

CHAPTER I

HUMAN PHYSIOLOGICAL SYSTEMS

1.1 INTRODUCTION

For anyone concerned with the field of bio-medical instrumentation, some knowledge on the Physiology is essential for further improvement in the design and development of the medical instrumentation. Physiology attempts to explain the physical and chemical factors that are responsible for the origin, development and progression of life. In human physiology, we are concerned with the specific characteristics and mechanisms of the human body that make it a living being.

1.2 CELLS AND THEIR STRUCTURE

The basic living unit of the body is the cell. To understand the function of organs and other structures of the body, it is essential to know about the basic organisation of the cell and the functions of its component parts. Each organ of our body is an aggregate of many different cells held together by intercellular supporting structures. Each type of cell is meant for performing one particular function.

The entire body contains about 100 trillion cells. Among these, there are 25 trillion red blood cells which transport oxygen from the lungs to the tissues. Generally all cells have the ability to reproduce new cells whenever the cells of a particular type are destroyed, until the appropriate number is replenished. Further in all cells, oxygen combines with carbohydrate, fat or protein to release the energy required for cell function.

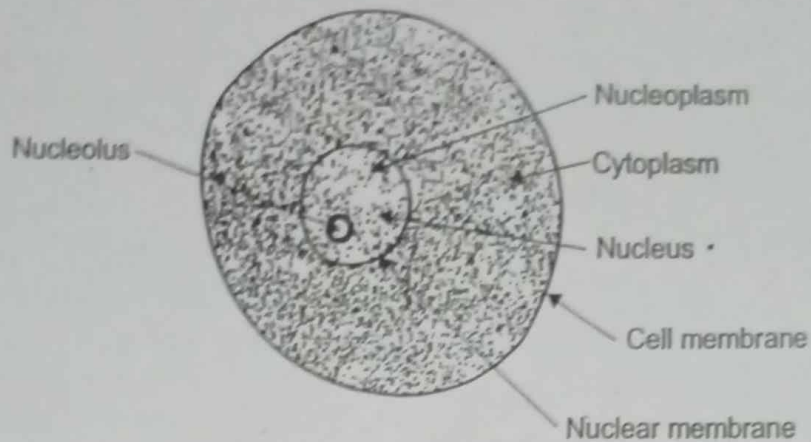


Figure 1.1: Structure of the cell

Figure 1.1 shows the structure of the cell as seen with the biological microscope. Each cell consists of a centrally located **nucleus** (cell core) surrounded by the **cytoplasm** (cell body). The nucleus is separated from the cytoplasm by a nuclear membrane and the cytoplasm is separated from the surrounding fluids by a cell membrane.

The different substances that make up the cell are collectively called protoplasm which is mainly composed of water, electrolytes, proteins, lipids and carbohydrates. **Water** is the principal fluid medium of the cell and its concentration is in between 70 and 85 percent. Water serves as a solvent for various chemicals to produce chemical reactions.

The **electrolytes** present in the cell are potassium, magnesium, phosphate, sulphate, bicarbonate and small quantities of sodium, calcium and chloride. The electrolytes provide inorganic chemicals for cellular reactions.

Further electrolytes at the cell membrane allow transmission of electrochemical impulses in nerve and muscle fibers and the intracellular electrolytes determine the activity of different enzymatically catalyzed reactions that are necessary for cellular metabolism. **Proteins** which constitute 10 to 20 percent of the cell mass, are divided into structural proteins and globular proteins (enzymes).

Structural proteins are in the form of long thin filaments which are composed of polymers of many protein molecules. These are used to provide the contractile mechanism of all muscles. The globular proteins are in globular form. These are mainly the enzymes which catalyze the chemical reactions which provide energy for cellular function. **Lipids** are composed of different types of substances. They are soluble in fat solvents and insoluble in water. Important lipids are phospholipids and cholesterol which are used to form membranous barriers that separate the different intracellular compartments. **Carbohydrates** play a major role in nutrition of the cell. They are stored in the cells in the form of glycogen which are used to supply the cells' energy needs rapidly and are present in the extracellular fluid in the form of glucose.

The cell also contains highly organised physical structures, called **organelles** consisting of cell's chemical constituents. The **cytoplasm** is filled with **cytosol** (the clear fluid portion of the cytoplasm), in which the minute and large particles and organelles are dispersed. **Ribosomes** are minute granular particles in the cytosol and are composed of a mixture of **ribonucleic acid (RNA)** and proteins and they function in the synthesis of protein in the cells. **Lysosomes** are vesicular organelles and provide an intracellular digestive system that allows the cell to digest and thereby remove unwanted substances and damaged or foreign structures such as bacteria.

The **mitochondria** organelles are called 'power houses' of the cell. The cells extract significant amounts of energy from the nutrients and oxygen by means of the mitochondria. The mitochondria contain **deoxyribonucleic acid (DNA)** similar to that found in the nucleus. DNA is the basic substance of the **nucleus** that controls replication of the cell. That is why, the nucleus is called as control center of the cell.

Nucleus contains large quantities of DNA which are called **genes**. The genes first reproduce themselves and after this, the cell splits by a special process called **mitosis** to form two daughter cells. The nucleus is surrounded by nuclear inner and outer membranes. Inside the nucleus, there is a structure called **nucleolus** which contains a large amount of RNA and proteins of the type found in ribosomes. The cell size is determined almost entirely by the amount of functioning DNA in the nucleus. The size of the cells is in the range 5-10 μm . When there is enormous quantities of DNA than normally, the cell size is larger. DNA grows more due to the increased production of RNA and cell proteins.)

1.3 NATURE OF CANCER CELLS

Generally **Cancer** is caused by mutation or abnormal activation of cellular genes that control cell growth and cell mitosis. The abnormal genes are called oncogenes. Only a minute fraction of the cells that mutate in the body even lead to cancer. The probability of mutations can be increased by the following factors:

i) Exposure of ionizing radiations

Like X-rays, gamma rays and even ultraviolet rays can produce ions in tissue cells. These ions are highly reactive and can rupture DNA strands thus causing many mutations.

ii) Chemical substances

Like aniline dye derivatives from chemical plants cause mutations. The chemical substances which cause mutation are called carcinogens. Carcinogens, present in cigarette smoke, cause about one quarter of all cancer deaths.

iii) Physical irritants

Such as continued abrasion of the linings of the intestinal tract by some types of food, produce damages to the tissues which lead to rapid replacement of the cells by mitosis which causes the mutation.

iv) Hereditary

Most cancers require not one mutation but two or more mutations before cancer occurs. Therefore after development of fewer additional mutations, a cancer begins to grow.

v) Viruses

Certain types of viruses can cause some kinds of cancer, including leukemia. There are three major differences between cancer cell and normal cell. First the cancer cell does not respect usual cellular growth limits. Secondly they can wander and enter into blood stream. Thirdly cancer cells produce angiogenic factors that cause many new blood vessels to grow into the cancer cells thus supplying the nutrients required for cancer growth. Since the cancer cells demand all nutrition for their uncontrolled growth, the normal tissue cells suffer for nutrients and gradual dying of the tissue cells leads to death.

1.4 TRANSPORT OF IONS THROUGH THE CELL MEMBRANE

The fluid which lies outside the cell membranes is called the *extra cellular fluid* and the fluid which lies inside the cell membranes is called the *intra cellular fluid*. Table 1.1 gives the approximate compositions of the extracellular fluid and intracellular fluid. It is seen that the extracellular fluid contains large quantities of sodium and small amount of potassium. But in intracellular fluid, the concentration of potassium ions is more than the concentration of sodium ions. Similarly the concentrations of phosphates and proteins are more in the extracellular fluid. Meanwhile the concentration of chlorides is more in the extracellular fluid. The correct concentrations of ions are necessary for the normal functions of the cells and the body.

The cell membrane consists of a lipid bilayer with large numbers of protein molecules. It constitutes a barrier for the movement of the water soluble substances between the extracellular and intracellular fluid regions. The transport of the substances through the cell membrane occurs by *diffusion* (which is also called as passive transport) and *active transport*. Diffusion takes place either through intermolecular spaces in the membrane or in combination with a carrier protein. It is evident that no substances can diffuse against an electrochemical gradient. When a cell membrane moves molecules or ions uphill against a concentration gradient the process is called active transport. Particularly sodium ions, potassium ions, calcium ions, chloride ions and most of the amino acids are actively transported through cell membranes.

Active transport is divided into two types according to the source of the energy used to cause the transport: In the case of primary active transport, the energy is derived directly from the breakdown of *adenosine triphosphate (ATP)* or some other high-energy phosphate compound. In the case of secondary active transport the energy is derived secondarily from ionic concentration gradients that have been created in the first place by primary active transport. Both transports depend upon carrier proteins that penetrate through the membrane. The sodium potassium pump and the calcium pump are good examples of primary active transport mechanism.

1.5 RESTING AND ACTION POTENTIALS

The diffusion and drift processes give rise to membrane potential. The various ions seek a balance between the inside and outside of the cell by diffusion and drift. But the membrane of excitable cells, such as nerve and muscle cells, readily permits the entry of potassium and chloride ions while it effectively blocks the entry of sodium ions. For example the permeability of sodium ions is about 2×10^{-8} cm/s and for potassium and chloride ions, that are 2×10^{-6} cm/s and 4×10^{-6} cm/s respectively. Due to difference in the permeability of different ions, the concentration of sodium ions inside the cell becomes much lower than the outside the cell. Since the sodium ions are positive, the outside of the cell is more positive than the inside.

Similarly the concentration of potassium and chloride ions is more inside than the outside. Thus the charge balance is not achieved. However an equilibrium is reached with a potential difference across the membrane such that negative on the inside and positive on the outside. This membrane potential caused by the different concentration of ions is called the **Resting potential** of the cell.

Characteristics of Resting Potential

- 1) The value of resting potential is maintained as a constant until some kind of disturbance upsets the equilibrium.
- 2) It is strongly depending on temperature.
- 3) Since the permeabilities of different cell types vary, the corresponding resting potentials vary as well. Thus it varies from -60 to -100 mV.
- 4) By Goldman's equation, the resting potential ' V_r ' of a cell can be written as

$$V_r = -\frac{kT}{q} \ln \left[\frac{P_K [K^+]_i + P_{Na} [Na^+]_i + P_{Cl} [Cl^-]_o}{P_K [K^+]_o + P_{Na} [Na^+]_o + P_{Cl} [Cl^-]_i} \right]$$

where

k = Boltzmann's constant = 1.38×10^{-23} J/K

T = Absolute temperature of the cell in Kelvin

q = Charge of electron = 1.602×10^{-19} C

P_K = Permeability of potassium ion

P_{Na} = Permeability of sodium ion

P_{Cl} = Permeability of chlorine ion

$[K^+]$, $[Na^+]$ and $[Cl^-]$ = Concentration of potassium, sodium and chlorine ions and the subscripts i and o indicate inside the cell and outside the cell respectively.

Referring the Table 1.1, the resting potential of a cell at 37°C(310 K) can be calculated as

$$V_r = -\frac{1.38 \times 10^{-23} \times 310}{1.602 \times 10^{-19}} I_n \left[\frac{2 \times 10^{-6} \times 140 + 2 \times 10^{-8} \times 10 + 4 \times 10^{-6} \times 103}{2 \times 10^{-6} \times 4 + 2 \times 10^{-8} \times 142 + 4 \times 10^{-6} \times 4} \right]$$

$$= -86.8 \text{ mV.}$$

5) If $P_{Na} \approx 0$ and $P_{Cl} \approx 0$, then Goldman's equation is reduced into Nernst equation such that

$$V_r = -\frac{kT}{q} \ln \left[\frac{[K^+]_i}{[K^+]_o} \right] = -94.9 \text{ mV}$$

Table 1.1: Chemical compositions of extracellular and intracellular fluids

| | <i>Extracellular fluid</i> | <i>Intracellular fluid</i> |
|-------------------------------|----------------------------|----------------------------|
| Na ⁺ | 142 millimol/litre | 10 millimol/litre |
| K ⁺ | 4 millimol/litre | 140 millimol/litre |
| Ca ⁺⁺ | 1.2 millimol/litre | 0.00005 millimol/litre |
| Mg ⁺⁺ | 0.6 millimol/litre | 29 millimol/litre |
| Cl ⁻ | 103 millimol/litre | 4 millimol/litre |
| HCO ₃ ⁻ | 28 millimol/litre | 10 millimol/litre |
| Phosphates | 1.3 millimol/litre | 25 millimol/litre |
| SO ₄ ⁻ | 0.5 millimol/litre | 1 millimol/litre |
| Glucose | 90 mg/dl | 0-20 mg/dl |
| Aminoacids | 30 mg/dl | 200 mg/dl |
| Cholesterol | 0.5 g/dl | 2 to 95 g/dl |
| Phospholipids | 0.5 g/dl | 2 to 95 g/dl |
| Neutral fat | 0.5 g/dl | 2 to 95 g/dl |
| PO ₂ | 35 mm Hg | 20 mm Hg |
| PCO ₂ | 46 mm Hg | 50 mm Hg |
| pH | 7.4 | 7 |
| Proteins | 2 g/dl | 16 g/dl |

In the case of blood serum (plasma), if the concentration of sodium ion is at the elevated condition then it indicates the renal damage and dehydration; when it is decreased, then it indicates the renal failure and adrenocortical hypofunction.

When concentration of potassium ion is increased, it creates shock and acidosis. When the concentration of bicarbonates is increased, metabolic alkalosis is produced and it is decreased, metabolic **Acidosis** is produced.

Further an increase of chloride ions produces respiratory alkalosis and hyperparathyroidism and decrease of chloride ions produces diabetic acidosis, lactic acid acidosis and persistent vomiting.

In acidosis, the patient has a reduced consciousness, tachycardia develops, the blood pressure falls and signs of cyanosis develop. **Alkalosis** can also be a threat to life since it can create cancer. When the cell is in the resting state, it is said to **polarised** such that inside of the cell is negative with respect to outside of the cell.

When a section of the cell membrane is excited by the flow of ionic current or by some form of externally applied energy, the permeability of the membrane changes so that the sodium ions are allowed to enter inside the cell. This movement of sodium ions into the cell constitutes an ionic current which further reduces the barrier of the membrane to sodium ions. The net result is an avalanche effect such that sodium ions rush into the cell and try to balance with the ions outside. Meanwhile potassium ions are leaving the cell but are unable to move as rapidly as the sodium ions. Therefore the cell has a slightly positive potential on the inside due to the imbalance of potassium ions. This positive potential of the cell membrane during excitation is called **action potential** and is about 20 mV. As long as the action potential exists, the cell is said to be **depolarised**.

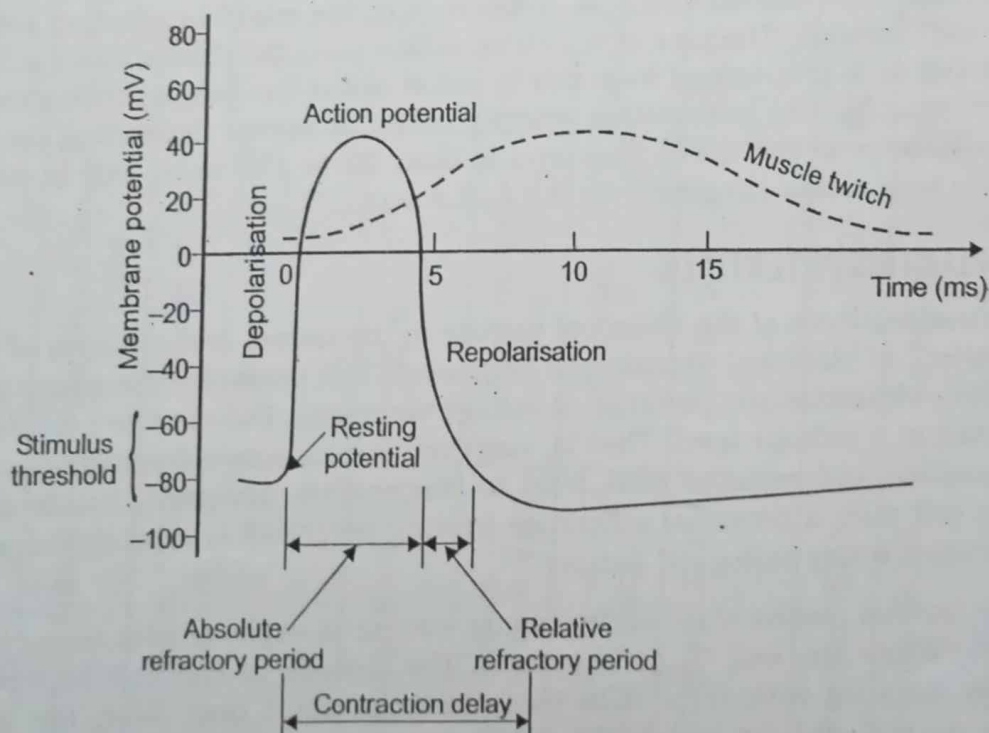


Figure 1.2: The relationship between the action potential and muscle contraction

When the passage of sodium ions is stopped, the ionic currents that lowered the barrier to sodium ions are no longer present and the membrane reverts back to the original (polarised) condition. By the action of sodium pump, the sodium ions are quickly transported to the outside of the cell and the cell is in its resting potential. Generally in nerve and muscle cells repolarisation occurs so rapidly following depolarisation that the action potential appears as a spike of as little as 1 millisecond total duration. But for heart muscle, the action potential is withstanding from 150 to 300 milliseconds and so it repolarizes much more slowly. Figure 1.2 shows the waveform of the action potential.

In a tissue the depolarisation disturbance of one cell is propagated to the next until the entire tissue depolarizes. In muscle, where cells are situated in an orderly manner, a time delay of 10 milliseconds between the action potential depolarisation and the subsequent muscle twitch as shown in figure 1.2 is observed.

Regardless of the method of excitation of cells or the intensity of the stimulus, which is assumed to be greater than the threshold of stimulus, the action potential is always the same for any given cell. This is known as the **all-or-nothing law**. A stimulus voltage generally does not affect a cell while it is changing its polarisation. Following the generation of an action potential, there is a brief period of time during which the cell cannot respond to any new stimulus. Thus the **absolute refractory period** is the time duration of cell nonresponse to further stimuli. It is about 1 millisecond in nerve cells. Following the absolute refractory period, there occurs a **relative refractory period** during which another action potential can be triggered but a higher stimulus is required to reinitiate an action potential and the subsequent contraction of muscle. In nerve cells, the relative refractory period is several milliseconds. The rate at which an action potential moves down a fiber of a nerve cell or is propagated from cell to cell is called the propagation rate or conduction velocity. The conduction velocity varies in nerves depending on the type and diameter of the nerve fiber and is from 20 to 140 m/s. But in heart muscle, it is very slower ranging from 0.2 to 0.4 m/s.

1.6 BIO-ELECTRIC POTENTIALS

As a consequence of the chemical activity in the nerves and muscles of the body, a variety of electrical signals are generated. For example, the heart and brain produce characteristic patterns of voltage variations. Bio-electric potentials are generated at a cellular level. That is, each cell is a minute voltage generator. Because positive and negative ions tend to concentrate unequally inside and outside the cell wall, a potential difference (resting potential) is established and the cell becomes a tiny biological battery.

In the normal resting state of the cell its interior is negative with respect to the outside. When the cell "fires" however, the outside of the cell becomes momentarily negative with respect to the interior. A short time later, the cell regains the normal state in which the inside is again negative with respect to outside. This "discharging" and "recharging" of the cell known as depolarisation and repolarisation respectively produces the voltage waveforms of interest to the clinician and biomedical engineer. Table 1.2 shows the various bioelectric signals, their frequency and voltage picked up by the respective electrodes.

Table 1.2: Bioelectric signals and their characteristics

| Bioelectric Signal | Frequency Range (Hz) | Voltage Range (μV) | Electrodes used | Origin |
|--|-----------------------------------|----------------------------------|--|---|
| Electrocardiogram (ECG) Vector Cardiogram | 0.05 to 100 | 10 to 5000 covers fetal range | Surface electrodes are used with jelly, paste or cream. Needle electrodes are less noisy | Heart muscles |
| Electroencephalogram (EEG) | 0.1 to 100 | 2 to 200 | Surface and Needle electrodes | Neuronal activity of the brain |
| Cerebral potentials (intracranially recorded) | Pulse duration 0.6 ms to 0.1 s | 10 to 100000 | Deep needle electrodes | Cerebrum of the brain |
| Electromyograph (EMG) (primary signal) | 5 to 2000 | 20 to 5000 | Surface or Needle electrodes | Skin muscles |
| Electrogastrogram (EGG) | 0.05 - 0.2 | 10 - 350 | Surface electrodes | Peristaltic movements of the gastrointestinal tract |
| Electroretinogram (ERG) | 0.01 to 200 | 0.5 to 1000 | Corneal electrodes | Retina of the eye |
| Electrooculogram (EOG) | d.c to 100 | 10 to 3500 | Miniature surface electrodes | Corneal-retinal potential variations |

1.7 NERVE TISSUES AND ORGANS

A group of cells of the same type is called a tissue. For example, a nerve tissue is constructed from nerve cells and glial cells. The nervous system is made up of nerve cells. Each nerve cell body has several dendrites along its boundary as shown in Figure 1.3 and a long nerve fiber called **axon**. The nerve cell with its dendrites and fiber is called **neuron**. Information is transmitted through an axon by means of short impulses of constant amplitude. The information is coded and sent through pulse frequency modulated impulses.

A connection between two excitable cells, in the form of a contact surface between two neurons is called a **synapse**. Thus a synapse is the structure in which nerve impulses can be conducted blocked, altered or integrated is acting as a transmission line. In the synapse the information is carried by a chemical substance called a neurotransmitter which diffuses across the gap. The nerve cells synthesize the neurotransmitters into **acetylcholine** and **norepinephrine**. The nerve which contains acetylcholine is called cholinergic. The nerve which contains norepinephrine is called adrenergic. The nerve impulse is conducted in thick neurons is 100 m/s and in thin neurons is 0.5 m/s.

The **organ** of the body is composed of various tissues. The organ contains tissue that furnishes some mechanical strength and specialised tissue that gives a particular function. There are five sense organs in our body. They are eye, ear, nose, tongue and skin. These are exposed outside the body and help us in sensation. There are certain internal organs which serve the purpose of maintaining the body in good condition for work. The main functions of them are breathing, digesting food, circulating blood and removing wastes.

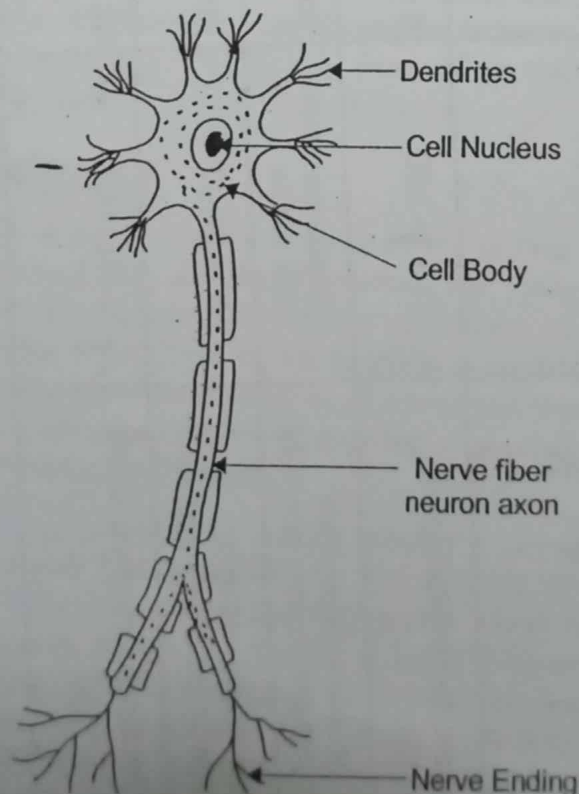


Figure 1.3: Nerve cell

1.8 DIFFERENT SYSTEMS OF HUMAN BODY

A number of organs in the body that function in a coordinated manner form a **system**. For example, the heart, arteries, capillaries and veins constitute the circulatory system.

The human body is functioning properly due to the coordinated action of various systems given below:

- | | |
|------------------------|-----------------------|
| a) Skeletal system | b) Circulatory system |
| c) Respiratory system | d) Digestive system |
| e) Excretory system | f) Regulatory system |
| g) Reproductive system | h) Muscular system |

a) Skeletal system

If we assume the human body as a building, its frame work is the skeleton. The main purpose of the skeletal system is to provide mechanical stability for the body, to protect the delicate organs and to serve as an anchorage for the muscles in order to make possible through lever action. The skeleton also serves as a reservoir for calcium and phosphorus and contains the bone marrow in which blood cells are formed.

The skeleton consists of 206 bones. The skeletal bones are completely enclosed by a membrane called **periosteum**, from which a new bone is formed in the healing of fractures. At the top of the skeleton, **Cranium skull** is placed. At the middle, we have **pelvis**. At the bottom we have **foot bones**. Friction in the joints is reduced by a smooth articular cartilage that covers the bone surfaces. These surfaces along with the articular capsule attached to the bones form a closed cavity. The inner surface of the articular capsule is covered by a membrane that secretes a viscous lubricating fluid.

b) Circulatory System

The circulatory system is a type of transport system. The circulatory system helps in supplying the oxygen and digested food to different parts of our body and removing carbon dioxide from the blood. The heart is the centre of the circulatory system. The heart is made up of muscles. It acts as a pump. The heart pumps blood by a movement called **heart-beating**. The heart pumps the blood through the pulmonary circulation to the lungs and through the systematic circulation to other organs of the body.

In the pulmonary circulation the venous (impure or non-oxygenated) blood flows from the right ventricle of the heart through the pulmonary artery to the lungs where it is oxygenated and gives off carbondioxide. The arterial (pure or oxygenated) blood flows through pulmonary veins to the left atrium of the heart.

Then the pure blood flows into left ventricle where it is pressurised and is pumped through the aorta and its branches called arteries to the different parts of the body. Through small arteries called arterioles, the blood is distributed to the capillaries in the tissues where it gives up its oxygen and other chemicals and

takes up carbon dioxide and products of combustion. The blood returns to the heart through different routes. Blood vessels which carry pure blood from the heart to various organs are known as the **arteries**. Blood vessels through which impure blood returns to the heart are known as **veins**.

The impure blood from the upper half of the body returns to right atrium through superior vena cava and from the lower half of the body through inferior vena cava. The blood vessels which carry pure blood from the lungs to heart are called **pulmonary veins** and the blood vessel which carries impure blood from the heart to lungs is called **pulmonary artery**.

c) Respiratory system

The respiratory system is concerned with breathing and respiration. Its main organs are the lungs. The respiratory system starts from the nose and ends in the lungs. We breathe through our nose. The nose has a cavity which leads to the wind-pipe. This is known as the nasal cavity. The nasal cavity contains some hair at the opening. These hairs filter dirt particles as the air passes through the nose. The nasal cavity is also wet at the back.

So when we breathe in through the nose we inhale air that is free from dirt. Breathing in is called **inspiration** and breathing out is called **expiration**. The air passes from the nose to the wind pipe and from the wind pipe to the two bronchi where it is distributed to the left and right lungs. In the lungs, the air stream is distributed throughout the bronchial tree via the finer airtubes to the alveoli where gas exchange takes place.

d) Digestive system

The digestive system is responsible for digesting the food one eats. In the digestive system the food is disintegrated chemically so that it can be absorbed. First the food is cut into smaller pieces and mixed with saliva in the mouth.

The gullet carries the food from the mouth to the stomach. The stomach wall contains various kinds of glandular cells which secrete hydrochloric acid, pepsin and mucus. The food remains in the stomach for about four to five hours.

Here it is made into a paste by the juices of the stomach. The bile is produced by the liver. Then the food passes to the small intestine where it is further digested. The small intestine is connected to the large intestine. It keeps the food long enough to absorb the water contained in the waste. The waste is thrown out of the body as faeces.

