Madenat Alelem University College

Medical physics dept.

Third stage

Medical instruments

lecture 1

Medical instrumentation

- In the last several years, there has been a tremendous progress in the field of electronics. Electronics has pervaded all fields of engineering and instrumentation. Manually operated instruments, mechanical instruments are all being replaced by electronic instruments.

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In the field of medicine we now find electronic blood pressure measuring instruments, blood glucose monitors and a wide types of hospital equipment. That It is imperative to learn the working and design of biomedical instrumentation systems. it is also imperative to have knowledge of the human body, its anatomy and physiology.

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Biomedical instrumentation deals with the measurement and analysis of current or voltage signals from different parts of the body. The human body is like a power station which generates a variety of voltages. However, these voltages are extremely small.

In most of the biomedical instrumentation systems, currents between two points on the surface of the body, these currents are very small, of the order of μA and therefore amplified by amplifiers.

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After amplification, the signal is processed noise is filtered, bandwidth is restricted and then it is displayed either on cathode-ray tube (CRT), strip chart recorder, camera or a magnetic tape.

An example; a continuous signal is the Electrocardiogram (ECG) signal obtained due to the electrical activity of the heart.

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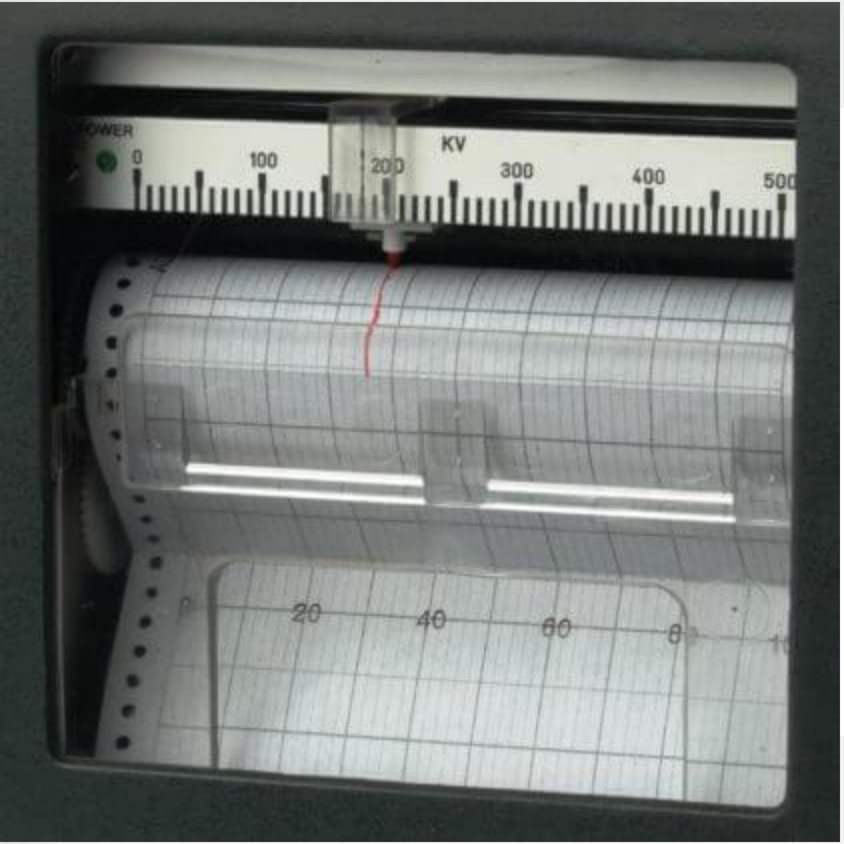
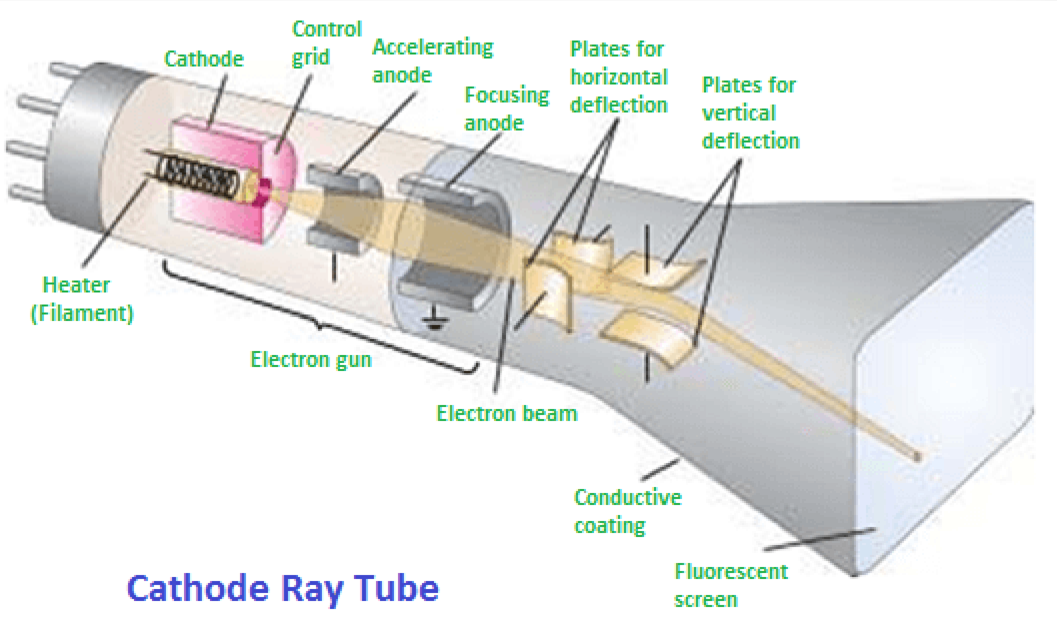


KV
0
100
200
300
400
20
40
60



Cathode
Control grid
Accelerating anode
Focusing anode
Plates for horizontal deflection
Plates for vertical deflection
Heater (Filament)
Electron gun
Electron beam
Conductive coating
Fluorescent screen
Cathode Ray Tube

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some cases, an external stimulus is given to the patient and the response to the stimulus, which is a voltage signal, is recorded. Sometimes a transducers are required to obtain an electrical signals.

Many physiological processes in the body are accompanied with electrical changes. Signals are produced in the body by muscles and nerves.

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Specification of medical instrumentation systems

❑ Range

The range of an instrument is generally considered to include all the levels of input amplitude & frequency over which the device is expected to operate.

❑ Sensitivity

The sensitivity of an instrument determines how small a variation of a variable or parameter can be really reliably measured.

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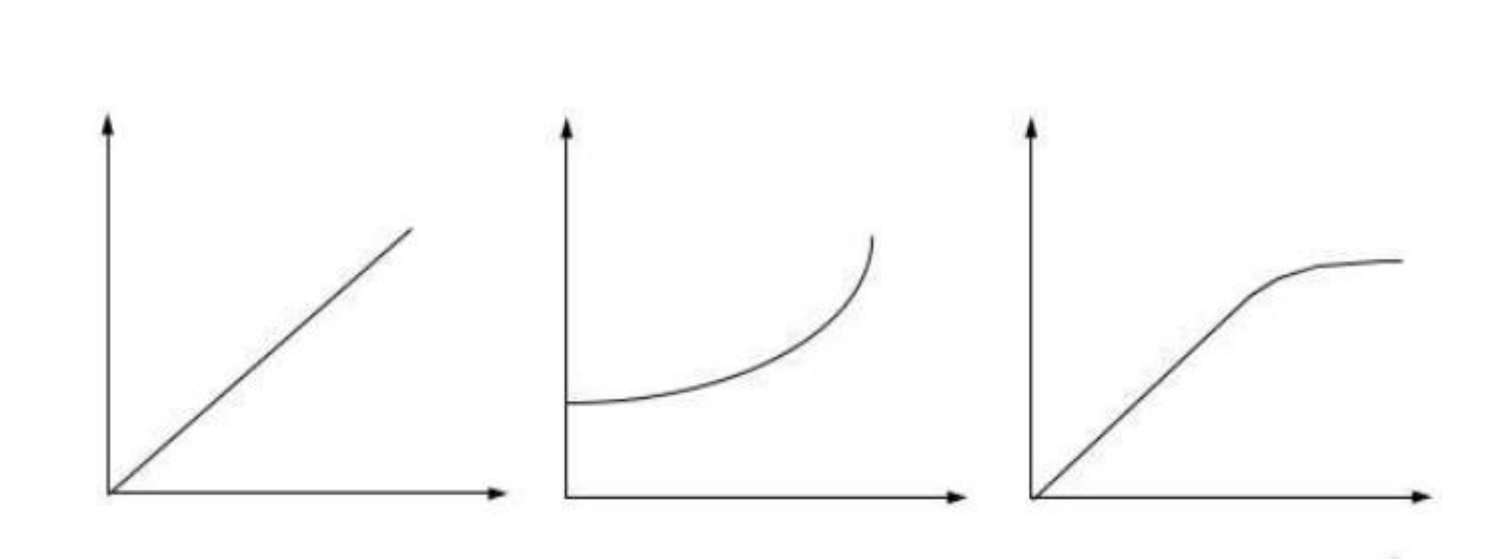
❑ LINEARITY

The degree to which variation in the output of an instrument follow input variation.



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❑ HYSTERESIS

It is a characteristic of some instruments where by a given value of the measured variable results in a different reading when reached in an ascending direction from that obtained when it is reached in a descending direction.

When the input of an instrument is varied from zero to its full scale and then if the input is decreased from its full scale value to zero, the output varies.

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❑ACCURACY

It is the degree of closeness with which an instrument reading approaches the true value of the quantity that measured, It is a measure of systemic error. Errors can occur in different ways, Although they are not always present together.

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❑ Signal to Noise ratio

Signal-to-noise ratio (SNR or S/N) is a measure used to compare the level of a desired signal to the level of background noise. Its often expressed in decibels and its important that the SNR be as high as possible.

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- **Isolation**

Electrical Isolation is to be made for avoiding interference between different instruments using together.

- **Simplicity**

All systems & instruments should be as simple as possible to eliminate the chance of component or human error.

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❑ Stability

The ability of an instrument to keep its performance throughout its specified storage life and operating life is called as Stability.

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Medical physics dept.

Third stage

Medical instruments

lecture 2

Components of the Man–Instrumentation system

The basic components of the system are given below:

1. The subject
2. Stimulus
3. The transducer
4. Signal conditioning equipment
5. Display equipment
6. Recording, data processing and transmission equipment
7. Control devices

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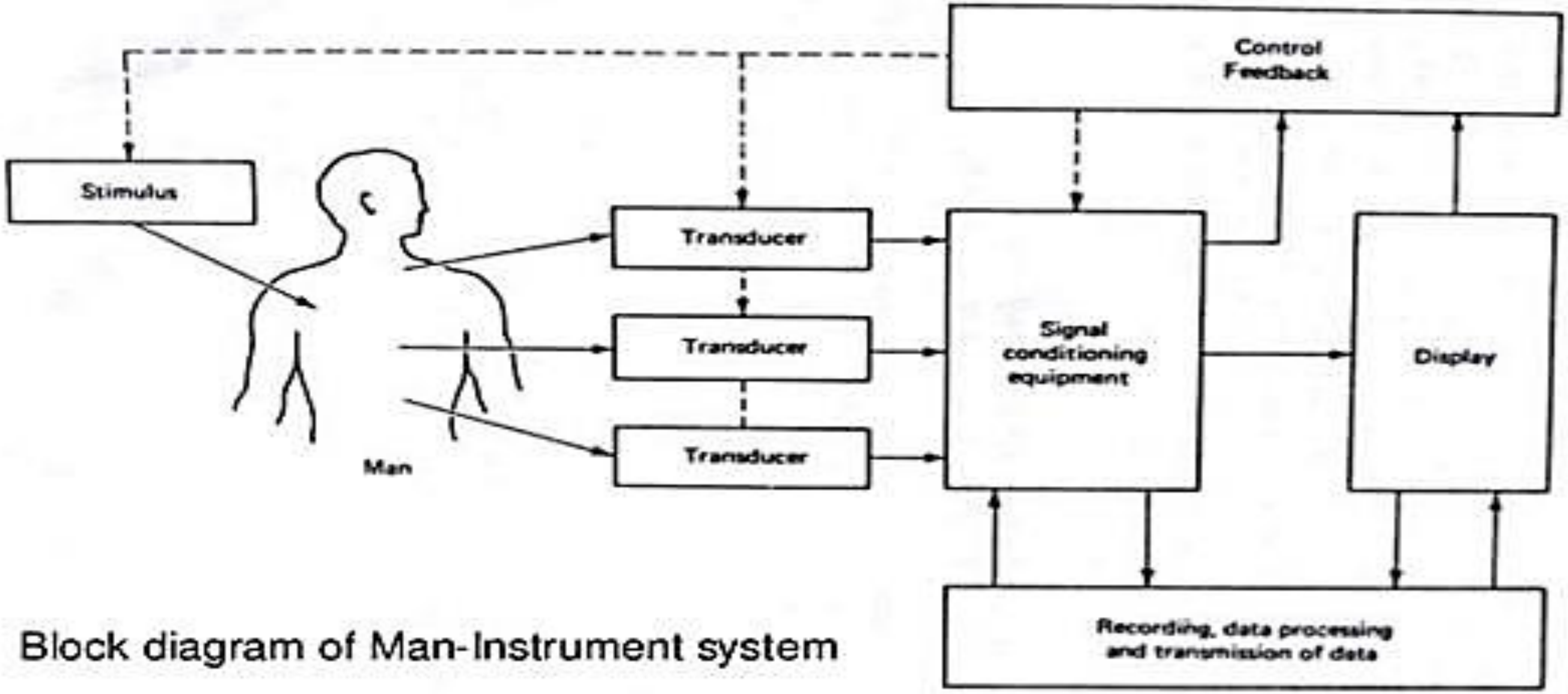
Components of the Man - Instrument System



Block diagram of Man-Instrument system

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- The subject

Is the human being on whom the measurements are made

- Stimulus

In many measurements, the response to some form of external stimulus is required, the stimulus may be visual (flash or light), auditory (tone), tactile (blow to the achilles tendon) or direct electrical stimulation of some part of the nervous system.

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❑ The transducer

It's a device capable of converting one form of energy or signal to another. In the man – instrument system, each transducer is used to produce an electric signal that is analog of the phenomenon being measured.

The transducer may measure temperature, pressure or any other variables that can be found in the body, but its output is always electric signal.

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❑ Signal conditioning equipment

Is the part of the system that amplifies, modifies or in any other way changes the electric output of the transducer, the purpose of this part is to process the signals from the transducers in order to satisfy the functions of the system and to prepare signals suitable for operating the display or recording equipment that follows.

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❑ Display equipment

The electrical output of the signal-conditioning equipment must be converted into a form that can be detected by one of man’s senses. The input to the display device is the modified electric signal from the signal-conditioning equipment, its output is some form of visual or audible information.

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❑ Recording, data processing and transmission equipment

Its often necessary or at least desirable, to record the measured information for possible later use or to transmit it from one location to another, whether across the hall of the hospital or around the world.

Equipment of these functions required an automatic storage or processing of data or where computer control is employed.

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❑ Control devices

A control system is incorporated when its necessary or desirable to have automatic control of the stimulus, transducers or any other part of the man-instrument system.

This system usually consist of a feedback loop in which part of the output from the signal-conditioning or display equipment is used to control the operation of the system in the same way.

