propanoic acid	β–lactic acid
$CH_3-CHOH-COOH$	2-hydroxypropanoic acid	α–Lactic acid
$HOCH_2-CHOH-COOH$	2,3-dihydroxypropanoic acid	Glyceric acid
HOOC-CHOH-COOH	Hydroxypropanedioic acid	Malic acid
HOOC-CHOH-CHOH-COOH	Dihydroxybutanedioic acid	Tartaric acid

7.1.2. Isomerism in carboxylic acids

Carboxylic acids show various types of isomers either among themselves or with other compounds that have different functional groups.

Chain isomers

Chain isomers have the same molecular formula and they differ in the longest carbon chain (carbon backbone) of the molecule.

Example: CH_3-CH_2-CH_2-COOH (butanoic acid) and CH_3-CH(CH_3)-COOH (2-methylpropanoic acid) are chain isomers of $C_4H_8O_2$

Functional isomers with esters

Functional isomers have the same molecular formula and they differ from the functional groups that are found in the structure of the molecule.

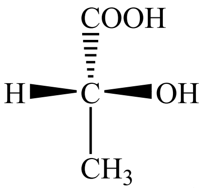
Example: CH_3-CH_2-COOH (propanoic acid) and CH_3-COO-CH_3 (methyl ethanoate) are functional isomers of $C_3H_6O_2$.

Optical isomers

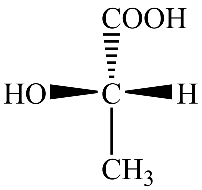
Optical isomers have the same molecular formula and the same structural formula, but they are different in the spatial arrangement of atoms (different connectivity) and their optical properties.

An organic compound shows optical isomerism, when there is **chiral carbon** (a carbon atom attached to four different atoms or groups) in its structure. A chiral carbon is also known as **asymmetric carbon** or asymmetric centre or stereogenic centre.

Example: Lactic acid can exist in two isomers that are mirror images of one other and they cannot be superimposed on each other. This is caused by the molecule which has an *asymmetric carbon*.



D-Lactic acid



L-Lactic acid

Just as the right hand and left hand are mirror images of one another but not super-imposable, optical isomers, also known as ***enantiomers***, are different from each other and can have different properties. For example, muscles produce *D-lactic acid* when they contract, and a high amount of this compound in muscles causes muscular pain and cramps.

These molecules are optical isomers, because they have opposite optical activities. They *can be distinguished by a plane-polarized light where one enantiomer rotates the light to the right by an angle* α*, while the other rotates it to the left by an angle* $-\alpha$.

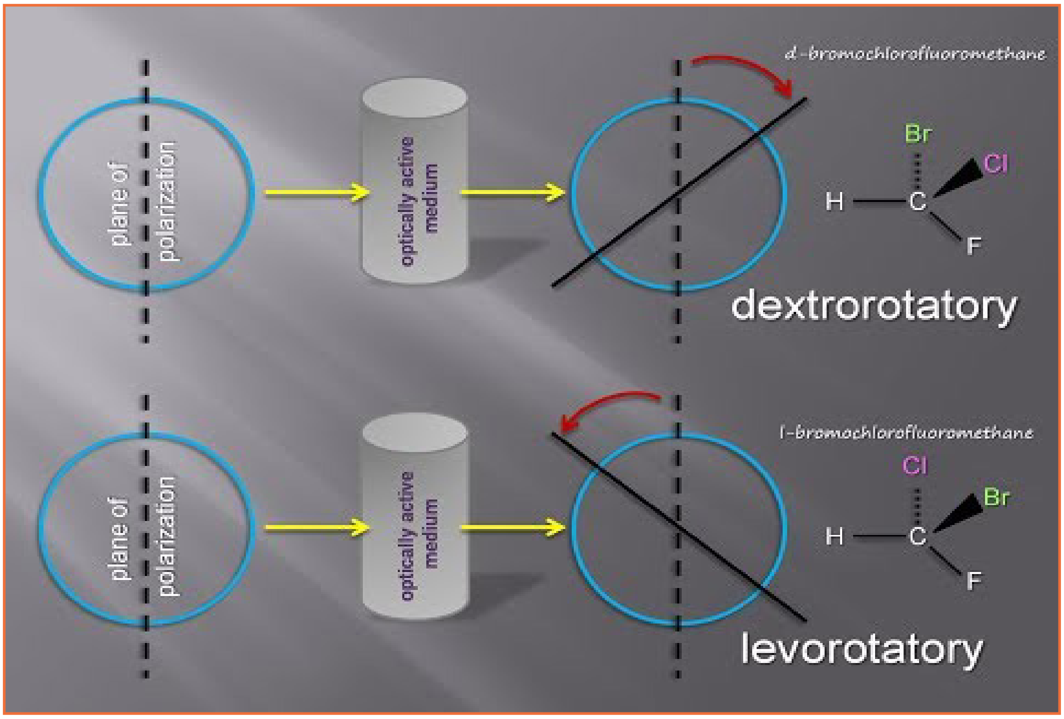


Figure 7.1: Dextrorotatory compound (D) and laevorotatory compound (L)

Enantiomers are often identified as **D-** or **L-** prefixes because of the direction in which they rotate the plane polarized light as shown in *figures 7.2*.

Enantiomers that rotate plane polarized light in clockwise direction are known as *dextrorotatory* (right-handed) molecules and enantiomers that rotate plane polarized light in anticlockwise direction are known as *laevorotatory* (left-handed) molecules.

A solution containing equal amounts of enantiomers, 50% laevorotatory and 50% dextrorotatory is known as a ***racemic mixture*** that will not rotate polarized light, *because the rotations of the two enantiomers cancel each other out*. This means that the angle of rotation $\alpha = 0^\circ$

Application activity 7.1

1. Write the structures of the following compounds:
   a) 2,3-dimethylpentanoic acid
   b) 2-methylhexanedioic acid
2. Give the IUPAC names of the organic acids below:
   a) CH_3-$CH(CH_3)$-CH=CH-CH_2-CH_2-COOH
   b) CH_3-CH(OH)-CH_2-COOH

3. Identify the type of isomers that are found in each of the following pairs of compounds:
   a) CH_3-CH_2-$CH(CH_3)$-CH_2-COOH and CH_3-CH_2-COO-$CH(CH_3)_2$
   b) $CH_3CH_2CH_2CH_2COOH$ and $CH_3C(CH_3)_2COOH$
4. Which of the compounds below is/are optically active: 2-hydroxybutanoic acid, 3-hydroxybutanoic acid, 2-methylpropanoic acid and 2-methylbutanoic acid? Explain
5. State the type of isomerism shown by 2-hydroxypropanoic (*lactic*) acid, $CH_3CH(OH)COOH$, and point out the structural feature of the molecule which causes the existence of two isomers. With the aid of diagrams, show the structural relationship between the two isomers and state how these isomers can be distinguished.

7.2. Physical properties and uses of carboxylic acids

7.2.1 Physical properties of carboxylic acids

Activity 7.2.1

The intermolecular forces are the main factors that explain the physical properties of molecules.

- Use a diagram to explain the type of intermolecular forces that hold molecules of carboxylic acids together.
- How do you compare the melting and boiling points of carboxylic acids and alcohols which have the same number of carbon atoms? From your research give supporting examples with relevant experimental values.

(a) Physical state:

Aliphatic carboxylic acids with 1 to 10 carbon atoms (C_1-C_{10}) are ***liquids*** at room temperature and pressure. They predominantly have a “goaty” odour (odour of cheese). The acids with more than 10 carbon atoms are ***wax-like solids***, and their odour diminishes with increasing molar mass and resultant decreasing volatility. Anhydrous acetic acid freezes at 17°C (slightly below ordinary room temperature), reason why it is called **glacial acetic acid** (Figure 7.3). But a mixture of acetic acid with water solidifies at much lower temperature.

Figure 7.2: Glacial ethanoic acid at 17°C

(b) Melting and boiling point:

Carboxylic acids show a high degree of association through hydrogen bonding. Because of this, they have high melting and boiling points compared to other organic compounds of the same mass or number of carbon atoms.

Table 7.3: Comparison of melting and boiling points of carboxylic acids and alkanes

Formula	Molar mass (g/mol)	Melting point (°C)	Boiling point (°C)
HCOOH	46	8	100.5
$CH_3CH_2CH_3$	44	-190	-42
CH_3COOH	60	17	118
$CH_3CH_2CH_2CH_3$	58	-138	-0.5

Carboxylic acids have high melting and boiling points *because their hydrogen bonds enhance the possibility of bringing two acid molecules together* by forming a kind of **dimer**.

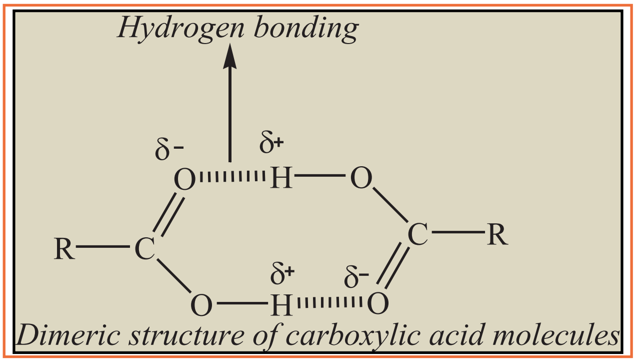


Figure 7.3: Carboxylic acids form hydrogen bonds in a dimeric structure

(c) Solubility:

The carboxyl group readily engages in hydrogen bonding with water molecules (Figure 13.2.c). The acids with one to four carbon atoms (C_1 to C_2) are completely miscible with water. Solubility decreases as the carbon chain length increases *because of increasing of the non-polar hydrocarbon chain which is insoluble in water*.

For example, *Hexanoic acid*, $CH_3(CH_2)_4COOH$, is slightly soluble in water but *Palmitic acid*, $CH_3(CH_2)_{14}COOH$, with its large non polar hydrocarbon part, is essentially insoluble in water. The carboxylic acids generally are soluble in organic solvents such as ethanol, toluene, and diethyl ether.

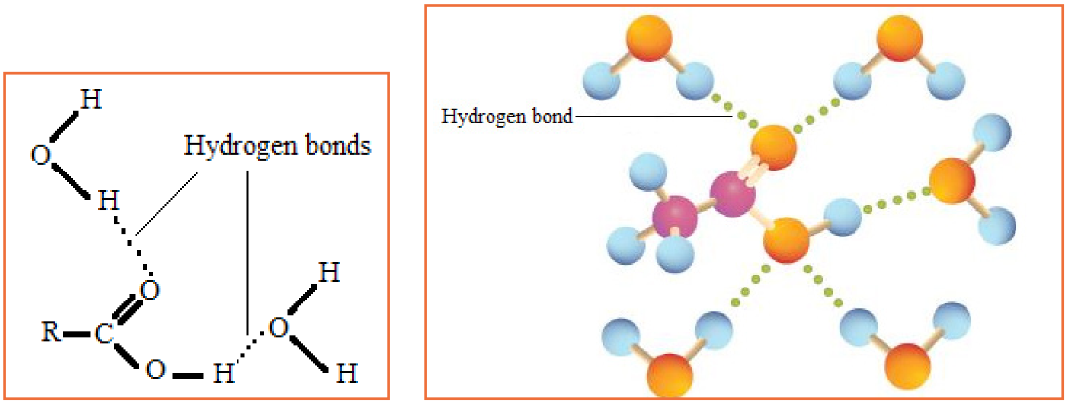


Figure 7.4: Carboxylic acids form hydrogen bonds with molecules of water

Application activity 7.2.1

1. How do you compare the melting points of hexadecanoic acid and octadecanoic acid?
2. Butanoic acid has molar mass of 88 and pentan-2-one has a molar mass of 86. Which of these compounds has the higher boiling point? Explain.
3. Would you expect butyric acid (butanoic acid) to be more soluble than butan-1-ol in water? Explain

7.2.2. Uses of carboxylic acids

Activity 7.2.2

Observe the following images and answer the questions related.

1. Is there any relationship you can find between carboxylic acids and the manufacture process of some of the substances represented in the above images? Show it.
2. Suggest other instances where carboxylic acids are used in our daily life.

Carboxylic acids occur naturally in fats, acidic dairy and citrus fruits, and among their most important uses are:

Food industry and nutrition

- Food additives: Sorbic acid, benzoic acid, etc.
- Main ingredient of common vinegar (acetic acid).
- Elaboration of cheese and other milk products (lactic acid).

Pharmaceutical industry

- Antipyretic and analgesic (acetylsalicylic acid or aspirin).
- Active in the process of synthesis of aromas, in some drugs (butyric or butanoic acid).
- Antimycotic and fungicide (Caprylic acid and benzoic acid combined with salicylic acid).

- Active for the manufacture of medicines based on vitamin C (ascorbic acid).
- Manufacture of some laxatives (Hydroxybutanedioic acid).

Other industries

- Manufacture of varnishes, resins and transparent adhesives (acrylic acid).
- Manufacture of paints and varnishes (Linoleic acid).
- Manufacture of soaps, detergents, shampoos, cosmetics and metal cleaning products (Oleic acid).
- Manufacture of toothpaste (Salicylic acid).
- Production of dyes and tanned leather (Methanoic acid).
- Manufacture of rubber (Acetic acid).
- Preparation of paraffin candles (Stearic acid)

Application activity 7.2.2

Explain different uses of carboxylic acids either in our daily life or in industries.

7.3. Preparation methods and reactions of carboxylic acids

7.3.1. Preparation methods of carboxylic acids

Activity 7.3.1

1. We normally prepare or manufacture substances because we need them in our daily life to solve some of the problems that we have. Are carboxylic acids useful to us?
2. Now that we accept that carboxylic acids are in the category of organic compounds that are widely used in our daily life; either in industry or in our household activities, so they are needed, they must be obtained from somewhere.
    a) Suggest diverse ways carboxylic acids can be obtained.
    b) Describe how acetic acid that is used to make vinegar can be prepared.

Carboxylic acids are common and vital functional group; found in amino acids, fatty acids, etc, and provide the starting raw material for acid derivatives such as acyl chlorides, amides, esters and acid anhydrides. There are several methods of preparation of carboxylic acids where the most common are discussed in this section.

(a) From primary alcohols and aldehydes

Different carboxylic acids can be prepared by oxidation of either primary alcohols or aldehydes.

In the process, the mixture of alcohol and oxidizing agent such as acidified potassium permanganate or potassium dichromate is heated under reflux. Primary alcohols are first oxidized to aldehydes then further oxidation of aldehydes produces carboxylic acid.