Thus the vital processes require energy which is obtained through metabolism whereby the digestive system burns carbohydrates, fats and proteins. In the combustion process oxygen is consumed; it is taken up by the respiratory organs. The combustion products consist of carbondioxide, water, urea and other nitrogenous substances. The combustion products are excreted by the respiratory system and the excretory system. Thus

Food + Oxygen $\xrightarrow{\text{Metabolic activity}}$ **Energy + Wastes (Carbondioxide)**

The digestive system is in the form of a long tube consisting the mouth at its upper end and the anus at its lower orifice and the food is advanced by peristaltic movements produced by automatic rhythmic contractions of the smooth muscles present throughout the wall of the digestive tract.

e) Excretory system

Excretory system removes the waste products formed during combustion of the food from our body. The lungs, the kidneys, the skin and the large intestine form the excretory system. The lungs remove carbon dioxide. The nitrogenous breakdown products formed during the combustion of proteins are excreted through the kidneys in the form of urine. Thus the excretion of most volatile substances occurs through the lungs and of most non-volatile substances through the kidneys. The sweat glands in the skin remove water, salt and other waste products. The large intestine removes the undigested food through the anus, Further the liver, via the bile removes certain waste products. There is also some excretion through the colon.

f) Regulatory systems

Regulatory systems can be divided into two types as **Nervous system** for regulation of rapid events and **Endocrine system** for regulation of slower metabolic processes. **Nervous system** governs the rapid events like muscular contractions and secretion of most of the glands in the body. It ensures the smooth functioning of various systems in the body. It works through a system of nerves. Nerves act as tiny electric wires. **Sensory nerves** carry the information gathered by the sensory organs to the brain.

Thus they serve as message carriers for the brain. **Motor nerves** carry back the orders from the brain to the muscles and glands. Mixed nerves perform the function of both sensory nerves and motor nerves. i.e. they carry signals or impulses from the sense organs to the brain; At the same time, they convey the order of the brain or the spinal cord to the other parts of the body. Thus the nervous system coordinates the functions of organs. This occurs by the action of external and internal stimuli which result in reflexes. The nervous system consists of central nervous system and peripheral nervous system. The **Central nervous system** is made up of the brain and the spinal cord. The **peripheral nervous system** consists of all the nerves and groups of neurons outside the brain and spinal cord.

Central nervous system

The brain stem continues directly into the spinal cord. It consists of 10^{10} neurons. The brain consists of cerebrum, cerebellum and the brain stem. The **cerebrum** consists of two hemispheres and the hemispheres are divided into frontal lobe, parietal lobe, occipital lobe and temporal lobe. The frontal lobes are responsible for intelligence, constructive imagination and abstract thought. The outer layer of the brain is called cerebral cortex. The areas in the cerebral cortex is responsible for sight, hearing, touch and control of the voluntary muscles of the body.

The upper side of the temporal lobe contains hearing center. The temporal lobes are also of importance for the storage process in the long term memory. The visual centre is situated in the occipital lobe which is in the back side of brain. Motor center in the cerebral cortex corresponds to a certain body movement which

can be elicited by electrically stimulating the brain surface. In the anterior part of the parietal lobe contains the sensory center where the sensory nerves are terminated.

Cerebellum consists of two hemispheres. They regulate the coordination of muscular movements elicited by the cerebrum. It is also a balance center. In the brain stem, we have diencephalon, which consists of thalamus and hypothalamus, and medulla oblongata. Thalamus is a relay station for sensory pathways to the cortical sensory center of the cerebrum. Hypothalamus consists of centers for temperature regulation, metabolism, fluid regulation, appetite, thirst, sleep, feelings and emotions. The medulla oblongata contains centers for regulating the working of the heart and lungs. The brain consists of a system of cavities called ventricles. The ventricles contain cerebrospinal fluid which helps to resist the stresses due to acceleration.

Spinal cord is the downward continuation of the medulla oblongata and is protected by the spinal canal. It runs through the vertebral column or through the back bone. The working of the entire body is linked with it. It is connected to a large number of nerves. The spinal cord makes the work of the brain easy by receiving messages from it and then sending them to different organs and vice-versa. The spinal cord is meant to take decisions where no thinking is required. If we feel thirsty, we drink water. This type of automatic or quick reaction is called reflex or reflexaction.

Peripheral nervous system

The peripheral nervous system consists of motor and sensory nerves. The motor pathways conduct outwards (**efferent**) and sensory pathways conduct inwards (**afferent**). The autonomic nervous system consists of two motor systems working in opposition. They are **sympathetic** and **parasympathetic** systems. If the nerve impulses are conducted through sympathetic motor system in an organ, they stimulate muscular activity in one direction and those conducted through parasympathetic system evoke the opposite effect. For example the pupil of our eye is dilated by the sympathetic and contracted by the parasympathetic. Through the coordinating action of the two systems homeostasis develops, that is equilibrium in the activity of the pupil.

Endocrine system

The endocrine system works by using hormones which are carried through circulatory system. The hormones are generated in the endocrine glands. The principal endocrine gland, the **pituitary** governs several other endocrine glands. The pituitary is controlled by the hypothalamus. The **thyroid gland** secretes thyroxin which increases the metabolism in the body. The deficiency of thyroid hormone results in low metabolic rate and mental retardation. An excess of thyroid hormone results in high metabolic rate and nervousness. The **adrenal gland** secretes corticoids and they regulate blood pressure and flow. The **pancreas gland** secretes insulin which is a hormone that regulates the metabolism of glucose.

A deficiency of insulin results in increased glucose in the blood which leads the condition called diabetes. **Duodenum gland** produces hydrochloric acid using its hormones. The **gonads**, the sex glands generate sex hormones (testosterone for male and estrogen and progesterone for female). These hormones regulate the sex drive and pregnancy. The **placenta** generates a number of hormones which are useful during pregnancy.

g) Reproductive system

A fetus develops through repeated cell division by means of reproductive system. The seminal vesicles and the prostate gland in the male genital organs produce two secretions which form the **semen**. This semen activates the sperm and makes them mobile. The ovaries in the female genital organ produce the **ova** and **eggs**. In ovulation, usually one is detached and spends a few days passing through the fallopian tube to the uterus. Fertilization takes place in the fallopian tube to which the sperm have swum through the uterus. When the ovum reaches the uterus, it becomes embedded in the endometrium where the fetus is developed through repeated cell division. The fetus receives nourishment from the mother via the umbilical cord and the placenta which is attached to the uterine wall.

h) Muscular system

The movements of the various parts of the body are caused by the muscles. There are three kinds of muscles: **voluntary muscles** which work at our will (example: arm muscles), **involuntary muscles** which work without our knowledge (example: muscles in the food canal) and **cardiac muscles** which help in functioning of the heart and are working day and night without tired. Already we know that the contraction of the muscles is regulated via nerves. There are two types of contraction, isotonic and isometric. In **isotonic contraction**, the muscle is shortened under constant load. In **isometric contraction** the muscle contracts without shortening. In a muscular movement, the first stage is usually an isometric contraction and then isotonic contraction is occurred.

In isometric contraction no work is obtained and all the energy is converted into heat energy. In isotonic contraction 20% of the energy is converted into work and the remaining is converted into heat. Thus the muscular contraction is the principle mechanism for generating heat. For example during winter, we involuntarily contract our muscles to increase the amount of heat generated and shrink the surface area of the body to reduce radiation heat losses.

In each skeletal muscle, a **motor nerve** conducts, impulses that cause contraction. The nerve consists of a large number of individual nerve fibers. Each fiber is divided into several branches and supplies a group of muscle fibers. Thus a bundle of muscle fibers in a muscle supplied by a single motor nerve fiber is called a **motor unit** because all the muscle fibers contract simultaneously when the nerve fiber is stimulated. A motor unit is the basic functional unit of the muscular system. Each contraction of a motor unit produces a constant force.

The movement of a whole muscle is regulated by a change in contraction frequency and by adding motor units as required. Thus a muscular contraction is the result of synchronous contraction of thousands of motor units. Fine movements are obtained by means of a feedback signal which is transmitted from the muscle to the controlling unit in the central nervous system. The sensors in the muscles are the muscle spindles. The setting of the desired value of contraction in a skeletal muscle and the measurement of the instantaneous "actual" value are effected by muscle spindles in the motor units. From the muscle spindle an error signal which is a function of the difference between the "actual" and the "desired" values for the contraction is transmitted via an "afferent" (conduction *to* the central nervous system) nerve fiber to higher nerve centers. Efferent gamma fibers (conducting *from* the central nervous system) adjust the spindle length to the required degree of contraction. There are also receptors for muscle control in the joints for transmitting to the central nervous system. By means of these, without the aid of vision we can touch the particular part of the body with fingers. Figure 1.4 shows the block diagram for the controlled muscular contraction and figure 1.5 shows the muscle spindle in a motor unit.

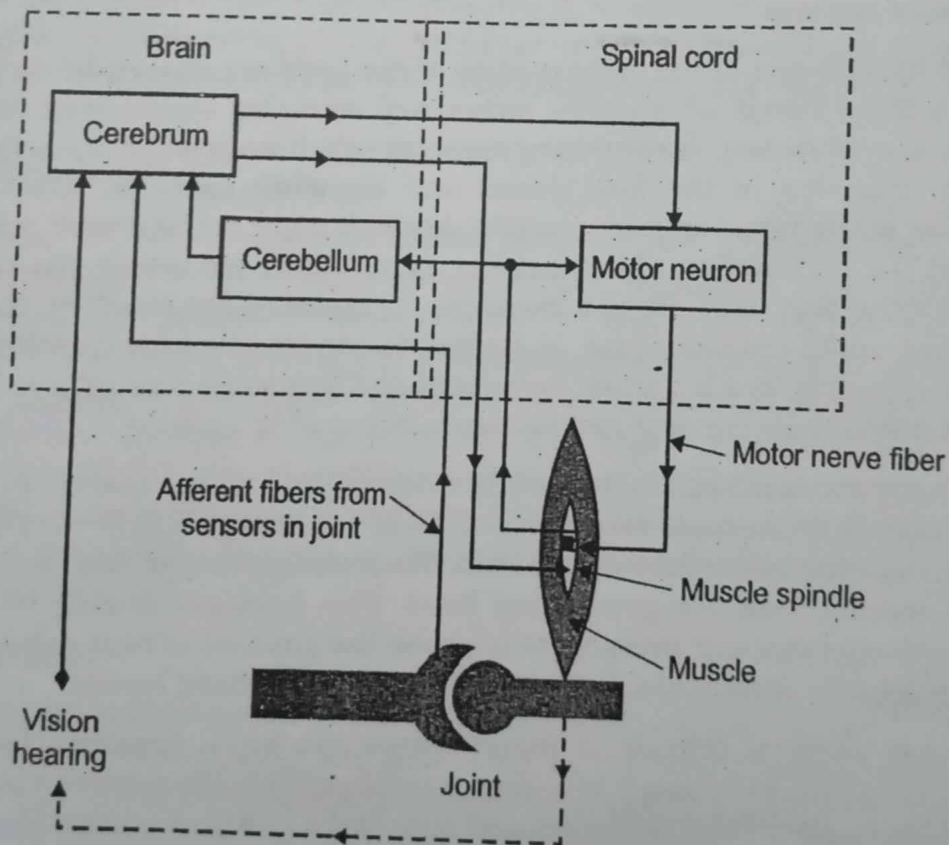


Figure 1.4: Block diagram for the controlled muscular contraction

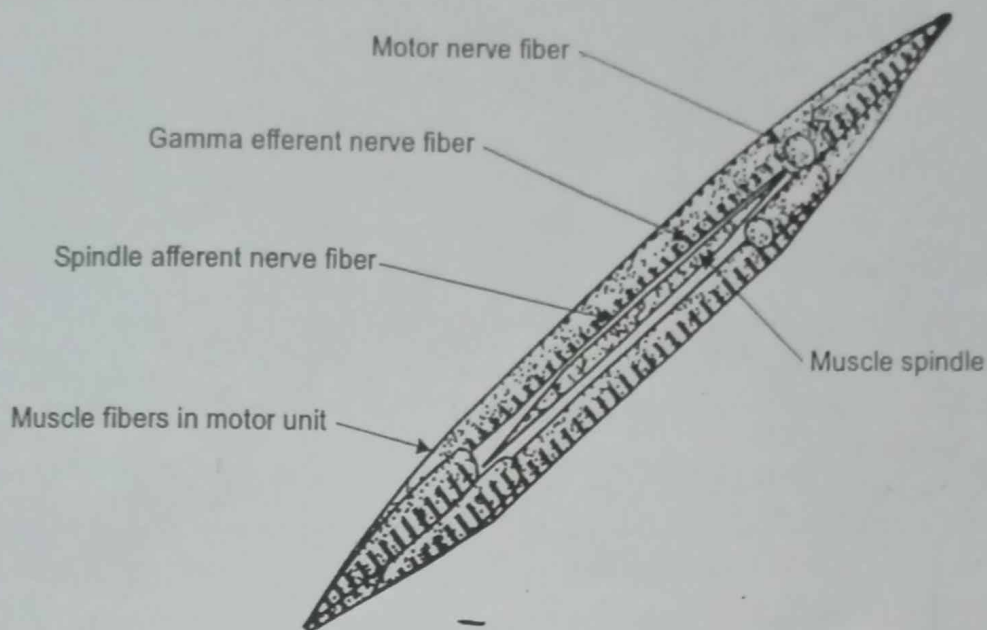


Figure 1.5: Muscle Spindle in a motor unit

The details regarding the heart, lungs, kidneys, ear and eye are given in separate chapters along with the related instrumentation.

QUESTIONS

1. Draw the structure of a living cell of our body and explain its constituents.
2. Discuss the different ways of transport of ions through the cell membrane.
3. What are resting and action potentials?
4. Give an account on the different chemical compositions in the intra and extra cellular fluids and their effects in the case of blood serum.
5. Discuss the development of action potential and muscular contraction.
6. What are bioelectric potentials? Discuss the frequency and voltage range of ECG, EEG, EMG and ERG signals?
7. Give the names of the different systems in our body. Briefly explain them regarding their function and constituents.
8. How does the blood circulate throughout the body?
9. What is meant by central nervous system? Explain the different parts of it and their activity.
10. What are the different types of muscles? Explain the importance of motor unit in the muscular contraction.

Many writers are constructed so that the pen arm moves in an arc. This introduces both amplitude and timing errors which increase in a non-linear manner with the deflection and cause some distortion of the waveshape. If the pen arm has a length of L cm and rotates through an angle of Θ radians, the amplitude error introduced by measuring along an equivalent straight line perpendicular to the base line instead of along the arc produced by the pen is $L\Theta^3/6$. This error is usually negligible.

If the length of the straight line is D cm and the distance difference between the arc and the straight line with respect to the base line produces a timing error of $D^2/(2Ls)$ seconds where s is the paper speed in cm/s.

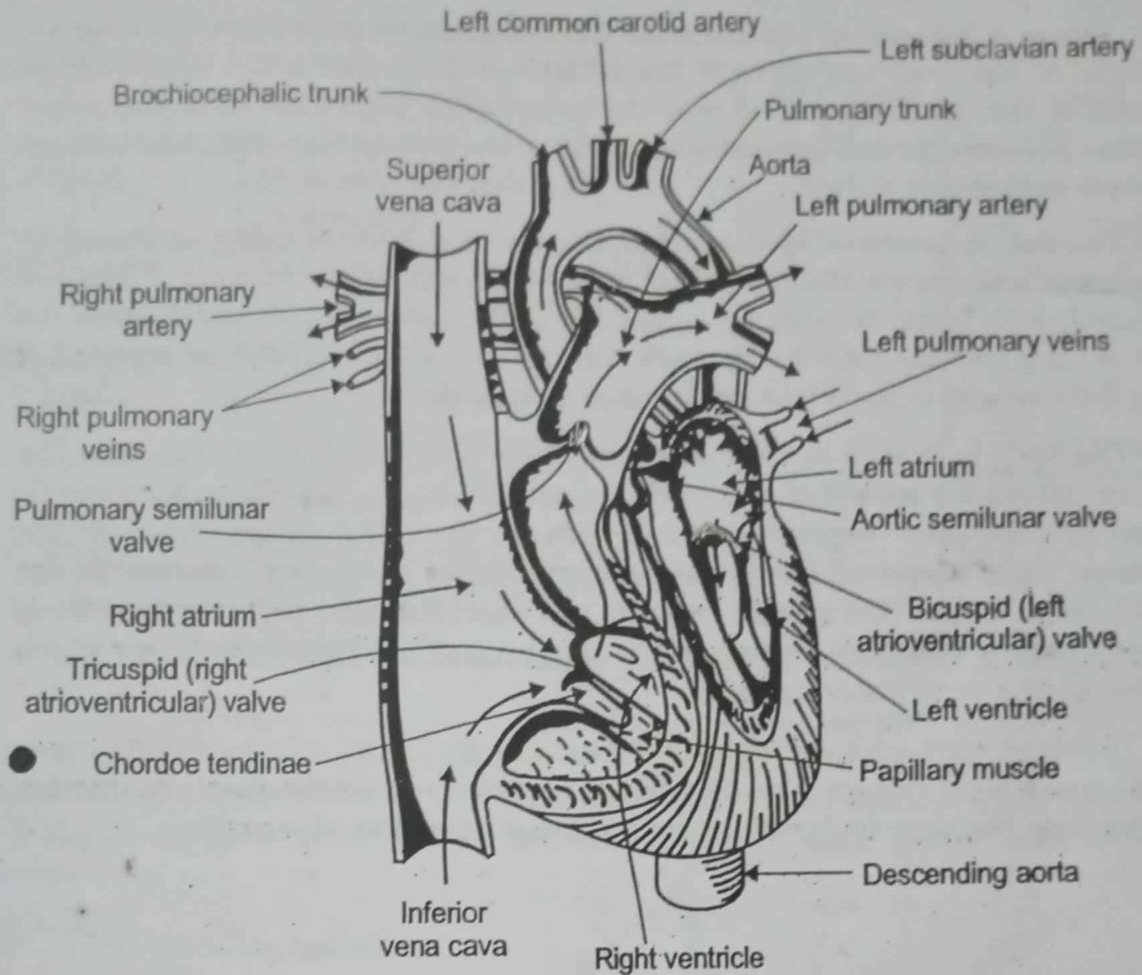
4.3 ELECTROCARDIOGRAPHY

The Electro Cardiograph (ECG) deals with the study of the electrical activity of the heart muscles. The potentials originated in the individual fibers of heart muscle are added to produce the ECG wave form. **Electro cardiogram** is the recorded ECG wave pattern. ECG sometimes called EKG which is derived from the German electrocardiogram.

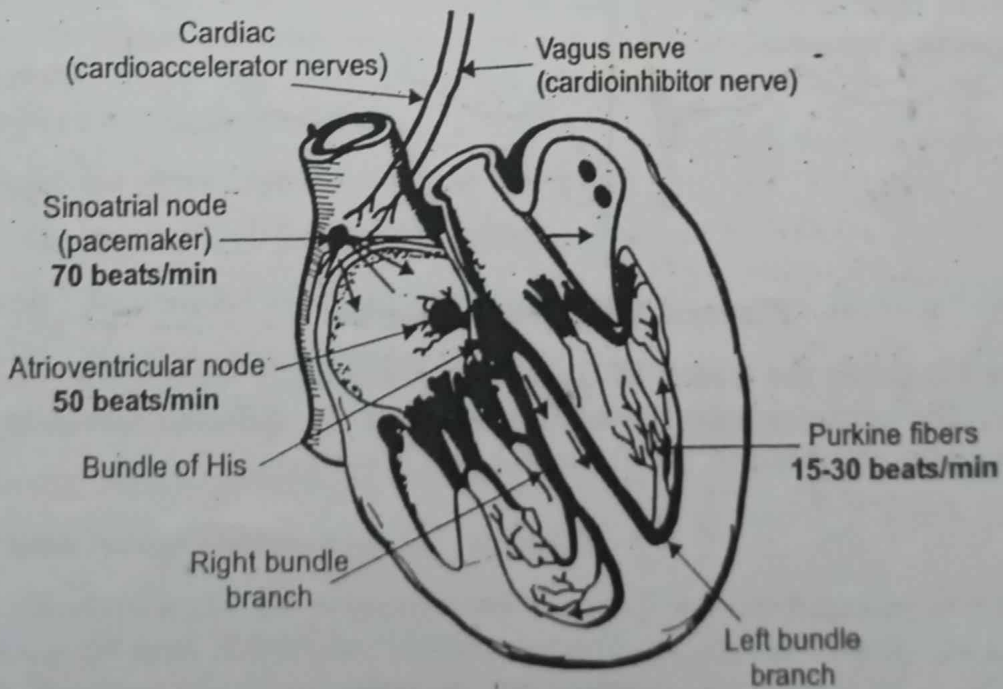
The electrocardiogram reflects the rhythmic electrical depolarisation and repolarisation of the myocardium (heart muscle) associated with the contractions of the atria and ventricles. The shape, time interval and amplitude of the ECG give the details of the state of the heart. Any form of arrhythmia (disturbances in the heart rhythm) can be easily diagnosed using electrocardiogram. But the valvular defects can be identified by phonocardiography which will be dealt later.

4.3.1 Origin of Cardiac Action Potential

Figure 4.2 shows the cross section of the interior of the heart. We know that the heart is divided into four chambers. The top two chambers are atria and lower two chambers are ventricles. The right atrium receives blood from the veins and pumps it into right ventricle. The right ventricle pumps the blood into the lungs where it is purified and oxygenated. The oxygen enriched blood enters the left atrium from which it is pumped into the left ventricle. Then the left ventricle pumps the blood into arteries through Aortic valve for circulation throughout the body. For circulation, blood requires proper pressure. Sufficient pressure is delivered by the ventricular muscle's contraction which is achieved through the cardiac action potential.



a) Anatomy



b) Conducting system of heart

Figure 4.2

Figure 4.2 (b) shows the electrical conducting system of heart. Each action potential in the heart originates at the **sinoatrial (SA) node** which is situated in the wall of the right atrium and near the entry of the Vena Cava. It is also called **cardiac pacemaker** and generates impulses at the normal rate of the heart, about 70 beats per minute at rest.

The rate is governed by the autonomic nervous system, being increased by the sympathetic nerves and decreased by the parasympathetic nerves. These are connected with brain through the spinal cord. The action potential contracts the atrial muscle and the impulse spreads through the atrial wall during a period of about 0.04 second to the **atrio-ventricular (AV) node**.

The node is located in the lower part of the wall between the two atria. The AV node delays the spread of excitation for about 0.11 second. Thus the AV node acts as a "delay line" to provide timing between the action of the atria and the ventricles. Then a special conduction system carries the action potential to the ventricular muscles. This system consists of a short common part (**the bundle of His**), two bundle branches on each of the septum and fine **Purkinje fibers** which arborize in the ventricular muscle.

Thus the atria and ventricles are functionally linked only by the AV node and the conduction system. The AV delay is provided so that the atrial contraction can complete the ventricular filling before the contraction of ventricles.

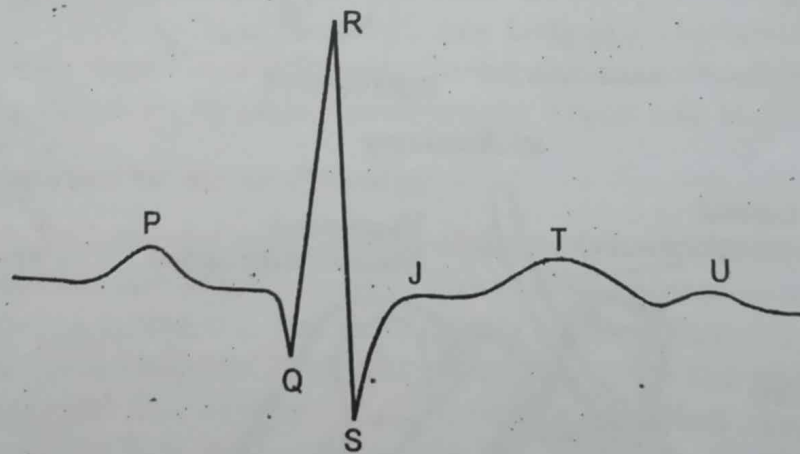


Figure 4.3: Electrocardiogram

Figure 4.3 shows the typical ECG wave. It consists of P wave, QRS complex and T wave. The origin, amplitude and duration of the different waves in the electrocardiogram are given in the Table 4.1.

Table 4.1: Physiological Nature of ECG Waveform

| | <i>Origin</i> | <i>Amplitude mV</i> | <i>Duration sec.</i> |
|-------------------------|--|-------------------------|--------------------------------|
| P Wave | Atrial depolarisation or contraction | 0.25 | 0.12 to 0.22 (P-R interval) |
| R Wave (QRS complex) | Repolarisation of the atria and the depolarisation of the ventricles | 1.60 | 0.07 to 0.1 |
| T Wave | Ventricular repolarisation (Relaxation of myocardium) | 0.1 to 0.5 | 0.05 to 0.15 (S-T interval) |
| S-T interval | Ventricular contraction | | |
| U Wave | Slow repolarisation of the intraventricular (Purkinje fibers) system | < 0.1 | 0.2 (T-U interval) |

The complete waveform is called electrocardiogram with labels PQRSTU indicating important diagnostic features. For example if the PR interval is more than 0.22 sec., the AV Block (First degree - heart attack) occurs. When the QRS complex duration is more than 0.1 second the bundle block (severe heart attack) occurs.

4.3.2 ECG Lead Configurations

Usually surface electrodes are used with jelly as electrolyte between skin and electrodes. The potentials generated in the heart are conducted to the body surface. The potential distribution changes in a regular and complex manner during each cardiac cycle. Therefore to record electrocardiograms, we must choose standardised electrode positions.

There are three types of electrode systems:

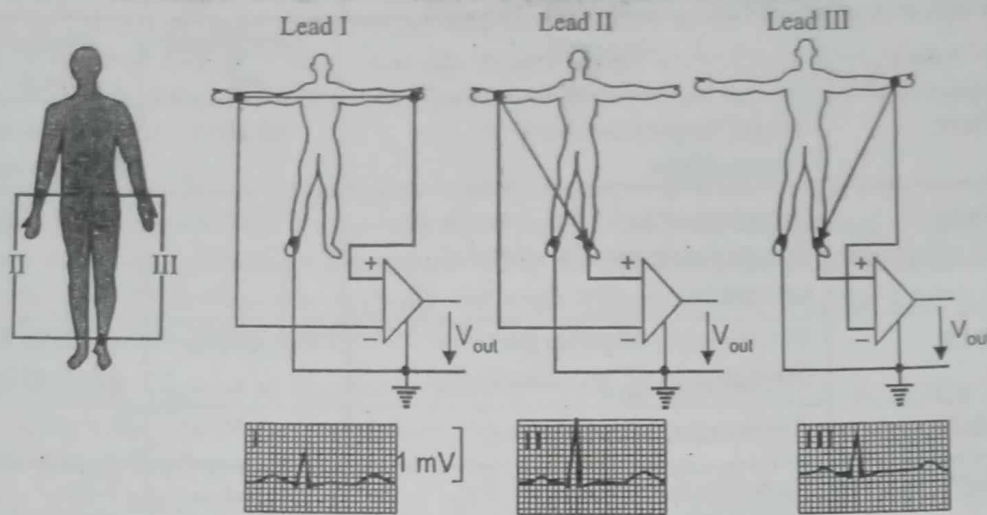
- 1) Bipolar limb leads (or) standard leads
- 2) Augmented unipolar limb leads
- 3) Chest leads (or) precordial leads
- 4) Frank lead system (or) corrected orthogonal leads

Among these four systems, the first three are widely used.

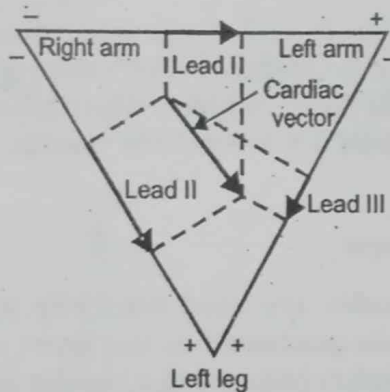
Bipolar limb leads - standard leads I, II and III

In standard leads, the potentials are tapped from four locations of our body. They are i) right arm, ii) left arm, iii) right leg and iv) left leg. Usually the right leg electrode is acting as ground reference electrode.