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Bio-Electric signals

Bio - electric signals are those signals which are used primarily for extracting information on a biological system under measurement. the process of extracting information could be very simple or very complex. bio-medical signals originate from a variety of sources such as:

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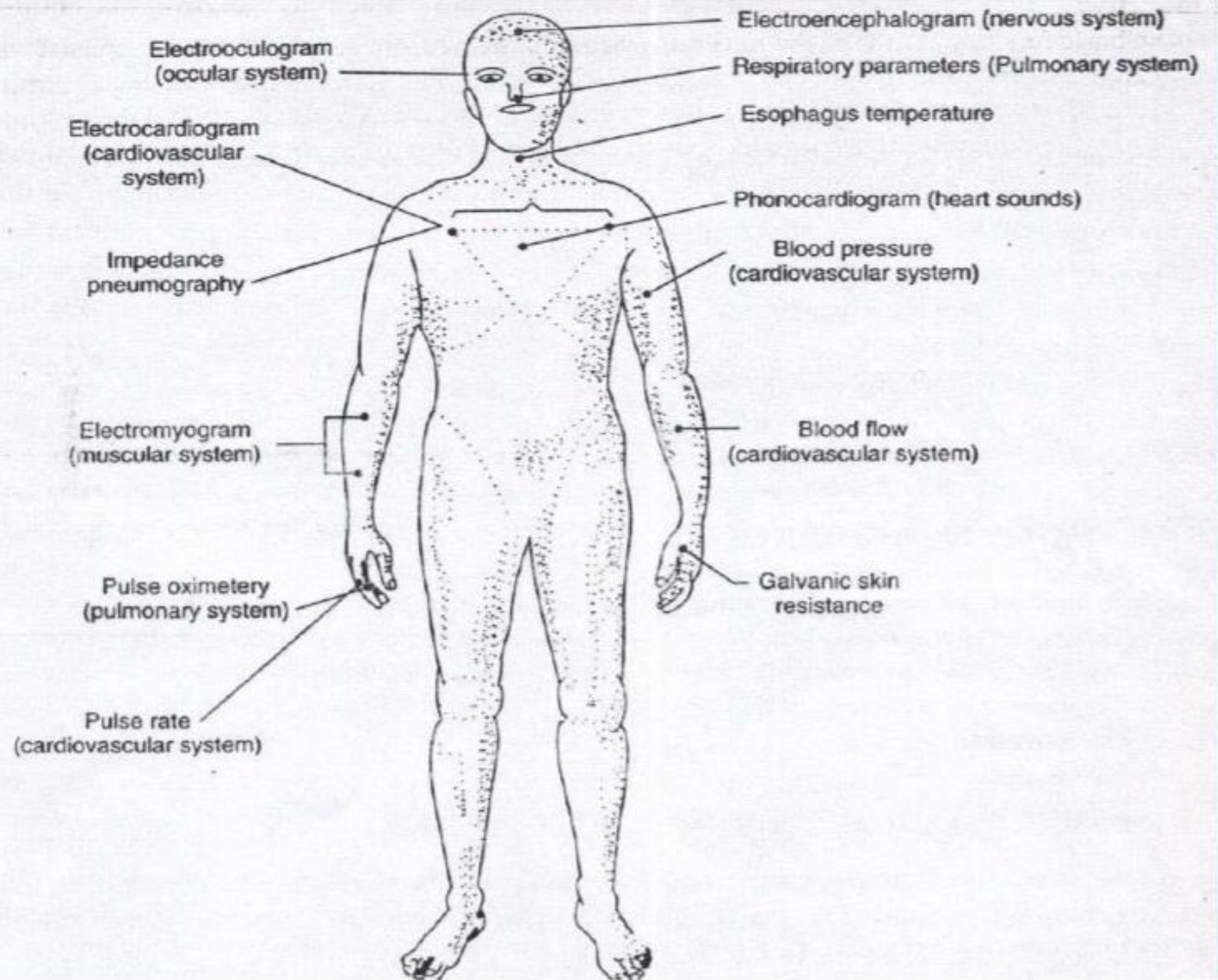
Electroencephalogram (nervous system)
Electrooculogram (occular system)
Respiratory parameters (Pulmonary system)
Esophagus temperature
Electrocardiogram (cardiovascular system)
Phonocardiogram (heart sounds)
Impedance pneumography
Blood pressure (cardiovascular system)
Electromyogram (muscular system)
Blood flow (cardiovascular system)
Galvanic skin resistance
Pulse oximetery (pulmonary system)
Pulse rate (cardiovascular system)

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Sources of bio-electric signals

- Bio-electric potentials are actually ionic voltages produced as a results of the electrochemical activity of cells associated with nerve conduction, brain activity, heartbeat, muscle activity and so on.
- The electric field generated by the action of cells that creates the electric signals.

Resting and action potentials

- The body cells are surrounding by fluids which are ionic and which provide a conductive medium for electric potentials.
- These fluids are conductive solutions containing charged atoms known as ions.
- The principal ions are Sodium(Na^+), Potassium (K^+) and Chloride (Cl^-).

The membrane of excitable cells readily permits-entry of Potassium and Chloride ions but blocks the entry of Sodium ions even though there may be a very high concentration gradient of Sodium across the cell membrane. this results in the concentration of sodium ion more on the outside of the cell membrane than on the inside.

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Since Sodium is a positive ion, in its resting state, a cell has negative charge along the inner surface of its membrane and a positive charge along the outer portion.

The membrane potential is called the **resting potential** of the cell and is maintained until some kind of disturbance upsets the equilibrium.

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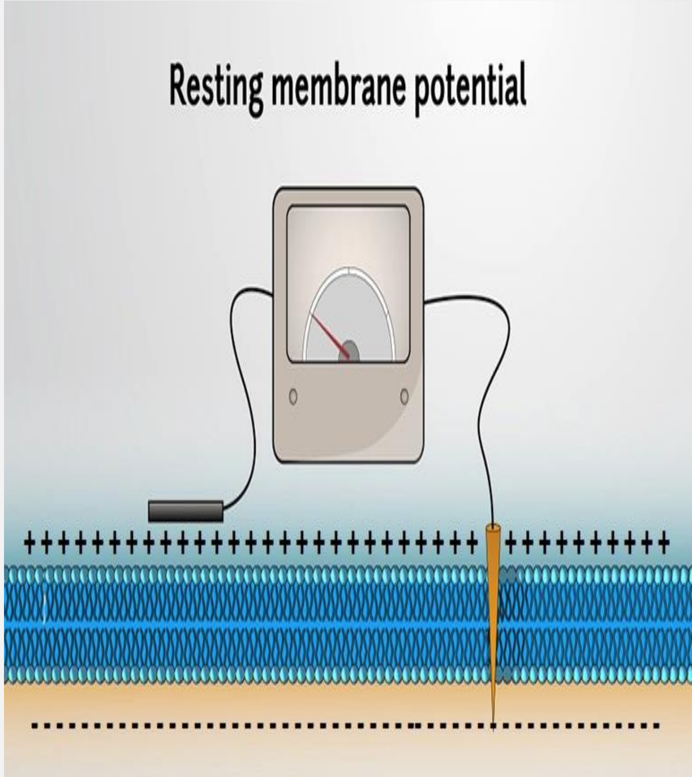
Since measurement of the membrane potential is generally made from inside the cell with respect to the body fluids, the resting potential of a cell is given as negative. Measuring membrane potentials in various cells ranging from - 60 to -100 mV. A cell in the resting state called polarized.



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When a section of the cell membrane is excited by the follow of ionic current or by some form of externally applied energy, the membrane changes its characteristics and begins to allow some of the Sodium ions to enter.

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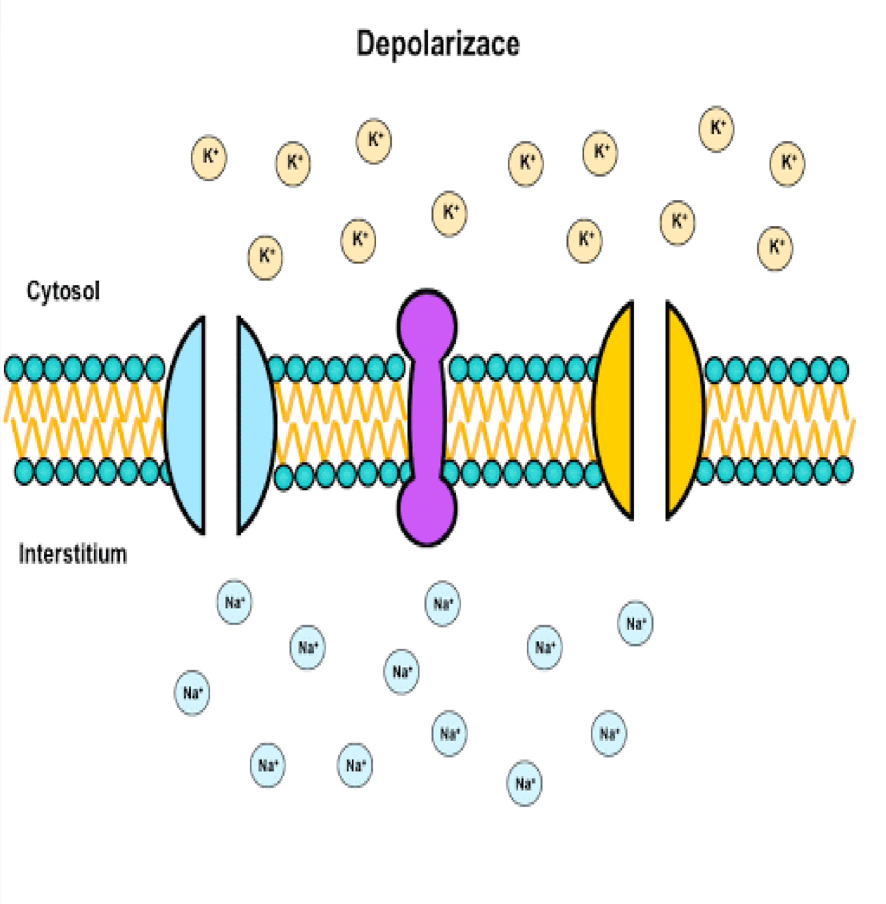
This movement of Sodium ions into the cell creates an ionic current flow, at the same time Potassium ions which were in higher concentration inside the cell during the resting state, try to leave the cell but are unable to move as rapidly as the Sodium ions.



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As a result, the cell has a slightly positive potential on the inside due to the imbalance of potassium ions (**action potential**) ≈+20 mV. And this cell said to be **depolarized**.

The process of changing from the resting state to the action potential is called **depolarization**.

When Sodium ions movement through the cell stopped , a new state of equilibrium is reached.

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The cell membrane reverts back to its original (selectively permeable condition), where in the passage of Sodium from outside to inside the cell is again blocked.

It would take a long time for resting potential to develop again. By an active process called "Sodium pump" the Sodium are quickly transported again from outside to inside the cell and the cell become polarized and assume its rest potential, this process is called "**repolarization**"

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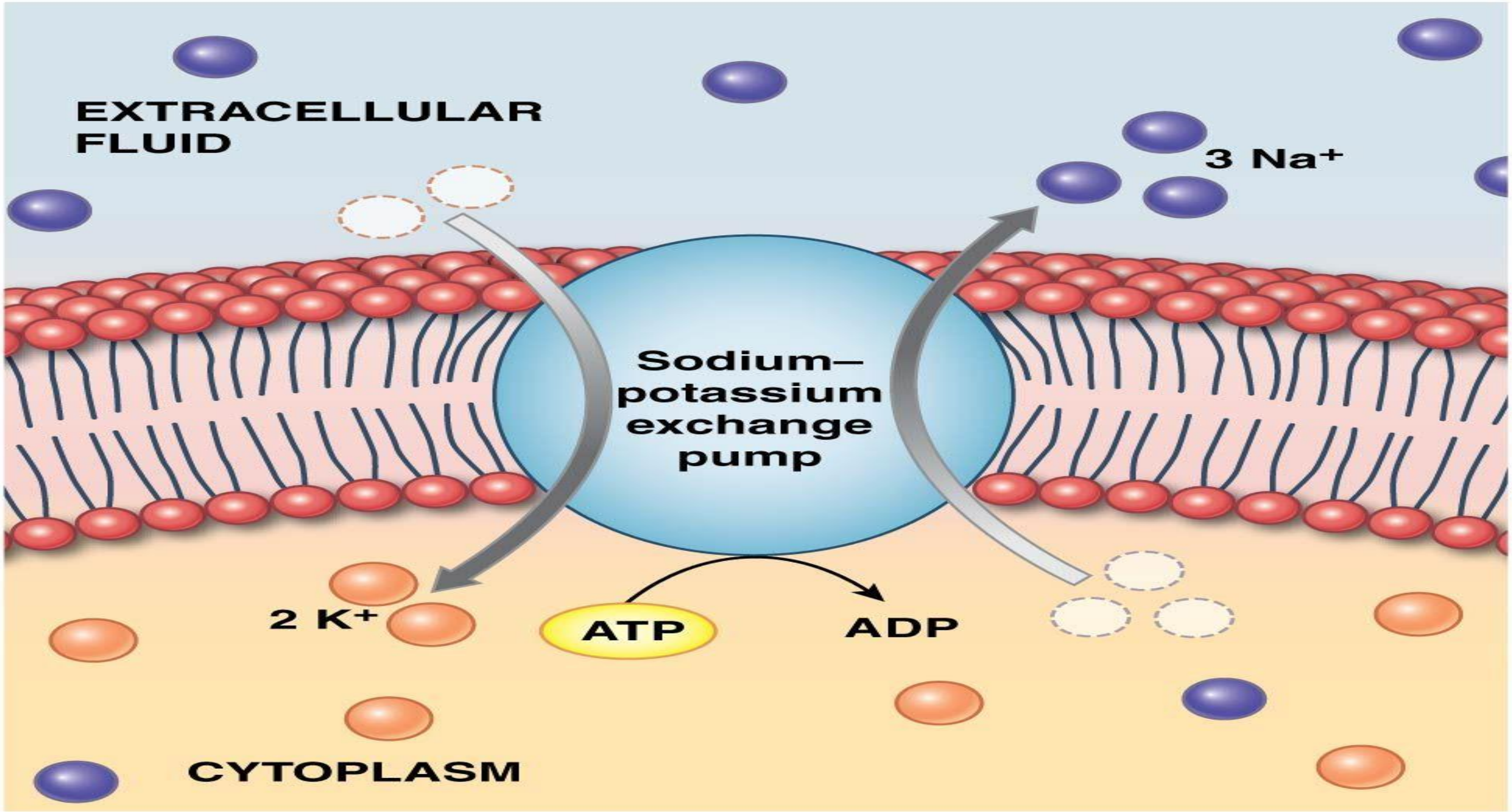

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Third stage

Medical instruments

Dr. Ruaa Almusa

lecture 3

Resting and action potentials

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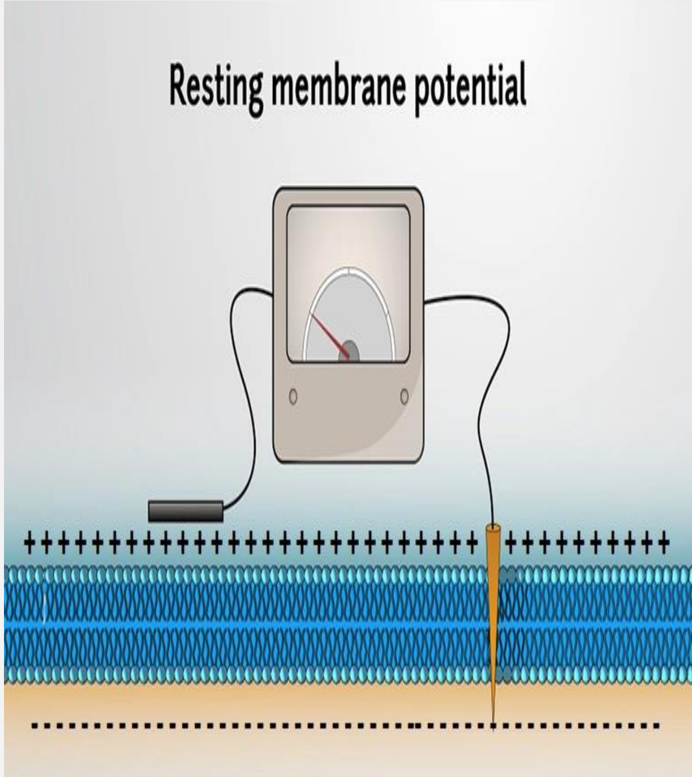