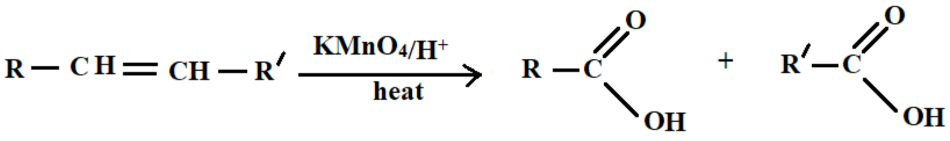
$$R-CH_2OH \xrightarrow[\text{heat}]{Cr_2O_7^{2-}/H^+(aq)} R-CHO \xrightarrow[\text{heat}]{Cr_2O_7^{2-}/H^+(aq)} R-COOH$$

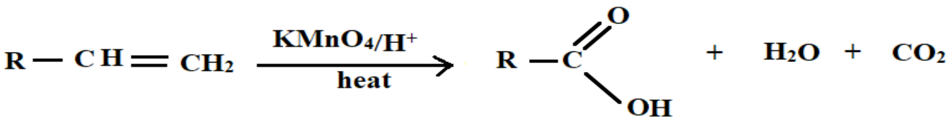
$$CH_3-CH_2OH \xrightarrow[\text{heat}]{Cr_2O_7^{2-}/H^+(aq)} CH_3-CHO \xrightarrow[\text{heat}]{Cr_2O_7^{2-}/H^+(aq)} CH_3-COOH$$

In fact, when excess oxidizing agents like acidified $K_2Cr_2O_7$ or $KMnO_4$ are used, primary alcohols are oxidized to carboxylic acids.

(b) From alkenes (Oxidation of alkenes)

Carboxylic acids are also obtained by heating alkenes with concentrated acidified potassium permanganate. The reaction unfortunately forms a mixture of compounds that must be later separated.





Note that the hydrolysis of carboxylic acid derivatives such as amide, esters, acyl chloride and acid anhydrides also produces the corresponding acids.

Application activity 7.3.1

1. Describe how the following inter-conversions can be carried out in one or more than one steps:
   a) 3-methylpentanoic acid from 1-bromo-3-methylpentane (in 2 steps)
   b) Propanoic acid from the alkene of your choice (in one step)

c) Propanoic acid from propanamine (in 2 steps)

2. When banana wine (the wine obtained locally from the fermented juice from ripe banana) stays for some time its taste becomes sour. Explain these observations by a chemical reaction.

7.3.2. Reactions of carboxylic acids

Activity 7.3.2

1. Carboxylic acids are starting materials for the synthesis of many other important organic substances such as esters used to make sweets and wines, acetic anhydrides used to make aspirin, etc. Explain the reason why it is possible to transform carboxylic acids into other compounds. What property of carboxylic acids is exploited in this regard?
2. Fatty acids are some of the raw materials used in the manufacture of soaps. How is this possible, to convert fatty acid into these important cleansing agents?
3. Experiment: To investigate the reactivity of carboxylic acid

Materials

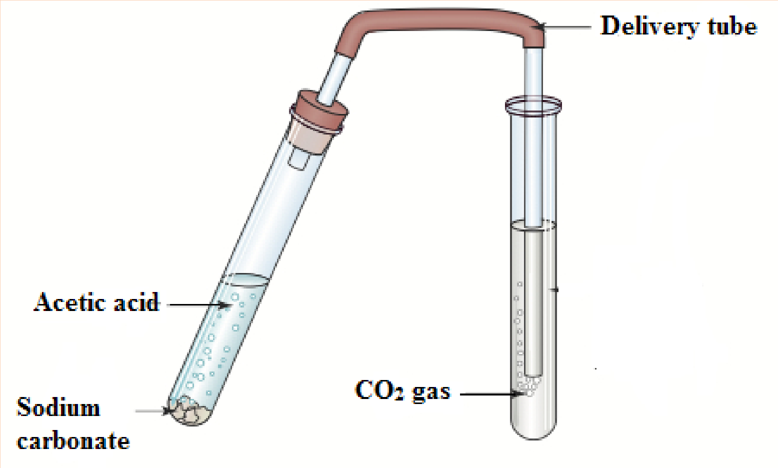
- 2 Test tubes
- Rubber stopper
- A delivery tube

Chemicals:

- Sodium carbonate
- Acetic acid
- Lime water

Procedure

- Put an end full spatula of sodium carbonate in a test tube
- Add about 10 cm^3 of acetic acid solution
- Immediately close it with a rubber stopper joined to a delivery, already immersed in lime water, as in the diagram below.



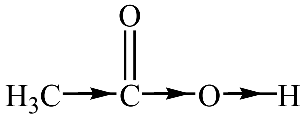
- Note all your observations.
- Write all the reactions involved in this experiment.

Carboxylic acids react with reactive metals, sodium carbonate, sodium hydrogen carbonate, NH_4OH and alkalis. These are typical reactions as **acids**.

Solutions of carboxylic acid turn blue litmus paper red; they do not change the colour of red litmus paper; therefore, they are acids as other mineral acids such as HCl(aq). Organic or carboxylic acids are weak acids in opposition to some mineral acids such as hydrochloric acids which are strong acids.

The carboxylate ion formed by ionization of the acid is more stable than the acid because it has many *resonance* structures.

Ethanoic acid is a weaker acid because its *methyl group has a positive inductive effect; that is to mean that it pushes electrons towards the O-H bond hence increasing the electronic density around the O-H bond and consequently make hydrogen ion stable and not easily leaving.*



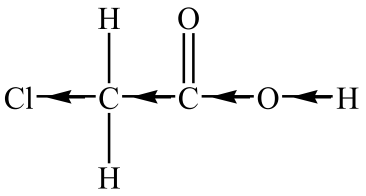
$$H_3C \rightarrow \overset{\overset{\displaystyle O}{\|}}{C} \rightarrow O \rightarrow H$$

Positive inductive effect of alkyl group

The greater the number of such groups, the greater the effected and therefore the weaker will be the acid. For example, *2,2-dimethylpropanoic acid* is weaker than *2-methylpropanoic acid* which is in turn weaker than *propanoic acid*.

The same applies to the increase in the length of the alkyl group chain. *Butanoic acid* is a weaker acid than *propanoic acid* which shows that the acidity strength decreases as the alkyl chain increases.

On the other hand, when an electron withdrawing group (a group with a negative inductive effect) is present, the opposite effect is observed. For example, chloroethanoic acid is a stronger acid than ethanoic acid. This is because chlorine *being electronegative, will withdraw electron towards itself thus reducing the electron density around the O-H bond thus weakening it. It causes O-H bond to easily break, and the concentration of hydrogen ions will be high in the solution.*

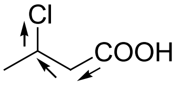


Negative inductive effect of chlorine

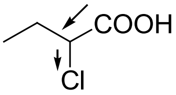
The more the number of groups with negative inductive effect, the greater is the effect and hence the more acidic will be the solution.

Trifluoroacetic acid is more acidic than *trichloroacetic*, *dichloroacetic*, *chloroacetic* and *acetic acid* because fluorine is more electronegative than chlorine and hydrogen. It will strongly withdraw electron towards itself, hence make easier for the proton to leave.

It must also be noted that the further away the electronegative element, the less the effect. For example, *3-chlorobutanoic acid* is therefore a weaker acid than *2-chlorobutanoic acid*.



3-chlorobutanoic acid



2-chlorobutanoic acid

Carboxylic acids are reactive, and their reactions can be classified into:

- Reaction involving –H of hydroxyl group O-H (i.e. reaction as acids)
- Reaction involving -O-H group of carboxylic acid (i.e. nucleophilic substitution reactions)
- Reaction involving carbonyl group –CO- (reduction reaction to alcohols)

(1) Reaction with metals

Carboxylic acids react with reactive metals to form salts of carboxylic acids and hydrogen gas. For example, acetic acid reacts with sodium metal to form sodium acetate and hydrogen gas

$$2RCOOH\,(aq) + 2Na\,(s) \longrightarrow 2RCOO^{-}Na^{+}\,(aq) + H_2\,(g)$$

$$2CH_3COOH\,(aq) + 2Na\,(s) \longrightarrow 2CH_3COO^{-}Na^{+}\,(aq) + H_2\,(g)$$

(2) Reaction with alkali solutions

Strong alkalis such as sodium hydroxide react with carboxylic acids by the process of neutralization that forms salts of carboxylic acids and water.

$$RCOOH\ (aq) + NaOH(aq) \longrightarrow RCOO^{-}Na^{+}\ (aq) + H_2O\ (l)$$

$$CH_3COOH\ (aq) + NaOH\ (aq) \longrightarrow CH_3COO^{-}Na^{+}\ (aq) + H_2O\ (l)$$

(3) Reaction with sodium carbonate and sodium hydrogencarbonate

Like other mineral acids, carboxylic acids react with carbonates and bicarbonates of metals to form salts, water and carbon dioxide. The reaction is followed by observable ***effervescence*** (bubbles of carbon dioxide in the solution) in figure 7.5

$$2\,R\text{-}COOH\,(aq) + Na_2CO_3\,(aq) \longrightarrow 2\,R\text{-}COONa\,(aq) + H_2O\,(l) + CO_2\,(g)$$

Example:

$$CH_3\text{-}COOH(aq) + Na_2CO_3(aq) \longrightarrow CH_3\text{-}COONa(aq) + H_2O(l) + CO_2(g)$$

Figure 7.6: Effervescence when acetic acid is added to sodium carbonate

The reaction of acids with carbonates is the basis for the chemical test of carboxylic acid functional group and it can be used to distinguish carboxylic acids from other functional groups in qualitative analysis.

Carbon dioxide produced is also tested by lime water and it turns *lime water milky.*

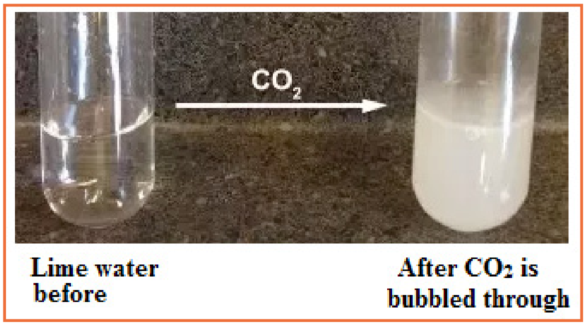
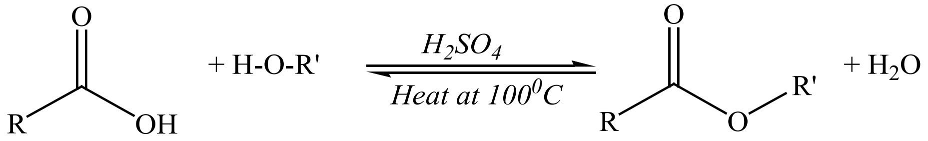


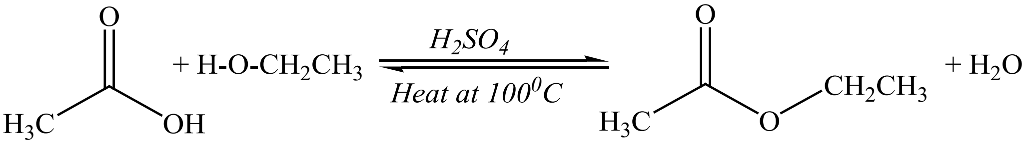
Figure 7.7: Testing carbon dioxide by lime water

(4) Reaction with alcohols (Esterification)

Carboxylic acids react with alcohols to form esters and the reaction is known as esterification reaction. The reaction requires heating under reflux and in the presence of concentrated H_2SO_4. It is a reversible reaction because all the reactants are not converted into products.



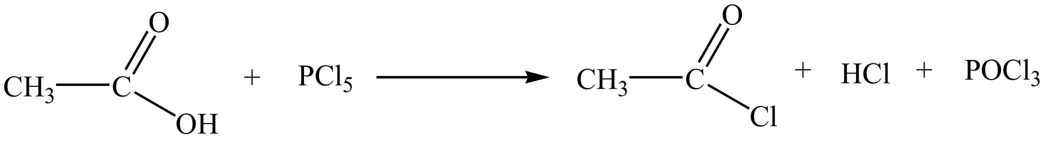
Example:

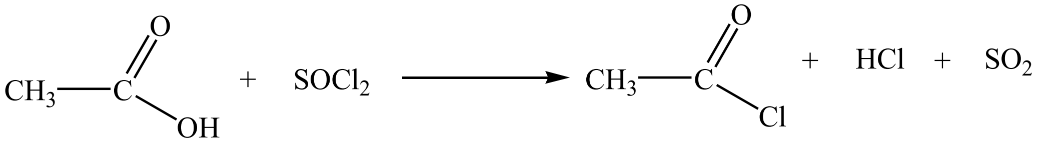


It is noted that the oxygen atom in the ester formed comes from the alcohol and the one in water is from the acid. In the mechanism of esterification, the acid loses -OH group while the alcohol loses H-atom.

(5) With phosphorus halides, thionyl chloride

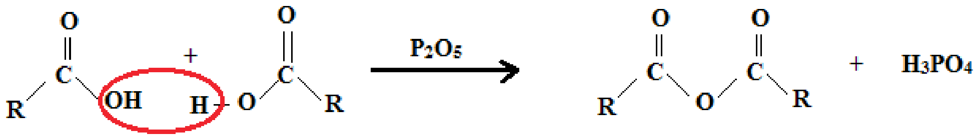
Due to the presence of -OH group in carboxylic acids, like alcohols, they react with PCl_5 and $SOCl_2$ and the organic product is acyl chloride. This is the basis reaction of the synthesis of acyl chlorides from carboxylic acids.

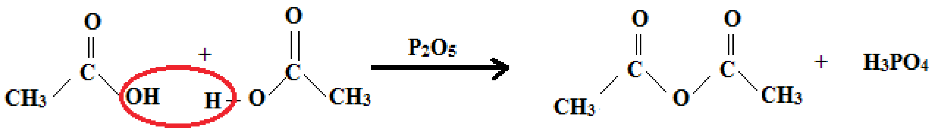




(6) Reaction with phosphorous pentoxide

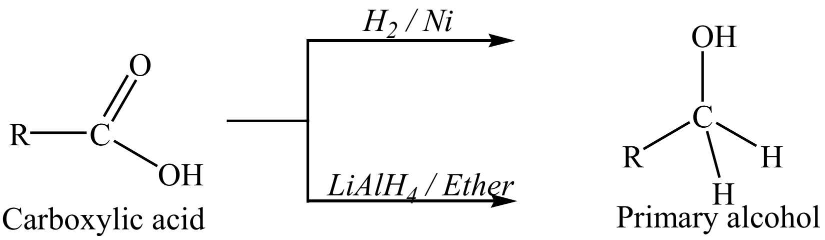
Carboxylic acids molecules can be dehydrated by phosphorous pentoxide to yield corresponding acid anhydrides.





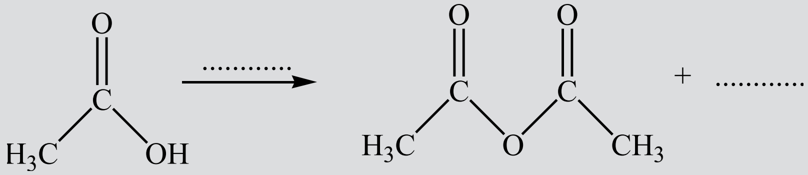
(7) Reduction of carboxylic acids

Carboxylic acids are reduced to primary alcohols on treatment with reducing agent such as $LiAlH_4$ in dry ether or by use of hydrogen in the presence of Ni catalyst. The reduction does not form aldehyde as an intermediate product, like in oxidation of primary alcohols.