Figure 4.4 (a) shows the standard bipolar limb leads positions and the corresponding wave patterns.



a) Standard bipolar limb leads and the corresponding ECG



b) The Einthoven triangle

Figure 4.4

- | | | |
|-------------------|---|--|
| Lead I Position | - | gives voltage V_I , the voltage drop from the left arm (LA) to the right arm (RA) |
| Lead II Position | - | gives voltage V_{II} , the voltage drop from the left leg (LL) to the right arm (RA) |
| Lead III Position | - | gives voltage V_{III} , the voltage drop from the left leg (LL) to the left arm (LA) |

The closed path RA to LA to LL and back to RA is called the **Einthoven triangle**. According to Einthoven, in the frontal plane of the body the cardiac electric field vector is a two dimensional one. The ECG measured from anyone of the three limb leads is a time variant single dimensional component of that vector. Along the sides of this triangle the three projections of ECG vector are measured as shown in figure 4.4 (b). Further the vector sum of the projections on all the three sides is equal to zero. Thus following Kirchoff's law, the R wave amplitude of lead II is equal to the sum of the R wave amplitudes of leads I and III. For example the R wave nominal voltage from different leads is given below:

| | Lead I | Lead II | Lead III |
|------------------|----------------|----------------|----------------|
| | V_I | V_{II} | V_{III} |
| | mV | mV | mV |
| R wave amplitude | 0.53 | 0.71 | 0.38 |
| | (0.07 to 1.13) | (0.18 to 1.68) | (0.03 to 1.31) |

The voltages given in brackets indicate the range of the measured voltage. Thus

$$V_{II} \approx V_I + V_{III}$$

Augmented unipolar limb leads

In the augmented unipolar limb leads system, which is introduced by Wilson, the electrocardiogram is recorded between a single **exploratory electrode** and the **central terminal** which has a potential corresponding to the center of the body. Thus two equal and large resistors are connected to a pair of limb electrodes and the center of this resistive network acts as central terminal and the remaining limb electrode acts as the exploratory electrode. By means of augmented ECG lead connections, a small increase in the ECG voltage can be realized. The augmented lead connections are augmented voltage Right arm (aVR), augmented voltage Left arm (aVL) and augmented voltage Foot (aVF) as shown in figure 4.5 (a).

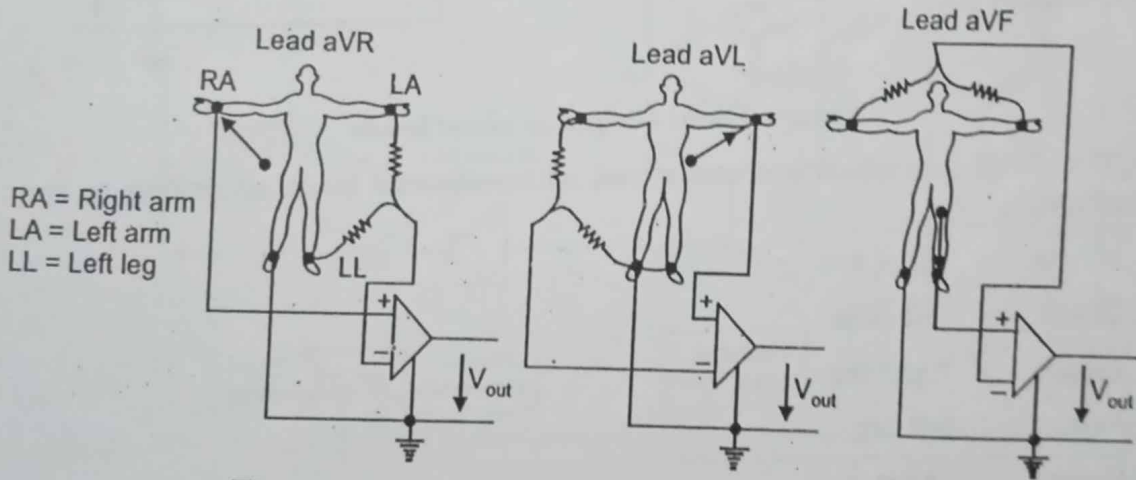


Figure 4.5: a) Augmented unipolar limb leads

Eventhough the resistors in these limb leads have large value, their values are smaller when we compare with the input resistance of the preamplifier. By Kirchoff's law, the augmented voltages can be written as in terms of standard leads voltage:

$$aVR = -V_I - \frac{V_{III}}{2}$$

$$aVL = V_I - \frac{V_{II}}{2}$$

$$aVF = V_{II} - \frac{V_I}{2}$$

Unipolar chest leads

In the case of unipolar chest leads, the exploratory electrode is obtained from one of the chest electrodes. The chest electrodes are placed on the six different points on the chest closed to the heart as shown in figure 4.5 (b). By connecting three equal large resistances to the left arm; right arm and left leg a reference electrode or central terminal is obtained. This lead system is known as Wilson system. Thus the electrocardiograms are recorded from these 12 lead selections such that 3 standard bipolar leads, 3 augmented unipolar leads and 6 chest leads.

V_1 -Fourth intercostal space,
at right sternal margin

V_2 -Fourth intercostal space,
at left sternal margin

V_3 -Midway between V_2 and V_4

V_4 -Fifth intercostal space,
at mid-clavicular line.

V_5 -Same level as V_4 , on
anterior auxiliary line

V_6 -Same level as V_4 , on
mid-auxillary line

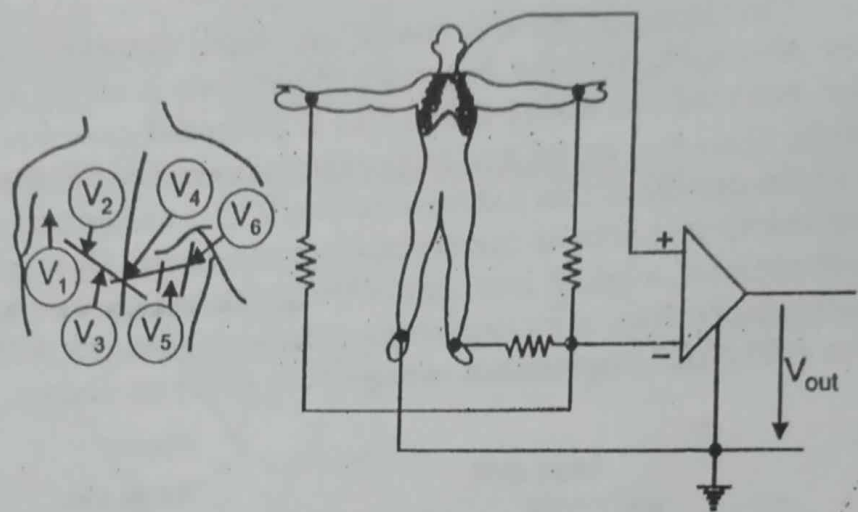


Figure 4.5: b) Unipolar chest leads

The ECG potentials are measured with coloured leads according to the convention,

- White - right arm
- Black - left arm
- Green - right leg
- Red - left leg
- Brown - chest

This is internationally adopted for easy reference.

Frank lead system

The corrected orthogonal leads system (or) Frank lead system is used in vector cardiography. Here one can get the informations from above said 12 leads. Further using this lead system, the heart's dipole field is resolved into three mutually perpendicular components and hence the state of the heart is studied three dimensionally.

4.3.3 ECG Recording set up

The important parts of ECG recorder are shown in figure 4.6.

1) Patient cable and Defibrillator Protection Circuit

The patient cable connects the different leads from the limbs and chest to the defibrillator protection circuit. It consists of buffer amplifiers and over voltage protection circuit. The leads are connected with the buffer amplifiers such that one buffer amplifier for each patient lead.

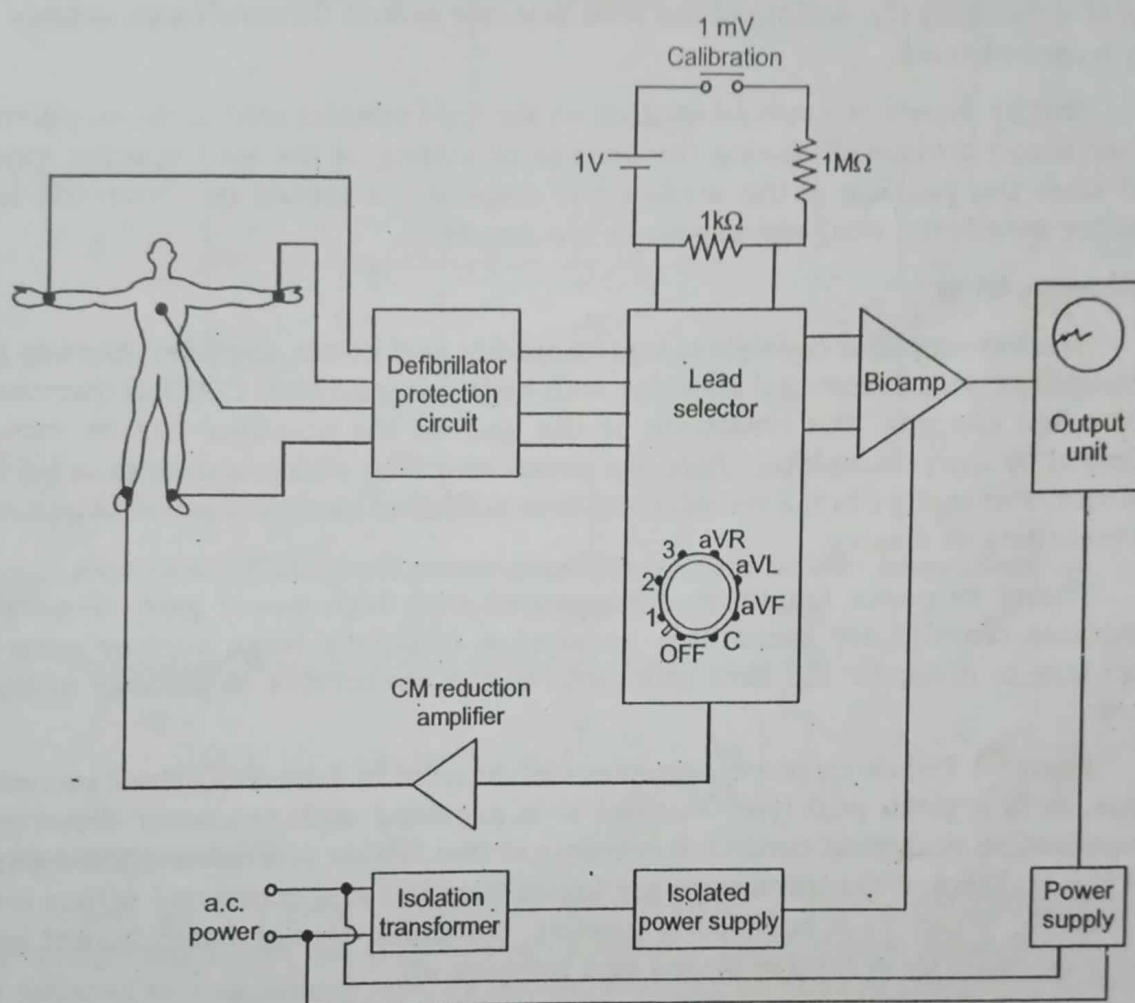


Figure 4.6: ECG Recording set up

By this means the input impedance is increased and the effects arising from the variations in the electrode impedance are reduced. Further the over voltage protection circuit is necessary to avoid any damage to the bioamplifiers in the recorder. The over voltage of the order of 1000 V may occur when the electrocardiograph is used during surgery in conjunction with radiofrequency diathermy units for cutting and coagulation or during the treatment of ventricular fibrillation using defibrillators. This over voltage protection circuit consists of a network of resistors and neon lamps which fire when a pulse from a defibrillator is present. During firing of the neon lamp, there is no input to the preamplifier of the recorder.

2) Lead selector switch

After the defibrillator protection circuit, there is lead selector switch which is used to feed the input voltage from the appropriate electrode to the preamplifier.

3) Calibrator

A push button allows the insertion of a standardization voltage of 1 mV to the preamplifier. This enables the technician to observe the output on the display unit and adjust the scale so that a known deflection corresponds to a 1 mV input signal. Changing the setting of the lead selector switch introduces an artifact on the recorded trace.

But by means of a special contact on the lead selector switch the amplifier is momentarily turned off during the change of setting of the lead selector switch and after the passage of the artifact the amplifier is turned on. From the lead selector switch the ECG signal goes to bio-amplifier.

4) Bio-amplifier

The bio-amplifier consists of a preamplifier and power amplifier. Already the preamplifier, as a differential amplifier with high gain and high CMRR is discussed in the last chapter. The sensitivity or the gain of the amplifier can be varied. Followed by the preamplifier, there is a power amplifier which is used to drive the recorder. Pen motors in the recorder requires sufficient electrical power to activate the recording or display.

Therefore power amplifiers are required with high power gain. Generally transistor circuits are favourable because a relatively large surface area is necessary to dissipate the heat generated in the circuit due to passage of high current.

Figure 4.7 shows a power amplifier circuit used to drive ECG chart recorder stylus. It is a push pull type. Further it is provided with crossover distortion compensation and offset control. It consists of two silicon power transistors such that the emitters of the transistors are joined together and connected with a load resistor, R_L . When V_B is sufficiently positive, transistor Q_1 is forward biased and conducts, while Q_2 is reverse biased and remains off.

$$\text{Output Power, } P_{\text{out}} = V_{\text{out}}^2 / R_L$$

$$\text{The amplifier efficiency, } \eta = P_{\text{out}} / (P_{\text{out}} + P_{\text{loss}})$$

To avoid the crossover distortion in a push pull amplifier, an ideal noninverting amplifier is inserted at the input. Since the input impedance of noninverting amplifier approaches infinity, the power gain also approaches infinity.

The crossover distortion is eliminated because the feedback resistance, R_f is so large and hence it raises the gain in a linear manner and in turn raises the output voltage. The offset control is provided by the resistance R_2 and is used to position the output stylus pen. Gain adjustment is provided with the resistance R_o .

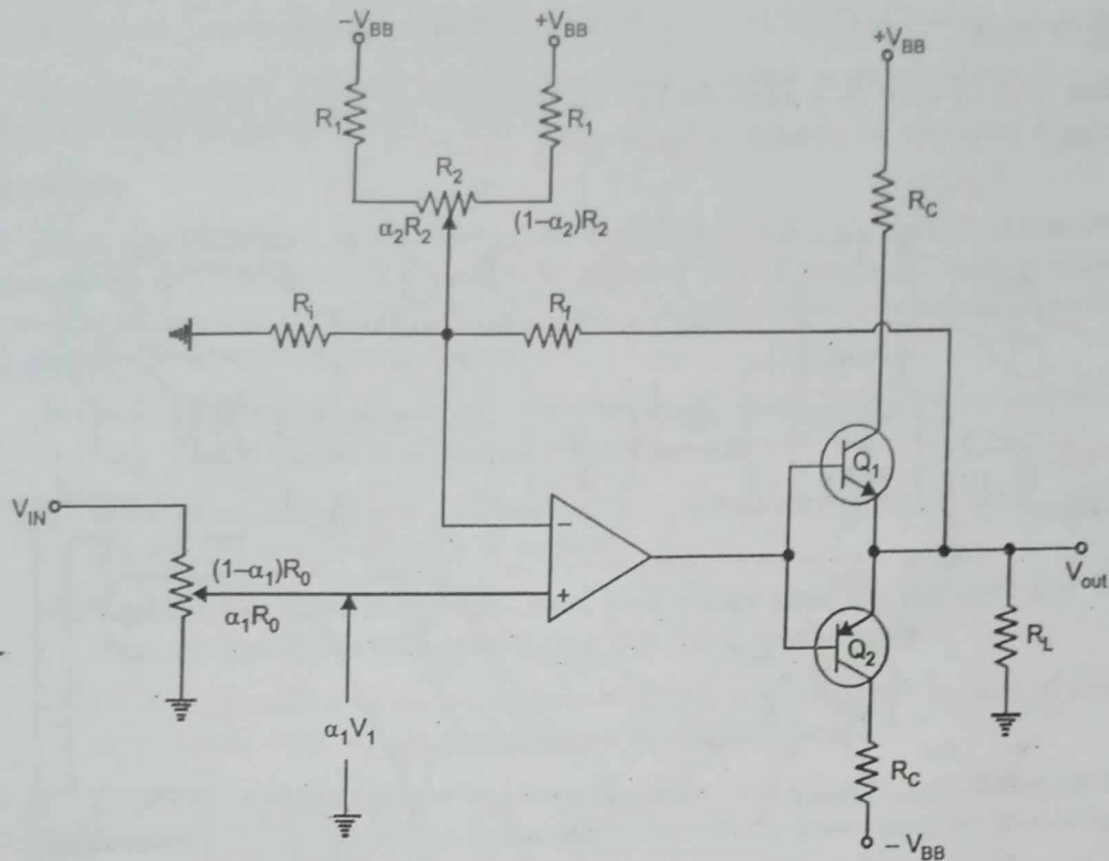


Figure 4.7: Push-pull power amplifier with crossover compensation and offset control

The output voltage of this amplifier circuit is given by

$$V_{out} = (\alpha_1 V_1) \left(1 + \left(\frac{R_f}{R_i} \right) \right) + R_f \left[\frac{\alpha_1 V_1 + V_{BB}}{\alpha_2 R_2 + R_1} + \frac{\alpha_1 V_1 - V_{BB}}{(1 - \alpha_2) R_2 + R_1} \right]$$

5) Auxiliary amplifier

Since the electrode impedances are not equal, a differential amplifier does not completely reject the common mode signals. The common mode signals can be reduced to a minimum level by means of adding an auxiliary amplifier between the driven right leg lead and the ECG unit. By this way, the right leg is not connected to ground but it is connected to the output of the auxiliary amplifier. If the body common mode voltage is different from zero, a summing network produces the sum of all common mode voltages from all other electrodes and feeds that sum of the voltages as input to inverting terminal of the auxiliary amplifier. Meanwhile its noninverting terminal is grounded. The output of the auxiliary amplifier is connected to the right leg. Therefore it drives the body to zero common voltage. Thus the common mode rejection ratio of the overall system is increased. Further in the right leg electrode the current flow is reduced.

6) Isolated Power Supply

The isolated power supply is used to give power to the bio-amplifier and by means of that, the electrical safety for the patient is increased (Refer isolation amplifiers in the Chapter III).

7) Output Unit

The output unit is a cathode ray oscilloscope as shown in figure 4.7 or a paper chart recorder as shown in figure 4.8.

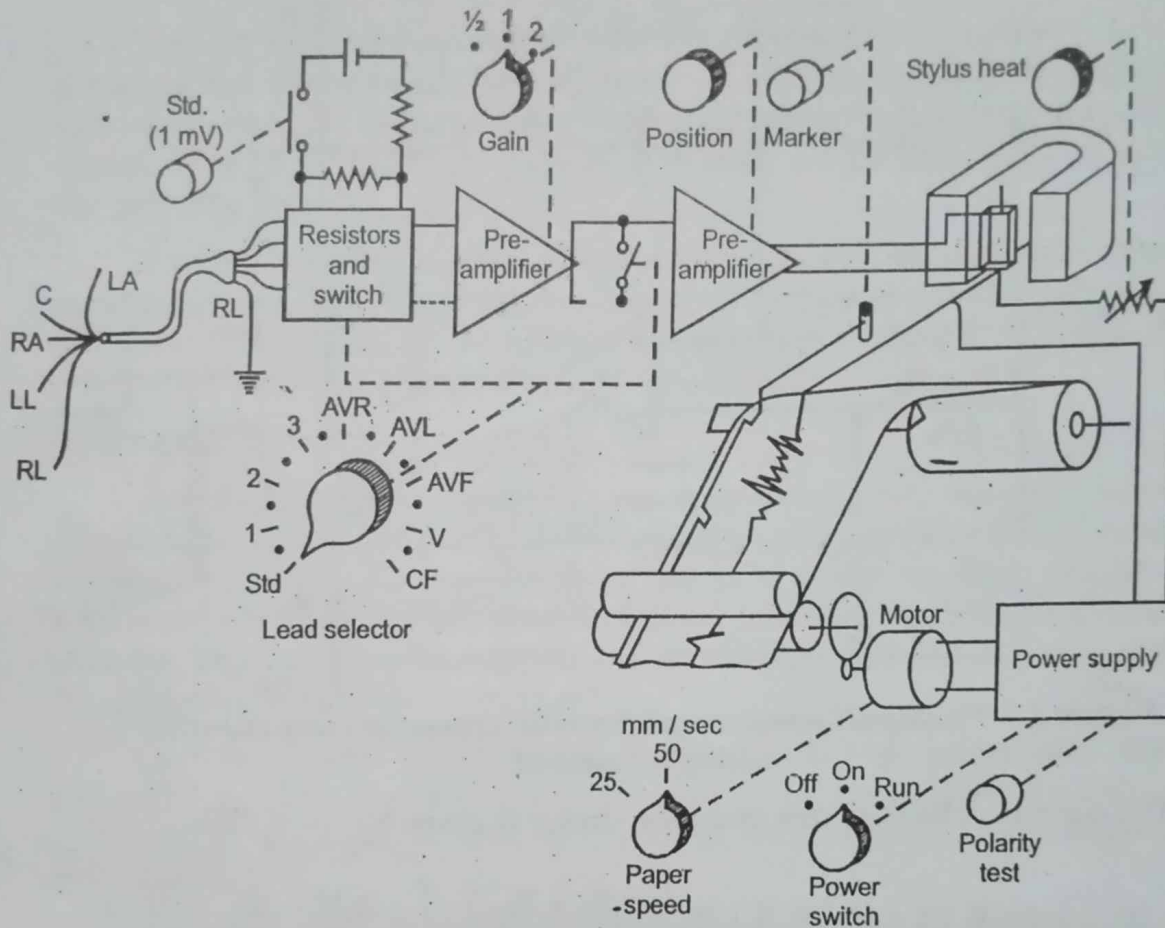


Figure 4.8: Paper chart recorder using pen as writer

In the case of paper chart recorder, the power amplifier or pen amplifier supplies the required power to drive **pen motor** that records the ECG trace on the wax coated heat sensitive paper. A position control on the pen amplifier is used to position the pen at the center on the recording paper. The **stylus pen** is heated electrically and the temperature of the stylus pen can be adjusted with a stylus heat control. There is a marker stylus which is actuated by a push button and allows the technician to mark a coded indication of the lead being recorded.

The paper speed is about 25 mm/s (U.S. paper speed) or 50 mm/s (European paper speed). The faster speed of 50 mm/s is provided to allow better resolution of the QRS complex at very high heart rates.

8) Power Switch

The power switch of the recorder has three positions. In the ON position the power to the amplifier is turned on, but the paper drive is not running. In order to start the paper drive the switch must be placed in the RUN position. In OFF position, the ECG unit is in switched off condition.

4.3.4 Practical considerations for ECG recording

Several practical aspects must be observed in order to obtain diagnostically useful electrocardiogram.

I) Artifacts

Since the ECG unit is a sensitive device, it can pick up unwanted electrical signals which may modify the actual ECG signals. Eventhough AC interference is reduced by increasing the CMRR of the bioamplifier, the operator before recording EEG should check the following things:

- i) Be sure that the patient does not touch or make contact with any metal object such as bed rail, bed stand or furniture.
- ii) Remove or unplug any other electrical appliances such as clocks, radios, lamps, etc in the vicinity of patient.
- iii) If adder ECG machines are used, make sure that the polarity test has been performed before connecting the cable to the patient.
- iv) Be sure that all electrodes have been applied with right amount of paste or jelly and that all electrode straps are tight enough.
- v) Be sure that the patient is in comfortable and relaxed condition. If the patient is not completely relaxed, the unsteady trace may be produced.

II) Wandering of Base line

The wandering of base line results from the gross movements of patients or from mechanical strain on the electrode wires. If there is no proper application of jelly between the electrode and the skin, during that time also the wandering of base line occurs.

III) Solid Base line

An indistinct trace or solid base line appears due to improper adjustment of stylus temperature or by buildup of waxy residue on heated stylus.

IV) Frequency Response

Generally the upper frequency limit of the bioamplifier is about 100 Hz. But the pen inertia limits the ECG unit response to about 50 Hz. This lowers the fidelity of QRS complex. The lower frequency limit of the bioamplifier is about 0.05 Hz.

$$\therefore \text{The time constant of the amplifier} = \frac{1}{2\pi \times 0.05} = 3 \text{ seconds}$$

If the time constant is less than 3 seconds, there is a distortion in the P and T waves. If the time constant is more than 3 seconds, the recovery time of the amplifier is so large. Thus it would not record properly when we go from one lead to another lead.

V) Other Specifications of the Ordinary ECG Recorder

| | | |
|------------------------|---|--|
| Sensitivity (max.) | : | 20 mm/mV |
| Input impedance | : | 5 Mega ohms |
| Output impedance | : | Less than 100 ohms |
| Standardisation signal | : | 1 mV |
| CMRR | : | 10000:1 |
| Recording techniques | : | Heated stylus and heat sensitive paper |
| Paper speed | : | 25 mm/s or 50 mm/s |
| Frequency response | : | 0.1 to 60 Hz |

4.3.5 Analysis of Recorded ECG Signals

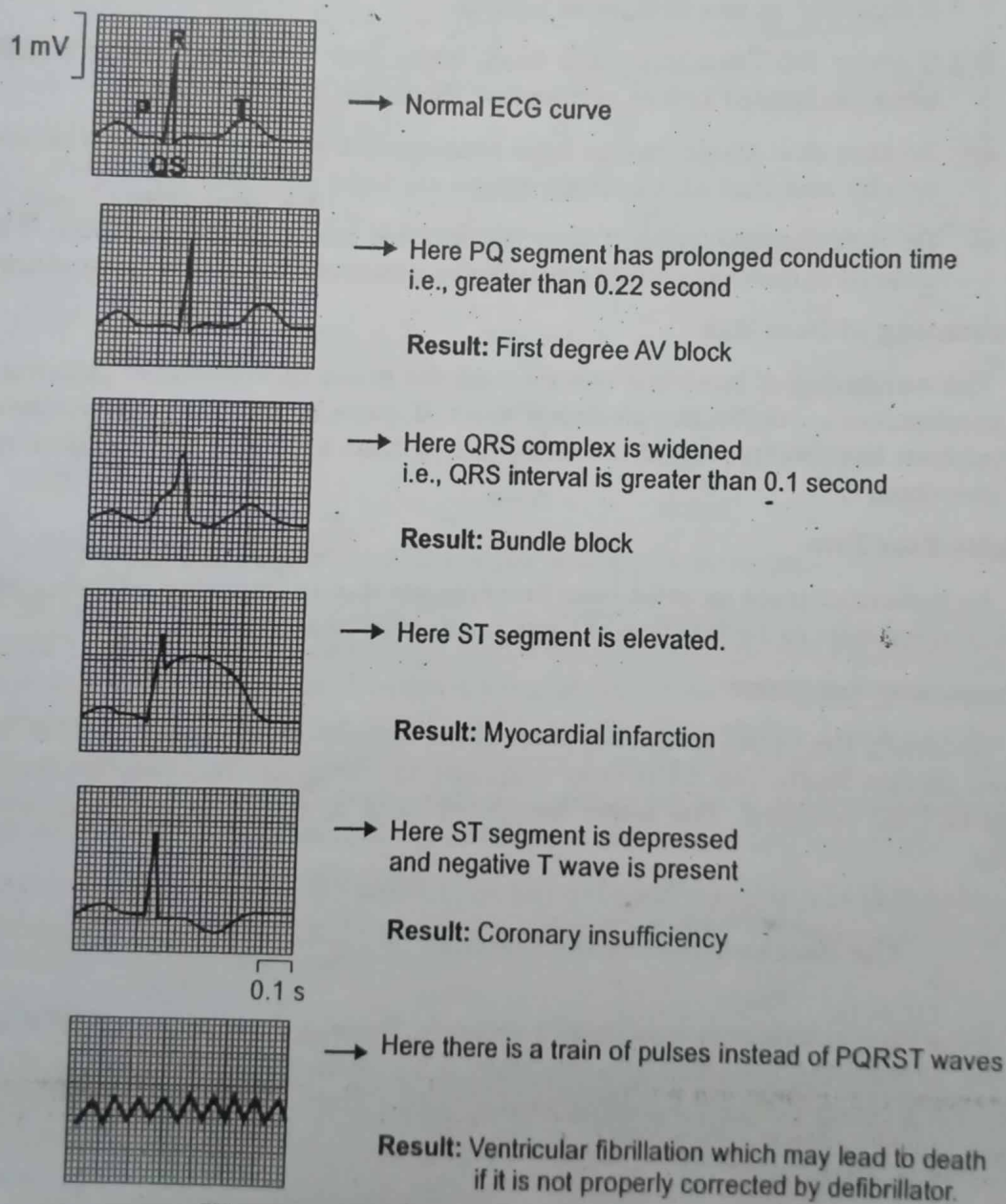


Figure 4.9: Analysis of ECG signals

Figure 4.9 shows the analysis of different ECG signals. If the normal conduction system is disturbed, then the beat rate will be slower than the normal rate. This state is called **heart block**. There are different types of heart block:

- 1st degree AV block** : Due to prolonged conduction time.
- 2nd degree AV block** : Due to conduction of few pulses instead of all from atrium.
- 3rd degree AV block** : Due to asynchronous action of atrium and ventricle.
- Adams - Stokes attack** : Due to sudden attack of total block (this can be treated by fixing electronic pacemaker).
- Bundle block** : Due to improper conduction of the stimulus to the ventricle.
- Atrial fibrillation** : Due to fast beating rate (300-500 beats/min) of the atrium. Here ventricles beat very slowly.
- Ventricular fibrillation** : Due to fast beating rate of the ventricles. No pumping of the blood to different parts of the body.