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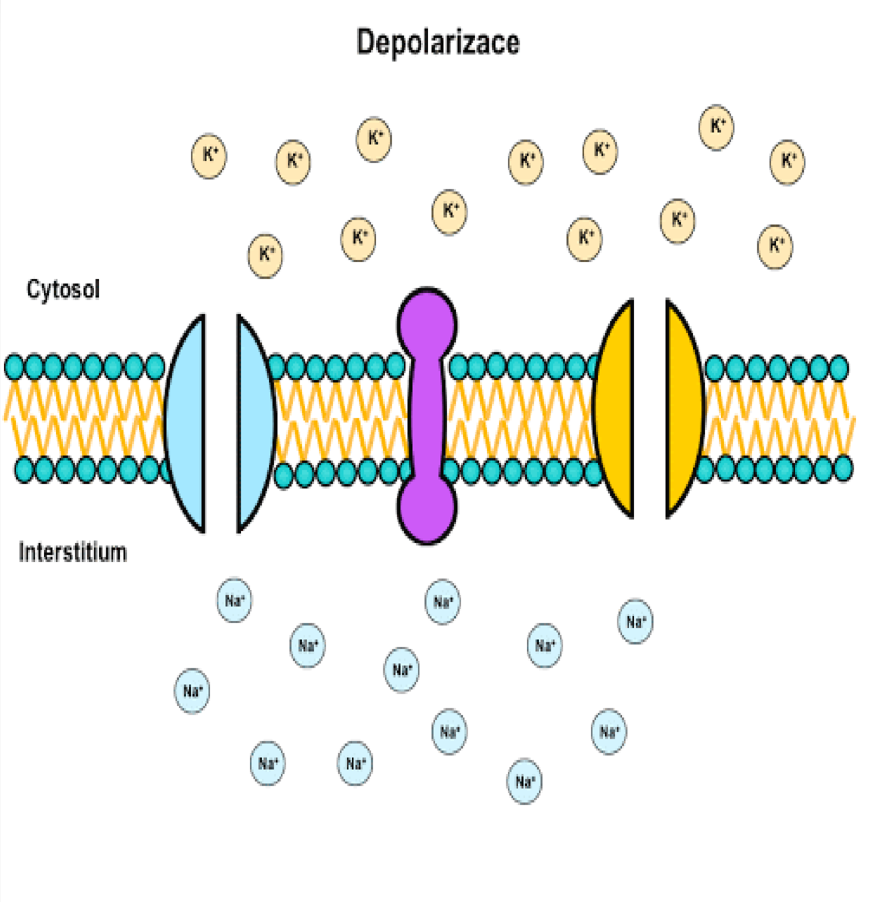

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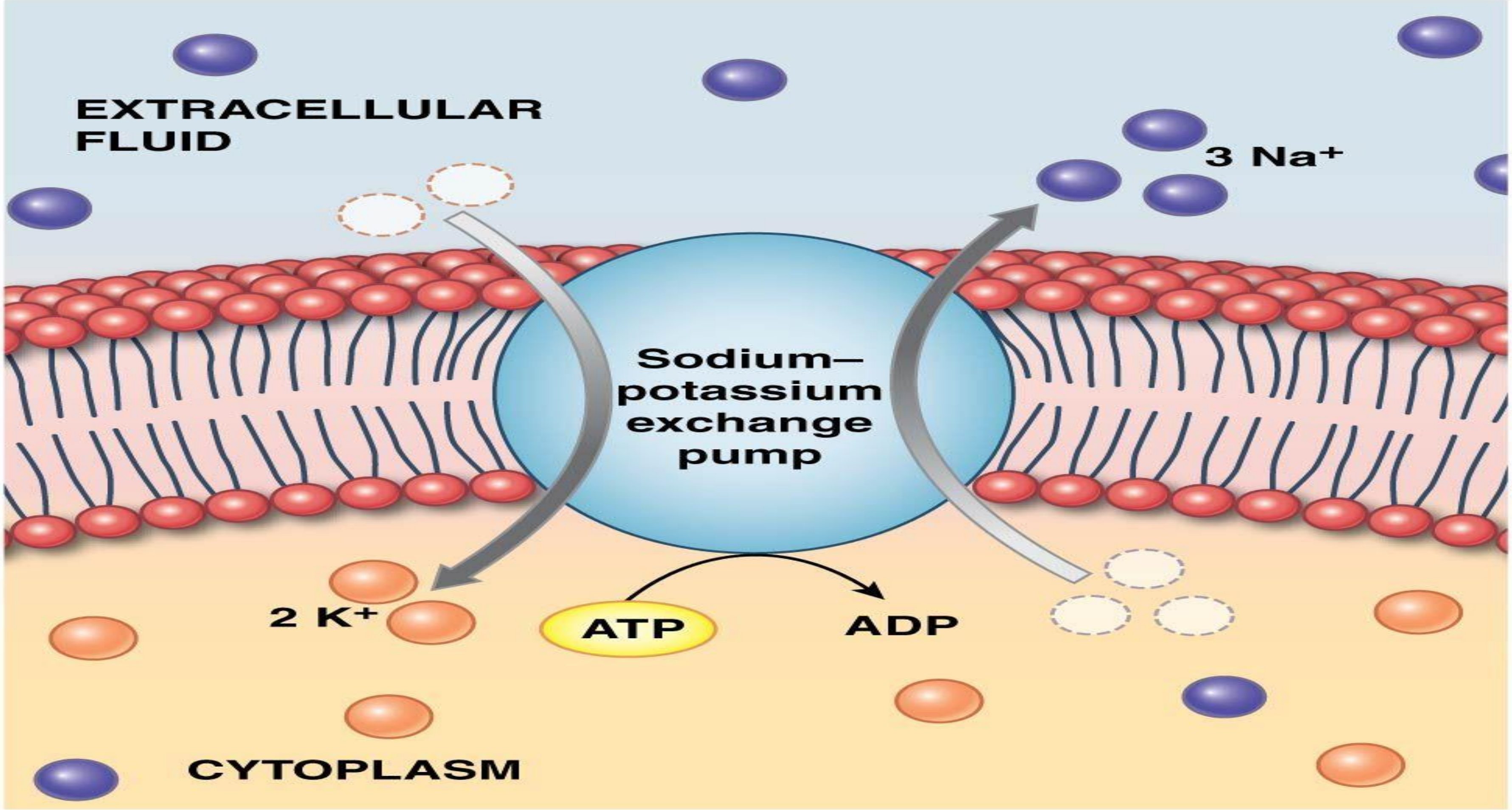

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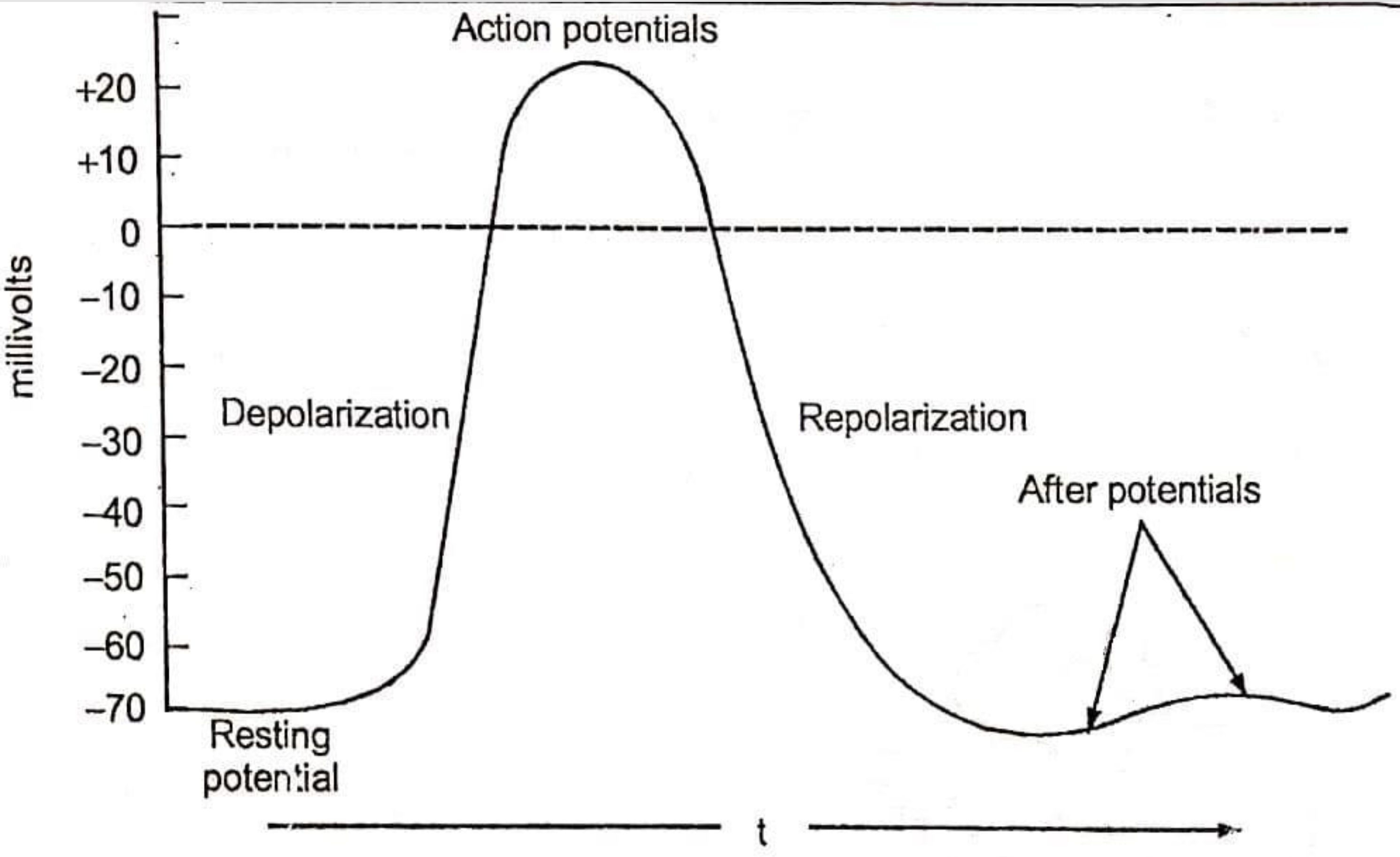

Waveform of the action potential

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The time scale for the action potential depends on the type of cell producing the potential.

- In nerve and muscle cells, repolarization occurs so rapidly following depolarization that the action potential appears as a spike of as little as 1mSec.
- In heart muscle repolarizes much more slowly, it usually lasting from (150 – 300) mSec.

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There is a brief period of time during which the cell can not respond to any new stimulus lasts about 1mSec in nerve cells known as "**absolute refractory period**".

Following this period "**relative refractory period**" in which another action potential can be released, but a much stronger stimulation is required in nerve cells and it lasts several milliseconds.

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Chapter Two
Bio-Potential Electrodes

Electrodes Theory

- Bio potential electrodes conduct current across the interface between the body and the electronic measuring circuit.
- Electrode has a transducing function, because current is carried in the body by ions, whereas it is carried in the electrode and its wire by electrons.
- Electrode serve as a transducer to change an ionic current into an electronic current.

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Third Stage

MEDICAL INSTRUMENTS

Dr. Ruaa Almusa

Lec 4 / Chapter 2

Electrodes Theory

- Bio potential electrodes conduct current across the interface between the body and the electronic measuring circuit.
- Electrode has a transducing function, because current is carried in the body by ions, whereas it is carried in the electrode and its wire by electrons.
- Electrode serve as a transducer to change an ionic current into an electronic current.

- The source of an electrode potential is when the membrane separates liquid solutions with different concentrations of the ions. an equation relating the actual potential across the membrane and the two concentrations of the ion is called the **Nerst equation:**

Concentration outside cell mole/cm^3

$$E\ (mV) = \pm 61\ \mathrm{Log}\left(\frac{C_o}{C_i}\right)$$

The resting potential millivolt

Concentration inside cell mole/cm^3

Example: the intracellular K^+ concentration of a group of cells averages 160 x 10^{-6} moles/ cm^3, the extracellular concentration of K^+ averages 6.5 x 10^{-6} moles/ cm^3 calculate:

1. The concentration ratio
2. Diffusion potential for K^+

Solution:

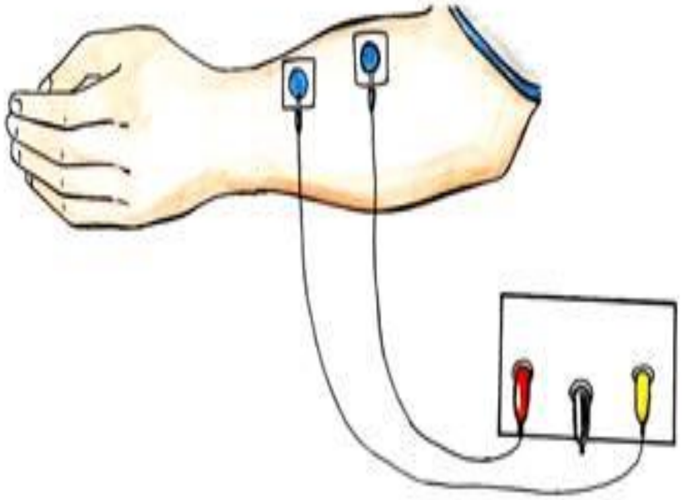
1. $$\frac{C_o}{C_i} = \frac{6.5\ x\ 10^{-6}}{160\ x\ 10^{-6}} = 0.0406$$

2. $$E_{K^+}(\mathrm{mV}) = -\ 61\ \mathrm{Log}\ (0.0406)$$
$$= -\ 84.86\ \mathrm{mV}$$

Electrodes classification according to position

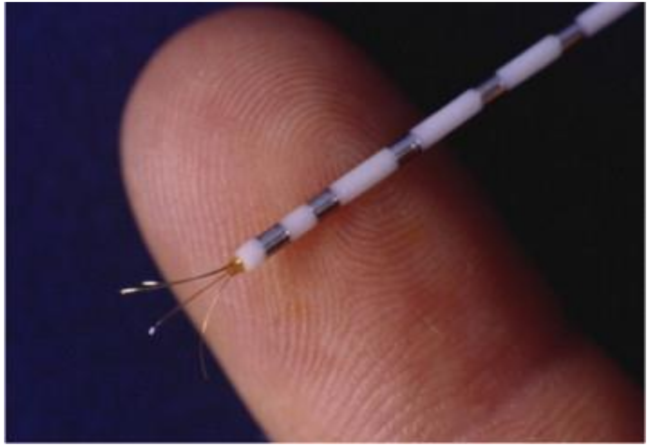
1) **Surface electrodes**

They pick up the signal from tissue surface without damaging it, its used in ECG, EEG and EMG, they have impedance (2-10) kΩ.