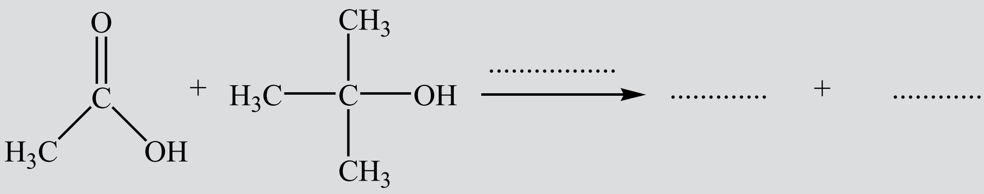


Application activity 7.3.2

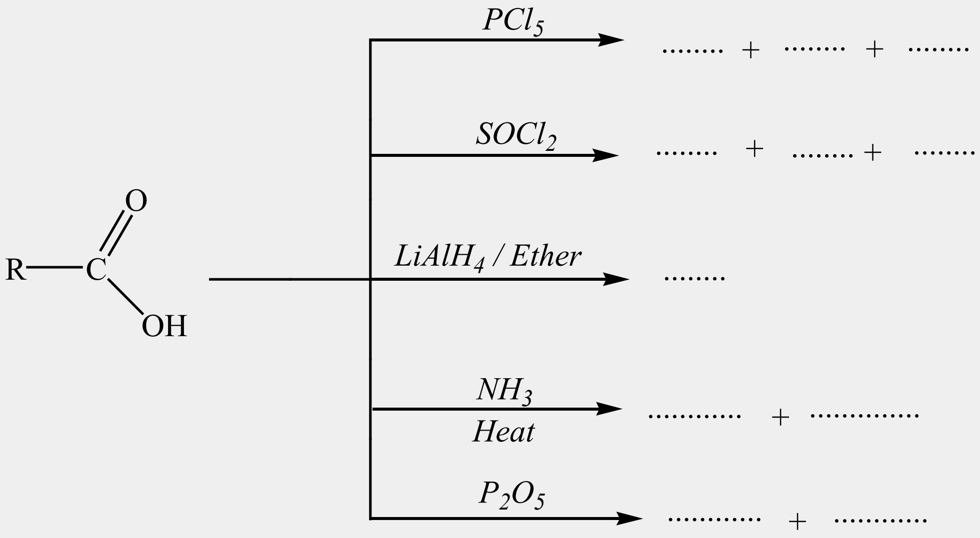
1. Explain the following observations:
   - a) Sodium hydroxide dissolves in acetic acid, but it does not dissolve in ethanol.
   - b) A student took a 10 cm^3 of 0.1 $moldm^{-3}$ potassium hydroxide solution, she/he then added 2 drops of phenolphthalein and the solution turned purple. When she/he added 10 cm^3 of 0.1 $moldm^{-3}$ ethanoic acid the mixture of solutions turned colourless.
2. Complete the following reactions:
   - a) CH_3CH_2COOH + ………. → CH_3CH_2COCl + ……….
   - b)



   - c)



3. Describe the chemical test that can be used to distinguish the following pairs of compounds:
   a) Ethanoic acid and 2-methylpropan-2-ol
   b) Ethanoic acid and phenol
4. Complete the following reactions:



Skills Lab 7

From alcohols, carboxylic acids can be obtained. The chemistry of alcoholic beverages shows that the alcohol known to be present in them is ethanol. You are asked to do the following:

- Locally prepare the wine. The procedure and materials needed must be in your basic skills, so refer to the experts for more information.
- Take a bottle half filled with the wine freshly prepared, taste it and measure its pH.
- Leave the wine (in the bottle) open to air during one week.
- Taste it measure its pH again after the week.

a) Make a description of the tastes (before and after).

b) What about the pHs?

c) Explain clearly all findings recorded. Include the equation for the reaction taking place, the changes in compounds and the cause.

End Unit Assessment 7

MULTIPLE CHOICE QUESTIONS

1. The reaction of Acyl chlorides with alcohols and phenols will give
    a) Esters
    b) Ketones
    c) Aldehydes
    d) Haloalkanes
2. Vinegar contains a carboxylic acid known as
    a) Citric acid
    b) Ethanoic acid
    c) Acetic acid
    d) Both **(b)** and **(c)**
3. Acyl chlorides are made by reacting carboxylic acids with
    a) PCl_5,
    b) PCl_3,
    c) $SOCl_2$,
    d) All of them

OPEN QUESTIONS

4. What is observed when:
    a) A few drops of litmus solution are added to aqueous propanoic acid?
    b) Aqueous propanoic acid is added to a test-tube containing solid sodium hydrogen carbonate until no further reaction occurs?
5. Given the following boiling points: 141°C, 186°C, 118°C, 299°C, match them with the compounds in the table below.

$CH_3—CO_2H$	
$CH_3(CH_2)_{10}—CO_2H$	
$CH_3(CH_2)_3—CO_2H$	
$CH_3CH_2—CO_2H$	

6. Arrange the compounds below in increasing order of boiling point:

    Propanoic acid, *Propanal*, *Propan-1-ol*. Explain your answer

7. Starting from any aliphatic carboxylic acid, how could you make its derivative;
   a) An acyl chloride
   b) An ester

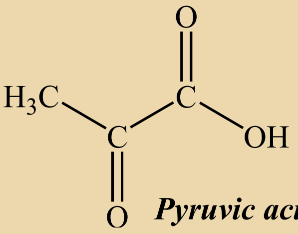
   In each case, give the necessary conditions for reaction and equations for the reaction.

8. Explain the reasons for the following observations
   a) Propanoic acid releases more hydrogen ions in solution than what 2-methylpropanoic acid releases.
   b) Fluoroethanoic acid is stronger than ethanoic acid.

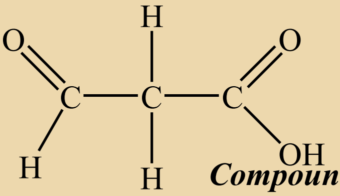
9. Consider the molecules in the following table, analyze them and rank the following acids according to increasing order of their acidity strength using their respective numbers and comparison signs.

Number	Molecule
1	4-chlorobutanoic acid
2	3-chlorobutanoic acid
3	2-chlorobutanoic acid
4	Butanoic acid

10. Pyruvic acid, shown below, is an organic compound that has a smell similar to ethanoic acid. It is soluble in water.



Pyruvic acid



Compound A

   a) Explain why pyruvic acid is soluble in water. Use a labeled diagram to support your answer.
   b) Pyruvic acid can be prepared in the laboratory by reacting an alcohol with excess acidified potassium dichromate (VI). Write the name of this alcohol.
   c) **Compound A** (shown at the right side of Pyruvic acid) is a structural isomer of pyruvic acid. Describe a chemical test that could be carried out in a laboratory to distinguish between samples of pyruvic acid and **compound A.**
   d) **Compound A** can be reduced by $NaBH_4$ to form another alcohol. Suggest the name for this new alcohol

UNIT 8

ESTERS

Key Unit Competence:

Relate the functional groups of esters to their reactivity, preparation methods and uses.

Introductory activity 8

The development of organic chemistry has led scientists to the production of new substances and materials that are necessary in our everyday life which could not be provided by our natural environment. Others were produced to satisfy the high demand of consumers which cannot be assured by natural products only. Analyze the items presented below and answer the questions listed down.

a) What kind of polymer is used to make the piece of cloth shown by its label in figures above? How did scientists make this kind of textiles? Suggest the main functional group (or bond) formed during that polymerization.

b) Why is it possible to make drinks with artificial flavours of natural fruits?

c) How are aspirin pain killer drugs manufactured? State two functional groups present in Aspirin, its molecular formula and hence give the IUPAC name of Aspirin.

d) What kinds of substances do you think they provide perfumes with their fragrances?

8.1. Structure and nomenclature of esters

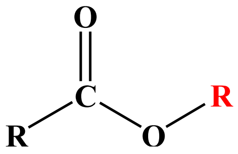
Activity 8.1

1. Carboxylic acids like propanoic acid can react with alcohols like ethanol at suitable conditions.
    a) Write the displayed formula for the organic product formed in this reaction
    b) Encircle and name the functional group present in that molecule.
2. Draw and name all possible isomers with molecular formula $C_4H_8O_2$.

8.1.1. Structure of esters

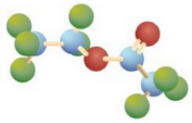
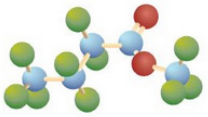
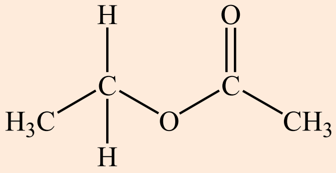
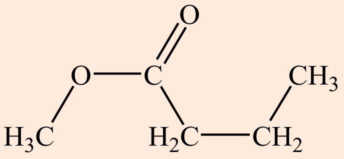
In the previous unit, the reactions of carboxylic acids were discussed. Most of the reactions of carboxylic acids produce the derivatives of acids including esters.

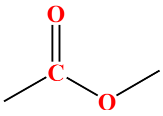
The general molecular formula of esters is $\mathbf{C_nH_{2n}O_2}$ and their general structural formula is: **RCOOR'** which is displayed as follows:



Where **R** may be a hydrogen atom or an alkyl group and **R** may be an alkyl group or an aryl group but not a hydrogen atom. In case that **R** is the hydrogen atom, the compound is no longer an ester but it is a carboxylic acid.

The following table shows models, structure and names for two common esters.

	
	
Ethyl ethanoate	**Methyl butanoate**

The functional group of esters is  . Esters are compounds produced by the reaction involving an acid (or its derivative) and an alcohol with the elimination of water molecule. For example, the reaction between *ethanoic acid* and *ethanol* yields an *ester* with *water*.

$$CH_3COOH + CH_3CH_2OH \rightarrow CH_3COOCH_2CH_3 + H_2O$$

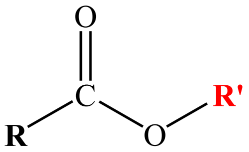
Ethanoic acid **Ethanol** **Ester** **Water**

Esters are known for their distinctive odour and they are commonly responsible for the characteristic of food (fruits) aroma, flowers and fragrances. Esters are found in nature but they can be also synthesized. Both natural and synthetic esters are used in perfumes and as flavoring agents.

8.1.2. Nomenclature of esters

The nomenclature of esters follows some steps.

- When naming esters, the alkyl group **R'** is named followed by the name of $RCOO^-$ group.



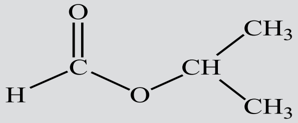
- The group name of the alkyl or aryl portion is written first and is followed by the name of the acid portion. In both common and IUPAC nomenclature, the ***-ic*** ending of the corresponding acid is replaced by the suffix ***–ate***.

Examples of structural formulae of some esters and their names

Structural formula	Common name	IUPAC name
CH_3COOCH_3	Methyl acetate	Methyl ethanoate
$HCOOCH_3$	Methyl formate	Methyl methanoate
$CH_3COOCH_2CH_3$	Ethyl acetate	Ethyl ethanoate
$CH_3CH_2COOCH_2CH_3$	Ethyl propionate	Ethyl propanoate
$CH_3CH_2CH_2COOCH(CH_3)_2$	Isopropyl butyrate	Isopropyl butanoate

Application activity 8.1

1. Name the following compounds by using the common and IUPAC names.
   a) $CH_3CH_2COOCH_3$,
   b) $CH_3CH_2COOCH_2CH_3$,
   c) $CH_3CH_2COOCH_2CH_2CH_3$
   d)



2. Draw the structural formulae corresponding to each of the following names.
   a) Propyl methanoate
   b) Octyl ethanoate
3. Give the structural formula and IUPAC names of all possible molecular structures whose molecular formula:
   a) $C_2H_4O_2$
   b) $C_4H_8O_2$

8.2. Physical properties and uses of Esters

Activity 8.2

Experiment 1: Analyzing the solubility of esters (fats and oils)

Materials and Chemicals

Cooking oil, margarine, water, ethanol, stirring rods (glass rods) and test tubes labeled **A** and **B**.

Procedure

- Pour water in a test tube **A** and ethanol in test tube **B** and add some cooking oil in each test tube. Shake well to mix and record your observation.
- Pour water in a test tube **A** and ethanol in test tube **B** and add a small piece of margarine in each test tube.
- Use a stirring rod to mix and record your observation.
- Conclude.

Experiment 2: Comparing boiling points of alcohols, carboxylic acids and esters

Materials and Chemicals

Propan-1-ol, propanoic acid and methyl ethanoate, test tubes, test tube holders (racks), heaters (bunsen burner or hot plate), and thermometers.

Procedure

- Put 10 mL of each substance in a labeled test tube.
- Boil carefully substances are volatile and flammable
- Use a thermometer to measure the boiling point of each substance.
- Record the results and compare them.
- Conclude (suggest a reason for the difference in boiling points of the three substances).

8.2.1. Physical properties of Esters

a) Physical state, colour and odour

They are colorless liquids or solids with fruity odours; therefore, the fruity odour is used as test for esters in qualitative analysis.

b) Boiling point

Most of the esters are liquids with much lower boiling point than those of the acids or alcohols of nearly equal weight, this is due to the absence of the polar hydroxyl group which found in alcohols and acids and leads to the association of the alcohol and carboxylic acid molecules with hydrogen bonds, esters have a neutral effect on litmus.

The boiling point of the ester is less than the boiling point of the acid and alcohol forming it due to the absence of polar hydroxyl group (presents in alcohols and acids) which has the ability to form hydrogen bonds between molecules.

c) Solubility

The solubility degree of ester in water is less than that of the corresponding acid due to the absence of polar hydroxyl group (presents in alcohols and acids) which has the ability to form hydrogen bonds between alcohol and acid molecules and water molecules.

8.2.2. Uses of Esters

Esters find various uses:

1. They are used as organic solvent eg ethyl acetate or ethyl ethanoate
2. Many esters have a fruity odour and are prepared synthetically in large quantities for commercial use as artificial fruit essences and other flavorings, as components of perfumes (essential oils from plants) and in cosmetics.
3. They are used to manufacture soaps, detergents and glycerol.
4. They are used to provide energy in the body.
5. Polyesters are used to produce plastics (polymers), etc.

Application activity 8.2

1. Discuss the solubility of esters.
2. Two compounds **A** and **B** of molecular formula $C_2H_4O_2$ were analyzed to compare their relative boiling points. Compound **A** had lower boiling point than compound **B**
   a) Draw the structural formula of each compound.
   b) Identify the relationship that exists between compounds **A** and **B**. Explain your reasoning.
3. The boiling point of acetic acid is 118°C; for ethanol is 78°C but closely the boiling points of the resulting esters ethyl ethanoate is 73.9°C. Explain why is it so?

8.3. Preparation and chemical properties of esters

Activity 8.3

1. Perfumes are manufactured using flowers and fruit essential oils to give them pleasant fragrances. Each essential oil has a specific odour. Suppose that you are working in a perfume's factory as a chemist, how can you proceed to produce perfumes of new odours? Suggest one physical and one chemical method.
2. Ethyl propanoate is used to make juices with a pineapple flavour.
   a) State the organic compounds used to synthesize this ester.
   b) Write down the reaction equation showing this synthesis.
   c) Suggest any three reactions undergone by ethyl propanoate naming the main products.