Thus the electrocardiography can diagnose any form of arrhythmia or disturbance in heart rhythm. The **Computer analysis of ECG** is discussed in the Chapter on Advances in Biomedical Engineering.

4.3.6 Vectorcardiography



Transverse plane Sagittal plane Frontal plane

Figure 4.10: Vectorcardiogram. Here R - Right, L - Left, P - Posterior, A - Anterior, S - Superior, I - Inferior



Transverse plane Sagittal plane Frontal plane

Figure 4.11: Vectorcardiogram in the case of myocardial infarction

In the case of electrocardiography only the voltage generated by the electrical activity of the heart is recorded. But in vectorcardiography, the cardiac vector is displayed along with its magnitude and spatial orientation. Eventhough the cardiac vector is a three dimensional, its projections on orthogonal planes converts it into two dimensional vector. By means of orthogonal lead system, the spatial relations of the cardiac dipole vector is usually displayed on a cathode ray oscilloscope. This is accomplished by resolving the signal into three images, corresponding to the frontal, sagittal and transverse planes. The vectorcardiogram appears as loops in each plane as shown in figure 4.10. There are three loops corresponding to PQRS and T waves. Among these the QRS complex loop is a dominating one. The iso-electric line in the standard lead system is represented by the endpoint of the vectors in the vectorcardiogram. A polaroid camera photographs the oscilloscope screen to provide a permanent record. In the case of any diseased heart, like myocardial infarction, the loops are altered in a characteristic fashion as shown in figure 4.11. With the modern computer facilities, the vectorcardiography may be clinically used in an extensive manner, eventhough it is not widely used clinically now.

4.3.7 Phonocardiography

The graphic record of the heart sounds is called "phonogram". Because the sound is from the heart, it is called **phonocardiogram**. The instrument used to measure the heart sounds is called **phonocardiograph**. This instrument uses a phonocatheter, a device similar to a conventional catheter, with a microphone at the tip. The basic aim of phonocardiograph is to pick up the different heart sounds, filter out the heart sounds and to display them (or) record them. Heart sounds are acoustic phenomena resulting from the vibrations of the cardiac structures. Acoustic events of the heart can be divided into two categories (i.e.) **heart sounds** and **murmurs**. Heart sounds have a transient character and are of short duration. Heart murmurs have a noisy characteristic and last for a longer time. But in general the hearts sounds are due to the closing and opening of the valves, whereas the murmurs are due to the turbulent flow of blood in the heart and large vessels.

Heart sounds

Heart sounds are classified into four group on the basis of their mechanism of origin; they are

- 1) Valve closure sounds
- 2) Ventricular filling sounds
- 3) Valve opening sounds and
- 4) Extra cardiac sounds

1) Valve Closure Sounds

These sounds occur at the beginning of systole (first heart sound) and the beginning of a diastole (second heart sound). The first heart sound is due to the closure of mitral and tricuspid valves. The second heart sound is due to closure of the aortic and pulmonary valves. The two sounds are normally present in an individual.

2) Ventricular filling sounds

These sounds occur either at the period of rapid filling of the ventricles (third heart sound) (or) during the terminal phase of ventricular filling (i.e.) atrial contraction and are believed to be caused by sudden distention of the ventricular wall. These sounds are normally inaudible.

3) Valve opening sounds

These sounds occur at the time of opening of the atrioventricular valves and semilunar valves.

4) Extra cardiac sounds

These sounds occur in mid (or) late systole (or) early diastole and are believed to be caused by thickened pericardium which limits ventricular distensibility.

Physical characteristics of the sound

Heart sounds and murmurs are usually characterised by three physical properties. They are

- i) Frequency
- ii) Amplitude
- iii) Quality

Practically all heart sounds and murmurs are made up of frequencies between **10 and 1000 Hz**. Within this range they are arbitrarily divided into low, medium and high-pitch categories depending upon which frequency predominates. The **low range is 10-60 Hz** and it is represented by the third and the fourth heart sounds. The **medium range is 60-150 Hz** and is represented by the first and second heart sounds. The **high range is 150-1000 Hz** and is represented by snaps, clicks and diastolic murmurs of aortic and pulmonary insufficiency.

Amplitudes of heart sounds and murmurs may differ by a factor of more than 1000. Usually low-frequency, heart sounds have the biggest amplitude while the high frequency murmurs have small amplitudes.

Quality depends upon the overtones (or) harmonics accompanying the fundamental frequency and applies to tones.

Origin of the heart sounds

There are four basic separate heart sounds that occur during the sequence of one complete cardiac cycle.

1) First heart sound

The first heart sound is produced by a sudden closure of the mitral and tricuspid valves associated with myocardial contraction.

- a) **Timing:** The low frequency vibrations occur approximately 0.05 second after the onset of the 'QRS' complex of the ECG.
- b) **Duration:** The first heart sound lasts for 0.1 to 0.12 second.
- c) **Frequency:** The first heart sound ranges from 30-50 Hz.
- d) **Ascultatory Area:** The first heart sound is best heard at the apex of the mid pericardium.

2) Second heart sound:

The second heart sound is due to the vibration set up by the closure of semilunar valves (i.e.) the closure of aortic and pulmonary valves.

- a) **Timing:** The second heart sound starts approximately 0.03 - 0.05 second after the end of 'T' wave of the ECG.
- b) **Duration:** This lasts for 0.08 - 0.14 second.
- c) **Frequency:** The frequency is upto 250 Hz.
- d) **Auscultatory Area:** The second sound is best heard in the aortic and pulmonary areas.

3) Third heart sound

The third heart sound arises as the ventricles relax and the internal pressure drops well below the pressure in atrium. Meanwhile the atrioventricular valves open and the blood has a rapid movement into the relaxed ventricular chambers.

- a) **Timing:** The third heart sound starts at 0.12 - 0.18 second after the onset of the second heart sound.
- b) **Duration:** The third heart sound lasts approximately 0.04 - 0.08 second.
- c) **Frequency:** The frequency is approximately 10 - 100 Hz.
- d) **Auscultatory Area:** The third sound is usually best heard at the apex and left lateral position after lifting the legs.

4) Fourth heart sound

The fourth heart sound also called an atrial sound is caused by an accelerated flow of blood into the ventricles (or) due to atrial contraction. This occurs immediately before the first heart sound.

- a) **Timing:** The fourth heart sound starts approximately 0.12 - 0.18 second after the onset of the P-wave.
- b) **Duration:** The sound lasts for 0.03 - 0.06 second.
- c) **Frequency:** 10 - 50 Hz
- d) **Auscultatory Area:** Because of its extremely low frequency it is usually inaudible.

Heart Murmurs

Murmurs are sounds related to non-laminar flow of blood in the heart and the great vessels. They are distinguished from the basic heart sounds such that,

- 1) they have noisy character.
- 2) they have a longer duration and
- 3) they are high frequency components upto 1000 Hz.

Typical conditions in the cardiovascular system which cause turbulence in Blood flow:

- 1) Local obstructions to the blood flow.
- 2) Abrupt changes in the diameter of the blood stream.
- 3) Pathologic communication in the cardiovascular system.
- 4) Ruptured cardiac structures.
- 5) Valve insufficiency.

Transduction of heart sound

The sounds and murmurs which originate from the heart can be picked up from the chest using a stethoscope (or) by transduction of the sound into electrical signals.

The heart sound are well conducted from the heart to the surface of the chest when the myocardial tissue lies in the close proximity to the chest wall.

Recording set-up

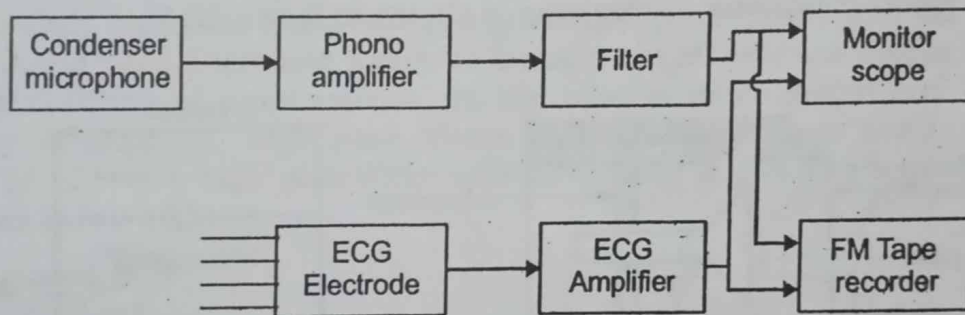


Figure 4.12: Block diagram of recording set up

A block diagram for the recording set up is shown in figure 4.12. The heart sounds are converted into electrical signals by means of a heart microphone fastened to the chest wall by an adhesive strip. The pick up is successively located at different areas mentioned in figure 4.13.

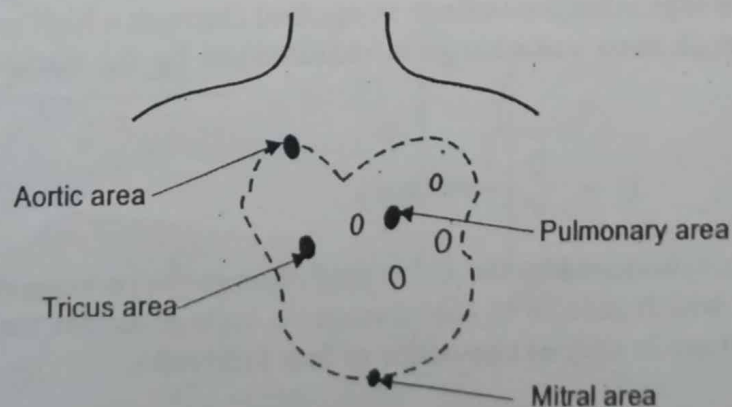


Figure 4.13: Placement of microphone on different areas of the chest for recording PCG

The electrical signals from microphone are amplified by a phonocardiographic preamplifier followed by suitable filters and recorder. Further the electrodes are also placed on the limbs to pick up the electrical activity of the heart and these signals are amplified and recorded. This recorded ECG is used as a reference for PCG.

Heart sound Microphone

The conversion of the heart sounds into electrical signals can be done using a variety of transducers *viz.*, condenser microphone, moving coil microphone, piezoelectric crystal, carbon microphone, etc. There are two main categories of microphones used in phonocardiography.

- 1) The air coupled microphone and
- 2) The contact microphone

In the former case, the movement of the chest is transferred (via) an air cushion and presents a low mechanical impedance to the chest. But the second one is directly coupled to the chest wall and presents a higher impedance, high sensitivity, low noise and light weight. Therefore the second one is more suitable.

A typical condenser microphone is shown in figure 4.14.

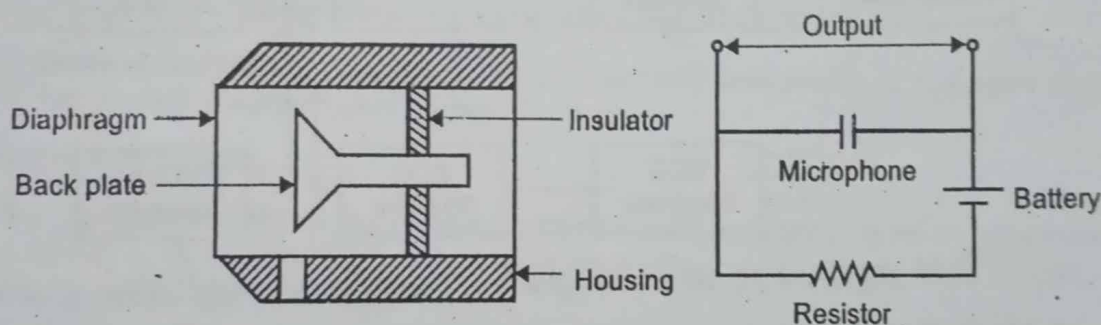


Figure 4.14: Condenser microphone along with its circuit

It consists of a diaphragm which acts as the "rotor" and the back plate as "stator" of a variable capacitor. The two electrodes are spaced very close to each other. When a well regulated d-c voltage is applied through a high resistance across the two electrodes, a constant charge is maintained by the electrodes as per the formula,

$$C = \frac{Q}{V} \text{ (constant)}$$

The vibrations produced by the chest wall change the position of the diaphragm of the condenser, which results in the change in voltage across the electrode. The developed a.c. voltage is only of the order of few millivolts.

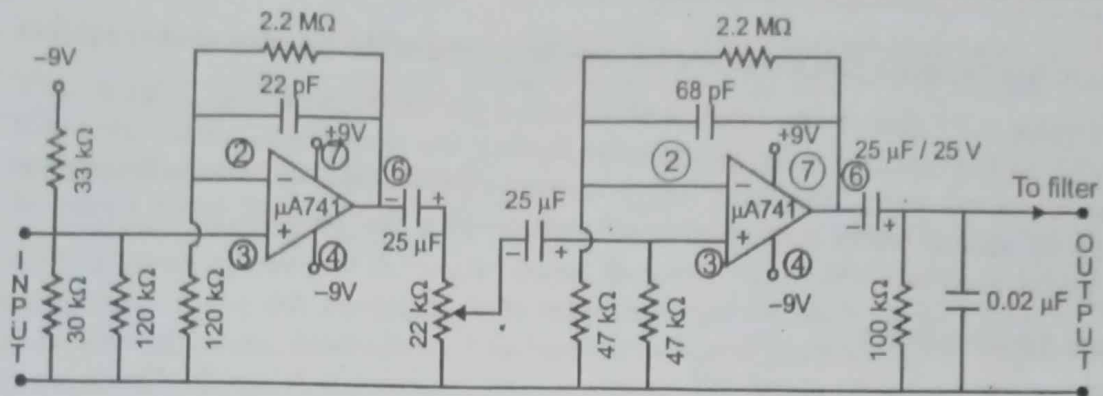


Figure 4.15: Phonocardiograph preamplifier

The preamplifier shown in figure 4.15 has two stages. First stage has amplification of about 20. Second stage has amplification of about 50. Therefore the expected total gain is about 1000. Continuous variation of gain can be achieved through a 22 kilo-ohm potentiometer. The shunt capacitance ($0.02 \mu\text{F}$) and the feedback loop capacitance (68 pF) of the second stage limit the response from 10Hz to 1000 Hz.

Filters for phonocardiogram

Generally high pass filters having a gradual slope of attenuation are needed since the band pass filters and filters with sharp cut off produce transients and mask the splitting of heart-sounds. In the case of murmurs, where greater selectivity is required, high pass filters with sharper slopes are required, Figure 4.16 shows a high pass filter with increasing slopes of attenuation for frequencies below 1000 Hz.

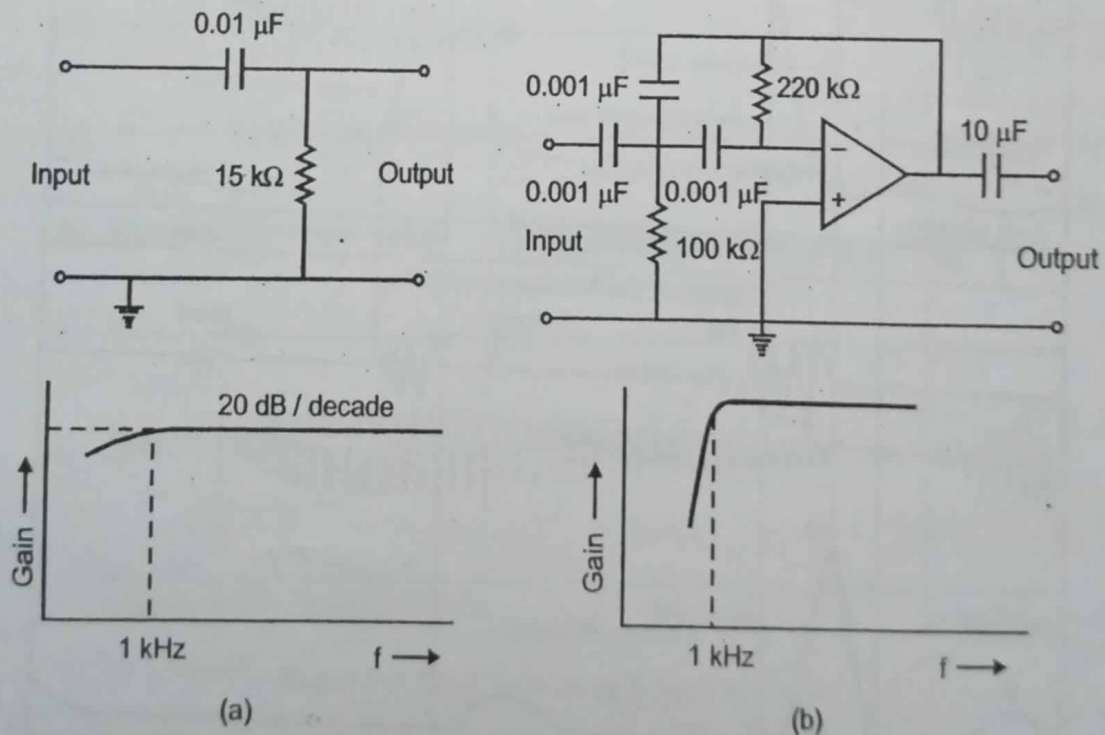


Figure 4.16: a) R - C Filter

b) Active Filter

Figure 4.16 a) shows the R-C filter where the gradual slope is obtained and in figure 4.16 b) shows the active filter where a sharp cut off is achieved.

Relationship between the heart sounds and function of the cardiovascular system

Figure 4.17 shows the relationship between the blood pressure, heart sounds and ECG in the normal case, pictorially. During the opening of aortic valve and closing of mitral valve, the first heart sound is developed. Similarly during the opening of mitral valve and closing of aortic valve the second heart sound is developed and so on.

Medical Applications

Rheumatic Valvular Lesions

The greatest number of valvular lesions results from rheumatic fever. Rheumatic fever is an autoimmune (or) allergic disease in which the heart valves are likely to be damaged or destroyed.

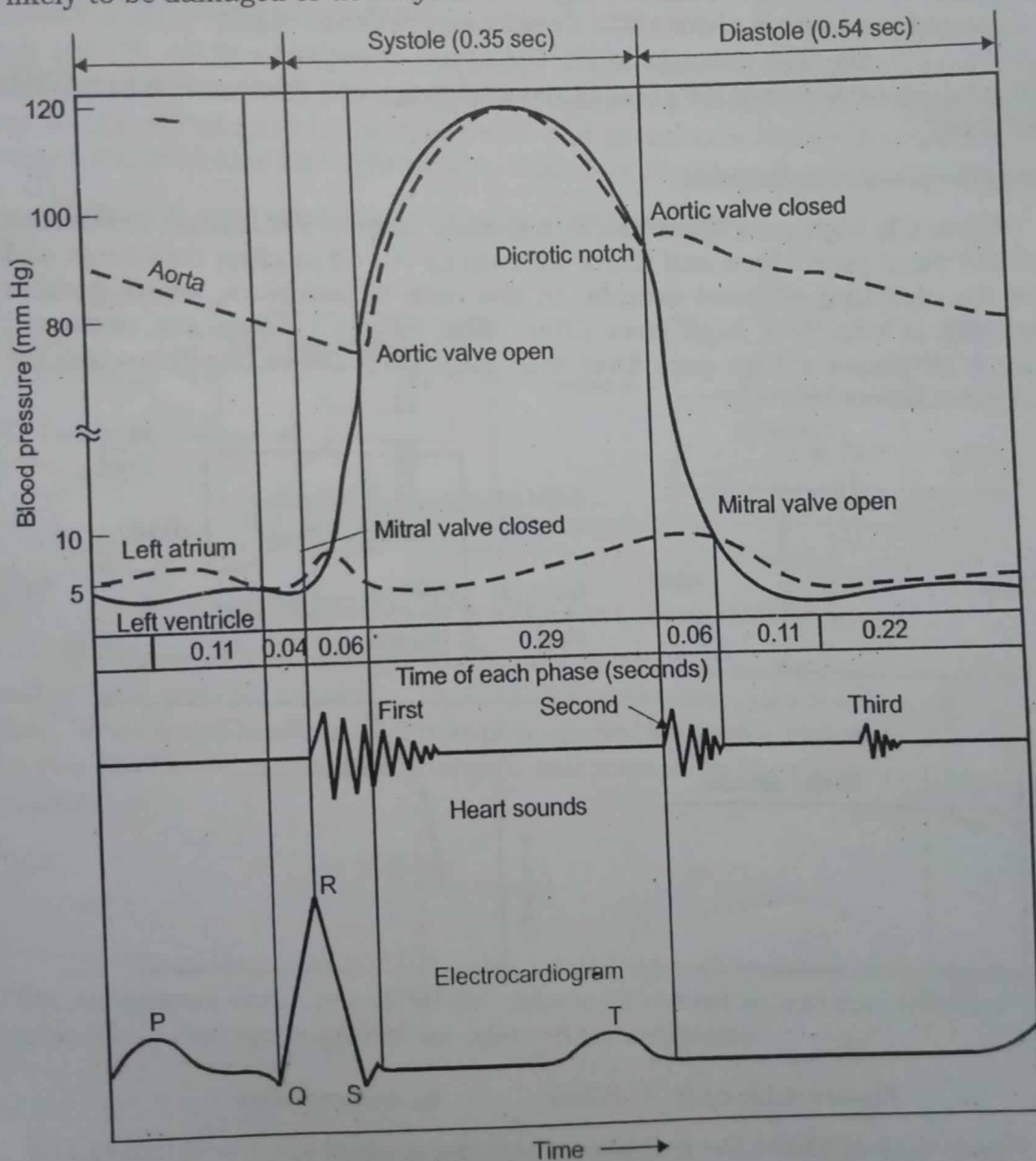


Figure 4.17: Blood pressure, heart sounds and ECG on the time scale

This can be detected by phonocardiograph. The valvular lesions cause the abnormal heart sounds as given below: Figure 4.18 (a) shows the normal heart sounds.

i) The murmur of Aortic Steonosis

In aortic stenosis (figure 4.18 (b)) the blood is ejected from the left ventricle through a small opening of the aortic valve. Because of the resistance to ejection, the pressure in the left ventricle rises sometimes to as high as 350 mm of Hg. This causes turbulent blood flow. This turbulent blood impinging the aortic valve causes intense vibration, it produces loud murmur. This sound can be heard several feet away from the patient.

ii) The murmur of aortic regurgitation

In aortic regurgitation (figure 4.18 (c)) no sound is heard during systole, but during diastole blood flows backward from the aorta into the left ventricles, causing a "blowing" murmur, the sound is not as high that of aortic stenosis. This is produced during the valves are damaged.

[Regurgitation: Backward flow of blood through a defective heart valve].

Analysis of phonocardiograms

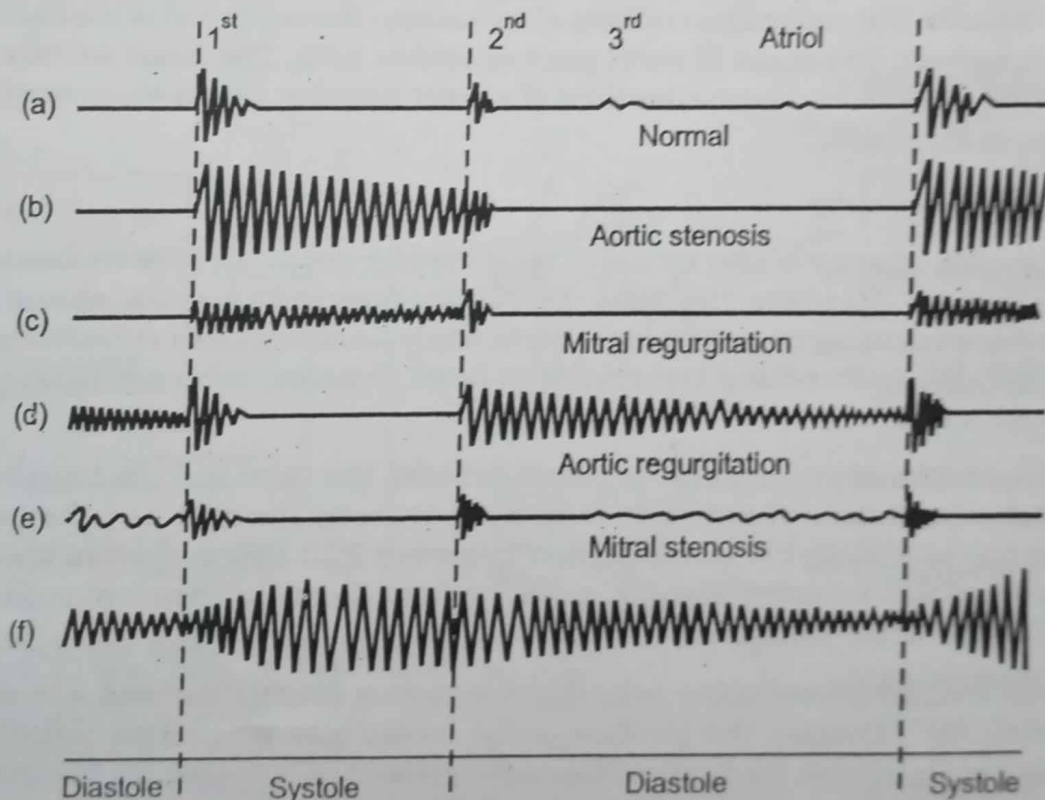


Figure 4.18: Analysis of heart sounds

iii) The murmur of mitral regurgitation

In the mitral regurgitation (figure 4.18 (d)) blood flows backward through the mitral valve during systole. This produces sound during systole.

iv) The murmur of mitral stenosis

In mitral stenosis (figure 4.18 (e)) blood passes with difficulty from the left atrium into the left ventricle due to the pressure difference. It produces murmur, which is very weak.

Special applications of phonocardiogram

1) Fetal Phonocardiogram

A stethoscopic microphone with a large chest piece is applied over that part of the maternal abdomen where auscultation reveals fetal heart tones. Simultaneously with the fetal sound tracing, maternal ECG is recorded for comparison.

2) Esophageal Phonocardiogram

Basis of interest in the method lies in the fact that the heart sounds are collected from inside the chest. In general, sounds and murmurs have lower frequencies than when recorded by conventional techniques. The heart sounds are with shorter duration.

3) Tracheal Phonocardiogram

Tracheal Phonocardiograms have been recorded in patients by means of a tracheal cannula. The technique consists of connecting the outer end of the cannula with a microphone by means of short piece of rubber tube. The heart sounds are with shorter duration and have vibrations of a lower frequency than when recorded from outside the chest.

4.3.8 Echocardiography

Echocardiography is also an useful technique for diagnosis of heart diseases. Echocardiogram displays the time versus motion information about the intra-cardiac structures on slow speeds. Particularly for detection of mitral stenosis and for preliminary screening test related to heart diseases, echocardiography is the test one among all.

The piezoelectric transducer is placed between the third and the fourth ribs on the outer chest wall where there is no lung between the skin and the heart. From this transducer, an ultrasonic beam of frequency 2.25 MHz is directed towards the heart and the reflected signals, called *echoes* from the heart muscle are collected by the same transducer.

Thus a single piezoelectric transducer acts as a transmitter and a receiver alternatively. By changing the position of the transducer we can get reflections from the desired areas on the heart. An aqueous gel is used to couple the transducer to the skin and the beam from the transducer to a depth of 5 to 10 cm. There is a time compensated signal amplifier so as to collect the deeper low amplitude signals with the same signal to noise ratio. Then these amplified signals are given to the cathode ray tube display unit.

A-mode display

In amplitude mode or A-mode display, the echoes produce vertical displacements of a horizontal trace on the screen such that the amount of vertical displacement is proportional to the strength of the echo and the distance along the horizontal trace represents the time taken by the ultrasound to travel through the tissue. Since the heart is moving, the echoes dance up and down during the cardiac cycle.

B-mode display

In brightness mode or B-mode display, the echoes are rotated through 90° towards the observer and so the echoes are presented as dots of light. The distance between dots represents the tissue depth. When the echoes are from the moving structure, the dots of light move back and forth.