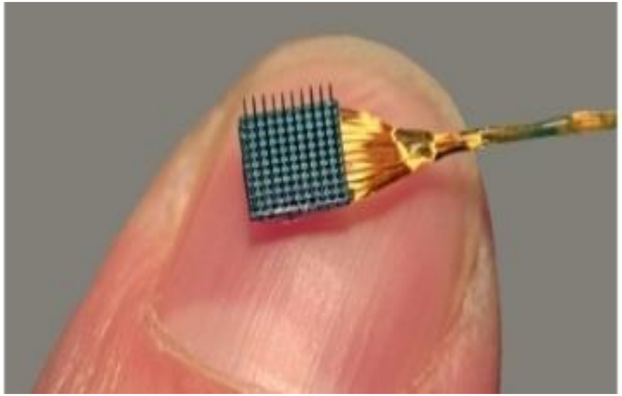
2) Deep electrodes

They called also "needle electrodes". These are inserted inside a live tissue or cells, they have higher impedance as compared with surface electrodes.



3) Microelectrodes

They measure potentials near or within a single cell their impedance is very high.



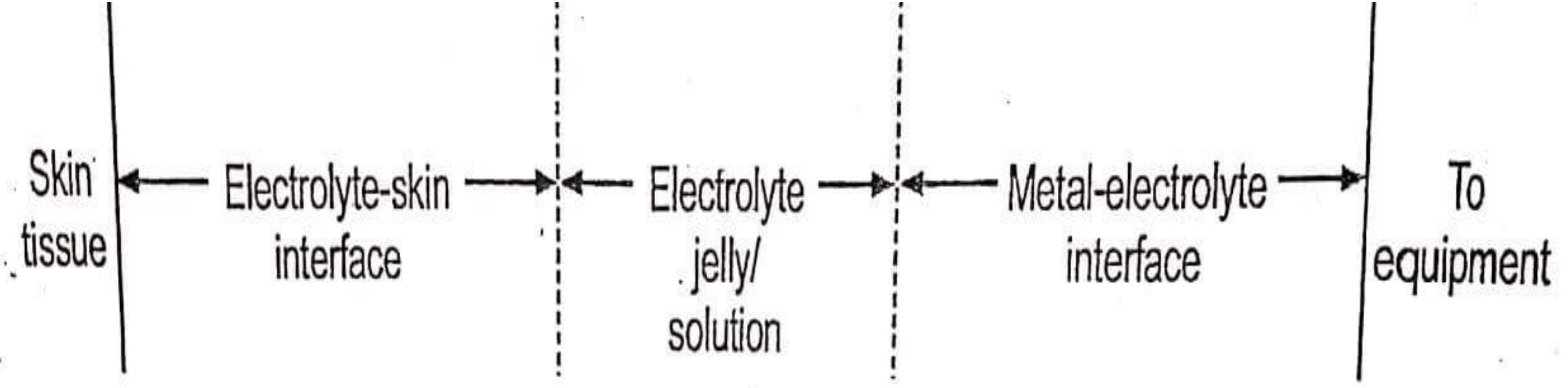
- ✓ When a measurement is made outside the body (using surface electrodes) is called “ **Vitro measurement**”.
- ✓ When a measurement is made by inserting needle electrode inside tissue is called “ **Vivo measurement**”.
- ✓ The electrodes movement cause a noise signals called “**artifact**”, to avoid artifact an electrolyte or jelly is applied to the area under electrodes contact after area cleaning.

Properties of Bio-electrodes

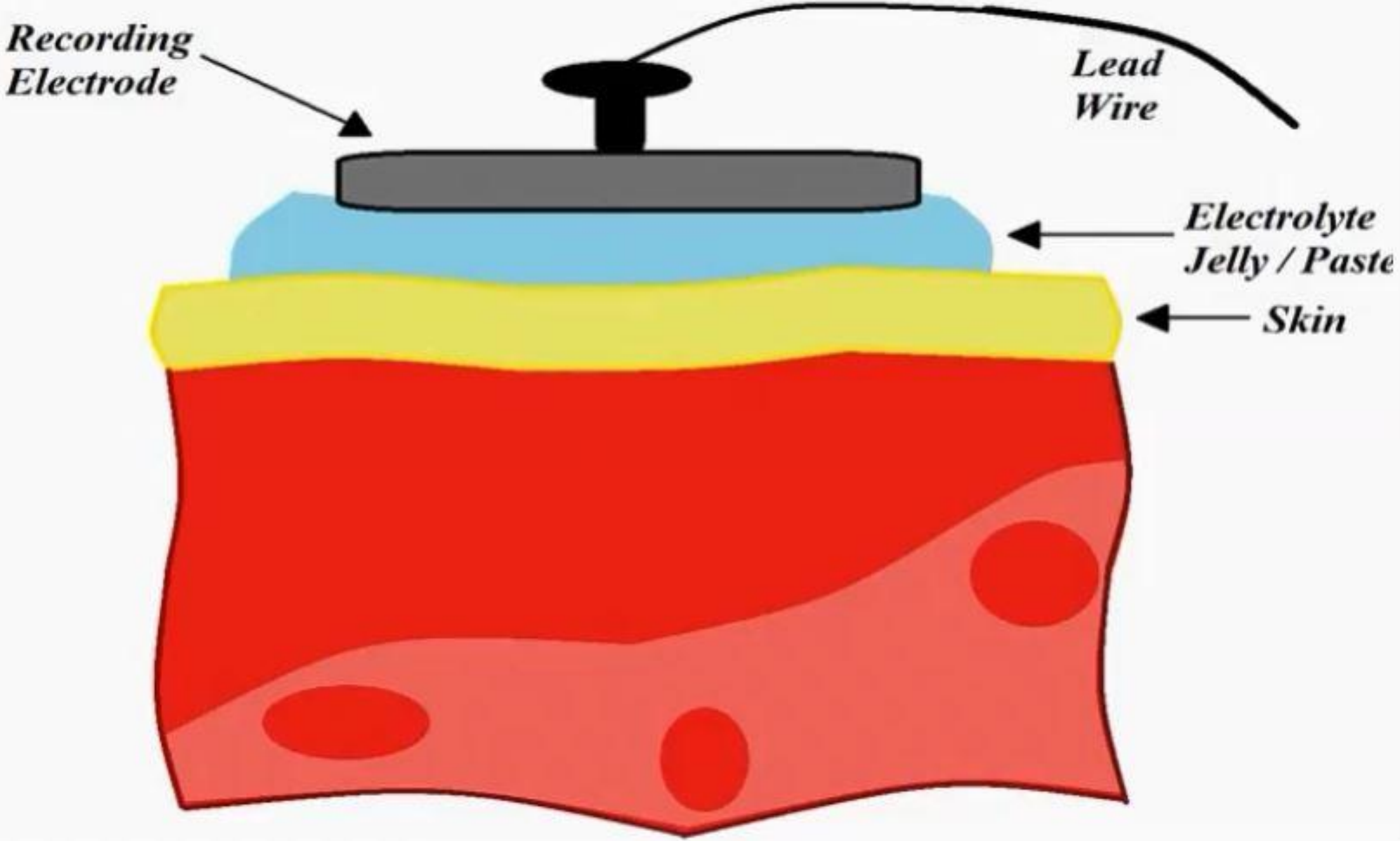
1) They should be good conductors
2) They should have low impedance
3) They should potentials generated at metal-electrolyte (jelly) surface should be low.
4) The metal should not cause itching, swelling or discomfort to the patient.
5) The metal soul not be toxic.
6) They should be chemically inert.
7) They should be mechanically rugged.
8) They should be easy to clean.

The need of ELECTRODE paste or electrolyte

1. Avoid movement artifacts.
2. Establish contact between metal electrode and tissue.
3. Help to reduce skin contact impedance (where skin impedance for 1cm^2 (200 kΩ at 1 Hz and 200 Ω at 1 MHz).



Electrode-tissue interface for surface electrodes used with electrode jelly


Recording
Electrode
Lead
Wire
Electrolyte
Jelly / Paste
Skin

METAL ELECTROLYTE INTERFACE

- The **potential difference** at the metal-electrolyte interface is generated due to process of "**diffusion**".
- **Diffusion** is a process in which electrodes discharged ions into the electrolyte solution. the ions in the electrolyte are **combine** with electrodes ions. this results a creation of difference of potential at each electrode, which forms the **electrical double layer**.

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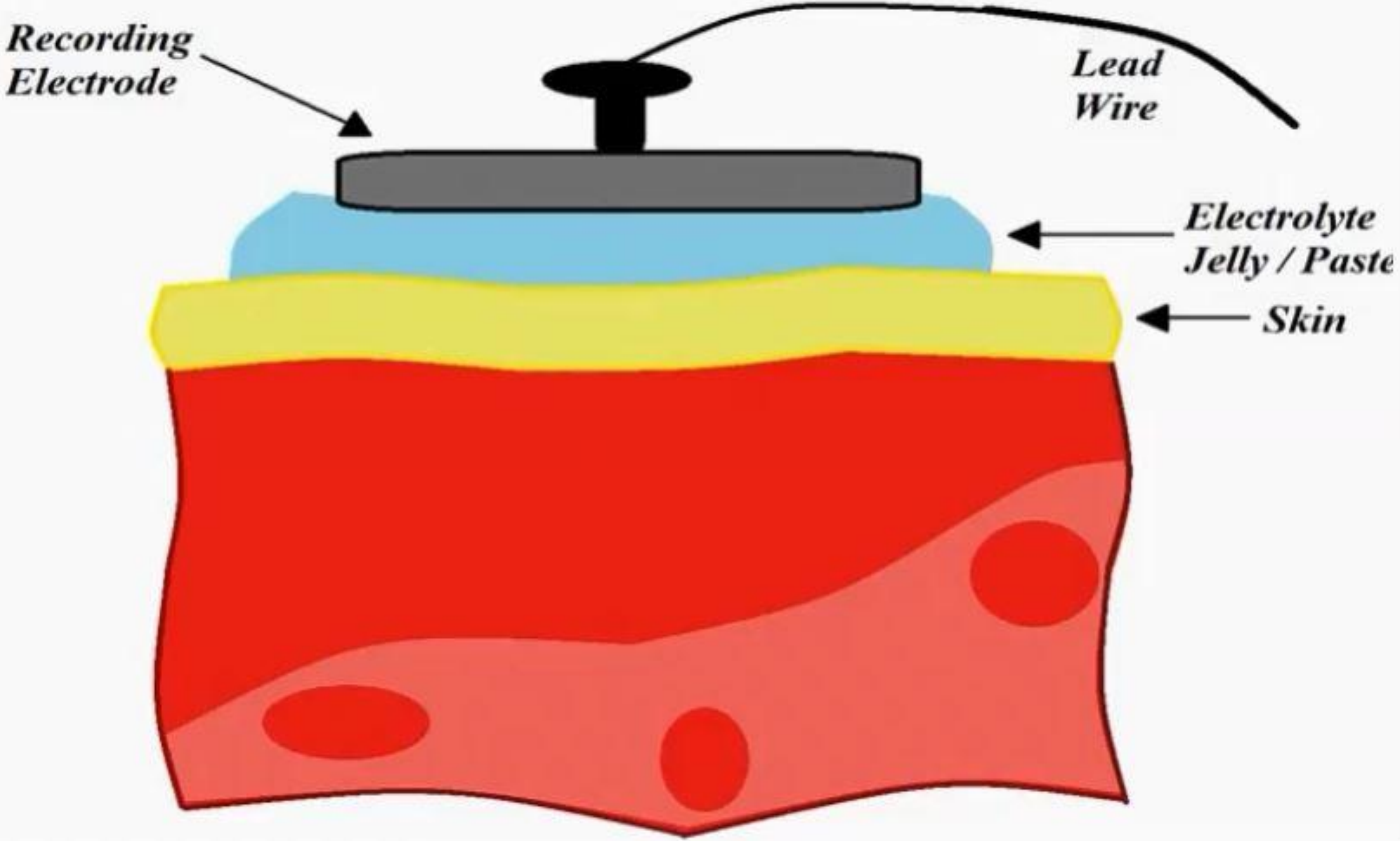
Third Stage

MEDICAL INSTRUMENTS

Dr. Ruaa Almusa

Lec 5 / Chapter 2


Recording
Electrode
Lead
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Metal electrolyte interface

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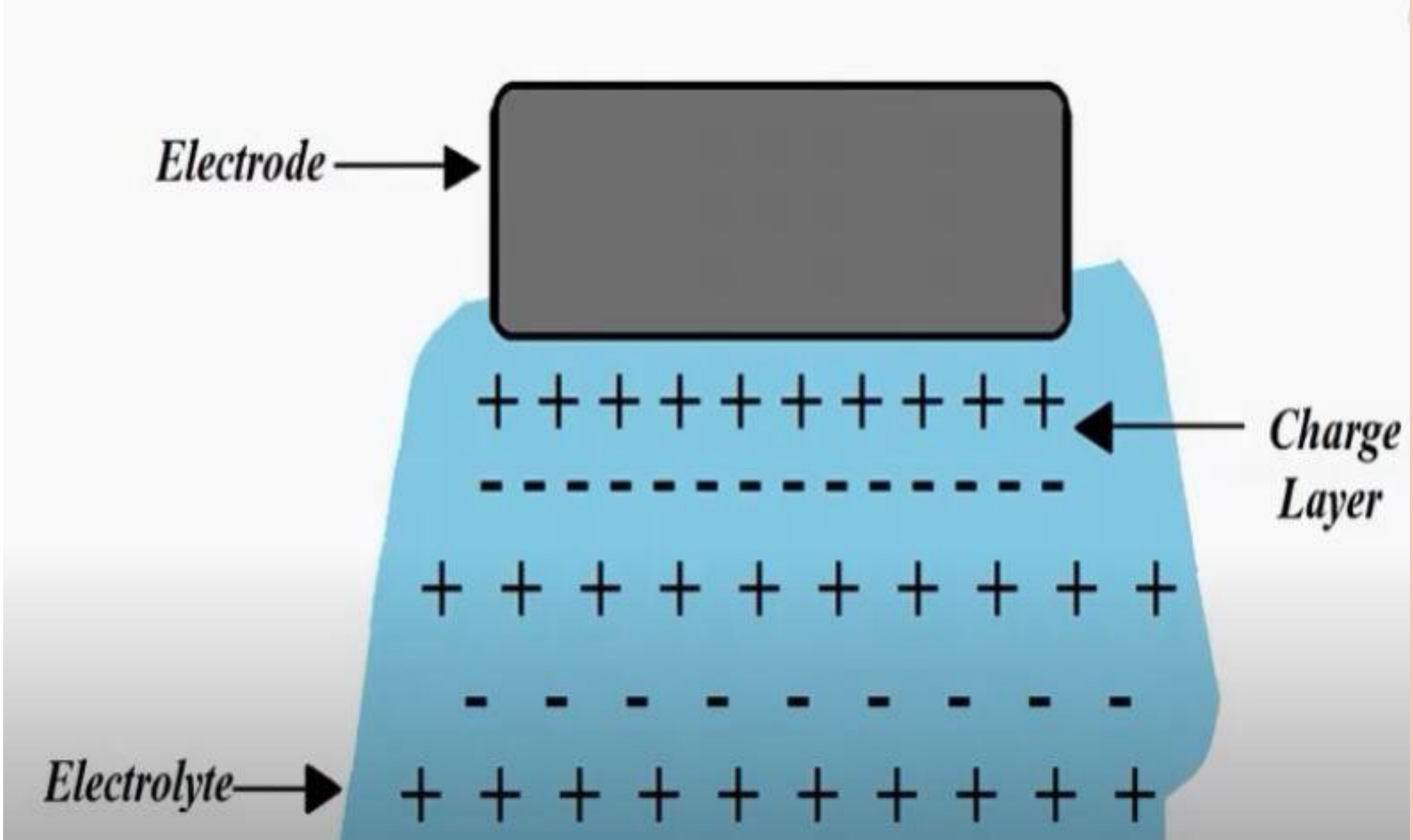
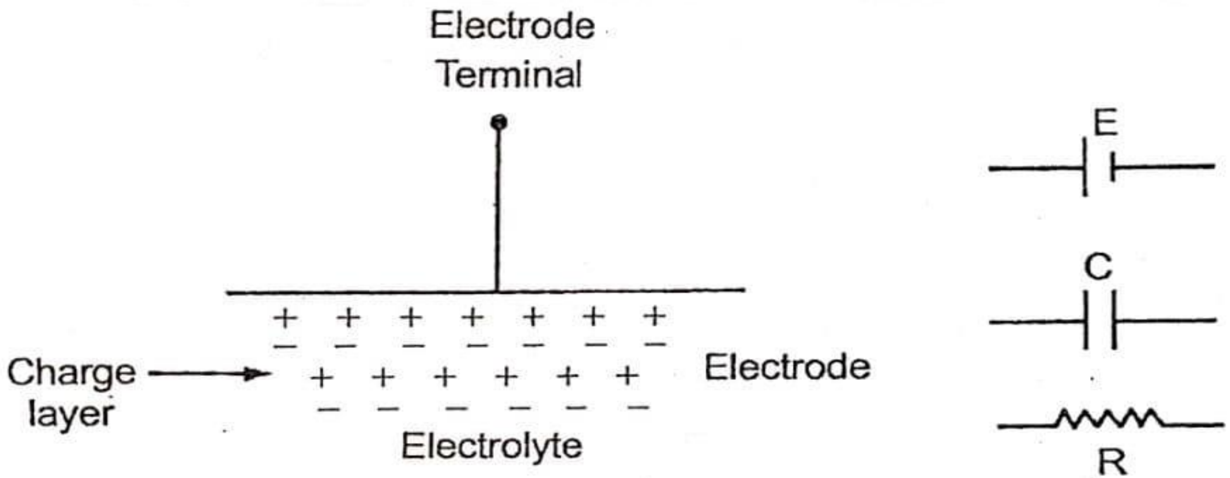