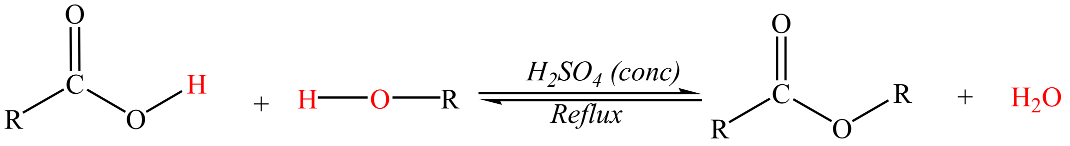
8.3.1. Preparation of Esters

The preparation of esters involves different types of reaction such as esterification, reaction of an acid chloride with an alcohol and the reaction of acid anhydrides with alcohols.

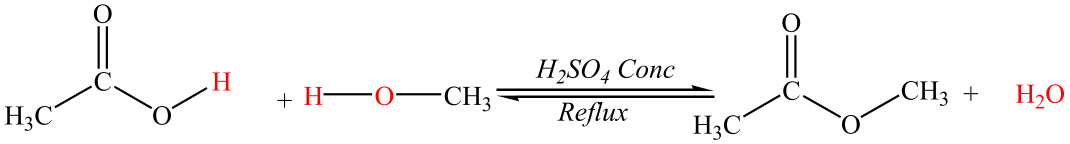
a) Esterification reaction

Esters can be produced by a reaction between alcohols and carboxylic acids in strong acidic medium acting as a catalyst. The acid is commonly a concentrated sulphuric acid, under reflux. The reaction is generally called "***esterification***" (a condensation reaction which involves the addition of the alcohol and acid molecules followed by an elimination of a water molecule).

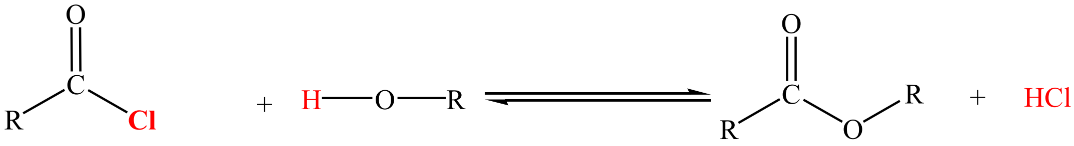
Note that this reaction is *reversible*.



Example:



b) Reaction of an acid chloride with an alcohol



Example:

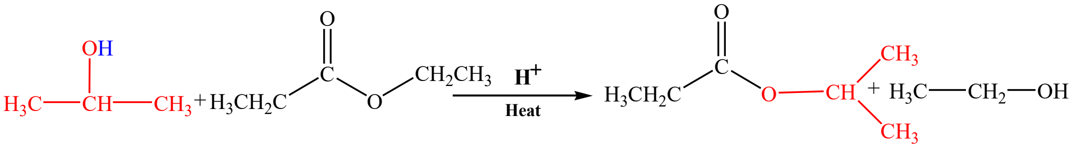
$CH_3COCl + CH_3CH_2OH \rightarrow CH_3COOCH_2CH_3 + HCl$

c) Reaction of acid anhydrides with alcohols (Trans-esterification)

Alcohols react with esters to undergo an exchange of the alkoxide segment. The reaction is acid catalyzed and the used alcohol must be in excess. This is a very common technique of producing new esters from available esters.

$$RCOOR + ROH_{(excess)} \xrightarrow[\text{Heat}]{H^{+}} RCOOR + ROH$$

Example:

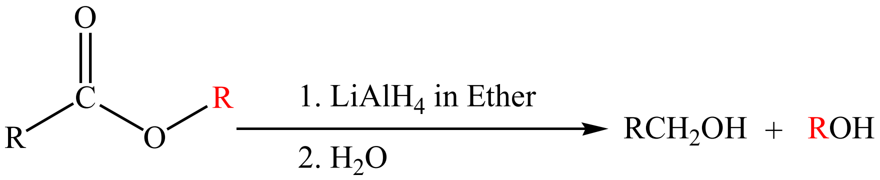


8.3.2. Chemical properties of esters

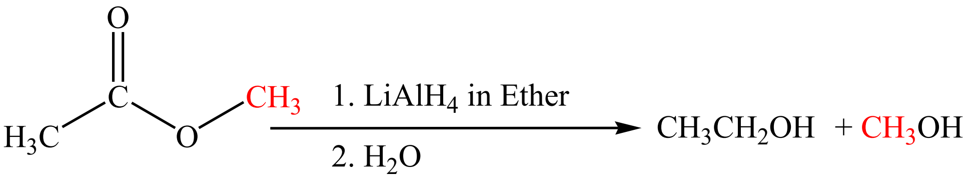
a) Reduction of esters

Compared to ketones and aldehydes, esters are relatively resistant to reduction.

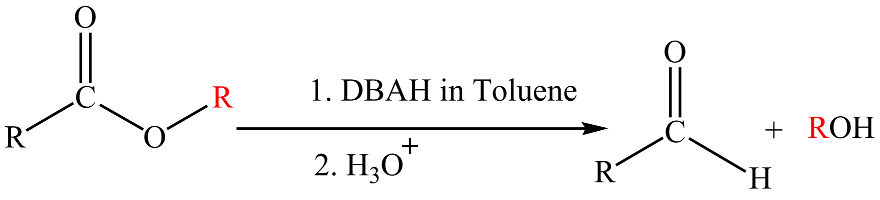
Esters are reduced by Lithium tetrahydridoaluminate ($LiAlH_4$) giving two alcohols, one from the acyl segment (RC=O) and one from the alkoxide segment (R-O) as shown by the reaction below.



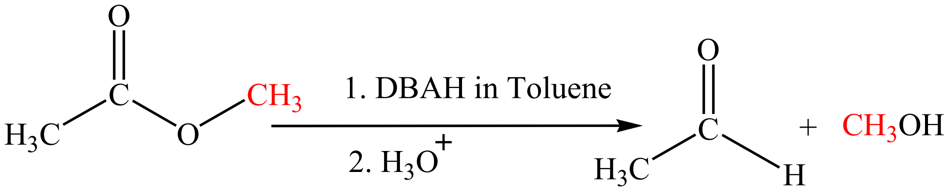
Example:



When a less reactive reducing agent such as diisobutylaluminium hydride (DIBAH) is used the acyl segment is converted into an aldehyde and the alkoxide group is still converted into an alcohol. Exactly one equivalent of the hydride must be used, and the reaction must be carried out at -78 ˚C

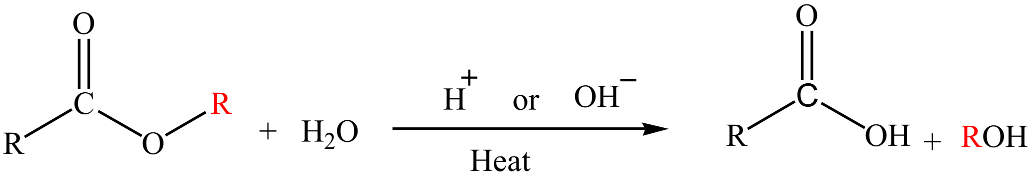


Example:

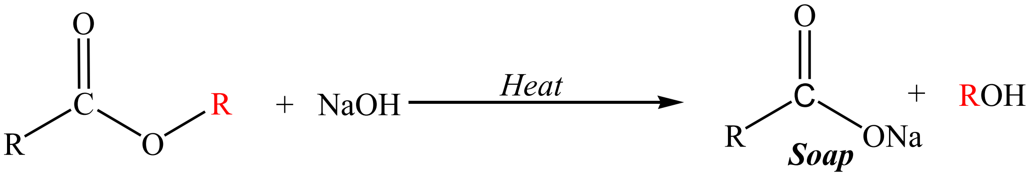


b) Hydrolysis of esters.

The reaction of an ester with water is called hydrolysis. This reaction is very slow unless catalyzed by a base or an acid.



The base catalyzed hydrolysis reaction is called ***saponification*** (derived from Latin word, “sapo”, which means soap). Soaps are sodium or potassium salts made by hydrolyzing the vegetable oil which contain higher molecular weight esters in the presence of sodium or potassium hydroxides.

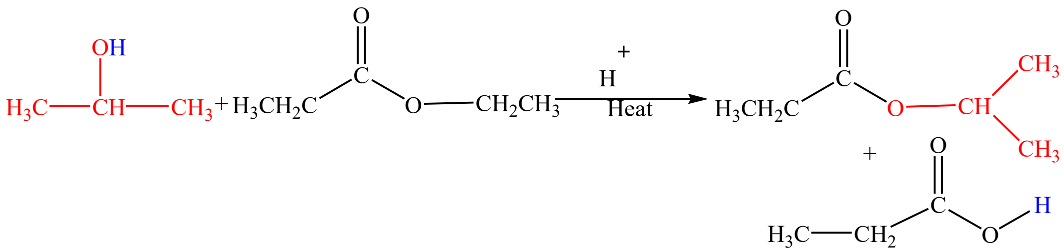


c) Trans-esterification

Alcohols react with esters to undergo an exchange of the alkoxide segment. The reaction is acid catalyzed and the used alcohol must be in excess. This is a very common way of producing new esters from readily available esters.

$$\mathrm{RCOOR} + \mathrm{ROH}_{\text{(excess)}} \xrightarrow[\text{Heat}]{H^{+}} \mathrm{RCOOR} + \mathrm{R}$$

Example:

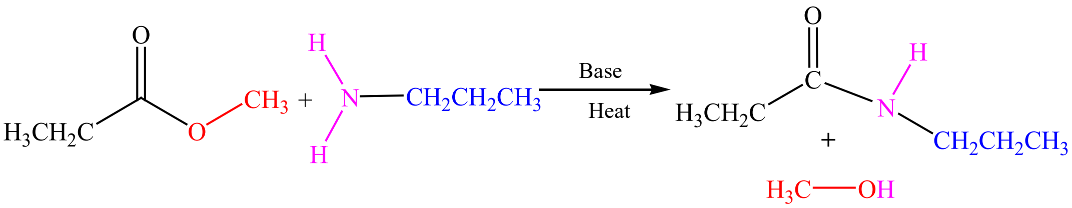


d) Reaction with amines: *Aminolysis*

Esters react with ammonia, primary or secondary amines to produce amides. The reaction is carried out at high temperature in basic medium. However, this reaction is not often used because higher yields are normally obtained by using acyl chlorides.

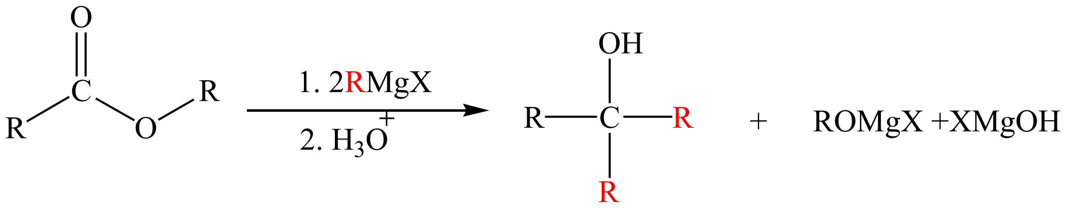
$$\mathrm{RCOOR} + \mathrm{RNH_2} \xrightarrow[\text{Heat}]{\text{Base}} \mathrm{RCOHNR} + \mathrm{ROH}$$

Example:



e) Reaction with Grignard reagents

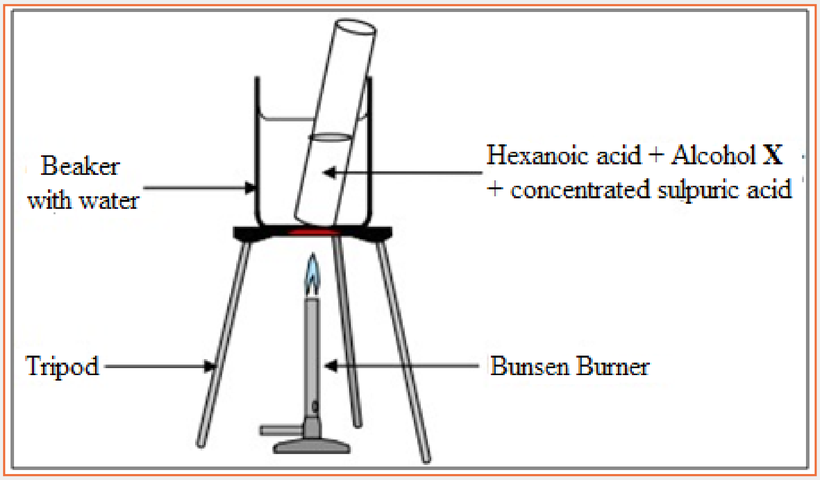
Esters react with two equivalents of a Grignard reagent to form tertiary alcohols. This reaction produces ketone intermediates which undergo a fast conversion into the alcohol because of being more reactive than esters.



Application activity 8.3

1. Write a balanced equation for the reaction between propanoyl chloride and butan-1-ol and name the organic product formed.
2. Investigate how to carry out the following conversions.
   a) Propan-1-ol to propyl propanoate
   b) Ethanal to ethyl ethanoate
3. Ethanoic acid reacts with an alcohol of molecular formula $C_4H_{10}O$ to produce an ester which is optically active.
   a) Identify the structure of the alcohol.
   b) Sketch the structure of the ester formed.
4. Complete the equations below:
   a) $CH_3CH_2COOCH_3 + NaOH \rightarrow$
   b) $CH_3CH_2OOCH + CH_3NH_2 \rightarrow$
   c) $CH_3COOCH_3 + CH_3MgCl \rightarrow$
5. For a reaction to take place, some conditions may be required depending on the type of reaction. Discuss the conditions to be used in order to carry out the reaction **4(a)**.

6. Reactions of amines with esters are not common. Explain briefly this statement.
7. Hexanoic acid is responsible for the unique odour associated with goats. When it reacts with alcohol **X**, ethyl hexanoate, which is used commercially as a fruit flavour, is formed. Learners set up the apparatus shown below to prepare ethyl hexanoate in a laboratory.



a) Write down the IUPAC name of alcohol **X**.
b) What is the role of the sulphuric acid in the above reaction?
c) Use structural formulae to write down a balanced equation for the preparation of ethyl hexanoate.
d) Give a reason why the test tube and its contents are heated in a water bath and not directly over the flame of the Bunsen burner.
e) Write down one use of esters in food manufacturing industry.

8.4. Saponification and Detergents

Activity 8.4(a)

Observe the above picture and answer the following questions

1. Describe the use of the products above –mentioned in the picture.
2. Explain the properties that these products have which make them suitable for their use as you have stated in part (1).
3. Explain how these products manufactured?
4. Propose the differences and similarities of these products?
5. Using NaOH and cooking oil, how can you prepare soap?

Surfactants like soaps and detergents are important cleaning products which play an essential role in our daily life. By safely and effectively removing soils, germs and other contaminants, they help us to stay healthy, care for our homes and possessions, and make our immediate environment more pleasant and conducive to live in. Esters can be cleaved back into a carboxylic acid and an alcohol by reaction with water and a base. This reaction is called *"saponification"*.

8.4.1. Saponification

Soaps are water-soluble sodium or potassium salts of fatty acids. Soaps are made from *fats and oils*, or their *fatty acids*, by reacting them with a strong alkali. The process is known as ***Saponification***.

a) Fats and Oils

The *fats* (solid lipids at room temperature and pressure) and *oils* (liquid lipids at room temperature and pressure) used to produce soaps find their sources from animal or plant tissues. Each fat or oil is made up of a distinctive mixture of several different triglycerides.