M-mode display

In the time-motion mode or M-mode display, the B-mode echo signal is recorded either by sweeping the oscilloscope screen or photographing the oscilloscope face on moving paper. Thus the conventional M-mode display is widely used in echocardiography such that time on the x-axis, distance on the y-axis and intensity of the echo on the z-axis, An ECG is also recorded simultaneously for timing and correlation with known events.

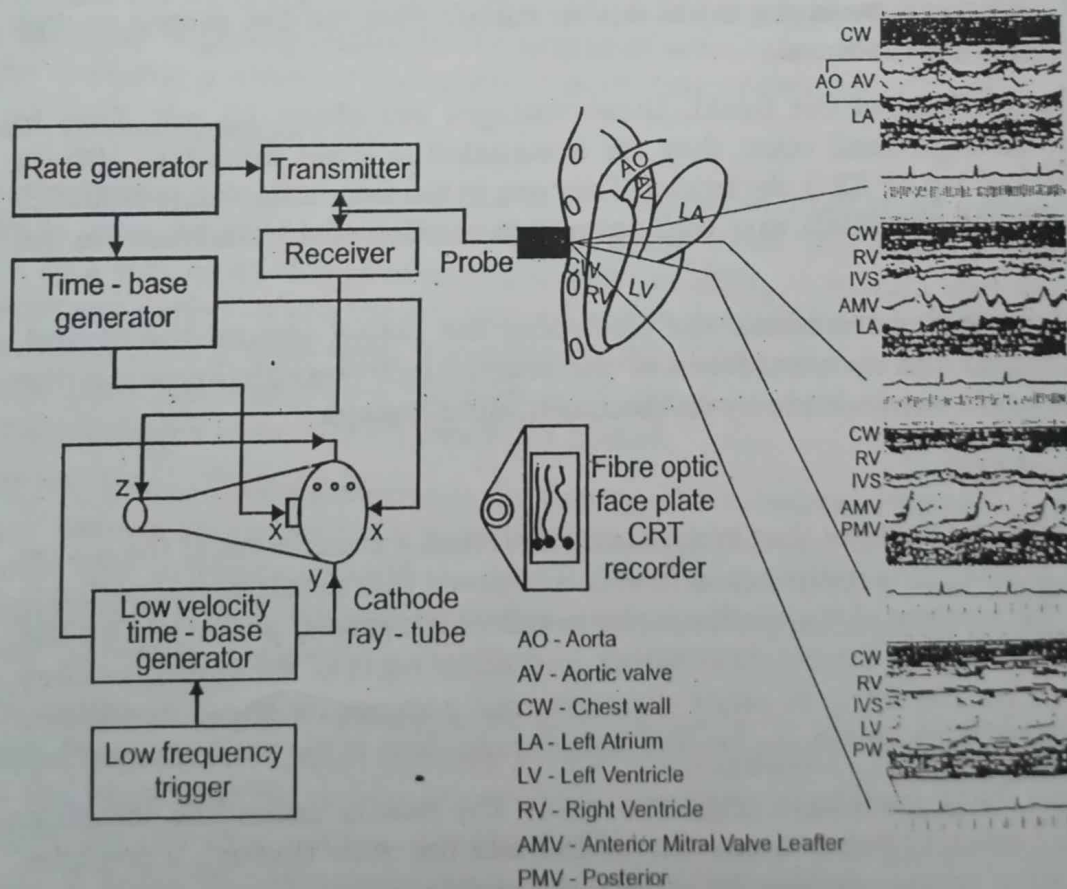


Figure 4.19 Block diagram of echocardiograph and the typical echocardiograms

Figure 4.19 shows the block diagram of echocardiograph and the typical echocardiograms. In the echocardiograms the hill and valley regions indicate the working heart. A rapid B-mode scan of the heart is known as real time scan which is also called crosssectional or 2-D echocardiography.

Now-a-days real time 2 dimensional echo-cardiography is widely used. A comparison between M-mode and two dimensional echocardiography is given below:

| | M- mode | 2 dimensional |
|--------------------|------------|---------------|
| Axial dimension | excellent | good |
| Axial motion | excellent | good |
| Lateral dimensions | impossible | good |
| Lateral motion | poor | good |
| Shape | poor | good |

4.4 ELECTROENCEPHALOGRAPHY (EEG)

Electroencephalography deals with the recording and study of electrical activity of the brain. By means of electrodes attached to the skull of a patient, the brain waves can be picked up and recorded. The brain waves are the summation of neural depolarisations in the brain due to stimuli from the five senses as well as from the thought processes.

On the surface of the brain, these voltages are about 10 mV; Due to propagation through skull bone, they are attenuated to levels from 1 to 100 μ V which are picked up by EEG electrodes. They are in the frequency range from 0.5 to 3000 Hz. These potentials vary with respect to position of the electrode on the surface of skull.

Therefore during recording, the electrodes are placed around the frontal, parietal, temporal and occipital lobes of the brain. Electroencephalogram is the record of the brain waves made by an electroencephalograph.

4.4.1 Origin of EEG

Initially it was thought that brainwaves represent a summation of the action potentials of the neurons in the brain. Now it is believed that the electrical patterns obtained on the surface of the skull are the result of the graded potentials on the dendrites of neurons in the cerebral cortex and other parts of the brain, as they are influenced by the firing of other neurons that impinge on these dendrites. **Graded potentials** are variations around the average value of the resting potential.

Thus the EEG potentials originate within the dendrite potentials. Electric charges are transferred between one nerve fiber and the other through a dendrite of a post synaptic neuron during the release of **acetylcholine**. A great number of these potentials are then summed to produce EEG rhythms.

The discharge of a single neuron or single nerve fiber in the brain cannot be recorded from the surface of the head. Instead, for an electrical potential to be recorded all the way through the skull, large portions of nervous tissue must emit electrical current simultaneously. There are two ways by which this can occur. First, tremendous numbers of nerve fibers can discharge in synchrony with each other, thereby generating very strong electrical currents. Secondly, large numbers of neurons can partially discharge, though not emit action potentials. Furthermore, these partially discharged neurons can give periods of current flow which is undulate with changing degrees of excitability of the neurons. Simultaneous electrical measurements within the brain while recording brain waves from the scalp indicate that it is the second of these that causes the brain waves.

To be more specific, the surface of the cerebral cortex is composed almost entirely of a mat of dendrites extending to the surface from neuron cells in the lower layers of the cortex. When signals impinge on these dendrites, the dendrites become partially discharged. This partially discharged state makes the neurons of the cortex highly excitable - that is, facilitates them and the negative potential is simultaneously recorded from the surface of the scalp, indicating this high degree of excitability.

One of the important sources of signals to excite the other dendritic layer of the cerebral cortex is the ascending reticular activating system. Therefore, brain wave intensity is closely related to the degree of activity in either the brain stem (or) the thalamic portions of the reticular activating system.

Action potentials of the brain

Progressive transient disturbance of the resting potential along a nerve fiber is used to transmit information from one end to the other. This action potential is caused by a very rapid change of membrane permeability to sodium ions followed by a recovery period. When the propagated action potential reaches the cell, the cell fires and thus a spike wave is produced. This firing spreads throughout the dendritic branches and causes the release of transmitter substances where the dendritic synapses terminate on other cell bodies.

If the transmitter substance is inhibitory, the membrane potential of the receptor neuron increases in a negative direction. So that it is less likely to discharge; this induced potential change is called an **Inhibitory Post Synaptic Potential (IPSP)**. If the transmitter substance is excitatory, the receptor membrane potential increases in a positive direction.

So that the receptor neuron is more likely to discharge and produces a spike potential. This induced change is called an **Excitatory Post Synaptic Potential (EPSP)**. We know that the neuronal system is acting in a synchronised manner such that the receptor neuron discharges by the simultaneous emission of excitatory transmitter substances coming from adjacent neurons.

Thus if EPSPs occur simultaneously at A and B, then C will become excitatory and it is more likely to discharge. If IPSPs occur simultaneously at A and B, then C will become less active. These action potentials can be as large as 30 mV and cause external currents to flow between the upper and lower layers of cortex.

Evoked potentials

Evoked potentials are the potentials developed in the brain as the responses to external stimuli like light, sound etc. The external stimuli are detected by the sense organs which cause changes in the electrical activity of the brain. Now-a-days the term '*event related potential*' has been used instead of evoked potential.

This is because there are some changes that are evoked by an external stimulus but are related to an event. The studies on evoked potentials are more prone to contamination by artifact than the clinical EEG.

The artifact is synchronised with the stimulus and eventually appear with the evoked potential. Therefore good recording techniques are to be used for evoked potential studies.

Anatomy of the brain

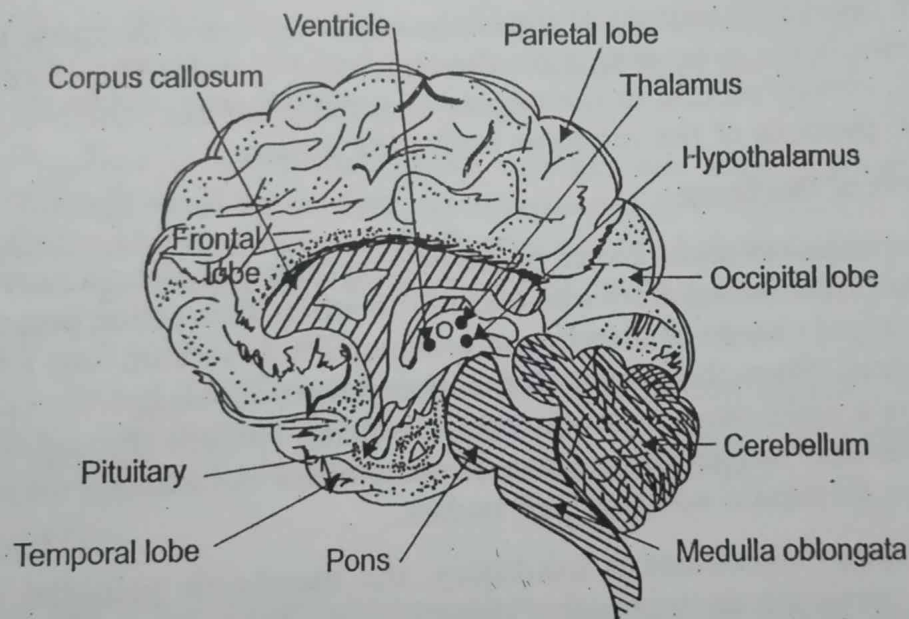


Figure 4.20: Median sagittal section of the brain

The brain (encephalon) consists of three parts such as cerebrum, cerebellum and the brain stem as shown in figure 4.20. Cerebrum consists of two hemispheres separated by a deep fissure.

The hemispheres are divided into frontal lobe, parietal lobe, occipital lobe and temporal lobe. The outer layer is called as cerebral cortex which is the center of intellectual functions (figure 4.21).

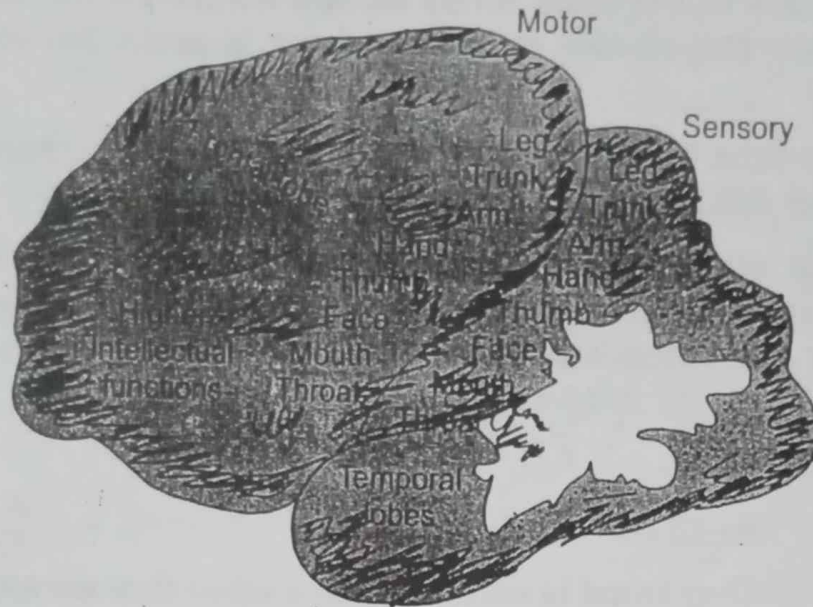


Figure 4.21: Cerebral cortex

The frontal lobe is for intelligence. The upper side of the temporal lobe consists of hearing center. In the posterior part of the occipital lobe, the vision center is situated. In the anterior part of the parietal lobe, there are sensory center and motor center. The temporal lobes are for the storage process in the long term memory.

4.4.2 Brain waves

Electrical recordings from the surface of the brain (or) from the outer surface of the head demonstrate continuous electrical activity in the brain. Both the intensity and patterns of this electrical activity are determined to a great extent by the overall level of excitation of the brain resulting, from functions in the reticular activating system i.e. awakening from sleep. The undulations in the recorded electrical potentials, shown in the figure 4.22 are called **brain waves**.

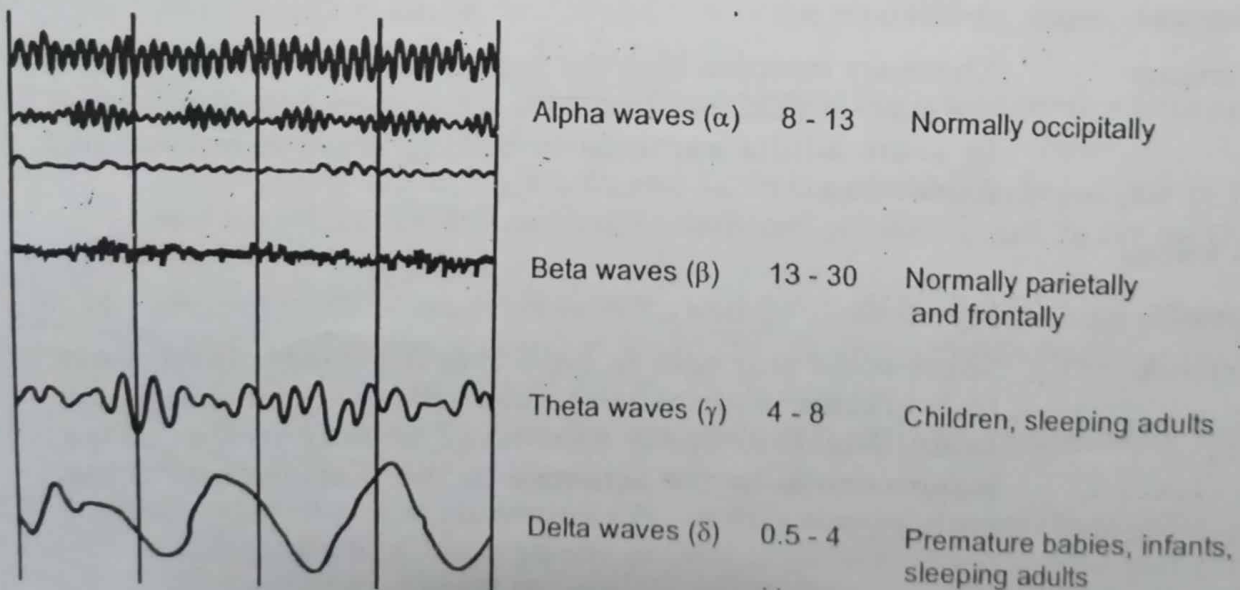


Figure 4.22: Brain Waves

The intensities of the brain waves on the surface of the scalp range from 0-300 μV and their frequencies range from once in every few seconds to 50 or more per second.

Much of the time, the brain waves are irregular and no general pattern can be discerned in the EEG.

However, at other times, distinct patterns do appear. Some of these characteristic of specific abnormalities of the brain occur during epilepsy, which is discussed later and others occur even in normal persons and can be classified into alpha, beta, theta and delta waves.

Alpha waves

Frequency : 8 - 13 Hz

Occurrence : They found in normal persons when they are awake in a quiet, resting state. They occur normally occipital region.

During sleep, these disappear. These have amplitude of 20-200 μV with mean of 50 μV .

Beta waves

Frequency : 13 - 30 Hz

(at intense mental activity, the frequency increases upto 50 Hz)

Occurrence : These are recorded from the parietal and frontal regions of the scalp. These are divided into two types as beta I which is inhibited by the cerebral activity and beta II which is excited by the mental activity, like tension.

Theta waves

Frequency : 4-8Hz

Occurrence : These are recorded from the parietal and temporal regions of the scalp of children. These also occur during emotional stress in some adults particularly during disappointment and frustration.

Delta waves

Frequency : 0.5 - 4 Hz

Occurrence : These occur only once in every 2 or 3 seconds. These occur in deep sleep, in premature babies and in very serious organic brain diseases. These can occur strictly in the cortex independently by the activities in the lower regions of the brain.

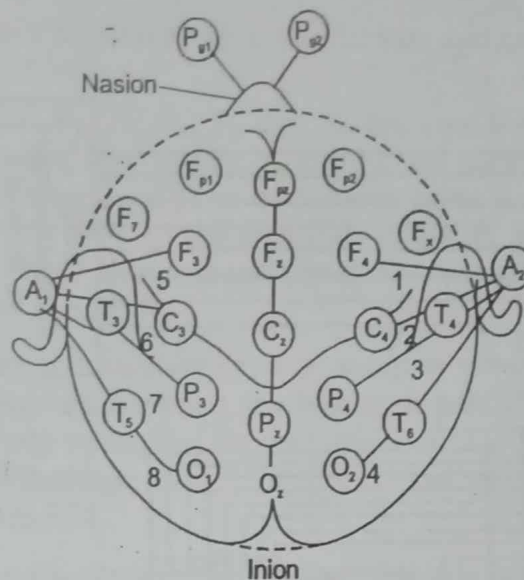


Figure 4.23: Placement of electrodes on the scalp for EEG recording

4.4.3 Placement of electrodes

In EEG, electrodes are placed in standard positions on the skull in an arrangement called 10 - 20 system, a placement scheme devised by the International Federation of Societies of EEG. The electrodes in this arrangement are placed as follows:

- i) Draw a line on the skull from the **nasion**, the root of the nose, to the **inion**, ossification center (bump) on the occipital lobe.
 - ii) Draw a similar line from the left preauricular (ear) point to the right preauricular point.
 - iii) Mark the intersection of these two lines as C_z which is the mid point of the distance between the nasion and inion (or) the distance between the auricular points.
 - iv) Mark points at 10, 20, 20, 20 and 10% of the total nasion - inion distance. These points are F_{pz} , F_z , C_z , P_z and O_z .
 - v) Mark points at 10, 20, 20, 20, 20 and 10% of the total distance between the preauricular points. These points are T_3 , C_3 , C_z , C_4 and T_4 . In these odd numbered points T_3 and C_3 are on the left and even numbered points C_4 and T_4 are on the right.
 - vi) Measure the distance between F_{pz} and O_z along the great circle passing through T_3 and mark points at 10, 20, 20, 20, 20 and 10% of this distance. These are the positions of F_{p1} , F_7 , T_3 , T_5 and O_1 .
 - vii) Repeat this procedure on the right side and mark the positions of F_{p2} , F_8 , T_4 , T_6 and O_2 .
 - viii) Measure the distance between F_{p1} and O_1 along the great circle passing through C_3 and mark points at 25% intervals. These points give the positions of F_3 , C_3 and P_3 .
- The ground reference electrode is a metal clip on the earlobe.

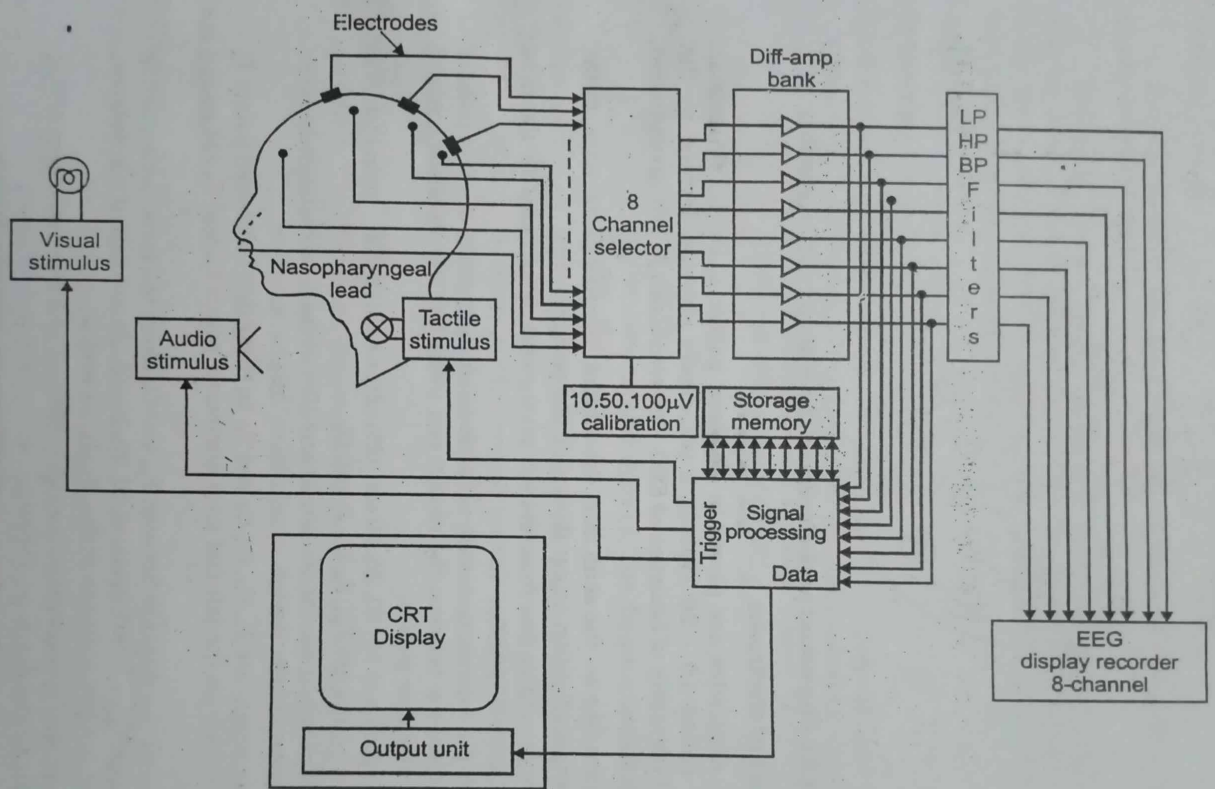


Figure 4.25: Modern EEG Unit

- ix) Repeat this procedure on the right side and mark the positions of F_4 , C_4 and P_4 .
- x) Check that F_7 , F_3 , F_2 , F_4 and F_8 are equidistant along the transverse circle passing through F_7 , F_2 and F_8 and check that T_5 , P_3 , P_2 , P_4 and T_6 are equidistant along the transverse circle passing through T_5 , P_2 and T_6 . In the figure 4.23 the positions of the scalp electrodes are indicated. Further there are nasopharyngeal electrodes P_{g1} and P_{g2} and ear electrodes A_1 and A_2 .

Before placing the electrodes, the scalp is cleaned, lightly abraded and electrode paste is applied between the electrode and the skin. By means of this application of electrode paste, the contact impedance is less than $10\text{ k}\Omega$. Generally disc like surface electrodes are used. In some cases, needle electrodes are inserted in the scalp to pick up EEG.

Both bipolar and unipolar (monopolar) electrode systems are used to facilitate the location of foci, that is cortical areas from which abnormal waves spread. The phase relationship of the waves indicates the position of the focus and in some cases, it enables the velocity at which the waves spread to be calculated. In **bipolar technique** the difference in potential between two adjacent electrodes is measured. In the **monopolar technique** the potential of each electrode is measured with respect to a reference electrode attached to ear lobe or nostrils. In the **Wilson technique** (or) average mode recording techniques the potential is measured between one of the electrodes (exploring electrode) and the central terminal which is formed by connecting all electrodes through high, equal resistors to a commonpoint. Multichannel electroencephalographs having as many as the channels permit simultaneous recording from several pairs of electrodes, reducing the total time required to complete the recordings. Eight channel recorders are very popular.

4.4.4 Recording Setup

Figure 4.24 shows the simple block diagram of EEG recording setup. In this there are pre and driver amplifiers whose gains are increased by cascading several stages of amplification.

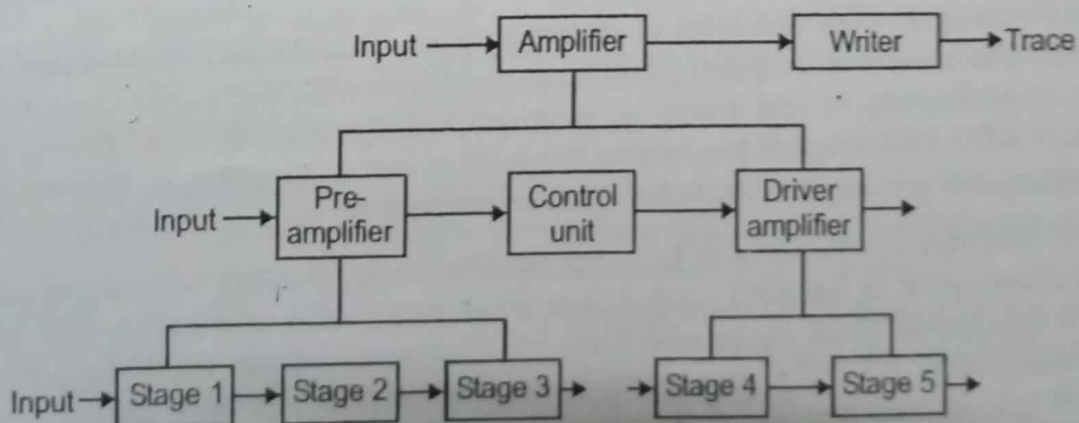


Figure 4.24: Simple block diagram of EEG recording setup

Figure 4.25 shows the modern 8 channel EEG recorder. The patient cable consists of 21 electrodes and is connected to the eight channel selector. The electrodes are attached to the channel selector in groups of eight called a *montage* of electrodes. A representative montage is shown in Figure 4.23 as numbers from 1 to 8. In that case, the right ear electrode acts as reference electrode for the right brain electrodes and the left ear electrode acts as reference electrode for the left brain electrodes. The 50 Hz interference is reduced by employing differential amplifiers as preamplifiers with more than 80 dB CMRR and by use of 50 Hz notch filters. The effect of notch filter on signal distortion is not so much because important EEG signals have frequencies below 30 Hz.

Further if the room, in which EEG unit is placed, is covered with ferrous metal screen, 50 Hz a.c. interference is greatly reduced. Because the source of brain wave has high internal impedance, the input impedance of the preamplifier should be more than 10 M Ω to prevent reduction of signal amplitude. Further by cascading, the gain of the amplifier is increased to 10^6 so as to drive the recorder or imaging CRT without any difficulty. The output voltage from the amplifier may either be applied directly to the eight channel display through the filter bank or it may be stored as data on a tape recorder or in a computer memory for further processing.

The filter bank consists of appropriate filters to select different types of brain waves. There are other facilities available to record evoked potentials from sensory parts of the brain such that there are external stimuli like visual stimulus, audio stimulus and tactile (touch) stimulus.

The time delay between the stimulus and response can also be measured in the signal processing unit. In the eight channel pen recorder there are 8 pens such that a pen for each channel. The normal paper chart speed is 30 mm/second. There are also 60 mm/second for higher frequency recording and 15 mm/second to conserve paper during setup time.

4.4.5 Analysis of EEG

EEG helps physicians to diagnose the level of consciousness, sleep disorders, brain death, brain tumors, epilepsy and multiple sclerosis.

i) Level of consciousness

EEG changes with the level of consciousness. Diminished mental activity usually results in a lower frequency and large amplitude EEG wave. EEG has made valuable contribution to the study of sleep physiology. Figure 4.26 shows the variation of EEG with respect to sleep or the level of consciousness. In that figure, REM means rapid eye movement. REM sleep coincides with the periods of dreaming.

EEG displays characteristic features during the application of anaesthesia. As the anaesthesia is applied, the brain wave frequency decreases and the amplitude increases. Thus theta and delta waves appear. In the case of cerebral death (brain death), EEG shows a permanent absence of brain wave even though respiration and circulation are maintained.