Electrode
Charge Layer
Electrolyte

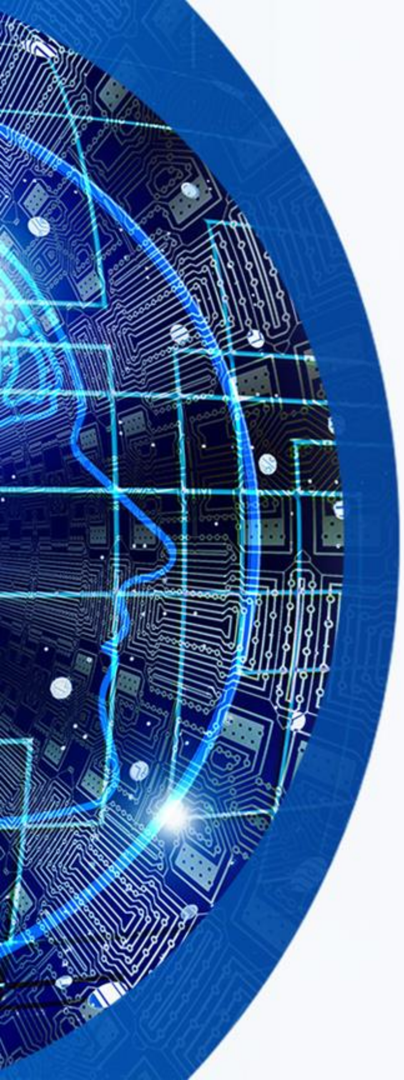
- Therefore, the metal-electrolyte interface appears to consist of a voltage source in series with a parallel combination of a capacitance and reaction resistance.



(a) Charge distribution at electrode-electrolyte interface

(b) Three components representing the interface Electrolyte

- The voltage developed is called " **half-cell potential**"
- Half cell potential can not be measured without a second electrodes.
- Half cell potential of the standard hydrogen electrode has been set to zero.
- The other half cell potentials are expressed as a potential difference with hydrogen electrode.



Metal	Electrode Potential (V)
Aluminum	- 1.66
Iron	- 0.44
Lead	- 0.12
Hydrogen	0
Copper	+ 0.34
Silver	+ 0.80
platinum	+ 1.2

The half-cell potential depends on the following factors:

- ✓ Type of metal
- ✓ Temperature
- ✓ Nature and composition of electrolyte

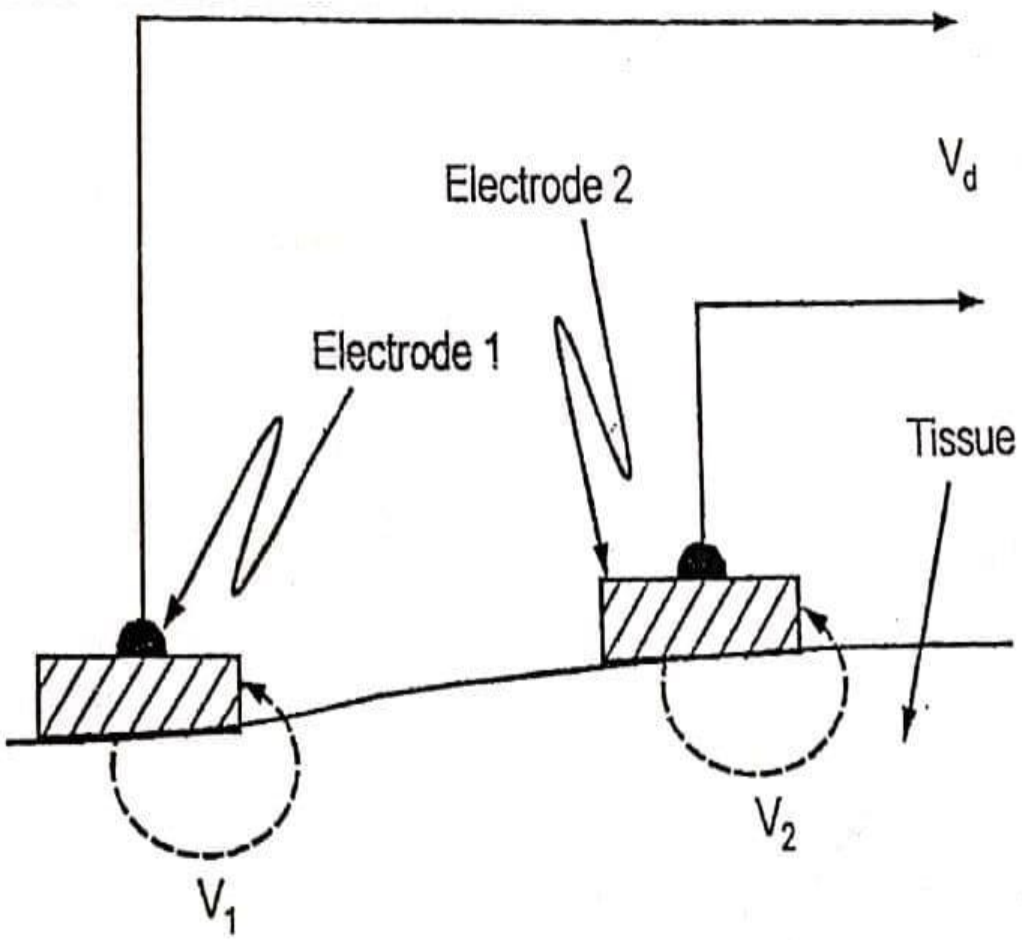
Electrodes classification according to material type

Polarizable electrodes	Non-polarizable electrodes
No charge crosses the electrodes when current applied.	All charge freely the interface when current applied.
Electrodes behave like a capacitor  .	Electrodes behave like a resister  .
Like platinum electrodes.	Like Ag/Agcl electrodes.
Use for recording.	Use for stimulation.

ELECTRODE MODEL CIRCUIT

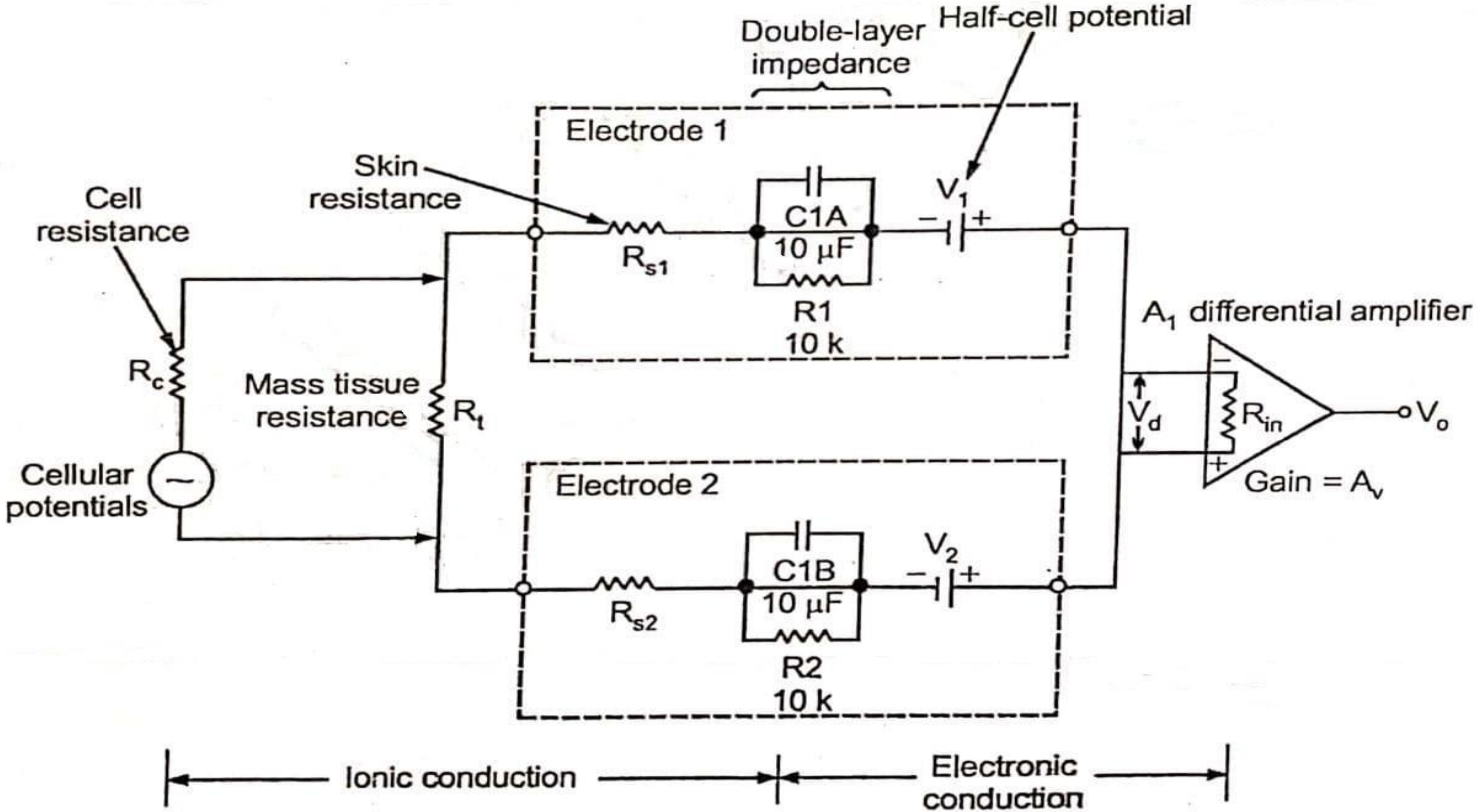
The electrode potential is generated at the metal-electrolyte interface which is proportional to the exchange of ions between the metal and electrolytes of the body.

The measurement of bio-electric potentials require **two electrodes.**



Two biomedical electrodes produce a differential voltage

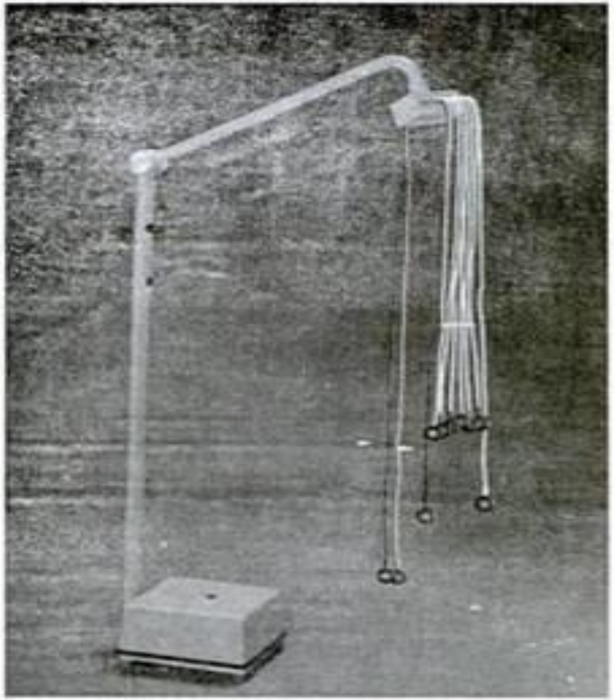
* If the **electrodes** are of the **same type**, the difference between the potentials of the two electrodes is small.
* If the **electrodes** are of the **different type**, it will produce a significant dc voltage that can cause current to follow through both electrodes and through the input circuit of an amplifier to which they are connected.
* This voltage called "**electrode offset voltage**"



Circuit model for biomedical electrode

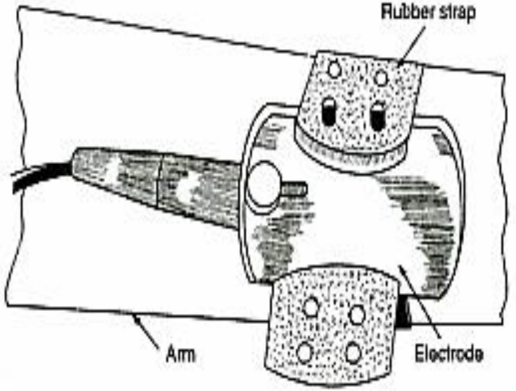
Electrodes for ECG

There are different types of electrodes for ECG like:



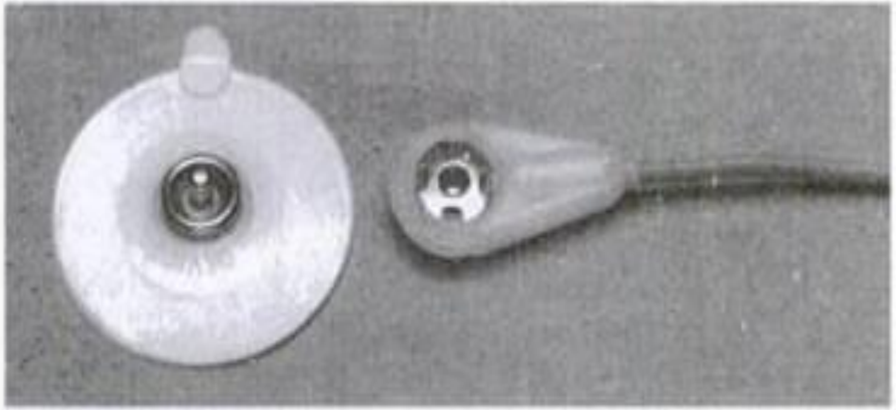
Air-jet electrodes

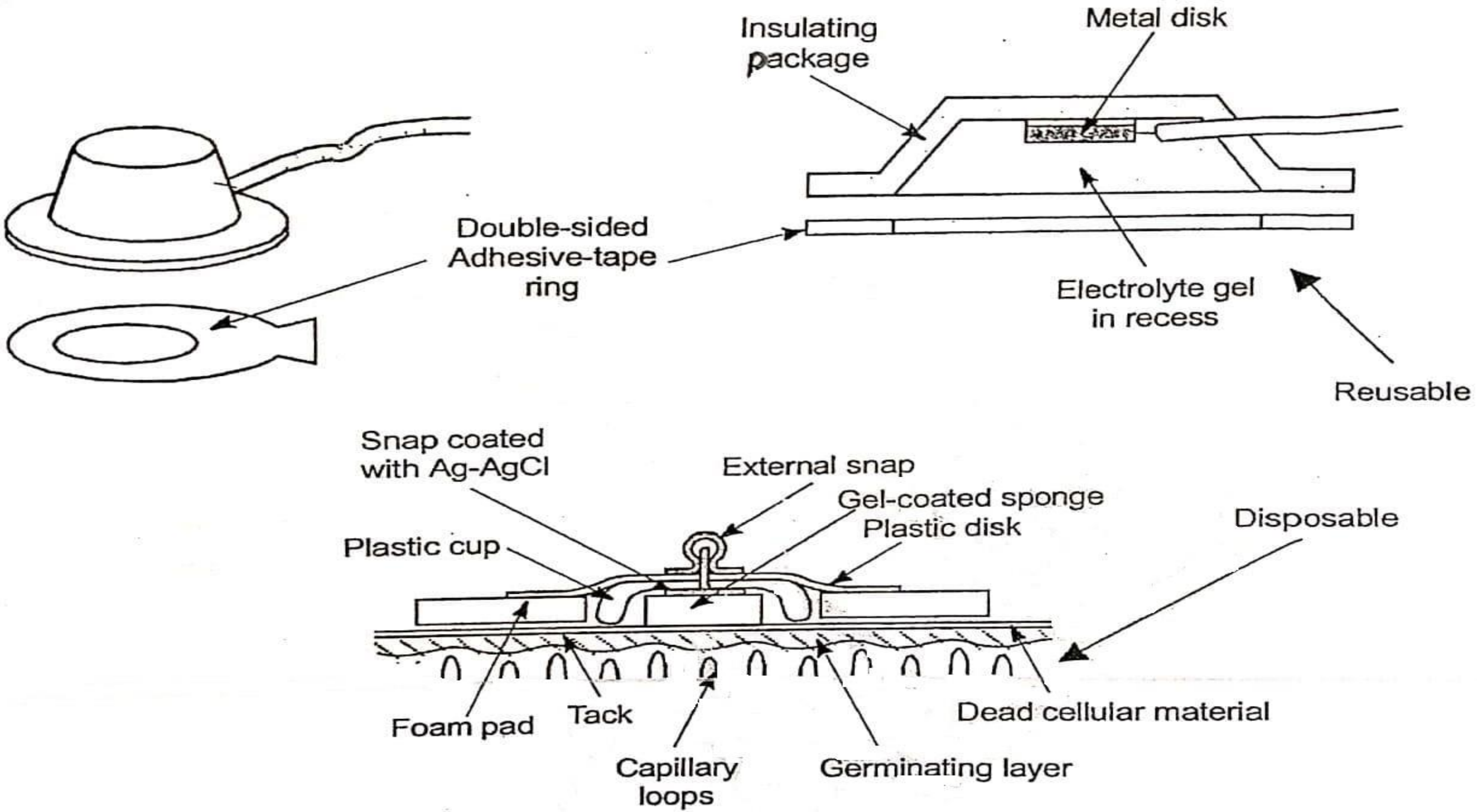
Air- Jet ECG electrode



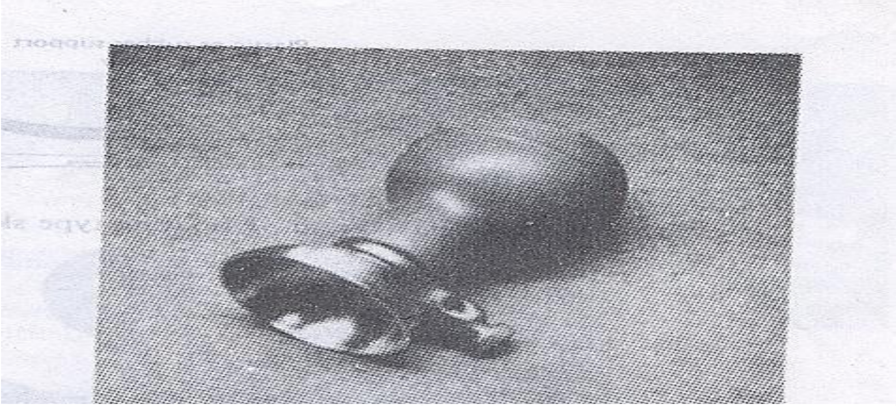
ECG plate (limb)electrode.
The electrode is usually fastened to the arm or leg with a perforated rubber strap which keeps it in position during ECG

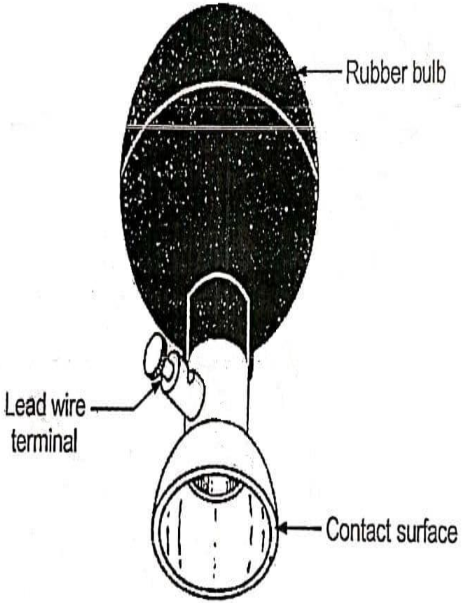
Light weight floating Electrode eliminate artifact by avoiding direct contact between metal and skin





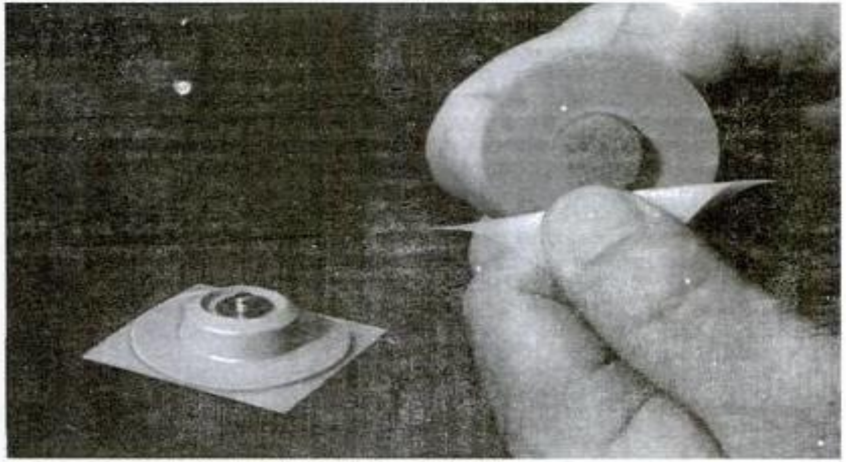
Floating electrodes

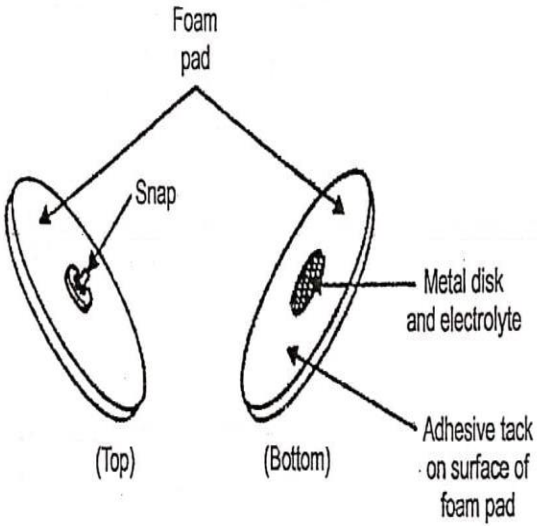




Suction-cup electrode.

Suction cup electrode (Unipolar chest ECG Electrode) only ring contact with skin



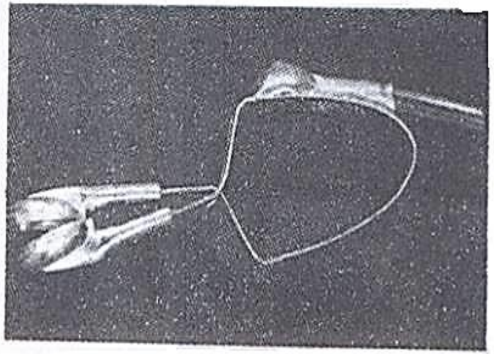


Disposable foam-pad electrodes, often used with ECG

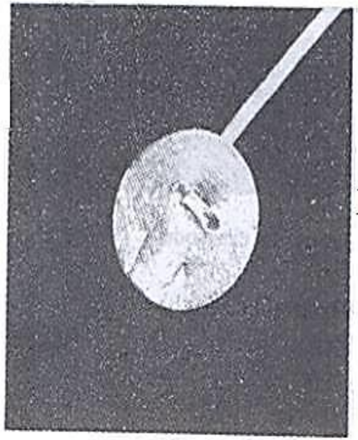
Disposable pre-gelled ECG Electrode, the porous tape overlaying placed over the electrode resists perspiration and ensures placement under stress conditions

Electrode for EEG

EEG Electrode which can be applied to the surface of the skin by an adhesive tape



Ear clip electrode



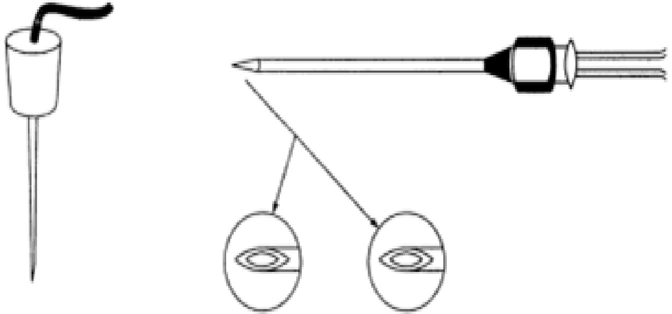
EEG Scalp surface electrode

ELECTRODE FOR EMG

- Electrodes for EMG work are usually of the **needle type.**
- Needle electrodes are used in clinical EMG, neuro-graphy and other muscle tissues underneath the skin and deeper tissues.
- The materials of needle electrodes is generally made of **stainless steel.**

- Microelectrodes have a small tips to penetrate a single cell and high impedance in MΩ because of their small size therefore amplifiers are used, generally Microelectrodes are classified into two types:

1. Metal (Tungsten or stainless steel wire and the wire coating with insulating material)



2. Micropipet (glass)

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Third Stage

MEDICAL INSTRUMENTS

Dr. Ruaa Almusa

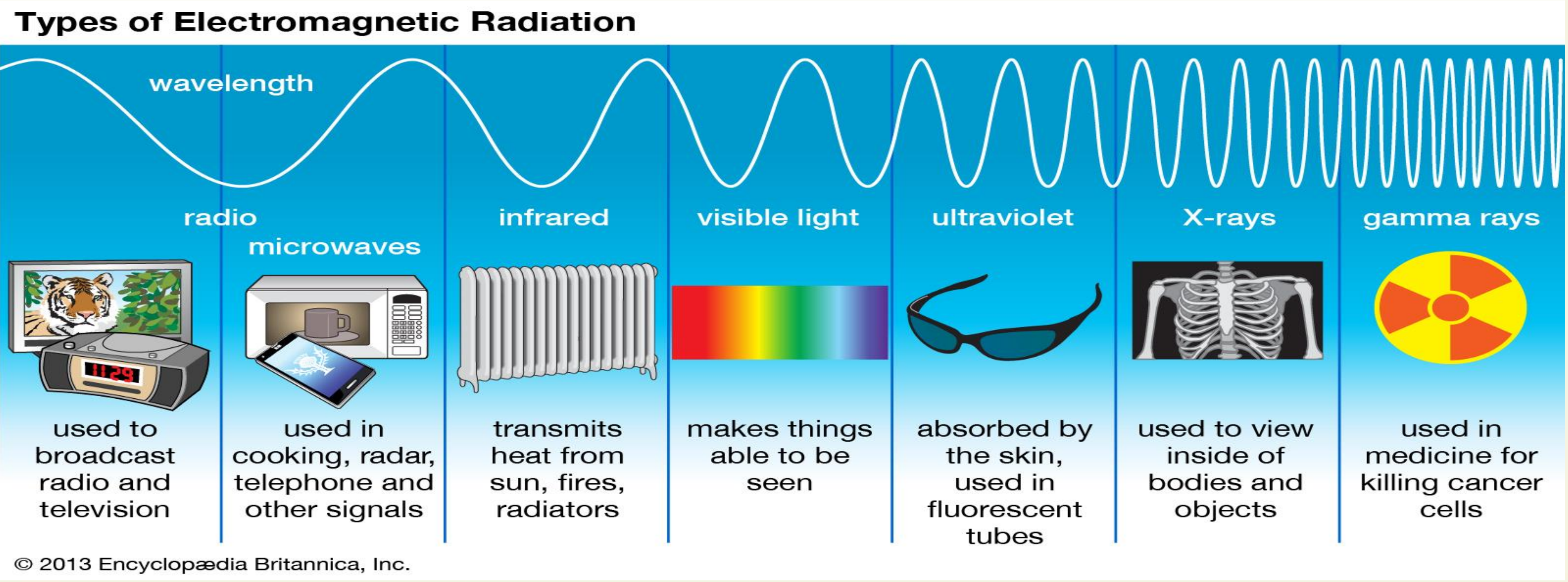
Lec 6 / Chapter 3

CHAPTER THREE

X-RAY MACHINE

X-RAY

- ✓ Are one of the more important diagnostically tools in medicine field since its discovery by Röntgen.
- ✓ X-rays are a type of electromagnetic radiation.