In the formation of a triglyceride molecule, three fatty acid molecules reacted with one molecule of propane-1,2,3-triol or glycerol as shown in ***Figure 8.4*** below.

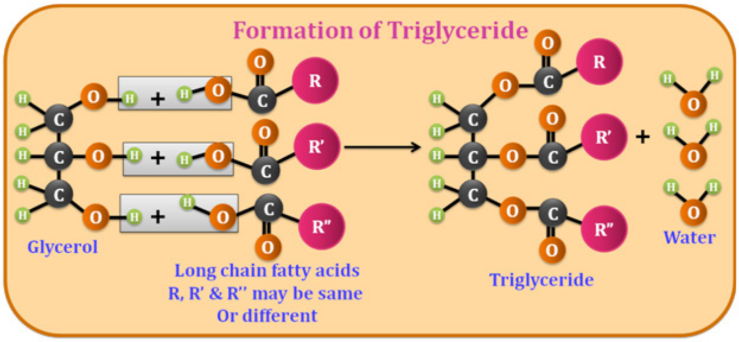


Figure 8.1: Formation of a triglyceride

Examples of other fatty acids include stearic acid ($CH_3(CH_2)_{16}CO_2H$), palmitic acid ($CH_3(CH_2)_{14}COOH$), …

b) Saponification reaction

The reaction of saponification involves the collision between *triglycerides* (in fat or oil) and *aqueous NaOH or KOH*. The result is the formation of soap and glycerol. See ***Figure 8.5*** below.

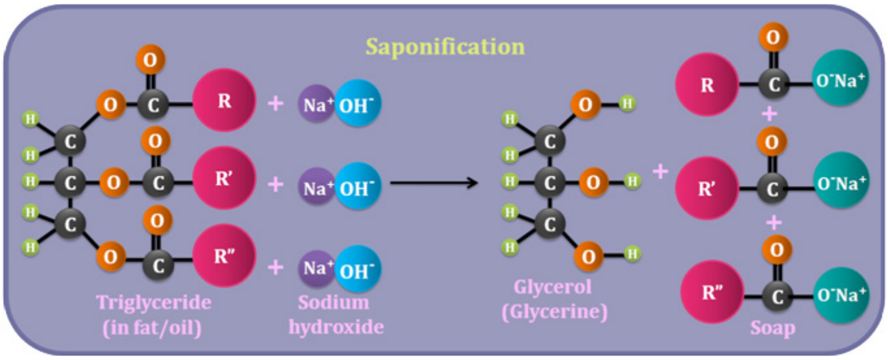


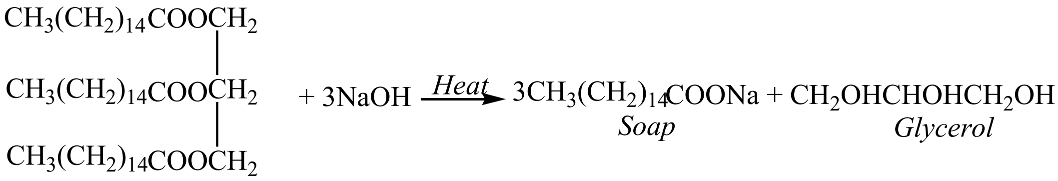
Figure 8.2: Saponification

Or

$$\begin{array}{l} RCOOCH_2 \\ \qquad | \\ RCOOCH_2 \quad + 3NaOH \xrightarrow{Heat} 3RCOONa + CH_2OHCHOHCH_2OH \\ \qquad | \qquad\qquad\qquad\qquad\qquad\quad \mathit{Soap} \qquad\qquad\quad \mathit{Glycerol} \\ RCOOCH_2 \end{array}$$

The reaction of saponification is *exothermic* because there is liberation of heat and the soap formed remains in suspension form in the mixture. Soap is precipitated as a solid from the suspension by adding *common salt* to the suspension.

Example:



$$\begin{array}{l} CH_3(CH_2)_{14}COOCH_2 \\ \qquad\qquad\qquad\quad | \\ CH_3(CH_2)_{14}COOCH_2 \quad + 3NaOH \xrightarrow{Heat} 3CH_3(CH_2)_{14}COONa + CH_2OHCHOHCH_2OH \\ \qquad\qquad\qquad\quad | \qquad\qquad\qquad\qquad\qquad\qquad\qquad \mathit{Soap} \qquad\qquad\qquad\qquad \mathit{Glycerol} \\ CH_3(CH_2)_{14}COOCH_2 \end{array}$$

Note: Sodium soaps are “hard” soaps whereas potassium soaps are soft.

Activity 8.4(b)

Experiment: SAPONIFICATION

PROCEDURE FOR SOAP MANUFACTURE

Note: Wear gloves and goggles as sodium hydroxide is caustic.

- Dissolve 3.25 g of sodium hydroxide in 8 mL of water contained in 250 mL Erlenmeyer flask.
- Swirl to help dissolve the solution. Set aside and allow cooling to room temperature.
- In a beaker, add 25 g of your oil (or fat) and heat gently to about 40 °C. If using a fat, it should be melted.
- Combine the sodium hydroxide solution and oils.
- Stir the mixture until it starts to harden (about 15-20 minutes). Once the mixture starts to harden then stir for 5 minutes at 15 minutes intervals. At the point when it starts to harden you can also add any 'essential oil' ingredients to scent your soap.
- Once the soap is relatively firm (your stir marks will remain for several seconds) pour raw soap into your prepared molds or keep it in the beaker. After a few days the soap can be turned out of the mold. If the soap is very soft, allow it to cure for a few days to firm the outside.
- Eventually remove the soap and set the bar out to cure and dry. This will allow the bar to firm and finish saponification. This can actually take days to cure properly—the longer you wait the less unreacted sodium hydroxide that will be present.

8.4.2. Detergents

Detergents are *organic liquid* or *water-soluble solid cleaning substances* that, unlike soap, are not prepared from fats and oils.

The chemical composition of detergents is different from that of soaps but they have the same cleaning mechanism and *are not adversely affected by hard minerals in the water* and this makes them more effective than soaps. However, they are less environmental friendly because of a reduced biodegradability.

Detergents may be used for household cleaning, laundry or for body and hand washing. They exist in the powder or liquid form.

How do soaps and detergents work?

When a soap or detergent is added to water, a polar solvent, the molecules form clusters, known as *micelles* (Figure 8.6), in which the polar ends of the molecules are on the outside of the cluster and the non-polar ends are in the middle.

The *carboxylate end of the soap molecule is attracted to water*. It is called the ***hydrophilic*** (water-loving) end. The *hydrocarbon chain is attracted to oil and grease* and repelled by water. It is known as the ***hydrophobic*** (water-hating) end. When washing, the hydrophobic part of the soap molecule (Figure 8.7) dissolves oil or grease the main source of dirt and it gets washed away by water as it is insoluble in it.

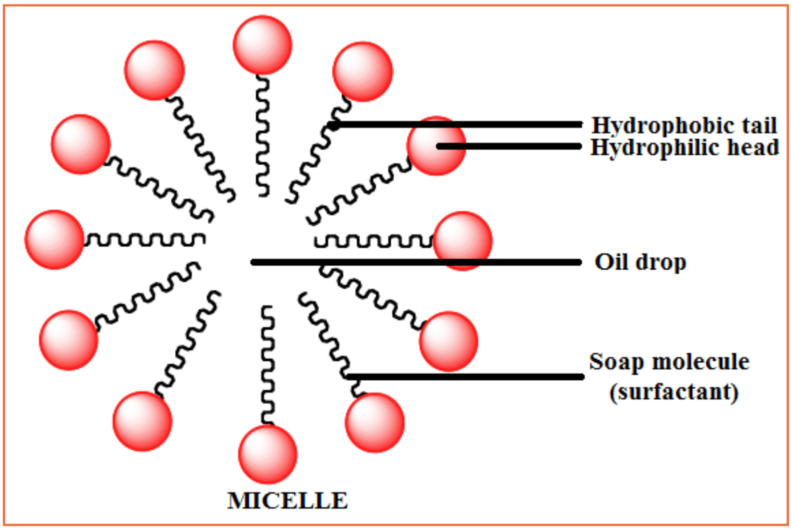


Figure 8.3: Soap or detergent micelle

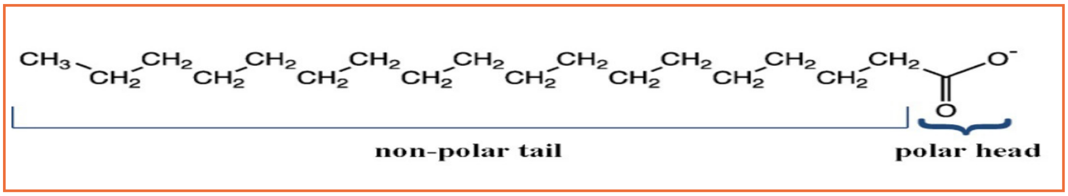


Figure 8.4: Representation of soap molecule

The cleaning property of both soaps and detergents results from their capacity to emulsify water-insoluble materials (dirt, oil, grease, etc) and hold them in suspension in water. This ability originates from the *molecular structure of soaps and detergents*.

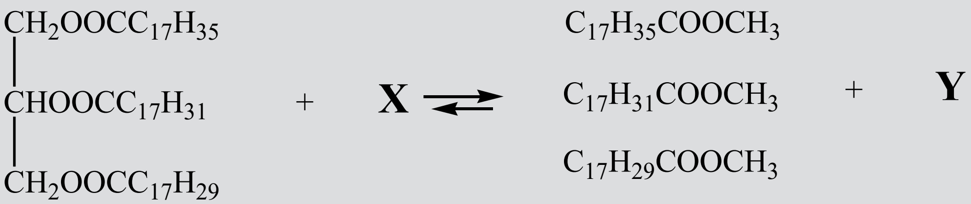
When a soap or detergent adds on to water that contains oil or other water-insoluble materials, the soap or detergent molecules surround the oil droplets. The oil or grease is “dissolved” in the alkyl groups of the soap molecules while the ionic end allows the micelle to dissolve in water. As a result, the oil droplets are dispersed throughout the water (this is referred to as *emulsification)* and can be rinsed away.

Comparison of soaps and detergents

Soaps	Detergents
Made of sodium salts of long chain carboxylic acids	Made of sodium salts of long chain benzene sulphonic acids of alkyl sulfate
Obtained from natural sources such as animal and plant tissues (fats and oils)	Synthetic products, hydrocarbons from petroleum products or coal
Create scum in hard water and therefore its cleaning action affected	Cleaning action not affected by hard water
In hard water, formed calcium and magnesium salts of higher fatty acid are insoluble in water	In hard water, the formed sulphonates are soluble in water
Biodegradable	Less biodegradable

Application activity 8.4

1. Propyl tristearate reacts with sodium hydroxide to form soap. Write a balanced equation for the reaction which takes place.
2. Describe the chemical difference of solid and liquid soaps.
3. Distinguish soaps from detergents based on how they are manufactured or prepared.
4. Describe briefly the difference in working of soaps and detergents.
5. Give the importance of soaps and detergents in our everyday life.
6. Demonstrate the importance of the following:
   a) Esters in the manufacture of soap.
   b) Esters as intermediate compounds in the manufacture of polyesters.
   c) The detergents in comparison to soaps (why are detergents more effective than soaps?).
7. Esters are produced by the reaction of alcohols with other esters and by the reaction of alcohols with carboxylic acids. The esters which make up biodiesel are produced industrially from the esters in vegetable oils. Complete the equation for this formation of biodiesel by stating the compounds represented by **X** and **Y**.



$$\begin{array}{l} CH_2OOCC_{17}H_{35} \\ | \\ CHOOCC_{17}H_{31} \\ | \\ CH_2OOCC_{17}H_{29} \end{array} + \mathbf{X} \rightleftharpoons \begin{array}{l} C_{17}H_{35}COOCH_3 \\ C_{17}H_{31}COOCH_3 \\ C_{17}H_{29}COOCH_3 \end{array} + \mathbf{Y}$$

Skills Lab 8

Figure 8.8: Liquid and solid soaps

1. Carry out a field study at a nearby soap and detergent making factory, observe all processes taking place, ask explanatory questions and make a field report.
2. Use the knowledge and skills you have acquired and locally available materials and substances to prepare a liquid and solid soap. It may be necessary to buy some products needed from your nearby shops.

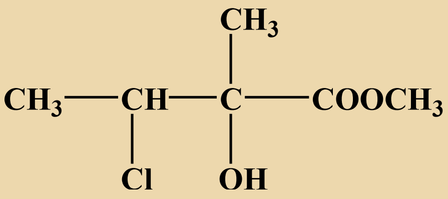
End Unit Assessment 8

Part I: Multiple choice questions

1. Esters are made from the reaction between
   a) Carboxylic acid molecules
   b) Alcohol molecules
   c) Alcohol and carboxylic acid molecules
   d) Acid anhydride and water molecules
2. Ethyl acetate is hydrolyzed by water to give a/an
   a) Lactone
   b) Ester
   c) Acid anhydride
   d) Carboxylic acid and an alcohol
3. The reaction between ethyl ethanoate and dimethylamine gives an
   a) Amide
   b) Imide
   c) Acid anhydride
   d) Ketone

Part II: Structured questions

4. Name the following compound according to IUPAC system.



$$\begin{array}{ccccccc} & & & & CH_3 & & \\ & & & & | & & \\ CH_3 & - & CH & - & C & - & COOCH_3 \\ & & | & & | & & \\ & & Cl & & OH & & \end{array}$$

5. Give reagents, essential conditions and equations for the conversion of ethanoic acid into Ethyl ethanoate

6. Discuss the uses of esters.

7. **(a)** Write an equation for the formation of ethyl ethanoate from ethanoyl chloride and ethanol. Name the mechanism for the reaction taking place.

(b) Explain why dilute sodium hydroxide will cause holes in clothing made from polymers such as Terylene while polythene containers can store caustic soda.

8. Ethyl oleate is an ester with the molecular structure below:

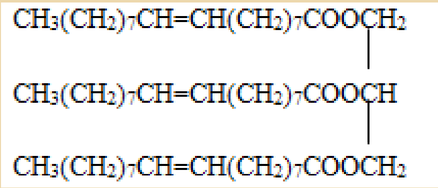
$$CH_3(CH_2)_6CH_2\text{-}CH{=}CHCH_2(CH_2)_6COOCH_2CH_3$$

It is possible the body could synthesize this compound from the ethanol present in alcoholic drinks and the natural fatty acid, oleic acid.

a) Write the structural formula of oleic acid

b) Construct the equation for the production of ethyl oleate from ethanol and oleic acid.

c) Suggest how oleic acid can be obtained from the triglyceride below



$$\begin{array}{l} CH_3(CH_2)_7CH{=}CH(CH_2)_7COOCH_2 \\ \qquad\qquad\qquad\qquad\qquad\qquad\quad | \\ CH_3(CH_2)_7CH{=}CH(CH_2)_7COOCH \\ \qquad\qquad\qquad\qquad\qquad\qquad\quad | \\ CH_3(CH_2)_7CH{=}CH(CH_2)_7COOCH_2 \end{array}$$

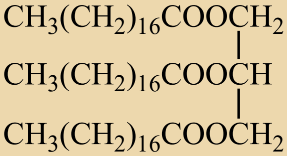
9. A carboxylic derivative **X** was found to contain C, H, N and O. Analysis gave the following percentage composition by mass: 49.4%, 9.6% and 19.1% for carbon, hydrogen and nitrogen respectively. Compound **X** had a relative molecular of 73.

a) Calculate the empirical and molecular formulae of **X**.

b) Suggest three possible structures of **X**.