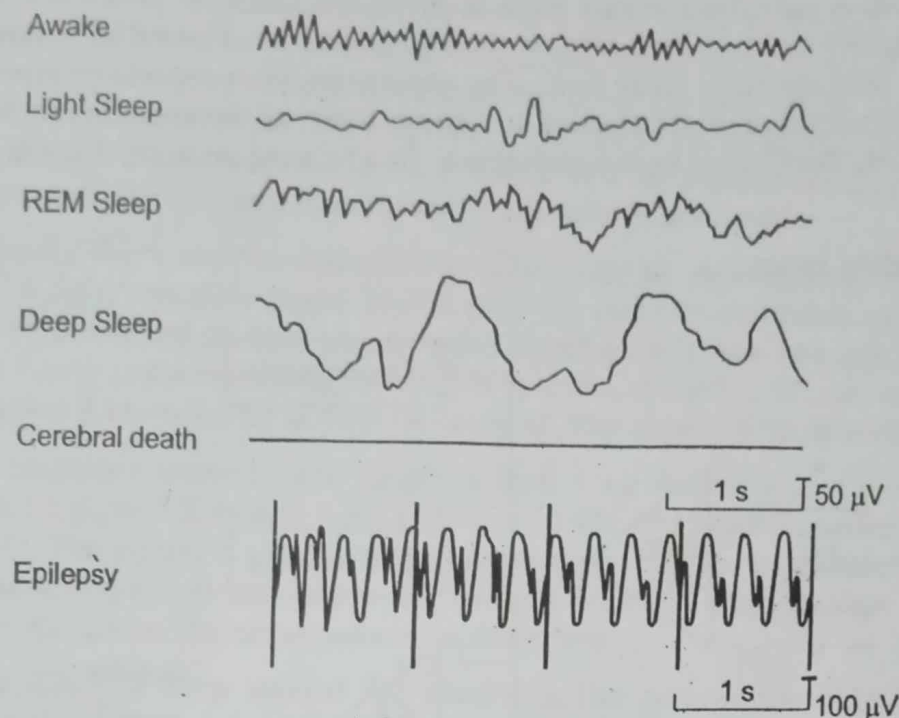


Figure 4.26: EEG waves for different level of consciousness

Brain Tumors

If the tumor displaces the cortex and if it is large enough, the electrical activity will be absent in that part of hemisphere, since no electric potentials originate in the tumor itself. Thus an extinguished or damped EEG over a certain part of cortex can thus be a sign of a tumor.

Epilepsy

Epilepsy is a symptom for brain damage. This may be due to defects in the birth delivery or head injury during accident or boxing. It may also be due to brain tumor. Epilepsy is a disease and is characterised by synchronous discharge of large groups of neurons, often including the whole brain. Epilepsy is divided into two types, **grandmal** and **petitmal**. Before grandmal attack, the patient recognizes a set of symptoms such that he sees a flash of light if the grandmal arises from visual center or he hears a noise if it arises from acoustic center. The grandmal seizure extends from few seconds to several minutes. In the petitmal attack spike type waves are produced with a frequency 3 Hz. and its seizure lasts for 1-20 seconds.

4.5 ELECTROMYOGRAPHY (EMG)

Electromyography is the science of recording and interpreting the electrical activity of muscle's action potentials. Meanwhile the recording of the peripheral nerve's action potentials is called **electroneurography**. The electrical activity of the underlying muscle can be measured by placing surface electrodes on the skin. To record the action potentials of individual motor units, the needle electrode is inserted into the muscle. Thus EMG indicates the amount of activity of a given muscle or a group of muscles and not an individual nerve fiber.

The action potentials occur both positive and negative polarities at a given pair of electrodes; so they may add or cancel each other. Thus EMG appears, very much like a random noise wave form. The contraction of a muscle produces action potentials. When there is stimulation to a nerve fiber, all the muscle fibers contract simultaneously developing action potentials. In a relaxed muscle, there is no action potential.

4.5.1 Recording setup

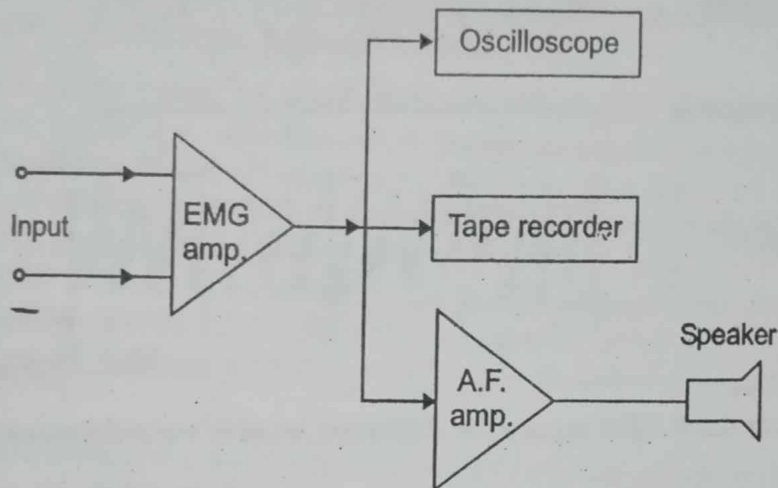


Figure 4.27: Block diagram for EMG recording set up

Figure 4.27 shown the typical setup for EMG recording. The surface electrodes or needle electrodes pickup the potentials produced by the contracting muscle fibers. The surface electrodes are from Ag-AgCl and are in disc shape. The surface of the skin is cleaned and electrode paste is applied. The electrodes are kept in place by means of elastic bands. By that way, the contact impedance is reduced below $10\text{ k}\Omega$. There are two types of conventional electrodes: bipolar and unipolar type electrodes. In the case of **bipolar electrode**, the potential difference between two surface electrodes resting on the skin is measured. In the case of **unipolar electrode** the reference surface electrode is placed on the skin and the needle electrode which acts as active electrode, is inserted into the muscle. Because of the small contact area, these unipolar electrodes have high impedances ranging from 0.5 to $100\text{ M}\Omega$. With needle electrodes, it is possible to pickup action potentials from selected nerves or muscles and individual motor units. In the case of **Coaxial electrode** which consists of an insulated wire threaded through a hyperdermic needle with an oblique tip for easy penetration, the surrounding steel jacket acts as reference and the metallic wire acts as exploring electrode. The needle is inserted into the muscle. Further to record the action potentials from a single nerve, microelectrodes are used.

The amplitude of the EMG signals depends upon the type and placement of electrodes used and the degree of muscular exertions. That is, the surface electrode picks up many overlapping spikes and produces an average voltage from various muscles and motor units. The needle electrode picks up the voltage from a single muscle fiber.

Generally EMG signals range from 0.1 to 0.5 mV. They may contain frequency components from 20 Hz to 10 kHz which are in the audio range. But using low pass filter, the electromyographer restricts this frequency range from 20 Hz to 200 Hz for clinical purposes. The normal frequency of EMG is about 60 Hz. Therefore the slow speed strip chart recorders are not useful and the signals are displayed on a cathode ray oscilloscope and photographic recordings are made.

Normally there are two cathode ray tubes, one for viewing and other one for recording. A light sensitive paper moves over the recording cathode ray tube and the image is produced on that paper. After developing it, one can see the visible image. For continuous recording, the paper speed is about 5 to 25 cm/second. For short duration it is about 50 to 400 cm/second. The paper width is about 10 cm.

The amplifier should have uniform frequency response in the frequency range from 10 Hz to 1 kHz with high CMRR (100 dB) and input impedance greater than 10 M Ω . The signal is also recorded in the tape recorder for future reference. Further the myographer can listen the sounds from the loud speaker and from that he can diagnose the neuromuscular disorders.

Thus EMG is very useful for studying the neuromuscular function, neuromuscular condition, reflex responses and extent of nerve lesion and diagnosing the muscular diseases like myasthenia gravis which can produce a highly damped impulses during contraction of the muscles due to too rapid fatigue of the neuromuscular synapses.

4.5.2 Determination of conduction velocities in motor nerves

The measurement of conduction velocity in motor nerves is used to indicate the location and type of the nerve lesion. Here the nerve function is examined directly at the various segments of the nerve by means of stimulating it with a brief electric shock having a pulse duration of 0.2 - 0.5 milliseconds and measuring the latencies, we can calculate the conduction velocity in that peripheral nerve. **Latency** is defined as the elapsed time between the stimulating impulse and the muscle's action potential.

Figure 4.28 illustrates the measurement procedure. The EMG electrode and the stimulating electrode are placed at two points on the skin, separated by a known distance l_1 . A brief electrical pulse is applied through the stimulating electrode. When the excitation reaches the muscle, this contracts with a short twitch.

Since all the nerve fibers are stimulated at the same time and the conduction velocity is normally the same in all nerve fibers, there is synchronous activation of the muscle fiber. This action potential of the muscle is picked up by the EMG electrode and is displayed on the oscilloscope along with the stimulating impulse. The elapsed time ' t_1 ' (latency) between the stimulating impulse and muscle's action potential is measured. Now the two electrodes are repositioned with the distance of separation as l_2 metres. Among the distances l_1 and l_2 , $l_2 < l_1$. The latency is now measured as ' t_2 ' seconds.

4.9 MEASUREMENT OF BLOOD PRESSURE

Determining an individual's blood pressure is a standard clinical measurement. Blood pressure is created in the human circulatory system by pumping heart, which is transmitted through the blood against the vessel walls.

Since blood pressure is resulted by ^{a place where} constriction and dilatation of vessels, it is never constant and our measurements always assume an average value.

A number of direct-invasive and indirect-non invasive techniques are available in clinical use. Out of these, blood pressure is usually indirectly measured using an simple instrument called sphygmomanometer. Since this method is easiest one it can also be automated easily.

The need for ^{Facility} automation of this technique is that during ^{Increased heart rate,} long-term monitoring of blood pressure. ^{Contract}

1. A medical person who constantly takes blood pressure readings have to spend more time on it and can't concentrate on anything else in the monitoring.
2. Since the korotkoff sounds used in blood pressure measurement is in the range of < 200 Hz, human hearing is not very accurate.

Indirect Blood Pressure Measurement

1. Sphygmomanometer
2. Automated Devices

Measuring using Sphygmomanometer

^{Rowden} The apparatus consists of an ^{tube} inflatable rubber bladder called the cuff, a squeeze-ball pump-valve assembly and a manometer which can be either a mercury column or a dial gauge. ^{filled with}



Figure 4.31: BP apparatus

The procedure is as follows.

1. Wrap the cuff around the patients upper arm midway between elbow and shoulder.
2. Place the stethoscope over the artery distal to the cuff (usually brachial which is at elbow level).
3. Palpate the radial pulse and inflate the cuff till the radial pulse disappear, and that point is the anticipated systolic blood pressure.
4. Now inflate further above the systolic blood pressure.
5. Slowly deflate the cuff at the rate of about 3 mm Hg/s and watch the pressure gauge or mercury column.
6. Place the stethoscope and hear sounds caused by the jetflow of blood through the occluded vessel, and then sounds are called korotkoff sounds. These sounds become less loud with the diminishing cuff pressure as the blood flow through occlusion becomes smoother, and disappear or muffled when the cuff pressure drops below the diastolic blood pressure.
7. Note the gauge pressure at the onset of Korotkoff sounds (systolic) and when the sounds muffled or disappear (diastolic). These pressures are usually recorded as ratio of systolic over diastolic (eg. 140/80 mm Hg).

Automated Devices

Numerous techniques have been developed to measure the blood pressure indirectly in automatic and semi-automatic methods. In semi-automatic inflation and deflation should be done manually whereas in automatic system everything done automatically. In both methods, basic procedure essentially parallel the manual method.

During development of these systems, most of the automatic meters worked well on a quiet, healthy subject but failed when used to measure blood pressure during activity of the subject or if the patient is in circulatory shock. Hence they tried methods other than utilizing korotkoff sounds to detect the pulse distal to the occlusion cuff. The striking technique is the impedance plethymography which indicated directly the pulsations of arterial blood flow and ultrasonic doppler which measures the arterial wall motions.

So, the ultimate technique involves all automatic sphygmomanometer that inflates and deflates an occlusive cuff at a predetermined rate and a sensitive detector is used to measure the distal pulse or cuff pressure. These detectors are of varieties like ultrasonic, piezoelectric, electroacoustic, rheographic and time-impedance devices. Three of the commonly and automatic techniques are discussed below.

The first technique employed in automated device to measure blood pressure is replacement of stethoscope by a microphone. The measurement begins with rapid inflation of the occlusive cuff just above the estimated systolic pressure. As a consequence, the vessel collapses which cease the flow in blood vessel beneath the cuff following which the cuff pressure gets reduced slowly.

The average generally within 10 mmHg

Self monitoring by patient at home and 24 hours ambulatory reading

Self monitoring is generally used by electronic device for oscillometric technique

Self arm monitoring equipment

Oscillometric monitoring equipment

Feeling of blood flow at the point is the result of heart pumping

insufficient blood flow through the body

Blockage or slowing of blood vessel. Puls rate. Based on their measurement of electric impedance at the body surface



Figure 4.32

The values at which the first korotkoff sound is detected and disappeared are both stored as systolic and diastolic blood pressure and shown in the display. Initially the display were conventional meters and now digital. Moreover, the instruments are added with sensors to measure heart rate and the electrocardiographic views too.

The second technique is the ultrasound determination of pressure in blood vessels. As known, ultrasonic waves are acoustical waves in the range above human hearing and subject to Doppler shift i.e., frequency activation when reflected from a moving object. If piezoelectric ultrasound sensors are placed over the artery under the cuff, then they detect the motion of the blood vessel walls during various states of occlusion.

PROBLEM

1. Design a notch filter to reject 50 Hz a.c. mains frequency. Also calculate the gain of this filter at 50 Hz.

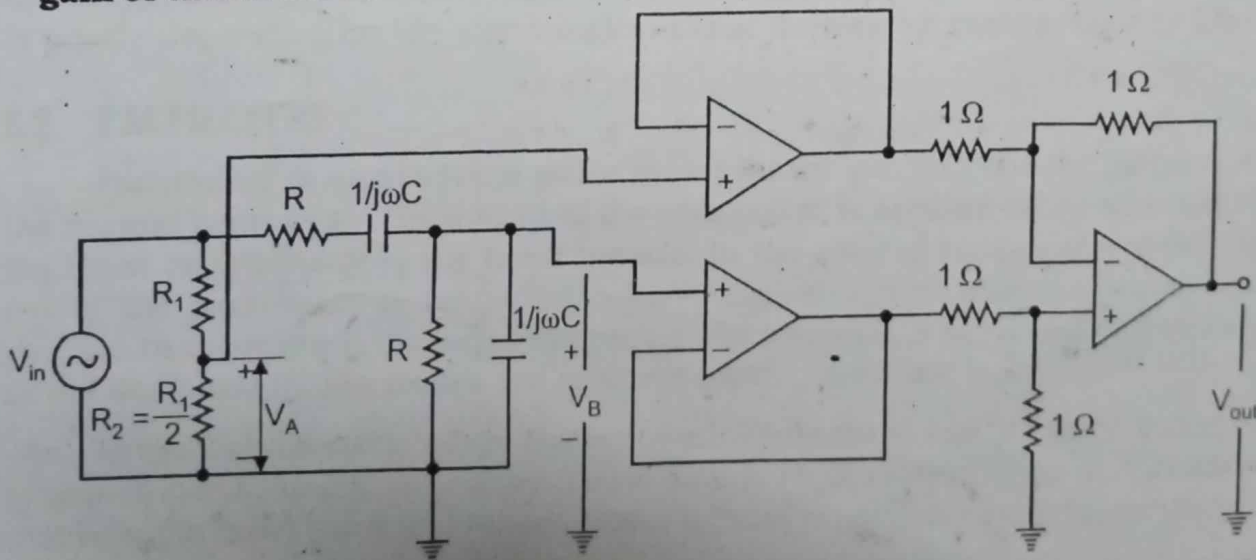


Figure 4.33

CHAPTER V

PHYSIOLOGICAL ASSIST DEVICES

5.1 INTRODUCTION

Physiological assist devices are very helpful to the patients belonging to different categories. For example, pacemakers are extending the life of the cardiac patients having total bundle block. Bladder stimulators are used for the correction of the urinary incontinence. Implanted artificial heart valves are maintaining the circulation of blood in a normal manner. Today, one part of the total population is purely depending on the physiological assist devices for their every day life.

5.2 PACEMAKERS

Pacemaker is an electrical pulse generator for starting and/or maintaining the normal heart beat. The output of the pacemaker is applied either externally to the chest or internally to the heart muscle. In the case of cardiac stand still, the use of the pacemaker is temporary - just long enough to start a normal heart rhythm. In cases requiring long term pacing, the pacemaker is surgically implanted in the body and its electrodes are in direct contact with the heart.

In cardiac diseases, where the ventricular rate is too low, it can be increased to normal rate by using pacemaker. The various arrhythmias (rhythm disturbances) that result in heart block and Adams stokes attacks represent a serious pathological condition.

During that time, the patient becomes invalid because of the constant risk of sudden loss of consciousness. By fixing the artificial electronic pacemakers, the above defects in the heart can be eliminated.

With conventional drug therapy, the failure within a year is about 50%. Pacemaker therapy lowers this figure to 15% and leads to a considerable improvement in the patient's mental and physical wellbeing.

5.2.1 Energy requirements to excite heart muscle

Like all muscle tissues, the heart muscle can be stimulated with an electric shock. The minimum energy required to excite the heart muscle is about $10 \mu\text{J}$. For better stimulation and safety purposes, a pulse of energy $100 \mu\text{J}$ is applied on the heart muscle. That is, a pulse of 5 V, 10 mA and 2 milli seconds duration is used. Too high a pulse energy may provoke ventricular fibrillation. Ventricular fibrillation is a dangerous condition.

During that time, the ventricular muscle contracts so rapidly and irregularly that the ventricles fail to fill and circulatory arrest follows. The patient loses consciousness in 10-15 seconds and the brain cells die within a few minutes from oxygen deficiency in the brain. This is caused by a pulse of energy $400 \mu\text{J}$.

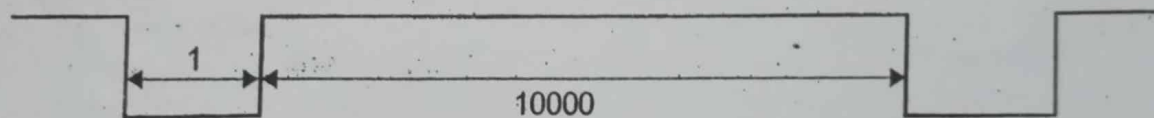


Figure 5.1: Pacemaker pulses

- Figure 5.1 shows the shape of the pacemaker pulses. These pulses should have the pulse to space ratio 1:10000 and that should be negatively going pulses to avoid the ionization of the muscles.

The pulse voltage is made variable to allow adjustments in the energy delivered by the pacemaker to the heart during each pulse. During the pulse duration, the stimulus voltage drives energy into the heart muscles.

The pulse repetition rate is usually 70 pulses/min but many pacemakers are adjustable in the range of 50-150 pulses/min. The duration of each pulse is between 1 and 2 milli seconds. Output pulses from the pacemaker appear at the pair of electrodes used for triggering the heart.

Table 5.1 gives the typical ranges of parameters of the pacemakers available today.

Table 5.1: Typical ranges of pacemaker parameters

| | | |
|-----------------------|---|---|
| Pulse rate | - | 25 - 155 pulses per minute |
| Pulse width | - | 0.1 - 2.3 milliseconds |
| Pulse amplitude | - | 2.5 - 10 volts |
| Battery capacity | - | 0.44 - 3.2 amp-hours |
| Longevity | - | 3.5 - 18 years |
| End-of-life indicator | - | 2 - 10% drop in pulse rate |
| Weight | - | 33 - 98 grams |
| Size | - | 22 - 80 cm ³ |
| Encapsulization | - | Silicon rubber, stainless steel, titanium |

5.2.2 Methods of stimulation

There are two types of stimulation or pacing: External stimulation and Internal stimulation. **External stimulation** is employed to restart the normal rhythm of the heart in the case of cardiac stand still. Stand still can occur during openheart surgery or whenever there is a sudden physical shock or accident. The paddle shaped electrodes are applied on the surface of the chest and currents in the range of 20 - 150 mA are employed. **Internal stimulation** is employed in cases requiring long term pacing because of permanent damage that prevents normal self triggering of the heart. The electrodes are in the form of fine wires of teflon coated stainless steel.

In some cases, during restarting of the heart after openheart surgery, spoon like electrodes are used. The currents in the range of 2-15 mA are employed. The bipolar and unipolar electrodes are used.

In the **bipolar electrode**, there are stimulating electrode and contact electrode which serves as a return path for current to the pacemaker.

In the **unipolar electrode**, there is only stimulating electrode and the return path for current to the pacemaker is made through body fluids.

Eventhough the internal stimulation is adopted in most cases, based on the placement of the pacemaker, there are two types, external pacemaker and implanted pacemaker.

| Sl. No. | External Pacemaker | Implanted Pacemaker (internal pacemaker) |
|---------|--|--|
| 1. | The pacemaker is placed outside the body. It may be in the form of wrist watch or in the pocket, from that one wire will go into the heart through the vein. | The pacemaker is miniaturized and is surgically implanted beneath the skin near the chest or abdomen with its output leads are connected directly to the heart muscle. |
| 2. | The electrodes are called endocardiac electrodes and are applied to the heart by means of an electrode catheter with electrode's tip situated in the apex of the right ventricle. These are in contact with the inner surface of the heart chamber. | The electrodes are called myocardiac electrodes and are in contact with the outer wall of the myocardium (heart muscle). Endocardiac electrodes are also used. |
| 3. | It does not necessitate the open chest surgery. | It requires an open chest minor surgery to place the circuit. |
| 4. | The battery can be easily replaced and any defect or adjustment in the circuit can be easily attended without getting any help from a medical doctor. | The battery can be replaced only by minor surgery. Further any defect or adjustment in the circuit cannot be easily attended. Doctor's help is necessary to rectify the defect in the circuit. |
| 5. | During placement, swelling and pain do not arise due to minimum foreign body reaction. | During placement swelling and pain arise due to foreign body reaction. |
| 6. | Here there is no safety for the pacemaker particularly in the case of children carrying the pacemaker, | Here there is a cent percent safety for the circuit from the external disturbances. |
| 7. | Mostly these are used for temporary heart irregularities. | Mostly these are used for permanent heart damages. |

5.2.3 Different modes of operation

Several pacing modes are possible with both internal and external pacemakers. They can be either competitive or noncompetitive. Asynchronous pacing is called competitive pacing because the fixed rate impulses may occur along with natural pacing impulses and would therefore in competition with them in controlling the heart beat. The noncompetitive pacemakers are generally programmed either in demand or synchronised mode.

Based on the modes of operation of the pacemakers, they can be divided into five types:

- 1) Ventricular asynchronous pacemaker (fixed rate pacemaker).
- 2) Ventricular synchronous pacemaker.
- 3) Ventricular inhibited pacemaker (demand pacemaker).
- 4) Atrial synchronous pacemaker.
- 5) Atrial sequential ventricular inhibited pacemaker.

1) Ventricular asynchronous pacemaker

It is the first type of pacemakers and can be used in atrium or ventricle. It has the simplest mechanism and the longest battery life. It is so cheap and easy to check and is the least sensitive device to outside interference. This pacemaker is suitable for patients with either a stable, total AV block, a slow atrial rate or atrial arrhythmia. It is basically a simple astable multivibrator. This produces a stimulus at a fixed rate irrespective of the behaviour of heart rhythm. There may be competition between the natural heart beats and the pacemaker beats. It is possible that such an event can be dangerous because if the pacemaker impulse reaches the heart during a certain vulnerable period (the apex of the T wave), the ventricular fibrillation may occur.

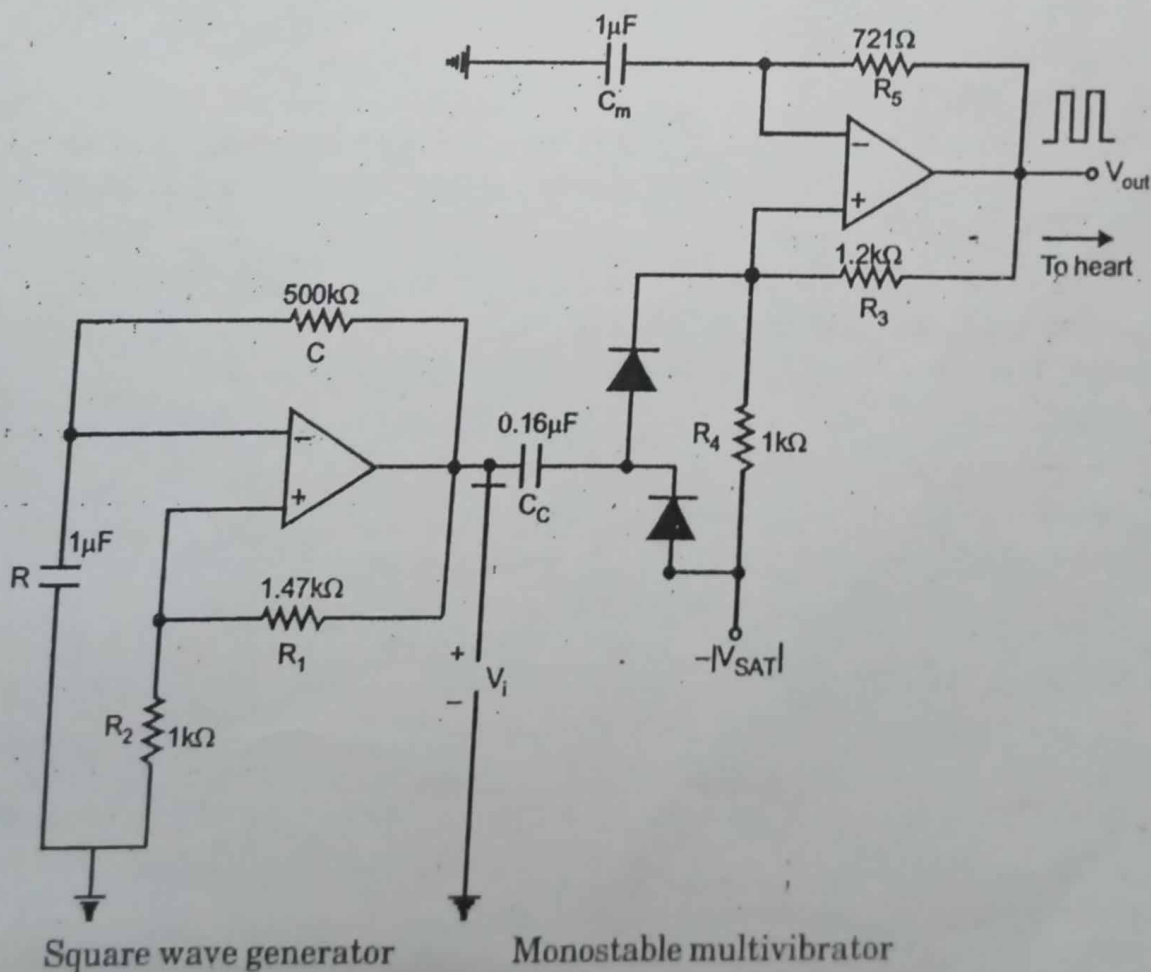


Figure 5.2: Ventricular asynchronous pacemaker

Figure 5.13 shows the block diagram of a telemetry type R.F. energised pacemaker. A free running multivibrator generates the desired pulses at the rate of 70 beats/minute and the pulses are used to turn a R.F. oscillator of frequency 2 MHz. The pulses modulate the R.F. oscillations. The modulated R.F. waves are amplified and transmitted through the transmitter coil.

The receiver coil receives these modulated R.F. waves. The capacitor and rectifier, connected to the receiver coil which is placed beneath the skin remove the 2 MHz carrier. Thus the output of the rectifier diode is used to stimulate the heart muscle. But this type is also not liked by the cardiac patients.

5.4 ARTIFICIAL HEART VALVES

Today cardiac surgery has advanced tremendously to enable repair of all congenital heart defects, replacement of damaged valves and bypassing of coronary blocks. About 1 in 1000 babies is born with deformed heart and 1/3 of them die in infancy. —

The imperfect functioning of the heart is due to various defects like hole in the heart, atrial septal defects and ventricular septal defects. In several cases like pulmonary stenosis, the valves of the major vessels are narrow. When the major vessels of the heart are wrongly connected, then there is mixing of pure and impure blood.