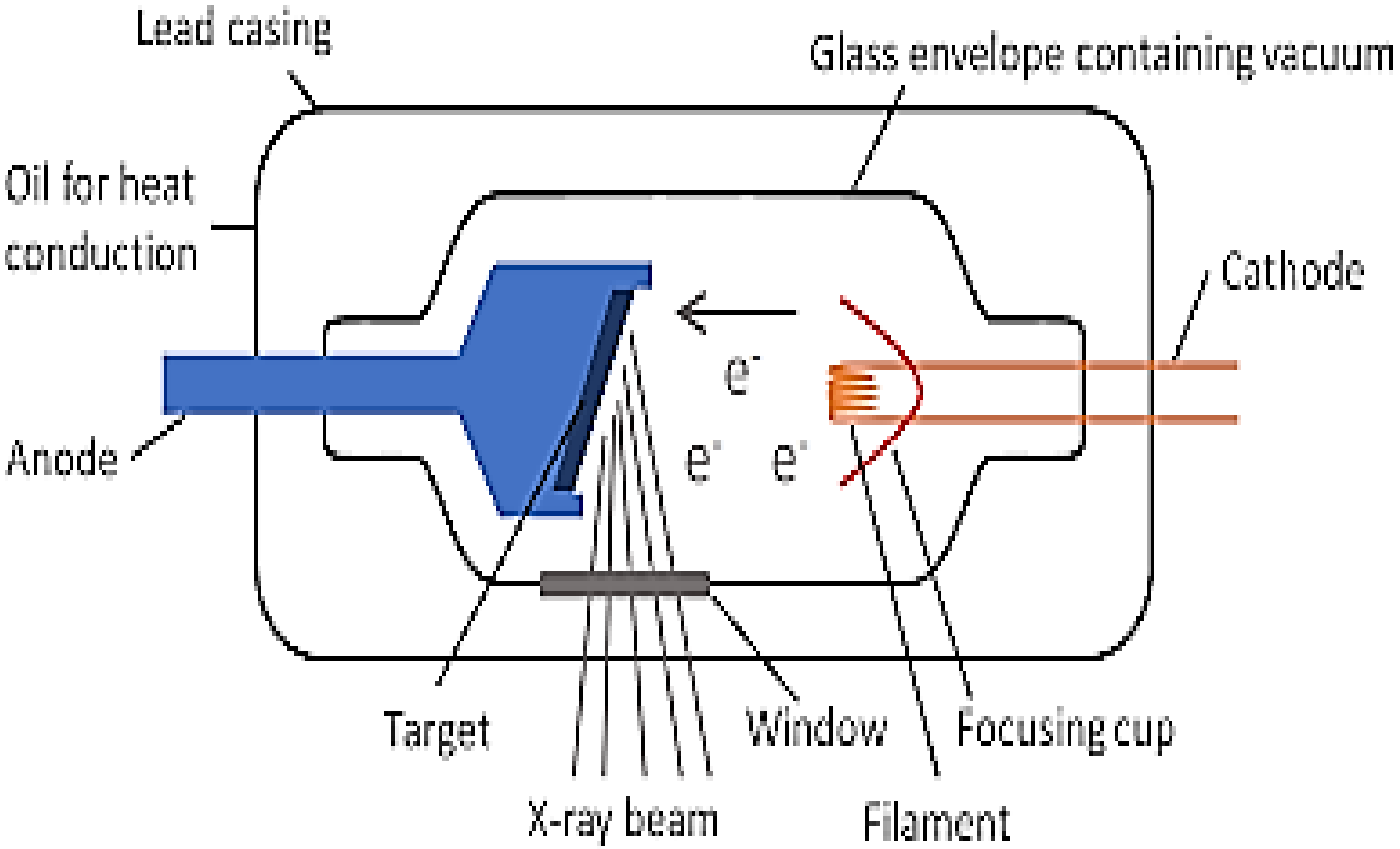
X-Ray Production

- X-rays are produced when electrons are accelerated and collide with a target
  - Bremsstrahlung x-rays
  - Characteristic x-rays
- X-rays are sometimes characterized by the generating voltage
  - 0.1-20 kV soft x-rays
  - 20-120 kV diagnostic x-rays
  - 120-300 kV orthovoltage x-rays
  - 300 kV – 1 MV intermediate energy x-rays
  - > 1MV megavoltage x-rays

COMPONENT OF X-RAY TUBES

- The production of both Bremsstrahlung and Characteristic radiation requires energetic electrons hitting a target.
- Principle components of an X ray tube are:
- An Electron source from a heated tungsten filament with a focusing cup serving as the tube cathode.
- An anode or target and a tube envelope to maintain an interior vacuum.

X-Ray Tube


Lead casing
Glass envelope containing vacuum
Oil for heat conduction
Cathode
e-
e-
e-
Anode
Target
Window
Focusing cup
X-ray beam
Filament

- X ray tube made of glass or metal partially evacuated.
- Cathodes are negatively charged portion contain a filament wire made of tungsten generates the electrons.
- Electrons are released at high temperature from filament that are **accelerated** toward the anode to produce x-ray.

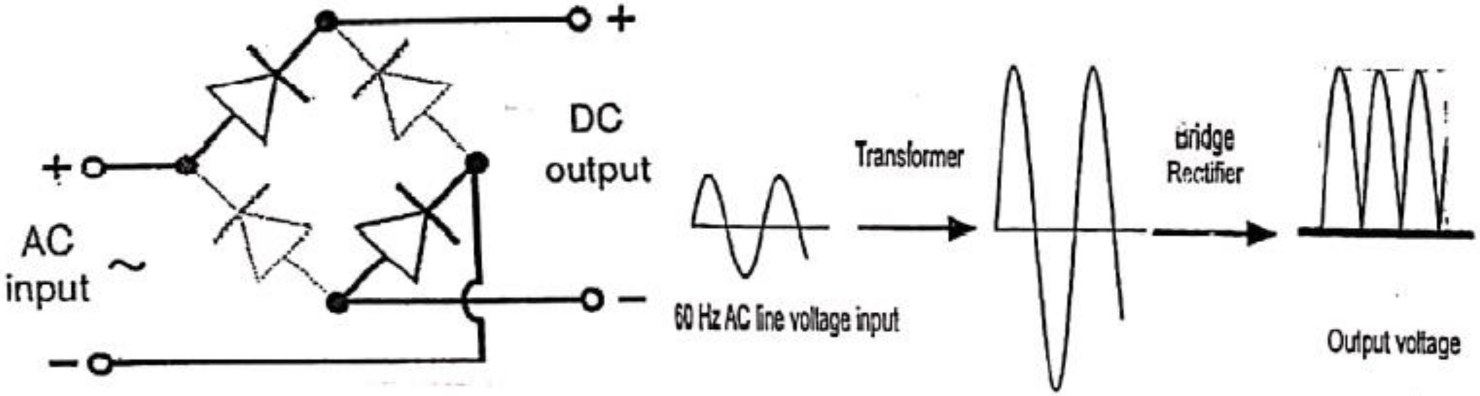
- Focusing cup is important for:
- ✓ Surrounds the filament.
- ✓ Direct the electrons toward the anode target.
- ✓ Increasing the focal spot size (FSS).
- ✓ Typical voltage is 10V and current 4A then the dissipation power in the filament is 40 watt.

- High voltage generator is important for:

✓ Increase the voltage.

✓ Convert alternating current AC to direct current DC by using diode as rectifiers.

✓ Current in diodes flow in one direction.



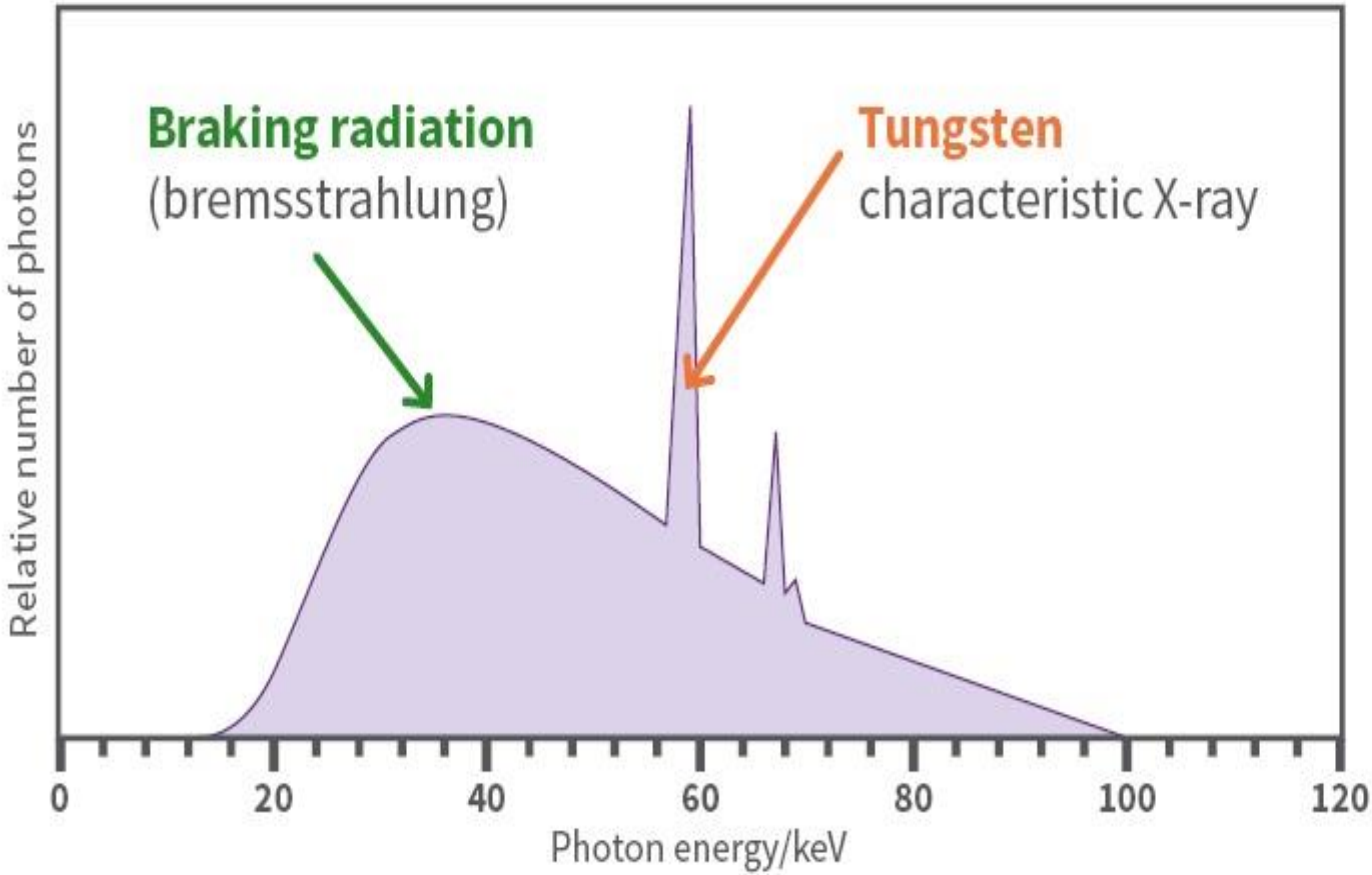
- Typically there are two filaments

✓ Long one: higher current, lower resolution

- Large focal spot

✓ Short one: lower current, higher resolution

- Small focal spot


Braking radiation
(bremsstrahlung)
Tungsten
characteristic X-ray
Relative number of photons
0
20
40
60
80
100
120
Photon energy/keV

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Third Stage

MEDICAL INSTRUMENTS

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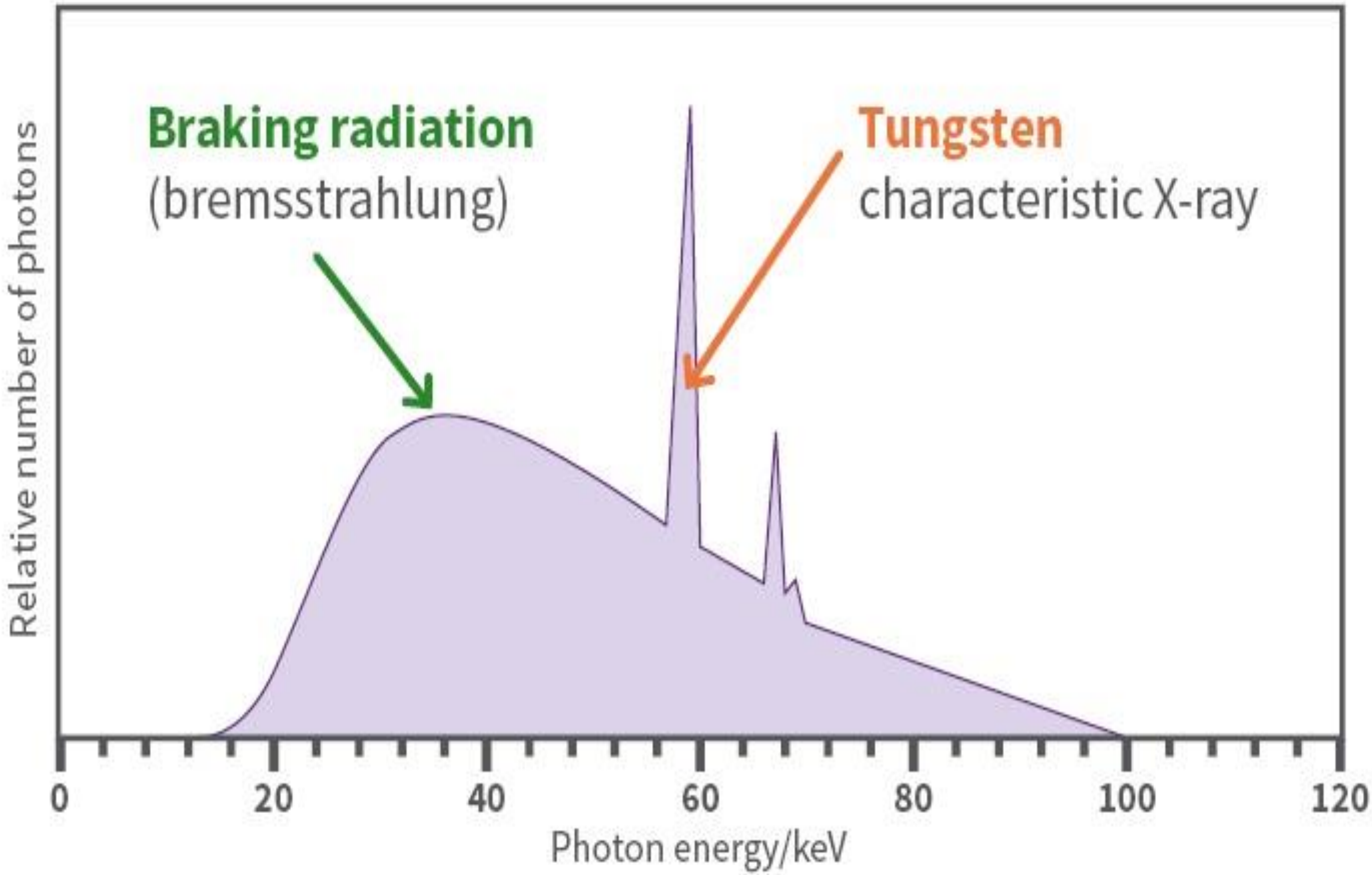
Lec 7 / Chapter 3


Braking radiation
(bremsstrahlung)
Tungsten
characteristic X-ray
Relative number of photons
0
20
40
60
80
100
120
Photon energy/keV