10. Compound, $HCOOCH_2CH_2CH_3$, is an ester. Write an equation for its reaction with aqueous sodium hydroxide.

11. A naturally-occurring triester, shown below, was heated under reflux with an excess of aqueous sodium hydroxide and the mixture produced was then distilled. One of the products distilled off and the other was left in the distillation flask.



$$\begin{array}{l} CH_3(CH_2)_{16}COOCH_2 \\ \qquad\qquad\qquad\quad | \\ CH_3(CH_2)_{16}COOCH \\ \qquad\qquad\qquad\quad | \\ CH_3(CH_2)_{16}COOCH_2 \end{array}$$

a) Draw the structure of the product distilled off and give its name.

b) Give the formula of the product left in the distillation flask and give a use for it.

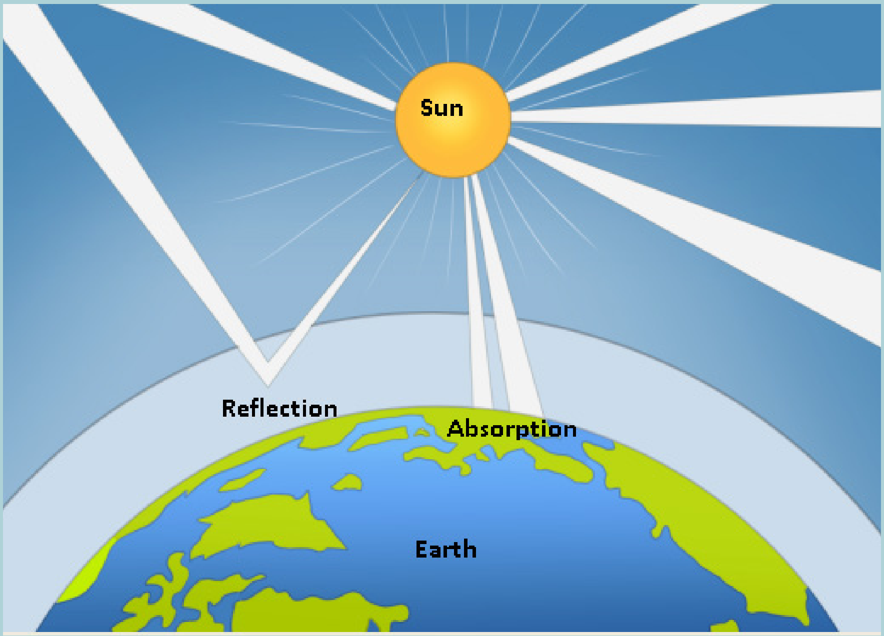
UNIT 9

CLIMATE CHANGE AND GREENHOUSE EFFECT

Key Unit Competence:

Evaluate the environmental survey conducted on climate change and greenhouse effect.

Introductory activity 9



Most of the solar radiation that is incident onto the Earth is absorbed and the rest is reflected into the atmosphere. Our Earth acts almost as a black body, thereby radiating back to the space part of the energy it has absorbed from the sun. The earth and its atmosphere are a part of the solar system. Life on the Earth cannot exist without the energy from the sun.

a) Basing on Physics concepts, how do humans and plants get energy from the sun? Account for the use of this energy.

b) Do humans and plants maintain the energy absorbed forever? Explain your reasoning using physics concepts.

c) State and explain the scientific term used to describe a body that can absorb or emit radiations that fall on them.

d) Basing on your ideas in (c) above what could be the effect on that body if:

   i) It maintains the energy for a long time.

   ii) Reflects energy after a given time.

   iii) Do you think that these reflected and absorbed radiations have effect on the Climate? Why?

e) Some radiations may be prevented from leaving the atmosphere and remain concentrated in the atmosphere. What do you think are effects of these gases as they remain in the atmosphere?

f) In your own view what changes have been brought by these concentration of radiations and how has man tried to control some of the changes.

9.1. Climate change

Activity 9.1

The sun is the major source of energy (in form of radiation) on the earth. Some of these radiations are absorbed by different aerosols in the space and part of it reaches the earth. Our earth has special features that lead to absorption of these radiations and these processes are continuous.

a) What do you think are the effects of these radiations on the earth and its atmosphere after absorption and reflection?

b) From your own understanding, what would happen if there is imbalance between the absorbed and radiated energy in the earth's atmosphere.

c) Can that incidence be avoided? How?

d) With practical examples, discuss how these situations have been noticed in our country Rwanda

e) In your own words, what are the scientific measures that can be done to avoid that kind of situation

9.1.1. Climate change and related facts

Climate is usually defined as the "**average weather**," or more rigorously, as the **statistical description in terms of the mean and variability of relevant quantities over a period of time** ranging from months to thousands of years. The classical period is 3 decades, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Weather is measured in terms of the following parameters: wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season. Climate can be described as the sum of weather. While the weather is quite variable, the trend over a longer period, the climate, is more stable.

However, climate change can be observed over a longer period of time. Climate change refers to any significant change in the climate parameters such as temperature, precipitation, or wind patterns, among others, that occur over several decades or longer Natural and human systems have adapted to the prevailing amount of sunshine, wind, and rain. While these systems can adapt to small changes in climate, adaptation is more difficult or even impossible if the change in climate is too rapid or too large. This is the driving concern over anthropogenic, or human induced, climate change. If climate changes are too rapid, then many natural systems will not be able to adapt and will be damaged and societies will need to acquire the costs of adapting to a changed climate (REMA).

There has been variation in the atmospheric conditions in a given time. This has affected the seasons leading to a less output of our produce especially from agriculture, fishing and other activities.

These changes are sometimes for a short time but also may take a long time. Some of these changes result from our practices like farming, industrialization, urbanization, mining and other infrastructure developments. Care should be taken so as these changes in the atmospheric conditions can be avoided.

Some of important terms we need to know

- **Climate feedback**: This refers to a process that acts to amplify or reduce direct warming or cooling effects.
- **Climate lag:** This is the delay that can occur in a change of some aspect of climate due to the influence of a factor that is slow acting.
- **Climate model**: This is a quantitative way of representing the interactions of the atmosphere, oceans, land surface, and ice. Models can range from relatively simple to quite comprehensive

This explains a delay that occurs in climate change as a result of some factors that changes only very slowly. For example, the effects of releasing more carbon dioxide into the atmosphere occur gradually over time because the ocean takes a long time to warm up in response to these emissions.

9.1.2. Causes of climate change

Physics behind climate change and causes

The climate of the earth is controlled by its absorption and the subsequent emission of the energy.

The Earth's surface temperature is determined by the balance between the absorption and emission of Sun's radiation.

The major cause of climate change is the concentration of greenhouse gases, especially water vapor and carbon dioxide. These gases trap thermal radiation from the earth's surface and this effect keeps the surface warmer than it would be.

(a) Human causes

Human activities are major factors that lead to natural greenhouse effect. Most of activities done by human lead to high concentration of greenhouse gases. From research it has been found that the concentration of carbon dioxide has risen by about 30% in this era as compared to pre-industrial era. This gives a projection that the concentration of these greenhouse gases is still increasing day and night as people continue using fossil fuels.

Such activities include bush burning, burning of fossil fuels, deforestation and agriculture. All these activities have a strong impact on the climate of a given area as they may lead to either warming or cooling the land.

On another hand, industries have also led to the change in climatic conditions as they emit carbon gases into the atmosphere. From what is happening currently, the climatic conditions are worsening if the world becomes more industrialized.

Man is trying to limit this by making machines that emit less carbon gases (REMA)

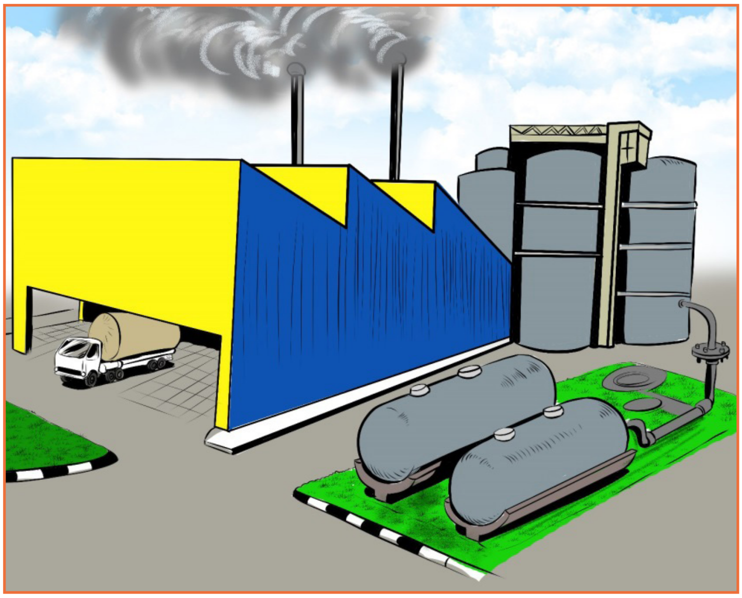


Figure 9.1: An operating industry giving out gases.

These gases affect the atmosphere that leads to climate change.

(b) Natural causes

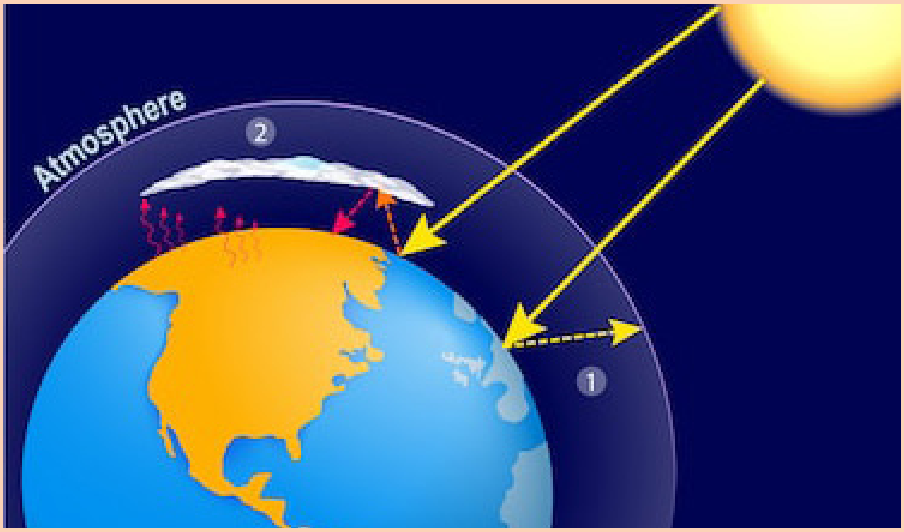
- **Volcanicity**: When volcanoes erupt, they throw out large volumes of Sulphur dioxide (SO_2), water vapor, dust, and ash into the atmosphere. Although the volcanic activity may last only a few days, the large volumes of gases and ash can influence climatic patterns for years. Millions of tons of Sulphur dioxide gas can reach the upper levels of the atmosphere (called the stratosphere) from a major eruption.
- **Ocean currents:** Oceans plays a major role in the change of climate. Oceans cover about 71% of the Earth and absorb about twice as much of the sun's radiation as the atmosphere or the land surface. Ocean currents move vast amounts of heat across the planet, roughly the same amount as the atmosphere does. But the oceans are surrounded by land masses, so heat transport through the water is through channels.

Application activity 9.1

1. What do you think are the factors that lead climatic change in your area? Make a general conclusion using a case study of Rwanda.
2. Using Physics Concepts, discuss why different areas found in the same region may have different climatic conditions.

9.2. Solar and black body radiations

Activity 9.2



The earth receives almost all its energy from the Sun's radiation. The heat or energy from the sun prevents the earth from becoming cold and lifeless planet. Because our earth is made in such that it absorbs some of radiations from the sun and reflects some.

a) From your scientific understanding, what is the mode of transfer of energy from the sun to the earth?

b) Do you think all radiations that are emitted from the sun reach the earth? Explain your reasoning.

c) Explain factors you think affect the intensity of radiations from the sun received by the earth.

d) From the introductory statement, it's clear that the earth absorbs some of the radiations from the sun. Discuss the factors you think makes the earth absorb radiations.

e) From knowledge you acquired in unit 2 in year two, what is the scientific name of the body that reflects absorbs radiations that falls on it.

9.2.1. Intensity of the sun's radiation and albedo

Sun produces heat of very high intensity that is spread and then received by all surrounding objects. These objects include all the planets and other objects around it.

The intensity of the sun (at the top of the earth's atmosphere) is **approximately 1400 W/m^2** also known as **the solar constant**.

The amount received on the earth surface is slightly below **1400 w/m²**. The main reasons for variation in intensity include:

- **The shape of the earth**: The earth has a spherical shape and therefore the sunlight is more spread out near the poles because it is hitting the earth at an angle, as opposed to hitting the earth straight on at the equator. There are **also fewer atmospheres at the equator**, **allowing more sunlight to reach the earth.** Therefore, the intensity varies depending on the geographical latitude of the earth's location.
- **The earth's rotation**: all areas are not consistently exposed to sunlight. Areas that are experiencing '**night time'** are not receiving a lot of the sun's power; therefore, the time of the day or night will affect the solar constant.
- **The angle of the surface to the horizontal at that particular location**: When the Sun is directly overhead, its rays strike Earth perpendicular to the ground and so deliver the maximum amount of energy. When the Sun is lower in the sky, a sunbeam strikes the ground at an angle and so its energy is "**spread out**" over a larger area

  The solar constant represents the mean amount of incoming solar electromagnetic radiation per unit area on the earth's surface. This constant takes into account all types of solar radiation, including UV and infrared. The accuracy of the solar constant is questionable due to the following generalizations: The radiation is assumed to be incident on a plane perpendicular to the earth's surface. It is assumed that the earth is at its mean distance from the sun.
- Our seasons also determine how much Sun's radiation strikes a square meter of ground in a given place on the planet's surface at a given time of the year. **The sun's radiation** is maximum in the summer and it is minimum in **winter.**

Scientists use a quantity called "**albedo**" to describe the degree to which a surface reflects light that strikes it. It can be calculated by the ratio of reflected radiation from the surface to the incident radiation upon it.

$$albedo = \frac{total\ \ scattered\ \ power}{total\ \ incident\ \ power}.$$

The albedo has no units since it is a ratio of the similar quantities.