This accounts for the blue colour of the baby, These defects must be corrected as early as possible to save the life of the patient. For young people, the mitral valve and aortic valve can be affected. The tricuspid valve may be affected at a later stage. Badly diseased valve has to be replaced by an artificial valve. There are two types of valves:

- i) **Prosthetic valves:** These are made from high grade plastics and metal. They need life long coagulating agent (i.e.) blood thinning agent. The average durability of these valves is about 8 to 10 years.
- ii) **Tissue valves:** These may be either homograft or heterograft. Homograft valves are taken from human beings. Heterograft valves are taken from animals. Here blood thinning agent is not necessary. The average durability of these valves is smaller than the prosthetic valves. Only the prosthetic or mechanical valves are discussed here.

5.4.1 Requirements for the design of artificial heart valves

- i) When the artificial heart valve is in contact with the blood, there would not be any hemolysis or blood clots.
- ii) The valve material must be tough enough to withstand the heart beat rate throughout the life of the patient.
- iii) It should be designed small, light, reliable and efficient enough to enable it to be inserted surgically into the heart.

5.4.2 Different natural heart valves

Since the left side of the heart is the one which normally functions with much higher pressure differentials, the left heart valves are usually failed to function properly. The **mitral valve** is located between the left atrium and the left ventricle and the **aortic valve** is located between the left ventricle and aorta. Occasionally the **tricuspid valve** which is located between the right ventricle and right atrium will fail. The procedure in valve replacement involves opening the chest (thoracotomy), placing the heart on bypass using a heart-lung machine, cutting through the heart muscle to expose the valve, excising the diseased valve and the surrounding tissue and attaching a prosthetic valve in its place.

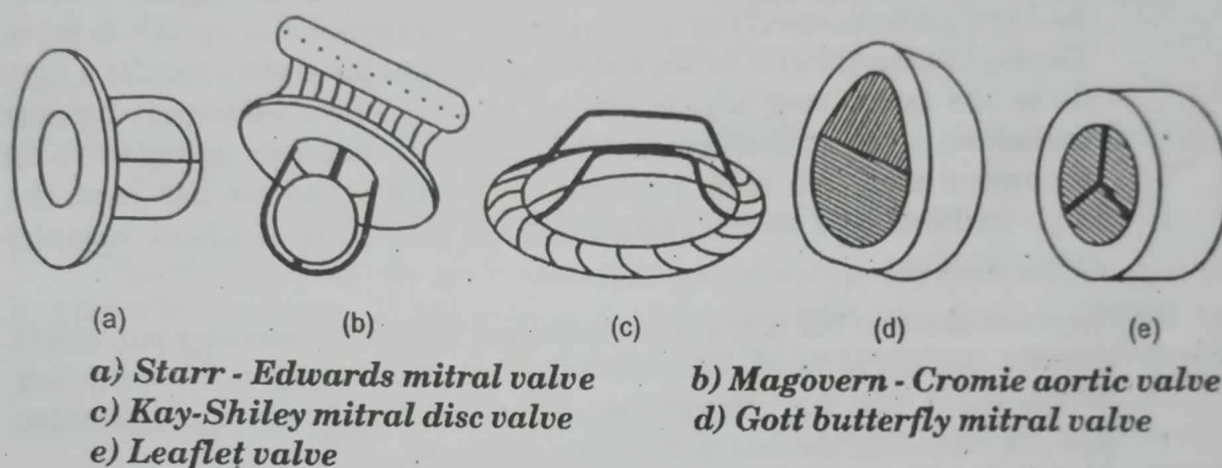


Figure 5.14: Different types of artificial heart valves

5.4.3 Different types of artificial heart valves

Most of the artificial heart valves are check valves of the caged-ball (Scandinavian type) or caged-disc (Alaskan type) variety. The ball or disc is made from silicone rubber. A metal ring surrounded by either Dacron or Teflon forms the connecting surface which is sewn to the natural seat from which the pathologic valve is removed. Starr and Edwards devised a mitral valve using a ball made of silastic 372 rubber (Figure 5.14 (a)). The Starr-Edwards aortic valve has large orifice and small regurgitation. It has large opening resistance. The closure of that valve is in a very slow manner. The Magovern-Cromie aortic valve (Figure 5.14 (b)) differs from others such that there is a series of needle like projections which are screwed out during the installation procedure. These attach themselves to the ring of tissue around the valve and form the fixation. Its main advantage is that time consuming sewing of the valve to the tissue is eliminated and the operation can be performed in much less time. In the Kay Shiley mitral valve (Figure 5.14 (c)) a caged disc replaces the silastic ball. This type is anatomically more suitable than other types. Gott butterfly mitral valve (Figure 5.14 (d)) has quick opening and closing and large orifice. It has a disadvantage that it has great regurgitation. Similarly the leaflet valve (Figure 5.14 (e)) used as mitral valve has the same functioning of Gott butterfly valve. Now-a-days the ball or disc is made of hollowed solid polymers (polypropylene, polyoxymethylene, polychlorotrifluoro ethylene, etc.), metals (titanium and vitallium alloys) and pyrolytic carbon.

5.4.4 Problems regarding artificial heart valves

- i) The early use of silicone rubber was found undesirable because of the valve swelling and dimensional changes of the valve. Further hemolysis and regurgitation were also produced.
- ii) In the aortic area, there are calcification and rupture of pericardial grafts within a few months when the artificial heart valve is used as a substitute for the aortic cusps. Calcification starts at the base and impairs the mobility of the valve.
- iii) In the Starr-Edwards aortic ball valve, there are some variations in the aortic ball after some months. Further this results in migration of the ball and embolization. The silicone rubber becomes susceptible to wear. During implantation of valve, abnormality of implantation results a tight fit in the aortic root which alters the blood flow velocities. Similar variations have not been observed in the Starr-Edwards mitral valve. In the mitral area, the main problem with artificial valves has been the high incidence of late thromboembolic (blocking of blood vessels) complications.
- iv) In some cases at the mitral site, the blood is slowly squeezing out which results clotting of blood. The blood clotting can even affect the operation of the valve. The fabric coverings of both seat and cage show promise toward replacing the clot with tissue ingrowth.
- v) In some occasions, the ball itself has become deformed causing incompetency of the valve which decreases the normal operating efficiency. In few cases, the ball has actually escaped from its cage with tragic results.
- vi) There are some cases in which the blood leaks around the insertion site causing a small degree of insufficiency and clot formation.
- vii) Surrounding the insertion site there are mal formation and tissue growth which reduce the opening and closing actions of the valve.
- viii) Infection at the implantation site is usually fatal, although survivals have been reported after removal and replacement of the infected valve.

Despite these drawbacks thousands of people owe their lives to these artificial plastic valvular replacements.

5.5 DEFIBRILLATORS

A defibrillator is an electronic device that creates a sustained myocardial depolarisation of a patient's heart in order to stop ventricular fibrillation or atrial fibrillation. Ventricular fibrillation is a serious cardiac emergency resulting from asynchronous contraction of the heart muscles. This uncoordinated movement of ventricle walls of the heart may result from coronary occlusion, electric shock or abnormalities of body chemistry. Because of this irregular contraction of the muscle fibers, the ventricles simply quiver rather than pump the blood effectively.

- 6) After the end of patient expiration, the system electronics trip the main solenoid, thereby initiating the patient, inspiration part of the cycle. Nowadays the microprocessor based control circuits are used in the ventilator system to improve the system's reliability and accuracy.

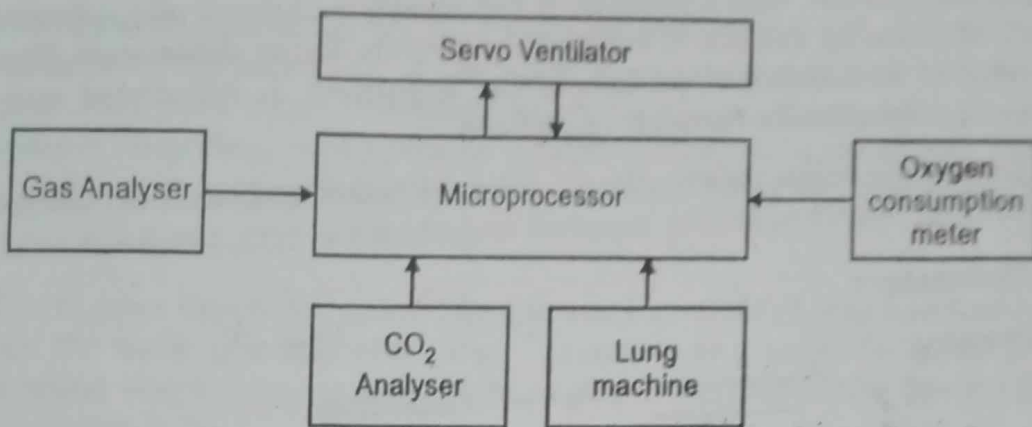


Figure 6.7: Microprocessor based ventilator

Figure 6.7 shows the microprocessor based automatic feedback control of a mechanical ventilator. It consists of a microprocessor with RAM, EPROM, A/D converter and a CRT controller. The input signals to the microprocessor are obtained from a CO₂ analyser, a lung machine, gas analyser, oxygen consumption monitor and the servo ventilator. The proper controlling signals are delivered to the servo ventilator so as to get correct ventilation adjustment in response to a patient's metabolism.

6.9 ANESTHESIA MACHINE

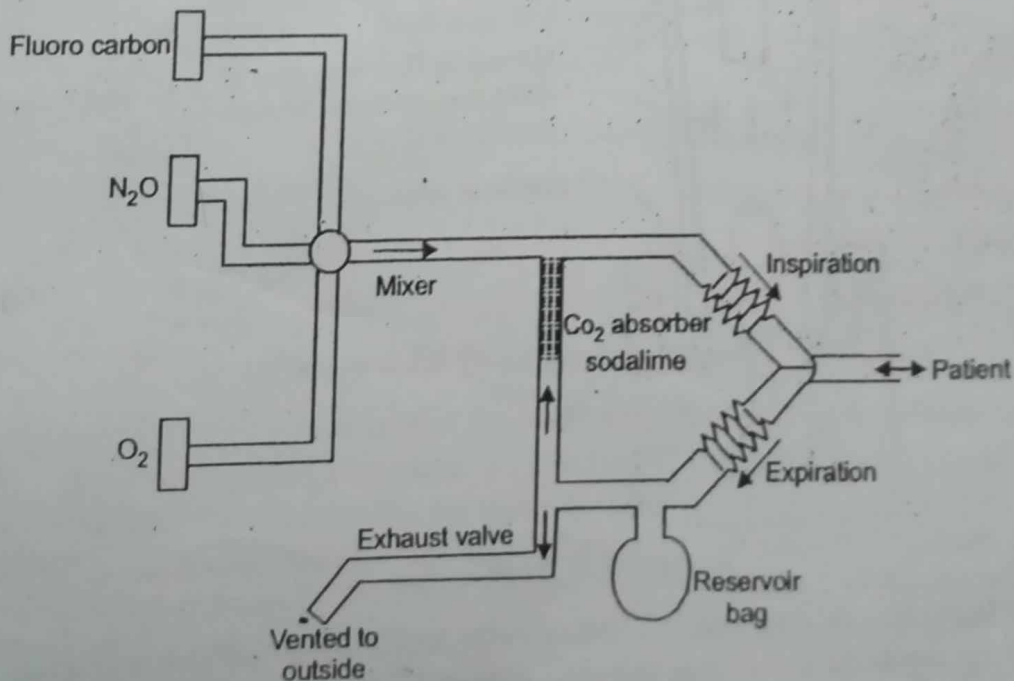


Figure 6.8: Anesthesia Machine

Figure 6.8 shows the block diagram of an anesthesia machine. It corresponds to the modern partial rebreathing system. The most commonly used anesthetic is nitrous oxide used in combination with fluorocarbons, such as halothane, enflurane,

methoxyflurane, etc. and oxygen. These are nonflammable. This mixture is delivered to the patient on the inspiration cycle. The flow rate is correctly maintained by the flowmeters in the each gas tubing (not shown in the figure). Exhalation passes through a one way valve, through a CO_2 absorber and is delivered again to the patient. The anesthetic is constantly monitored and adjusted for the correct mixture by means of controlling circuits using flowmeters like turbine flowmeter or rotameter. A portion of the anesthetic is exhausted and usually delivered to the outside through vent ducts.

During the supply of anesthesia, the respiration and blood circulation should be monitored eventhough the supplied anesthesia is very small.

6.9.1 Flowmeters

i) Rotameter

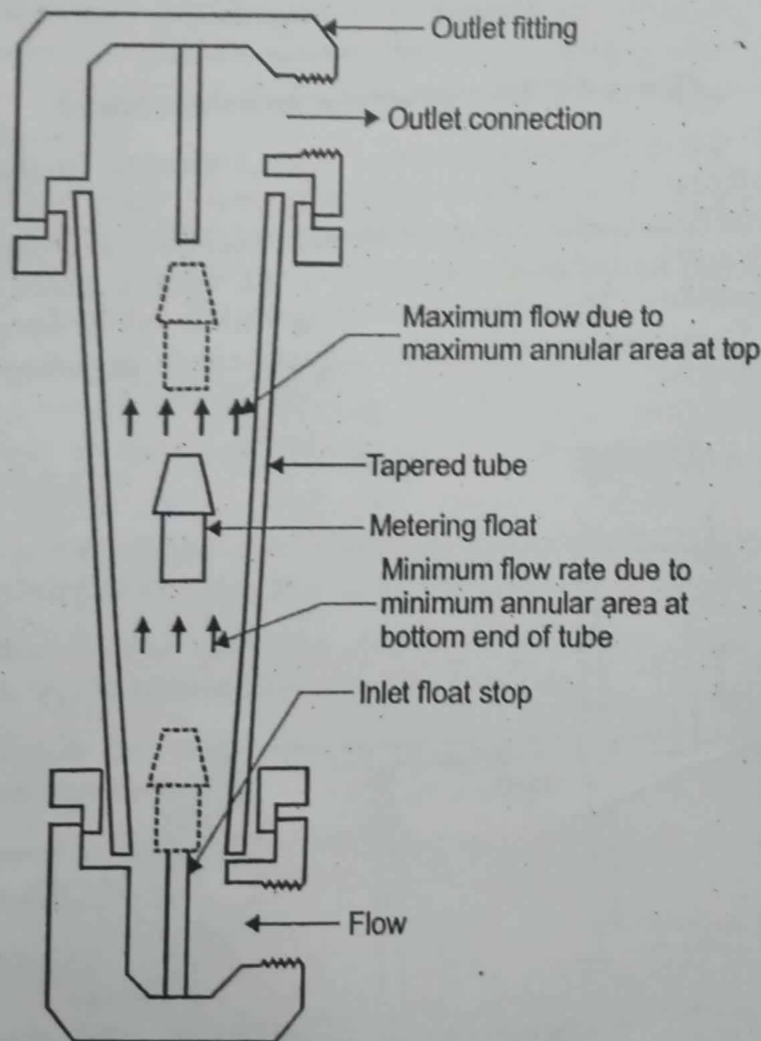


Figure 6.9: Rotameter

The rotameter is the most extensively used form of the variable area flowmeter. It consists of a vertical tapered tube with a float which is free to move up or down within the tube as shown in figure 6.9. The tube is made tapered so that there is a linear relationship between the flow rate and position of the float within the tube. The fluid to be measured enters the tube from the bottom and passes upward around the float and exit at the top. When the fluid enters the

metering tube, the float moves up. The float is pushed up until the lifting force produced by the pressure differential across its upper and lower surface is equal to the weight of the float. The pressure differential is proportional to the square of the flow rate. When the flow rate is maintained as a constant, the float is stationary. Any decrease in the flow rate causes the float to drop to a lower position. A calibration scale printed on the tube provides a direct indication of flow rate. In addition to flow rate indication at the point of measurement rota meters can be equipped with additional functions such as alarm, pneumatic or electric transmission recording, controlling or totalizing. The accuracy of rota meters is about $\pm 0.5\%$. It is more suitable for metering small flows like anesthetic flow.

ii) Turbine flowmeter

The turbine flowmeter is used for the measurement of very low flow rates. It works on the basic principle of turbine. It consists of a multibladed rotor called turbine wheel which is mounted at right angles to the axis of the flowing fluid as shown in figure 6.10.

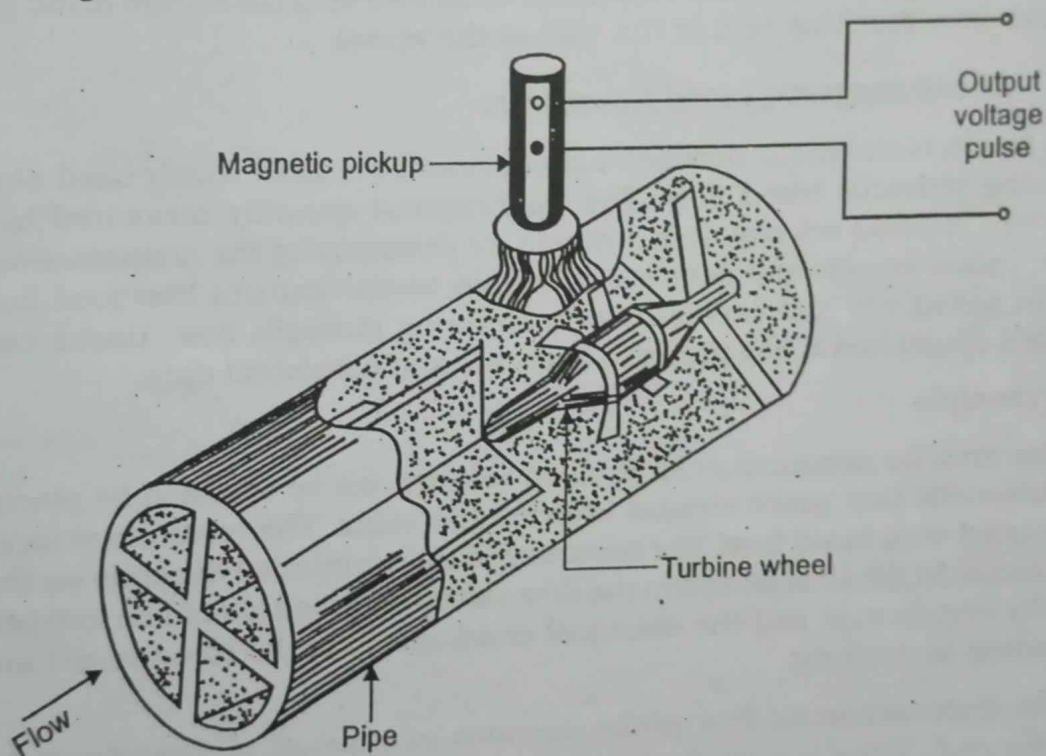


Figure 6.10: Turbine flowmeter

The rotor is free to rotate about its axis by means of ball or sleeve bearings on a shaft. The flowing fluid impinges on the turbine blades imparting a force to the blade surface which causes the rotation of the rotor. The rotating speed of the rotor is directly proportional to volumetric flow rate. The magnetic pick up coil, mounted in close proximity to the rotor but internal to the fluid channel, generates a voltage during each rotor blade passes it. Thus the total number of pulses obtained per second is a measure of the total flow. The electrical voltage pulses can be totalled, differenced and manipulated by digital techniques so that a zero error characteristic of digital handling is provided from the pulse generator to the final

read out. The accuracy is from 0.25% to 0.5%. This is widely used in the anesthesia monitors, such that when the flow rate is increased or decreased some error signal with suitable phase is given to the anesthetic column at the inlet section to change its flow rate. Whenever there is no error signal, the flow rate is maintained as a constant.

6.10 BLOOD FLOWMETERS

Blood flowmeters are used to monitor the blood flow in various blood vessels and to measure cardiac output. The above said flowmeters are not suitable for the blood flow measurements since they require cutting of blood vessel or they may form blood clotting. Currently electromagnetic flowmeters, ultrasonic flowmeters and laser based blood flowmeters are widely used to measure the blood flow rate. We know that temperature gradient in the upstream and the downstream of blood is also a measure of blood velocity. By this way also, one can measure the blood flow rate. But it is not adopted now. In the blood vessel, the blood flow rate is maximum along the axis of the vessel and decreases with the square of the distance from the axis, reaching zero at the wall of the vessel.

6.10.1 Electromagnetic blood flowmeters

The electromagnetic flowmeter is at present the most widely used device for measuring pulsatile blood flow. The fundamental quantity measured by these flowmeters is blood velocity. It is suitable for determining the instantaneous flow rates in intact vessels and consists of certain useful features like good linearity, direction sensitivity and capability of monitoring pulsatile flow. Under carefully controlled conditions it has provided accurate and consistent data.

Basic Principle

Continuous measurements of blood velocity can be obtained by placing the electromagnetic flow probe around arteries and veins. The resulting velocity can be correlated with blood flow. The accuracy of the correlation depends on the flow probe design. In the ideal situation the flow values obtained should be independent of velocity distribution and the electrical conductivity of the blood vessel and the surrounding instrument.

The electromagnetic flow probe operates as a result of **Faraday's law of induced e.m.f.** Blood is a conductor of electricity. Consequently when a magnetic field is applied to a blood vessel, the blood flow in the vessel causes an electrical field to be induced in a direction mutually perpendicular to the direction of the applied magnetic field and the blood velocity.

Figure 6.11 shows the principle of the electromagnetic blood flowmeter. If the magnetic field is assumed to be uniform, the induced electrical field strength, E , is proportional to the magnitude of the magnetic field, B and the mean blood velocity v i.e. $E = vB \sin \theta$, where θ is the angle between the direction of the applied magnetic field and that of the blood velocity. The direction of the magnetic field is generally arranged to be perpendicular to the direction of blood velocity so that $\sin \theta = 1$ and hence $E = vB$ and the largest signal is obtained.

The output from which contains the difference frequencies between the transmitted ultrasonic wave and the Doppler shifted received waves. The output from the demodulator is filtered to allow these difference frequencies to pass whilst unwanted (higher) frequencies are stopped. The difference frequencies which in general fall in the audible range are amplified. The amplified output may be given to the loud speaker to hear the sound by which a doctor can easily diagnose any abnormality in the blood flow and to spectrum analyser to analyse the frequency components electronically.

b) Recording fetal heart movements and blood circulation using Doppler ultrasonic method

Figure 6.14 shows the arrangement for recording fetal heart movements and blood circulation using doppler ultrasonic method. The transmitting and receiving transducers are placed in a single probe which is held against the mother's abdominal wall. A small amount of oil or gel is placed between the probe and the abdominal wall to get good acoustic coupling. The ultrasonic beam of frequency about 2 MHz is directed at the heart or umbilical cord of the fetus. The reflected signal is amplified and mixed with the emitted signal. The resulting beat frequency is proportional to the blood velocity in the fetus and mother. The mother's blood flow can be distinguished from that of the fetus by the higher pulse rate of the fetus. The beat frequency is amplified and can be heard with a loud speaker. By this method the presence of a pulsating heart and blood flow in the fetus can be determined. The echo can be obtained from the fetal heart as early as the 10th - 12th fetal week and from that time until delivery.

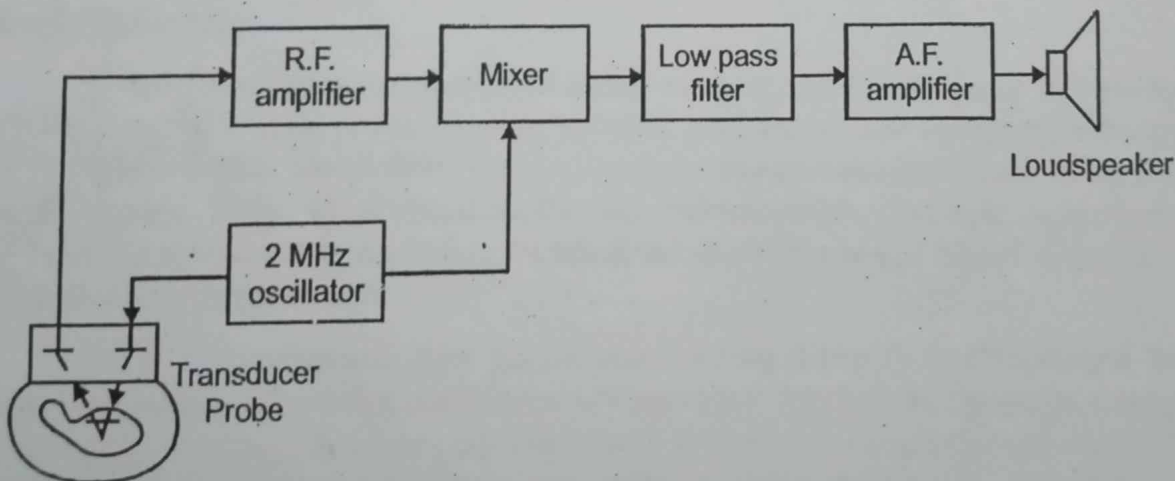


Figure 6.14: Recording fetal heart movements and blood circulation

The following diagnostic sounds can be heard.

- 1) Thump, Thump - low frequency note, rapid rhythm - fetal heart movement.
- 2) Swish, Swish - high frequency note, rapid rhythm - umbilical cord sound.
- 3) Thuummp, Thuummp - low frequency note, slow rhythm - mother's body movements due to vibrations transmitted from the heart.
- 4) Woooch, Woooch - mid frequency note, slow rhythm - mother's arteries.

Thus the status of the fetus in the mother's abdomen can be studied completely without any danger.

- 1) The pulse repetition rate is controlled by the clock which triggers the monostable to open the gate to allow the transmitting transducer to be excited for a period corresponding to the width of the target volume which is desired to study.
- 2) Echoes returning from within the blood vessel are amplified and mixed in the demodulator with the signal from the oscillator.
- 3) The delay monostable triggers the monostable controlling the receiver gate so that the gate opens to allow a voltage which is in effect a sample corresponding to the doppler shift due to the motion in the target volume, to be stored in the sample and hold circuit.
- 4) The << sample and hold >> is reset immediately prior to being updated by a new sample resulting from the following ultrasonic pulse.
- 5) The output from the << sample and hold >> is thus a rectangular wave with a long << mark >> and a short << space >>.
- 6) These rectangular waves are amplified and given to the loud speaker or spectrum analyser for further analysis after passing through the low pass filter.
- 7) A zero crossing rate meter is a comparator that produces an output pulse every time when the signal crosses the zero line going from negative to positive. Normally the blood flow signal contains a wide frequency spectrum in the audio range. By using pulsed doppler, the received signal can be limited to narrower frequency range. The zero crossing rate meter can measure the blood velocity or the change in blood velocity very accurately.
- 8) Because of some limitations of the zero crossing rate meter, spectrum analysers are used to derive blood flow velocity information from doppler signals. A spectrum analyser processes short length of audio signal to produce spectral displays which have frequency as abscissa, time as ordinate and spectral intensity represented by record darkening.

6.10.3 Laser based Doppler blood flowmeters

Similar to ultrasonic blood flowmeter, laser based doppler blood flowmeters are used to measure the blood flow velocities in various blood vessels.

Light from a He-Ne laser of 5 mW power and 632.8 nm wavelength (figure 6.16) is coupled into the quartz fiber using a converging lens which results in an increased power density at the skin surface and thus enables to detect flow in more deeply seated veins and arteris. The receiving plastic fiber collects the scattered signal and the collected signal is coupled to the photodiode through a laser line filter. The photo diode is a square law device and gives cut current which is proportional to the intensity of the reflected light and to the beating frequency of the shifted and unshifted signals. The diode output is given to the low noise preamplifier and then to the wide band amplifier having wide band performance (40 Hz - 40 kHz). System output is obtained by taking the RMS value of the total signal separating it from the total zero light noise and normalising it

for total back scattered light. An audio output of the signal before RMS conversion is also available to hear the flow pattern. Here the instrument measures an averaged blood cell velocity and not the absolute velocity of the flow. Laser doppler flowmeter is also a noninvasive one and it offers high reproducibility and high sensitivity.

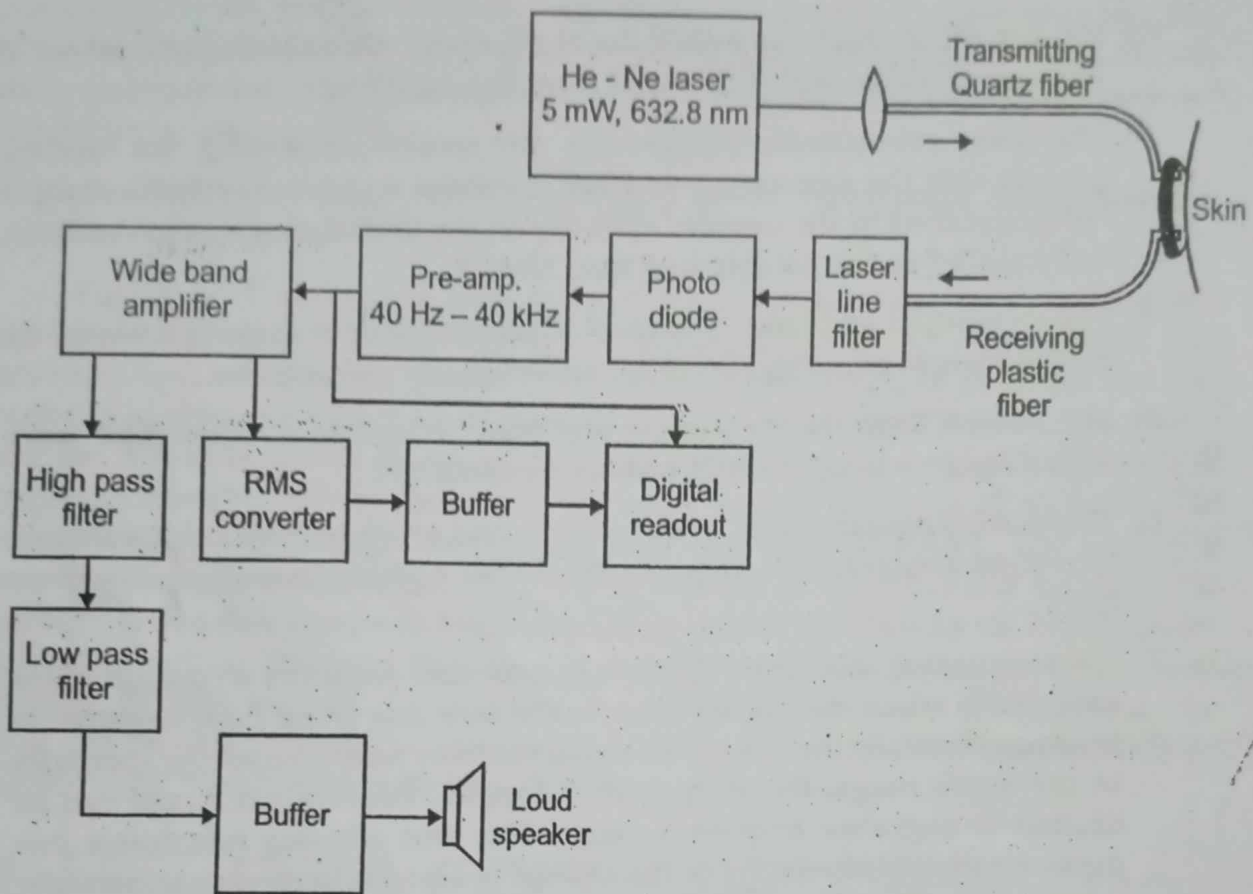


Figure 6.16: Laser doppler blood flowmeter

6.10.4 NMR blood flowmeters

There is also noninvasive blood flowmeters based on nuclear magnetic resonance principle. But this is very complex and costly. In the presence of an external magnetic field, the magnitude of magnetisation resulting from the alignment of nuclear magnets of hydrogen atoms is proportional to the blood flow rate. Thus measuring the magnetisation one can evaluate the blood flow rate in various blood vessels.

6.11 CARDIAC OUTPUT MEASUREMENTS

Cardiac output is the amount of blood delivered by the heart to the aorta per minute. During each beat, in the case of adults, the amount of blood pumped ranges from 70 to 100 ml and hence for normal adults the cardiac output is about 4-6 litres/minute. The measurement of cardiac output is necessary to study the various cardiac disorders. A decrease in cardiac output may be due to low blood pressure, reduced tissue oxygenation, poor renal function, shock and acidosis.

Using implanted electromagnetic flow probe on the aorta, we can find the cardiac output per minute directly by multiplying the stroke volume with the heart

CHAPTER VII SPECIALISED MEDICAL EQUIPMENT

7.1 INTRODUCTION

Many hospitals have a laboratory where the chemical analyses are going on. Measurement of chemical parameters is necessary to monitor the patients, who are in critical conditions. Already some of the clinical laboratory equipment are discussed in the last chapter. In this chapter the remaining clinical laboratory and diagnostic equipment and medical X-ray equipment are discussed.

7.2 BLOOD CELL COUNTER

The blood cells have important functions in our body. The red blood cell is used for the transport of oxygen and carbon dioxide. The white blood cells are part of the body's defenses against infections and foreign substances. The platelets are involved in the clotting of blood. The red blood cells in the blood consist of hemoglobin.

When the body produces too many red blood cells, the amount of hemoglobin in the blood increases and a chronic disease called *polycythemia* or dehydration is produced. When the hemoglobin in the blood decreases, *anemia* is produced. The anemia produces headache and giddiness. The amount of hemoglobin is normally 130-170 g/l for men and 120-160 g/l for women. Due to finite size of blood cells, they make up a portion of the total blood volume. The volume percentage of red cells in a given volume of blood can indicate the various diagnostic informations to the physician. To determine relative proportion of blood cells in a given volume of blood, *hematocrit* or packed cell volume is used.

The blood sample is placed in a test tube which is spun so that the cells are packed at the bottom under centrifugal force provided by the centrifuge.

Thus the packed cell volume is the ratio between the height of the packed cells and the height of the blood in the tube. Normal range of packed cell volume for men is 42%-54% and for women is 37%-47%.

The number of red blood cells is also counted using a microscope. Since the density of red blood cells is so large, the microscopic counting is time consuming. Therefore now-a-days automatic red blood cell counters are used. The method is based on the fact that red cells have a higher electrical resistivity than the saline solution in which they are suspended.

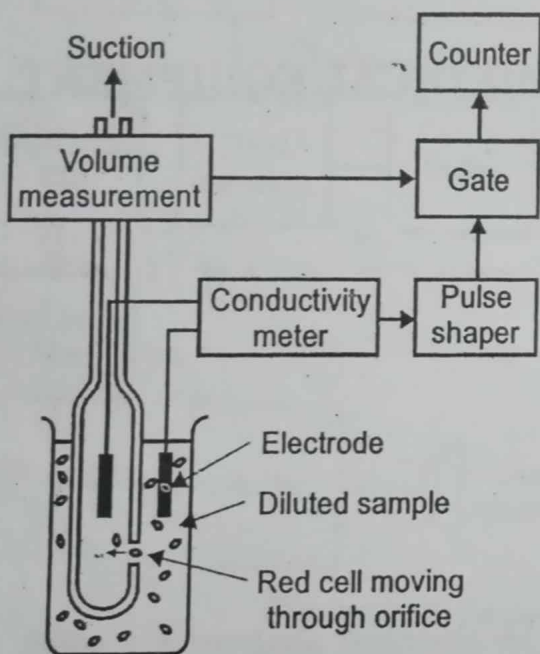


Figure 7.1: Automatic blood cell counter

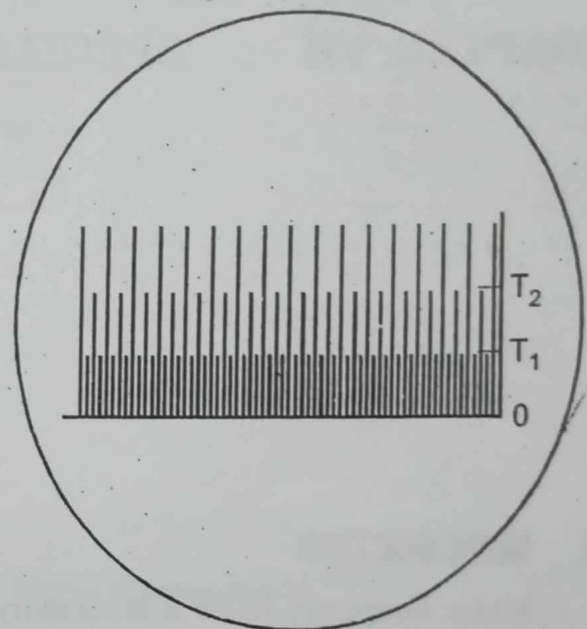


Figure 7.2: Counter display of impulses

Figure 7.1 shows the automatic blood cell counter using electronic circuitry. A diluted blood sample is drawn through a small orifice having diameter less than $100 \mu\text{m}$ by means of a suction pump. The electrodes are placed such that one is in the surrounding sample chamber and other in the suctioned blood.

The electrodes are attached with the conductivity bridge such that their resistance forms one arm of bridge. Before suctioning, the resistance of the electrode arm is equal to R .

After suctioning of blood, each red cell moving through orifice will produce a sudden increase in resistance such that the resistance of the arm is now equal to $(R + \Delta R)$ or R_{out} .

Assuming equal resistances R are placed in other arms, the bridge output voltage,

$$V_{\text{out}} = \left[\frac{R_{\text{out}}}{R_{\text{out}} + R} - \frac{1}{2} \right] V_{\text{BB}} = \frac{\Delta R}{4R + 2\Delta R} V_{\text{BB}}$$

$$\text{(or)} \quad V_{\text{out}} = \frac{\Delta R}{4R} V_{\text{BB}}$$

since $\Delta R \ll R$. Here V_{BB} is the constant excitation voltage of the bridge. Thus V_{out} is directly proportional to ΔR . The conductivity meter gives the amplified V_{out} as an impulse. The number of impulses is counted by a counter for a certain volume displacement through the orifice and this gives the density of red blood cells.

Figure 7.2 shows the counter display in terms of impulses. The impulses having highest peaks are fewest in number. These are due to WBCs which make highest resistance change in the orifice. The RBCs are represented by the peaks between threshold T_2 and T_1 .

During the operation of the instrument, the threshold is first set to zero and the counter output is given by the total number of particles (WBCs + RBCs + platelets) per litre. Then the threshold is set to T_1 and now the counter gives the total number of RBCs and WBCs per litre. After that the threshold is set to T_2 and the counter reads just the total number of WBCs, per litre.

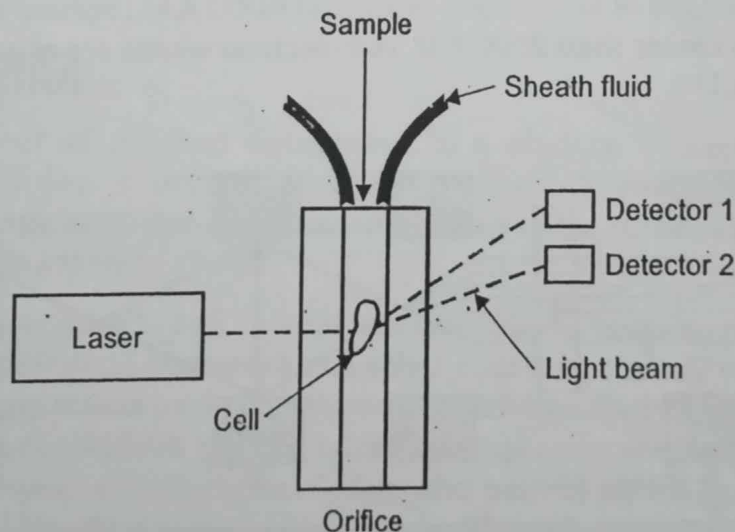


Figure 7.3: Principle of laser based blood cell counting

Figure 7.3 shows the principle of laser based blood cell counting. This is a modern technique which gives the number of RBCs, WBCs and platelets, hematocrit, mean cell volume of red blood cell and concentration of hemoglobin.

The basic principle behind this technique is that the angle of scattered light intensity is different for different sized particles. The sample blood is heavily diluted to reduce the number of particles counted to one at a time. A sheath fluid is directed around the blood stream to confine it to the center of aperture through which a laser beam is passed.

Thus the blood cells are illuminated by the laser light and they scatter light. The scattering angles of platelets and red blood cells are having large difference so that the scattered light from these two types of cells are directed into two different photo detectors.

The output of the photo-detector is given to a properly calibrated digital voltmeter which gives the density of red blood cells or platelets. To separate white blood cells from red blood cells, it is necessary to destroy the red blood cells with a lysing agent. This also frees the hemoglobin from the blood and the concentration of hemoglobin can also be measured. After separating the hemoglobin, once again measurements are made. By which the concentration of white blood cells can be measured.

7.3 ELECTRON MICROSCOPE

Any microscope has two functions (1) to magnify the object, under observation (i.e. to make it look bigger) and (2) to resolve the object (i.e. to make very close portions look much separated).

Magnification is achieved by increasing the number of lenses used. To increase the resolving power is not so easy since if two objects are closer than one third of the wavelength of light used, they are not resolved. The resolving power of the microscope is inversely proportional to the wavelength of the light used (Refer Problem No. 1).

Since the wavelength of visible light is around 6000 A.U., optical microscopes cannot resolve objects closer than 2000 A.U. But electron waves are of much smaller wavelength (1 to 30 A.U.).

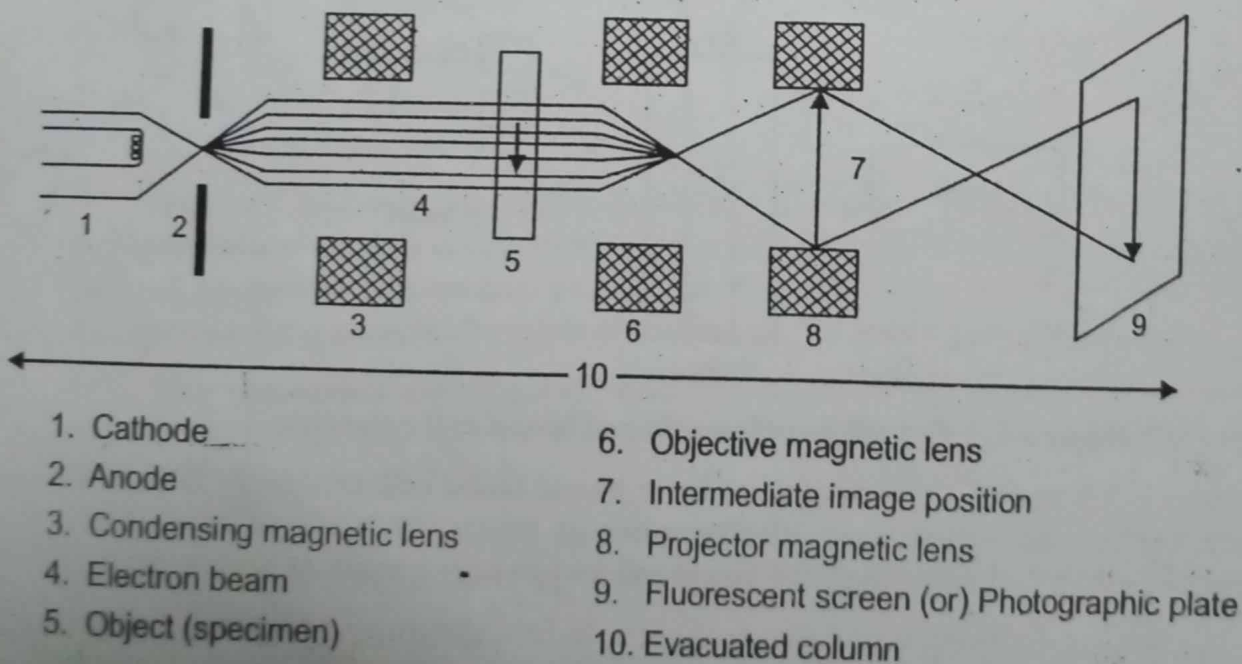


Figure 7.4: Electron microscope (transmission type)

CHAPTER IX

SAFETY INSTRUMENTATION

9.1 INTRODUCTION

The number of medical equipment in a modern community hospital is increasing day by day. In order to avoid electrical shock, excessive radiation, toxic exposure, fire, explosion and other hazards, many of the devices should be desired and handled with extreme care.

Dangerous accidents can be kept to a minimum if hospital physicians, health care workers, biomedical engineers and other staff are properly trained to exercise caution and if regulations and procedures are strictly adhered to. Radiation safety and hazards associated with the use of radioisotopes are very important problems for biomedical physicists. Electrical Safety and patient shock hazards associated with the use of biomedical electronic equipment have become important problems for bio-medical engineers.

9.2 RADIATION SAFETY INSTRUMENTATION

Today X-rays and radioisotopes are the powerful diagnostic and therapeutic tools. It is known that these agents for good become agents for evil if they are misused or used without adequate knowledge of their properties. The charged particles like α , β , protons and electrons from radiation produce ionization directly through coulomb interaction with atomic electrons.

The uncharged particles like X-rays and γ -rays from radiation produce ionization through knocking of electrons from the medium. The neutrons produce nuclear reactions at all energies and through that they produce biological damages. One of the side effects of X-radiation or nuclear medicine is the dose absorbed by the patient and those handling the X-ray machinery and nuclear medicines. It is very useful if one knows about the units of ionizing radiation.

One **Curie** is the unit of (radio) activity and is defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.7×10^{10} . The rate of decay of 1 gram of radium gives 1 curie activity. In cancer therapy, the intensity of the radioactivity applied is in terms of millicurie and microcurie.

One **Roentgen** is the unit of exposure of ionizing radiation and is defined as the quantity of gamma or X-rays required to produce 1.61×10^{12} pairs of ions in 1 gram of dry air at standard conditions of temperature (0°C) and pressure (760 mm Hg). Thus 1 Roentgen (R) = $1.61 \times 10^{12} \times 1.602 \times 10^{-19} \times 1000 = 2.58 \times 10^{-4} \text{C/kg}$ in S.I. units. That is, it is the amount of radiation exposure which produces 2.58×10^{-4} coulombs of charge by ionization in one kilogram of dry air at standard temperature and pressure.

One **rad** (acronym for radiation absorbed dose) is the unit of absorbed dose of ionizing radiation and is defined as the absorption of 1000 ergs of radiation energy per gram of absorbing material. Thus in S.I. units,

$$1 \text{ rad} = \frac{100 \times 10^{-7}}{10^{-3}} \text{ J/kg} = 0.01 \text{ J/kg}$$

That is 1 rad is the absorbed dose of 0.01 Joules of radiation energy per kilogram of absorbing material.

One **rem** (acronym for roentgen equivalent man) is the unit of dose of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X-rays.

9.2.1 Effects of radiation exposure

In the case of human body, the damage caused by nuclear or ionizing radiation depends on the dose and the rate at which it is being absorbed. It also depends on the part of the body which is exposed to the radiation.

Figure 9.1 shows the variation of the absorbed dose by the body tissues (bone and muscle) at different radiation photon energies for a given exposure. When the radiation photon energy is lying between 20 and 40 keV, bone absorbs maximum energy for a given exposure. But the muscle shows constant amount of absorption irrespective of the radiation photon energies.

The damages caused to the cells are pathological and genetical. The effects of ionizing radiation on human beings with respect to different amount of dose are given below.

| <i>Radiation dose (rem)</i> | <i>Effects of ionizing radiation on human beings</i> |
|----------------------------------|---|
| 0.03 | Average dose from chest X-rays |
| 5 | Annual exposure limit for the persons who are handling nuclear medicines and X-rays |
| 10 | Leukemia and cancer |
| 10 - 25 | Changes in blood cells |
| 100 - 200 | Vomiting within three hours at about 125 R and hair loss within 5 to 10 days |
| 225 | Death within 60 days for 5% of those exposed |
| 400 | Death within 60 days for 50% of those exposed |
| 500 - 600 | Death within 60 days for 90% of those exposed |
| > 1000 (in a single exposure) | Vomiting and death within 3 hours |

The annual safe exposure limit may decrease year to year in the case of medical attendants, who are handling sources of ionizing radiation. For persons who are handling nuclear medicines, the following precautions are to be taken against radiation hazards:

- i) Radioactive materials are kept in thick walled lead containers so that radiation cannot penetrate them.
- ii) Lead aprons and lead gloves are worn.
- iii) All radioactive samples are handled by a special remote control process using robots.

Any amount of the radiation whether it is below or above permissible level, it always produces biological damage.

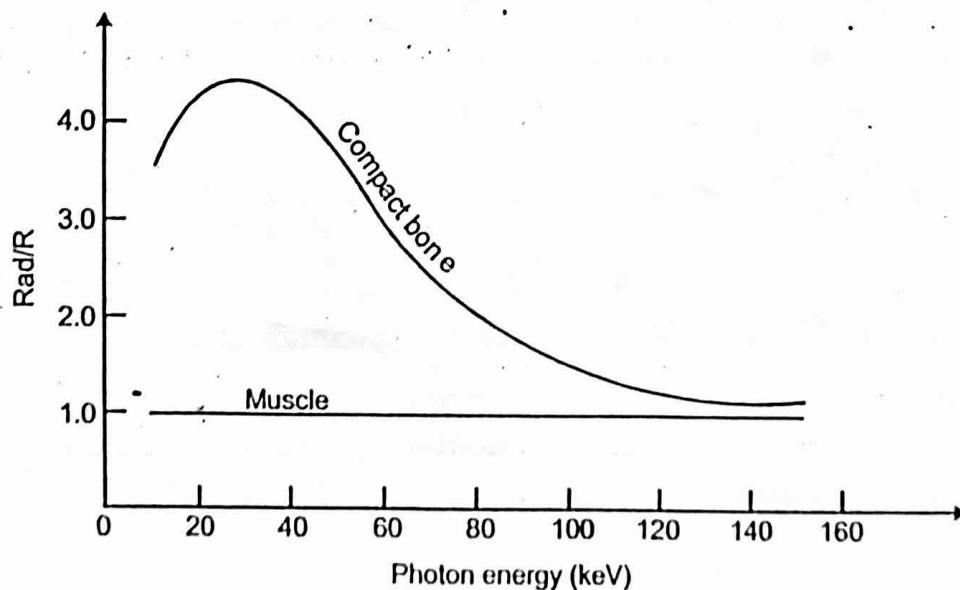


Figure 9.1: Relationship of the absorbed dose to given exposure in bone and muscle over the radiation energy range

The aim of **radiation protection** is the prevention of detrimental non-stochastic effect and limitation of the probability of stochastic effects to acceptable levels. The International Commission on Radiological Protection (ICRP) is looked upon as the appropriate body for giving general guidance on the widespread use of ionizing radiation sources. The **maximum permissible dose** for an individual is that dose, accumulated over a long period of time or resulting from a single exposure, having a negligible probability of severe somatic or genetic injuries and a minor nature. The maximum permissible dose is given by dose equivalent limits. The dose limits for occupational workers with respect to genetic effects are as follows:

Non stochastic effects (Production of cataract, shortening of life span and infertility)

| | |
|--------------|---------------|
| Eye lens | : 15 rem/year |
| Other organs | : 50 rem/year |

Stochastic effects (Production of carcinogenesis, leukemia and hereditary effects).

Uniform whole body irradiation: 5 rem/year

The dose equivalent limits for members of the public are a factor of ten below those for radiation workers.

9.2.2 Radiation monitoring instruments

With the growing use of ionizing radiations, considerable amount of attention has been given the 'safe' radiation exposure of wide-cross section of population. In particular, personnel working with radiation installations require continuous monitoring of the dose received and recording of the cumulative dose throughout the individual's life time. This is more commonly known as 'personnel monitoring'.

1) Pocket dosimeters

Pocket dosimeters are of fountain pen size and can conveniently be kept in the pocket. Basically, the dosimeter is an ionisation chamber which is charged to a suitable voltage obtained from a separate charger (150-200 V) (Figure 9.2).

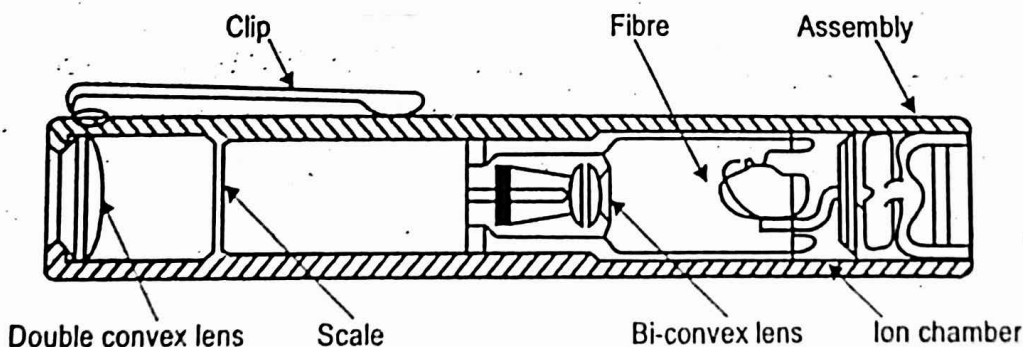


Figure 9.2: Cross-Sectional view of a typical Quartz-Fibre pocket dosimeter

In self-reading type pocket dosimeter, the chamber is coupled to a built-in electrometer (quartz-fibre electrometer) and a microscope to view the electrometer having a reticle calibrated in terms of Roentgen. In non-self reading type dosimeter, the measurements are made with a reading device which has a built-in charger.

The dosimeter is initially charged so that the deflection of the quartz fibre is at zero on the scale when viewed in the charger or in charger-reader. The dosimeter is then ready for use. After use, the self-reading type is viewed against light and the non-self reading type is fitted back to the charger-reader and viewed for the dose measurement.

ii) Pocket type radiation alarm

Radiation alarm is used extensively by radiation workers carrying out job in and around radiation installations. The instrument gives a visual as well as an aural signal to alert the personnel about the exposure rate while carrying out the work. Radiation on GM counter produces an avalanche current and charges the capacitor to a voltage at which the neon lamp fires and gives a signal to the audio stage (Figure 9.3). Preset radiation levels can be adjusted. The GM counter used in this type of instrument is generally having long plateau, less working voltage, good linearity between pulses/second and R/hr and flat response over a long energy spectrum.

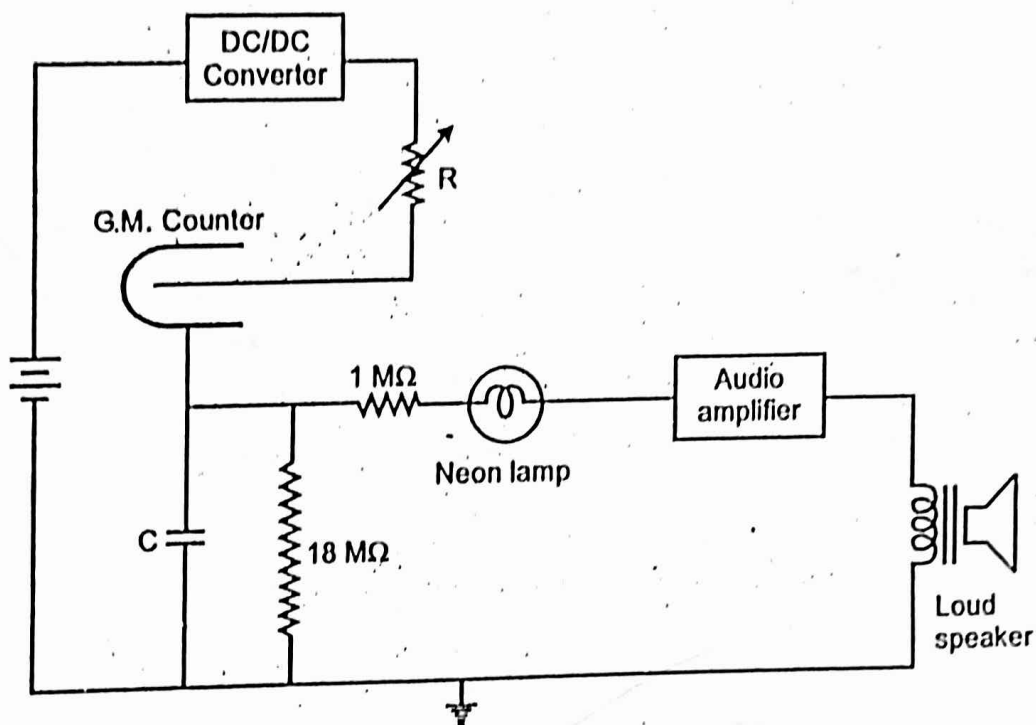


Figure 9.3: A typical radiation alarm

i) Film dosimeter

Film dosimeters are extensively used for cumulative dose measurement in routine personnel monitoring. The film badge is a simple plastic (with stainless steel lining) holder made to hold a conventional dental film with a number of suitable filters (viz. plastic, copper 1, copper 2, lead, cadmium etc.) and an open window. The filters are selected to make the sensitivity of the film independent of radiation energies. The paper wrapped film (e.g. Eastman Kodak type II - double coated emulsion) is placed inside the badge. The radiations passing through the filter cause formation of latent image in the film which after due processing forms