Being a dimensionless fraction, it can also be expressed as a percentage and is measured on a scale from 0 (0%) for no reflective power to 1 (100%) for perfect reflectors. The earth's albedo is about 0.3, meaning, on average, 30% of the radiation incident on the earth is directly reflected or scattered back into space. An object that has no reflective power and completely absorbs radiation is also known as **a black body.**

Table 9.1: Albedo of various surfaces

Surface	Albedo (%)	Surface	Albedo (%)	Surface	Albedo (%)
Fresh snow or ice	60-90	Tropical forests	13	Fresh snow	80-95
Old, melting snow	40-70	Woodland	14	Water bodies	10-60
Clouds	40-90	Sandy desert	37	Grass	25-30
Desert sand	30-50	Sea ice	25-60	Crops, grasslands	10-25
Soil	5-30	Grassland	20	Forests	10-20
Tundra	15-35	Snowy vegetation	20-80	Light roof	35-50
Grasslands	18-25	Stony desert	24	Dark roof	8-18
Forest		Snowy Ice	80	Brick, stone	20-40
Water		Water	8-10	Concrete, dry	17-27

9.2.2. Factors affecting earth's albedo

Among other factors, the following are some of the factors that affect the albedo of the earth:

- **Clouds**. The atmosphere is usually covered with clouds that usually pass over the earth's surface. This leads to reduction or increase in the temperature of the earth's surface. This is because these clouds may absorb or reflects back sun's light to the free space. However, this depends on the distance from which the clouds are from earth's surface. When sun's radiation is reflected, the earth's surface is cooled and when it is absorbed the earth is warmed.
- **Oceans** While observing from the space, you will find out that water bodies appear differently from land surfaces. They appear darker and therefore absorb more sun's radiations than land. However, some of the radiations heating the water surface (ocean) may be carried away by the currents while others may form water vapor.
- **Thick vegetation covers or forested areas.** Places covered with vegetation absorb a lot of sun's radiation. This is because the vegetation cover provides a dark surface which absorbs more radiations than the bare land.
- **Surface albedo.** Different surfaces appear differently. Light coloured surfaces absorb different amounts of radiations than dark coloured surfaces. Snow covered areas are highly reflective. They thus absorb less amounts of energy (Sun's radiation).

The snow cover reduces the heating effect of the earth's surface. However, if temperatures reduce, the snow cover reduces leading to the absorption of radiation by the exposed ground surface.

9.2.3. Black Body Radiation

An object that absorbs all radiation falling on it and therefore emitting radiation in whole spectrum of wavelengths is called a **blackbody**. At equilibrium temperature a black body has a characteristic frequency spectrum that depends only on its temperature.

A perfect blackbody is one that absorbs all incoming light and does not reflect any. At room temperature, such an object would appear to be perfectly black (hence the term blackbody). However, if heated to a high temperature, a blackbody will begin to glow with thermal radiation. Blackbody radiation is radiant energy emitted by an ideal black surface (blackbody) whose spectral power distribution is only governed by its own temperature.

Laws of black body radiation

(a) Stefan-Boltzmann law

The law states that, "the power per unit area radiated by a surface of a black body is directly proportional to the forth power of its temperature".

$$P = e\sigma A T^4$$

Where

- P Power radiated in watts
- e emissivity
- $\sigma = 5.67 \times 10^{-8}\ W.m^{-2}.K^{-4}$ Stefan-Boltzmann constant
- A surface area in m^2
- T Temperature in Kelvin

Using this formula, we can calculate the amount of power radiated by an object. A black body which emit in whole spectrum of wavelength would have an emissivity of 1. Since the earth is not a perfect black body, it has a certain emissivity value.

Example:

The earth is considered to be a perfect black body at temperature 25^{0}C. Assuming the earth to be a perfect sphere with radius 6380 Km. Calculate the total power radiated from the sun. Take $\sigma = 5.67 \times 10^{-8}\ W.m^{-2}.K^{-4}$

Solution:

Power radiated from a black body is given by:

$P = e\sigma AT^4$ and $e = 1$ for a perfect black body

$P = 1 \times 5.67 \times 10^{-8} \times 298 = 1.7 \times 10^{-5}\ W$

The emissivity is defined as the power radiated by a surface divided by the power radiated from a perfect black body of the same surface area and temperature.

In simpler terms, **it is the relative ability of a surface to emit energy by radiation.** A true blackbody would have an emissivity of 1 while highly polished silver could have an emissivity of around 0.02. **The emissivity is a dimensionless quantity.**

(b) Wien's displacement law

It states that **"the maximum wavelength of the emitted energy from a blackbody is inversely proportional to its absolute temperature".**

This law was formulated by the German physicist Wilhelm Wien in 1893 who related the temperature of a black body and its wavelength of maximum emission following the equation

$$\lambda_{\max} T = b$$

Where b is Wien's constant approximately equal to $2.9 \times 10^{-3} m\ K$, T is the absolute temperature in Kelvin and $\lambda_{\max}$ wavelength of maximum emission

Example:

Calculate the peak wavelength of emitted radiation from a black body at 1500 K. Take b is Wien's constant be $2.9 \times 10^{-3} m\ K$

Solution:

From $\lambda_{\max} T = b$

$$\lambda_{\max} = \frac{b}{T} = \frac{2.9 \times 10^{-3}}{1500} = 1.9 \times 10^{-6} m$$

It is thus found out that as the temperature of blackbody increases, the total amount of light emitted per second increases, and the wavelength of the spectrum's peak shifts to bluer colors.

Remember: It is not good to put on black clothes on a sunny day. This is because these dark clothes will absorb more radiations from the sun which may be harmful to our health.

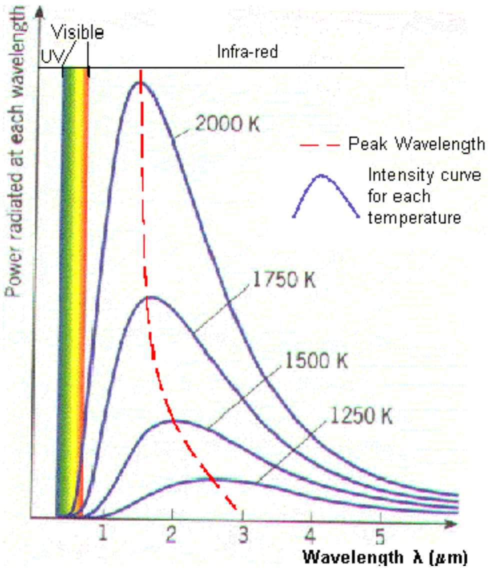


Figure 9.2: Black body radiation curves showing peak wavelengths at various temperatures

This Figure 9.2 shows how the black body radiation curves change at various temperatures. The graph indicates that as the temperature increases, the peak wavelength emitted by the black body decreases. It therefore begins to move from the infra-red towards the visible part of the spectrum. Again, none of the graphs touch the x-axis so they emit at every wavelength. This means that some visible radiation is emitted even at these lower temperatures and at any temperature above absolute zero, a black body will emit some visible light.

Features/Characteristics of the Graph

- As temperature increases, the total energy emitted increases, because the total area under the curve increases.
- It also shows that the relationship is not linear as the area does not increase in even steps. The rate of increase of area and therefore energy increases as temperature increases.

Application activity 9.2

1. Jane Says that clouds have a high albedo while Pierre says land vegetation has a low albedo? Using Scientific explanations, discuss what they base on to make their deductions
2. What do you think are major factors that influence the insolation at a particular location on a particular day? How do they affect it?

3. What latitudinal regions experience least variation in day-to-day solar radiation? Which one experiences the greatest? Why?

4. A student teacher in year III is constructing a spread sheet to calculate the radius R of some stars. To obtain the radius, the surface temperature T of the star must be first calculated. She/he is given values for the star's Luminosity L and the wavelength λ_{max} at which peak energy emission occurs. Part of the spreadsheet is shown, A is the surface area of the star.(Wien's constant is approximately equal to 2.9 × $10^{-3} m\ K$ and Stefan's constant $\sigma = 5.67\times10^{-8}\ W.m^{-2}.K^{-4}$)

	A	B	C	D	E
1	λ_{max} / 10^{-7} m	T / 10^{3} K	L / 10^{27} W	A / 10^{19} m^2	R / 10^{9} m
2	6.85	4.23	0.039		0.41
3	5.74	5.05	0.384	1.04	0.91
4	3.56	8.14	3.385	1.36	1.04
5					

a) Write an equation to show how the value B2 is calculated.

b) Show that the value in D2 is about 0.2

5. Explain the meaning of a black body.

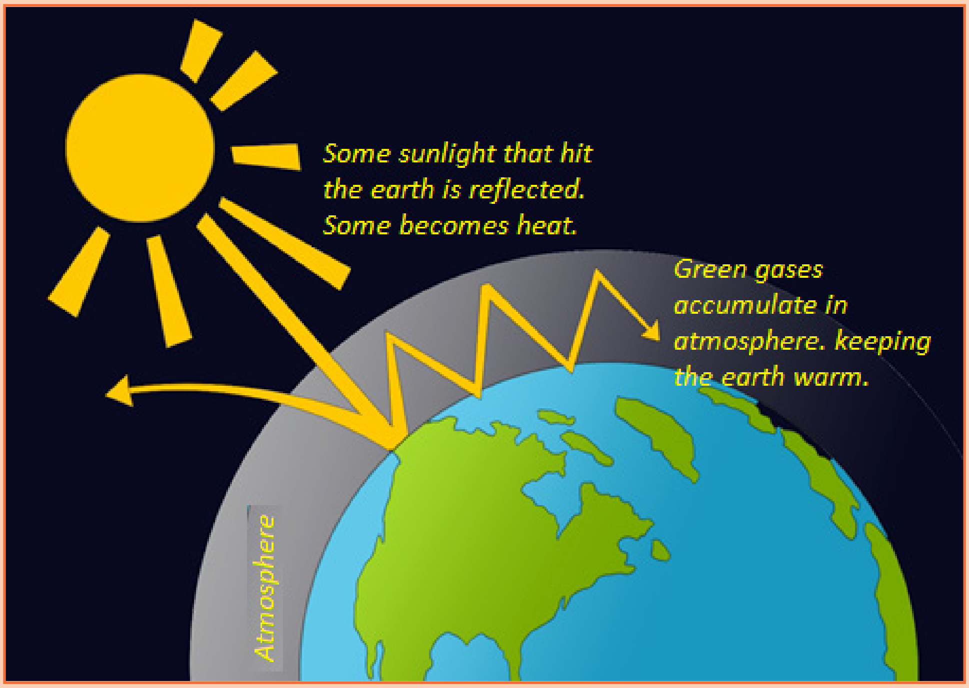
6. Differentiate Stefan-Boltzmann law from Wein's displacement law.

7. The sun behaves as an approximate black body radiator with peak energy radiation occurring at a wavelength of $5.2\text{x}10^{-7}$m. Show that the sun has a surface temperature of about 6000 K (Wien's constant b is approximately equal to 2.9 × 10^{-3}m K)

9.3. Greenhouse effects and its impact on climate change

Activity 9.3

The diagram below represents greenhouse effect. Observe and answer related questions.



a) What do you know about greenhouse?

b) Different activities like industrialization and others give out gases after burning fossil fuels. What special name do you think is given to these gases?

c) If these gases accumulate in the atmosphere. What effect do they have on to the temperature of the earth and its atmosphere?

d) Suggest measures that can be done to limit high accumulation of these gases in the atmosphere.

Greenhouse effect is the process by which thermal radiation from the sun is prevented from leaving the atmosphere and then re-radiated in different directions.

The relationships between the atmospheric concentration of greenhouse gases and their radiative effects are well quantified. The **greenhouse effect** has the root from greenhouses that becomes warmer when heated by sun's radiation. The mode of operation of a greenhouse is that a part of the sunlight radiations incident on the ground surface of the greenhouse are absorbed and warms the surface inside the greenhouse. Both the reflected radiations and the heat emitted by the ground surface in the greenhouse are trapped and re-absorbed inside the structure. Thus, the temperature rises inside the greenhouse compared to its surrounding environment.

Therefore, the greenhouse effect heats up the earth's surface because the green gases that are in the atmosphere prevent radiations from leaving the atmosphere. The absorption of these radiations contributes to the increase of the atmosphere's temperature.

A greenhouse is constructed by using any material that allows sunlight to pass through usually plastic or glass. This prevents reflected radiations from leaving the structure thereby leading to the increase in the temperature within. If a small puncture is made on to the greenhouse, the temperature within reduces.

Since some of these re-radiated radiations come back to the earth's surface, they lead to the increase in the temperature of the earth's surface leading to global warming.

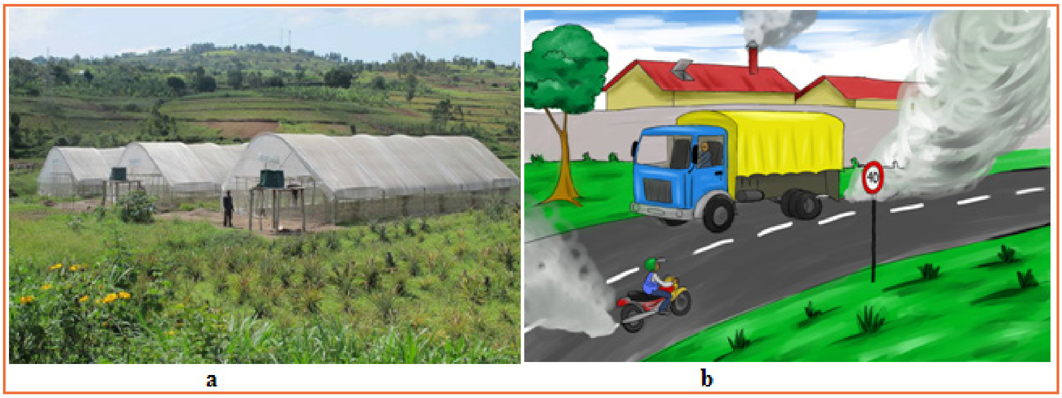


Figure 9. 3: (a) Greenhouses in one of the part of Rwanda and (b) emission of greenhouse gases.

9.3.1. Greenhouse gases

Some gases in the earth's atmosphere act a bit like the glass in a greenhouse, trapping the sun's heat and stopping it from leaking back into space.

Many of these gases occur naturally, but human activity is increasing the concentrations of some of them in the atmosphere, in particular:

- Carbon dioxide (CO_2)
- Methane
- Nitrous oxide
- Fluorinated gases

CO_2 is the greenhouse gas most commonly produced by human activities and it is mainly **responsible for man-made global warming**. Its concentration in the atmosphere keeps on increasing with industrialization.

Other greenhouse gases are emitted in smaller quantities, but they trap heat far more effectively than CO_2, and in some cases are thousands of times stronger.

Methane is responsible for 17% of man-made global warming, **nitrous oxide** for 6%.

Causes for rising emissions:

- **Burning coal, oil and gas** produce carbon dioxide and nitrous oxide.
- **Cutting down forests (deforestation): t**rees help to regulate the climate by absorbing CO_2 from the atmosphere. So when they are cut down, that beneficial effect is lost and the carbon stored in the trees is released into the atmosphere, adding to the greenhouse effect.
- **Increasing livestock farming: c**ows and sheep produce large amounts of methane when they digest their food.
- **Fertilizers containing nitrogen** produce nitrous oxide emissions.
- **Fluorinated gases** produce a very strong warming effect, up to 23 000 times greater than CO_2. Thankfully these are released in smaller quantities and are being phased down by European Union regulation.

9.3.2. Impact of greenhouse effect on climate change

With the greenhouse effect, the earth is unable to emit the excess heat to space and this leads to increase in atmosphere's temperature and global warming. Scientists have recorded about 0.75°C increase in the planet's overall temperature during the course of the last 100 years. The increased greenhouse effect leads to other effects on our climate and has already caused:

- Greater strength of extreme weather events like: heat waves, tropical cyclones, floods, and other major storms.
- Increasing number and size of forest fires.
- Rising sea levels (predicted to be as high as about 5.8 cm at the end of the next century).
- Melting of glaciers and polar ice.
- Increasing acidity in the ocean, resulting in bleaching of coral reefs and damage to oceanic wildlife.

Solutions to reduce the impact of greenhouse gases

- High efficiency during power production
- replacing coal and oil with natural gas
- combined heating and power systems (CHP)
- renewable energy sources and nuclear power
- carbon dioxide capture and storage
- Use of hybrid vehicles.

9.3.3. Global warming

Global warming is the persistent increase in temperature of the earth's surface (both land and water) as well as its atmosphere. Scientists have found out that the average temperature in the world has risen by about 0.75^0C in the last 100 years and about 75% of this rise is from 1975.

Previously the changes were due to natural factors but currently the changes are due to both natural and human activities. From research, Natural greenhouse maintains the temperature of the earth making it a better place for human kind and animal life.

However ever since the evolution of industries, there has been significant change in the temperature. The causes are both natural and human activities and they are the ones that cause climate change.

Note: *If these greenhouse gases were completely not there, the Earth would be too cold for humans, plants and other creatures to live*.

Can you now see the importance of these greenhouse gases! Though they cause greenhouse effect, they are responsible for regulating the temperature of the earth.

Global warming is damaging the earth's climate as well as the physical environment. One of the most visible effects of global warming can be seen in the Arctic region where glaciers, permafrost and sea ice are melting rapidly. Global warming is harming the environment in several ways. Global warming has led to: desertification increased melting of snow and ice, sea level rise, stronger hurricanes and cyclones

Application activity 9.3

1. Below is a bar graph showing emitted Greenhouse gases worldwide from 1990 to 2005. Use it to answer the questions that follow.

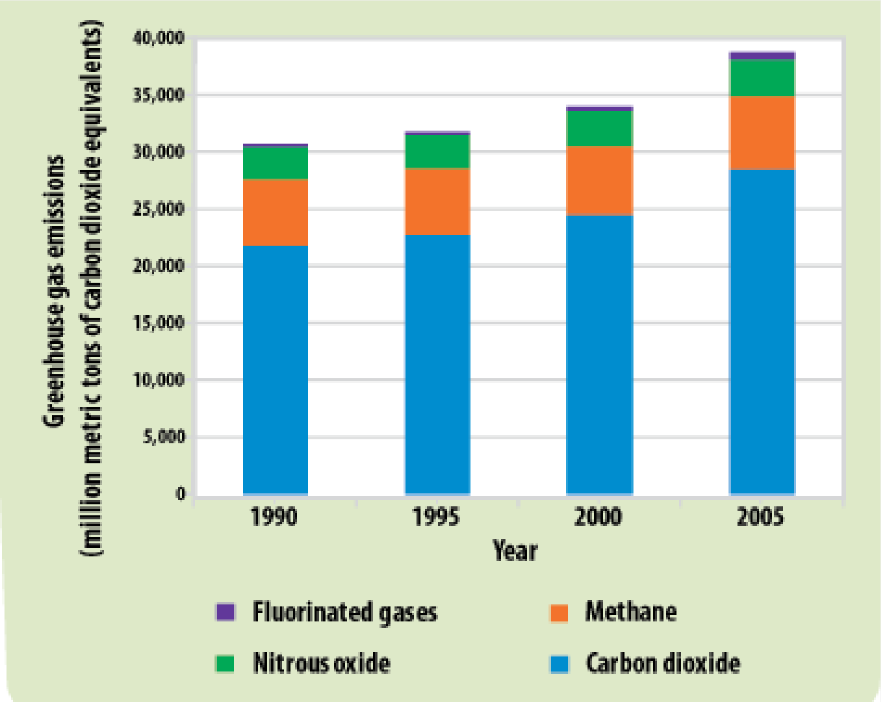


Figure 9.4. Emissions of greenhouse gases worldwide from 1990 to 2005 by Rwanda Environment Management authority (REMA)

a) From your analysis (using the graph) which kind of gas was emitted in excess for the specified period?

b) What could be the factors that led that gas to be emitted in large quantities?

c) What do you think one can do to limit such emissions?

d) From your own point of view, do you think it's a good idea to stop completely emission of these gases? Explain your reasoning by giving valid examples.

e) Differentiate the term "greenhouse effect from global warming".

9.4. Climate change mitigation

Activity 9.4

Read the text below and answer the questions that follow.

The government of Rwanda is trying to sensitize people not to cut down trees for charcoal, drying wetlands for farming activities and regulating people from approaching wetlands, forests (Both Natural and artificial) and Fighting all activities that may lead to climate change.

a) As a good citizen of Rwanda, do you support these plans of the government? Support your stand with clear justifications.
b) If yes, what have you done to implement some of these policies?
c) What are some of the New Technologies that the government is advocating for to stop these negative climate changes?

9.4.1. Climate change mitigation

Climate change mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior.

Climate change is one of the most complex issues we are facing today. It involves many dimensions including science, economics, society, and moral and ethical questions and is a global problem, felt on local scales that will be around for decades and centuries to come.

Carbon dioxide, the heat-trapping greenhouse gas that has driven recent global warming, lingers in the atmosphere for centuries, and the earth (especially the oceans) takes a while to respond to warming.

So even if we stopped emitting all greenhouse gases today, global warming and climate change will continue to affect future generations. In this way, humanity is "**committed**" to some level of climate change.

Because we are already committed to some level of climate change, responding to climate change involves a two-pronged approach:

1. Reducing emissions and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere **("mitigation")**;
2. Adapting to the climate change already in the pipeline **("adaptation")**.

9.4.2. Mitigation and adaptation

Because of these changes in climatic conditions, man has devised all possible measures to see how he/she can live in harmony on this planet. This has made man to think harder so that these greenhouse gases can be minimized.

The process of preventing all these greenhouse gases is what is known as **mitigation**. This is very important as it is aimed at controlling the rise in temperatures of the earth while regulating earth's temperature.

The main goal of mitigation is to reduce human interference to nature thereby stabilizing the greenhouse gas levels in a given time to allow ecosystem to adapt naturally to the climate changes. Care should be taken while these adjustments are made not to affect food production and other economic developments.

Among other strategies, mitigation strategies include:

a) Retrofitting buildings: Retrofitting is the process of modifying something after it has been manufactured.

Retrofitting a building involves changing its systems or structure after its initial construction and occupation. This work can improve amenities for the building's occupants and improve the performance of the building. As technology develops, building retrofits can significantly reduce energy and water usage hence conserving energy sources.

Retrofitting has come to prominence in recent years as part of the drive to make buildings more thermal efficient and sustainable. This can help cut carbon emissions, make it cheaper and easier to run buildings, and can contribute to overcoming poor ventilation and damp problems.

b) Adopting renewable energy sources like solar, wind and small hydro-electric plants:

Human activities are overloading our atmosphere with carbon dioxide and other global warming emissions. These gases act like a blanket, trapping heat. The result is a web of significant and harmful impacts, from stronger, more frequent storms, to drought, sea level rise, and extinction.

In contrast, most renewable energy sources produce little to no global warming emissions. Even when including "**life cycle**" emissions of clean energy (i.e, the emissions from each stage of a technology's life manufacturing, installation, operation, decommissioning), the global warming emissions associated with renewable energy are minimal.

a) Helping **cities develop more sustainable transport** such as **bus rapid transit**, **electric vehicles**. This helps in reducing carbon emissions.
b) Promoting more **sustainable uses of land and forests** and making people aware of the impacts of mis-using these natural gifts.
c) **Creating carbon sinks** like in big oceans in case there are no alternatives.

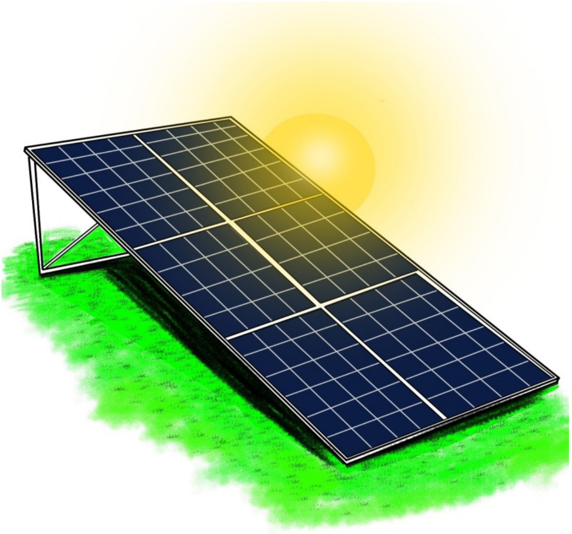


Figure 9. 4: Solar panels have been used to reduce some of the problems caused by other sources of energy

Application activity 9.4

Make a research about climate change mitigation in your neighborhood (either for the school or for your home). Attempt the next related questions.

a) What are some of the conditions you have experienced that used not to occur?

b) How have you adapted to the changes in conditions you have mentioned in a) above.

c) What are you doing to stop these climatic changes?

Skills Lab 9

Constructing a greenhouse

(Can be done over a long period of time)

In this activity you may need:

- Polyethene paper (should be relatively white in colour)
- Wood
- Nails
- Any fiber that can be used while Tying
- Laboratory thermometer.
- Bean seeds

Procedures:

a) Collect materials listed above.

b) Chose a place where to construct the greenhouse. It may either be near your school or near your home.

c) Fix and connect the materials together until you make a structure similar to the one indicated in the figure below.

d) Each day measure temperatures and keep noting down records

e) What do you think are the causes of temperature variations in your records?

f) Sow seeds of beans in your greenhouse

g) After seeds have germinated, keep observing changes in the development of the bean plant.

h) Make a comprehensive Report about your Greenhouse. (Include temperature and vapour changes within the greenhouse). Share it with your colleague.

End Unit Assessment 9

Part I: Multiple choice questions.

1. The emissivity (ε) can be defined as the ratio of
   a) Emissive power of real body to the emissive power of black body
   b) Emissive power of black body to the emissive power of real body
   c) Reflectivity of real body to emissive power of black body
   d) Reflectivity of black body to emissive power of real body.
2. Imagine two planets. Planet A is completely covered by an ocean and has and overall average albedo of 20%. Planet B is blanketed by clouds and has an overall average albedo of 70%. Which planet reflects more sunlight back into space?
   a) Planet A
   b) Planet B

c) the two planets reflect the same amount of light

d) more information is needed to answer this question

3. _______________ is a term used to a process that acts to amplify or reduce direct warming or cooling effects

   a) Climate change
   b) Weather
   c) Climate feedback
   d) Climate model

4. The filament of an electric bulb has length of 0.5 m and a diameter of $6x10^{-5}$ m. The power rating of the lamp is 60 W Assuming the radiation from the filament is equivalent to 80% that of a perfect black body radiator at the same temperature. The temperature of the filament is (Stefan Constant is $5.7x10^{-8}$ $Wm^{-2}K^{-4}$):

   a) 1933 K
   b) 796178.3 K
   c) 64433333.3 K
   d) 60 K

5. The long-term storage of carbon dioxide at the surface of the earth is termed as

   a) Black body radiation
   b) Thermal expansion
   c) Solar radiation management
   d) Sequestration

6. The balance between the amount of energy entering and exiting the Earth system is known as

   a) Radiative balance
   b) Black body Radiation
   c) Paleoclimatology
   d) Solar radiation

7. The following are examples of greenhouse gases except

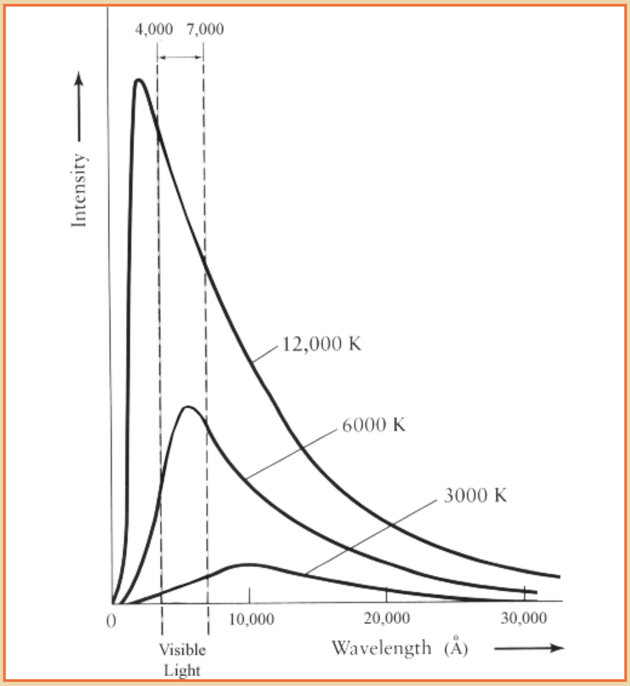
   a) Carbon dioxide
   b) Nitrous oxide
   c) Methane
   d) Oxygen

8. The government of Rwanda is advising the people to conserve the nature. This is intended to limit the incidence of rise in the temperature. This conservation of nature
   a) Reduces the amount of water vapour that leads to increase in temperature
   b) Reduces the amount of Carbon dioxide in the space
   c) Increases the amount of plant species that is required to boost our tourism industry
   d) Provides a green environment for human settlement

Part II: Structured questions.

9. a) State Wien's displacement law and its practical implications.

   b) Use the graph indicated below to answer the questions that follow:



   i) What does the graph explain?

   ii) Explain the spectrum that is found between temperatures of 4000 and 7000 K

   iii) Why do you think the three curves have different shapes?

10. Discuss any 4 main reasons that brings about variation of sun's Intensity

11. a) Calculate the albedo of a surface that receives 15000 Wm^{-2} and reflects 15 KWm^{-2} .Comment on the surface of that body.

    b) Discuss some of the scientific factors that affect planets Albedo.

12. a) What do you understand by the following terms?

    i) Climate change as applied in physics

    ii) Greenhouse Effect

    b) With Clear explanations, discuss how Greenhouse effect can be avoided.

13. Clemence a year 3 student in the faculty of engineering in University of Rwanda, found out in her research that a strong metal at 1000K is red hot while at 2000K its white hot. Using the idea of black body, explain this observation.

14. John defined black body as anybody that is black. Do you agree with his definition? If YES, why? And if NOT why? Also sketch curves to show the distribution of energy with wavelength in the radiation from a black body varies with temperature.

15. An electric bulb of length 0.6 m and diameter 5 x 10^{-5} m is connected to a power source of 50 W. Assuming that the radiation from the bulb is 70% that of a perfect black body radiator at the same temperature, Estimate the steady temperature of the bulb. (Stefan's constant = 5.7 x 10^{-8} W m 2 K^{-4}.)

16. Write short notes about greenhouse effect and explain all its effects.

17. What do you understand by the term greenhouse gases? How do these gases contribute to the global warming?

18. REMA is always advising people to plant more trees and stop cutting the existing ones. Using scientific examples, explain how this is aimed at controlling global warming.

19. Explain climate change mitigation and explain why it's important.

20. Explain what happens to most radiation that is absorbed by the surface of earth?

21. Is there difference between sensible and latent heat?

22. Write short notes on the following terms as applied in climate change

    a) Climate feedback

    b) Climate lag

    c) Climate model

23. Plan and write a good composition about causes of climate change and how it can be controlled. (Your essay should bear introduction, body and conclusion,)

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