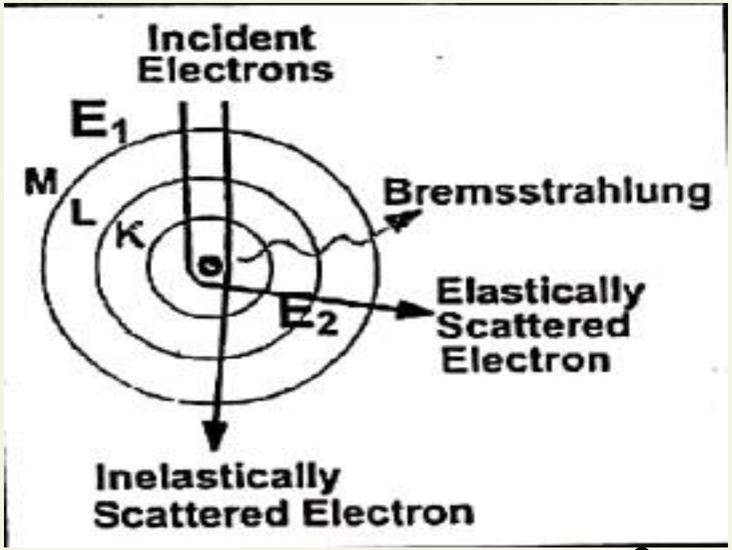
BREMMSTRAHLUNG

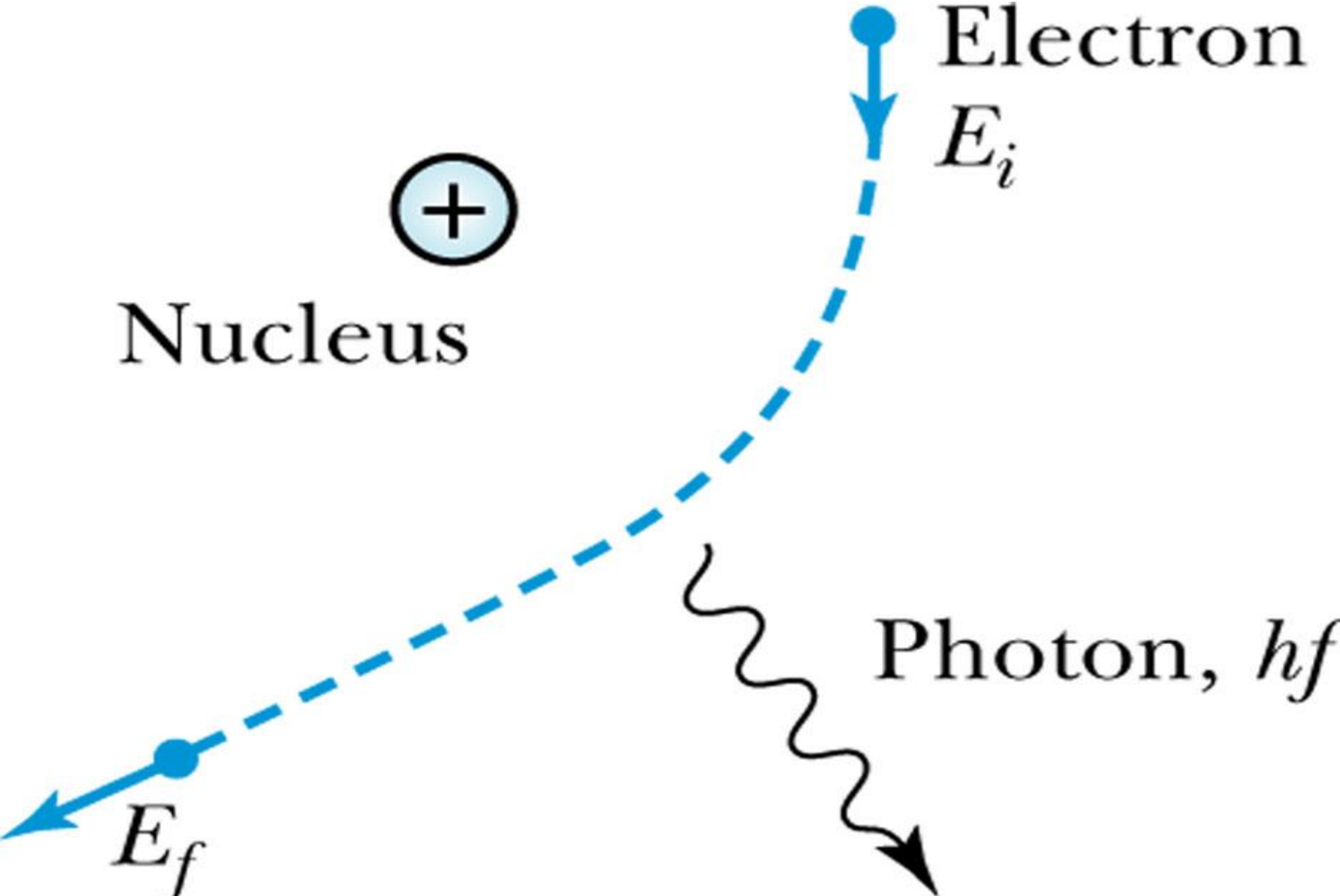
- Bremsstrahlung x-rays (braking radiation) occur when electrons are interact with coulomb field of a nucleus, the incident electrons are:

✓ Slowing down (deaccelerated).

✓Change their direction.

✓Lose some of their energy.





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BREMSSTRAHLUNG

Bremsstrahlung

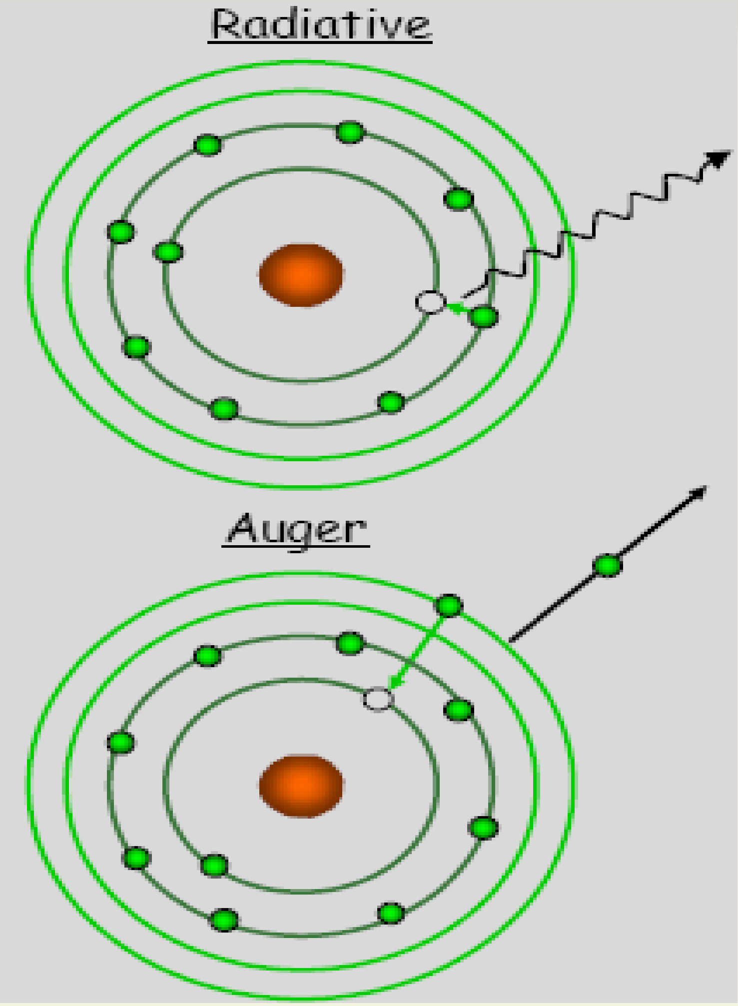
- The probability of bremsstrahlung goes as Z^2, hence high Z targets are more effective than low Z.
- The energy of the x-rays varies from zero to the maximum kinetic energy of the electron (x-ray tube kVp).
- Bremsstrahlung x ray (are contentious spectrum) production increase with:

✓ increasing Z

✓ Increasing kinetic energy.

CHARACTERISTIC X-RAYS

- Incident electron is interact with internal K shell electron of an atom and removes it out of its orbital, this leaves the atom in excited state.
- Transition electron from outer to inner shell is emitted energy in form of characteristic x ray.



INTENSITY OF X-RAY

- Is define as the number of the photons in the beam per unit time, it measured by R/m, mR/m and mG/m:

$$I = I_o \, e^{-\mu x}$$

Where I the original intensity at thickness x

I_o is the intensity at x=0

μ is linear attenuation coefficient cm^{-1}

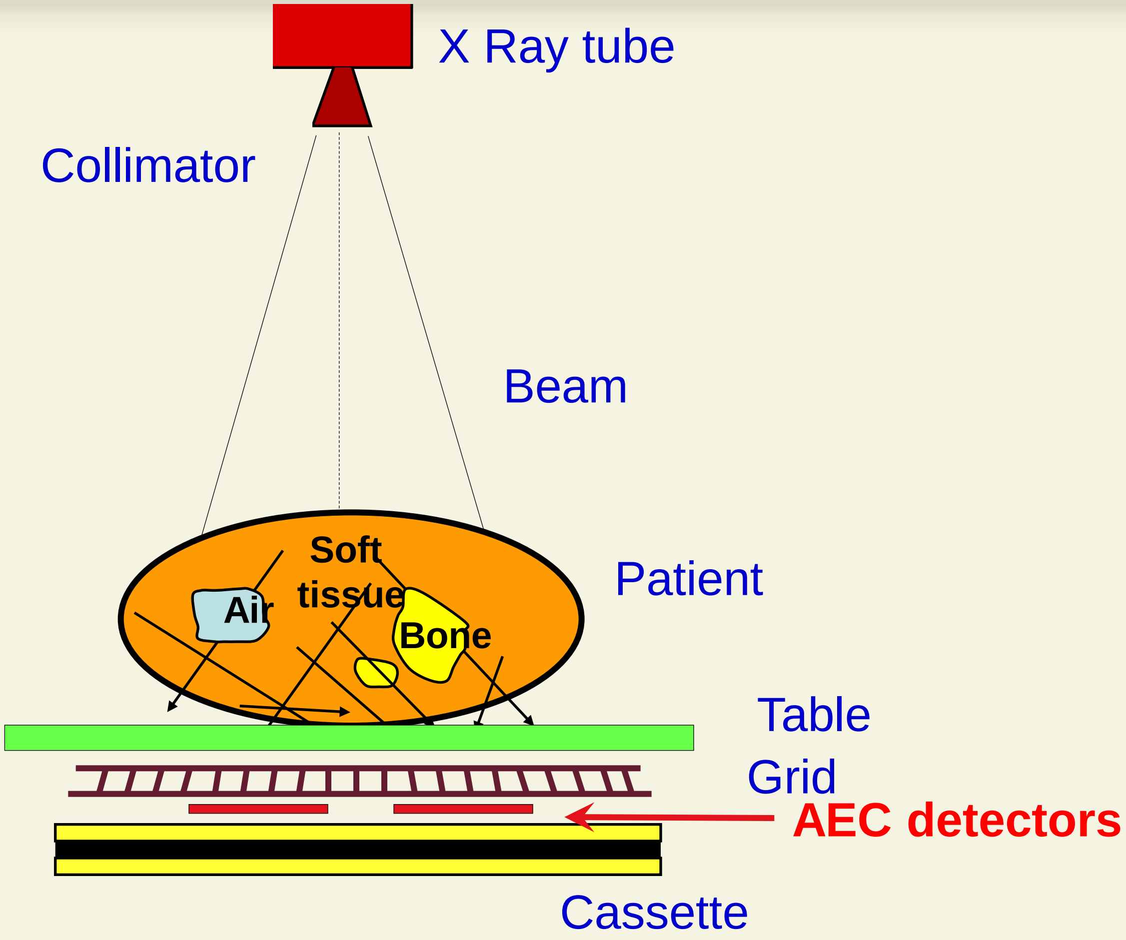
x is the absorber thickness cm

X ray intensity depends on:

1. Square peak voltage ($I\ \alpha\ kvp^2$)
2. Tube current and exposure time ($I\ \alpha\ mAs$)
3. Atomic number of the anode (linear relation)
4. Increasing distance from x ray tube ($I\ \alpha\ \frac{1}{d^2}$)

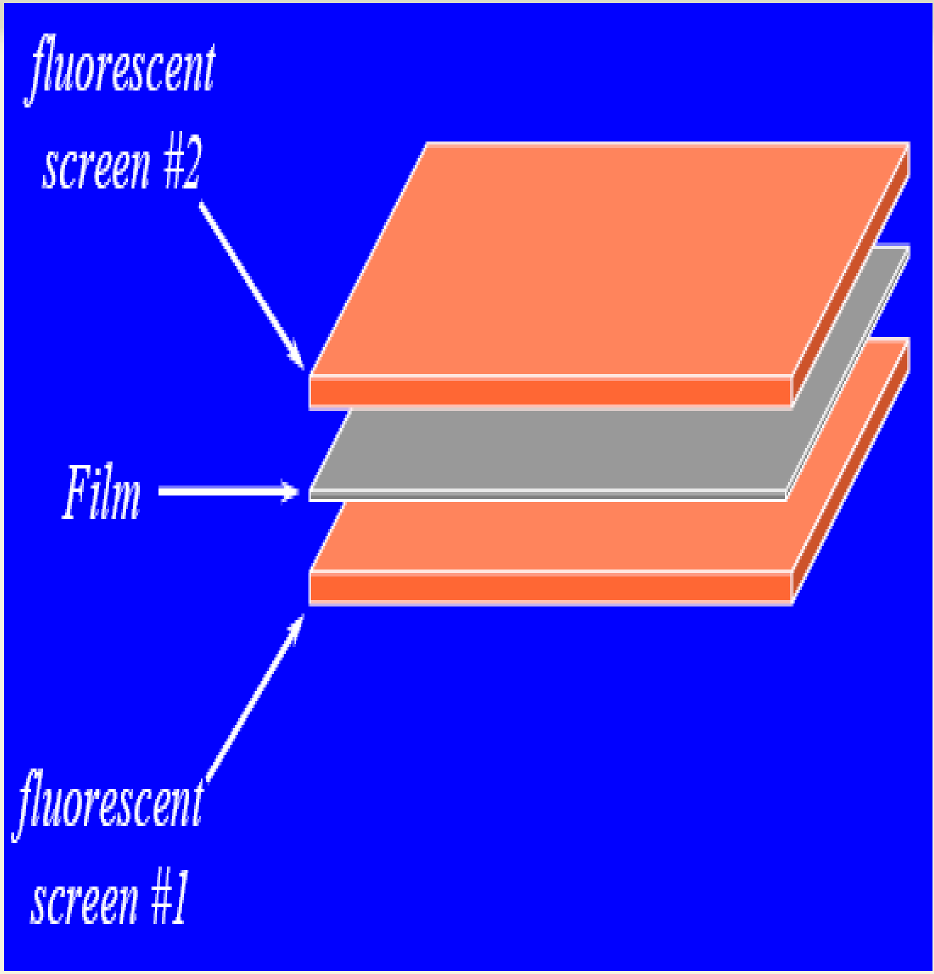
Automatic Exposure Control

- AEC detectors can ionization chambers or solid-state detectors

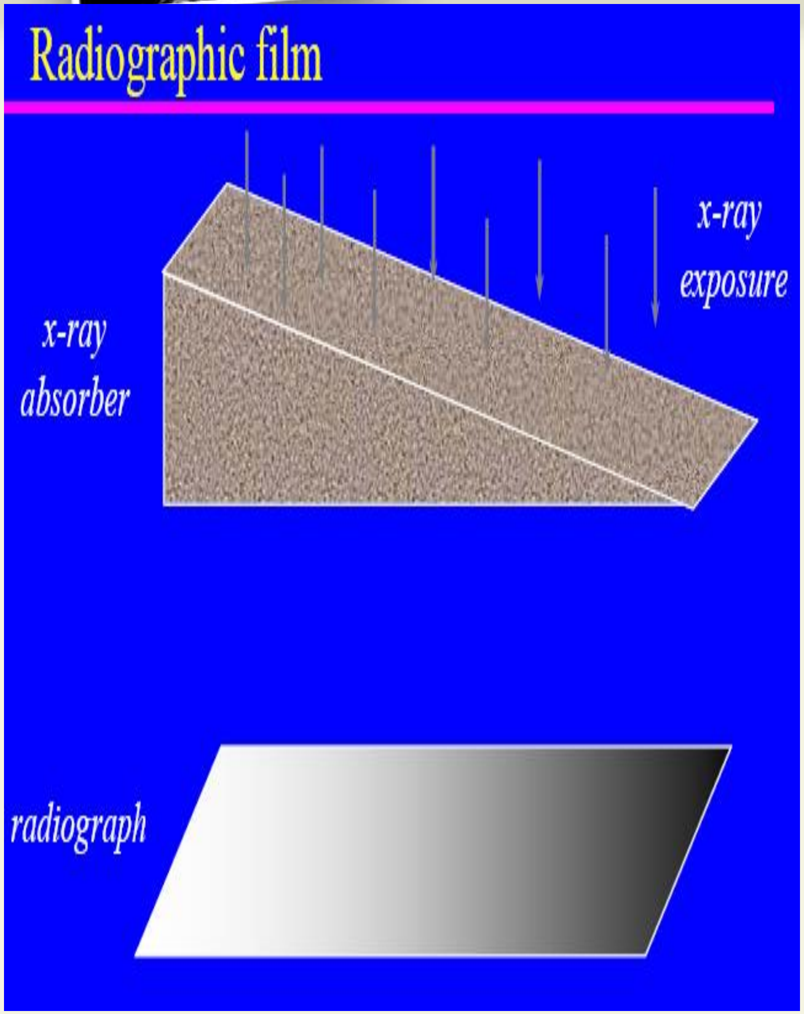


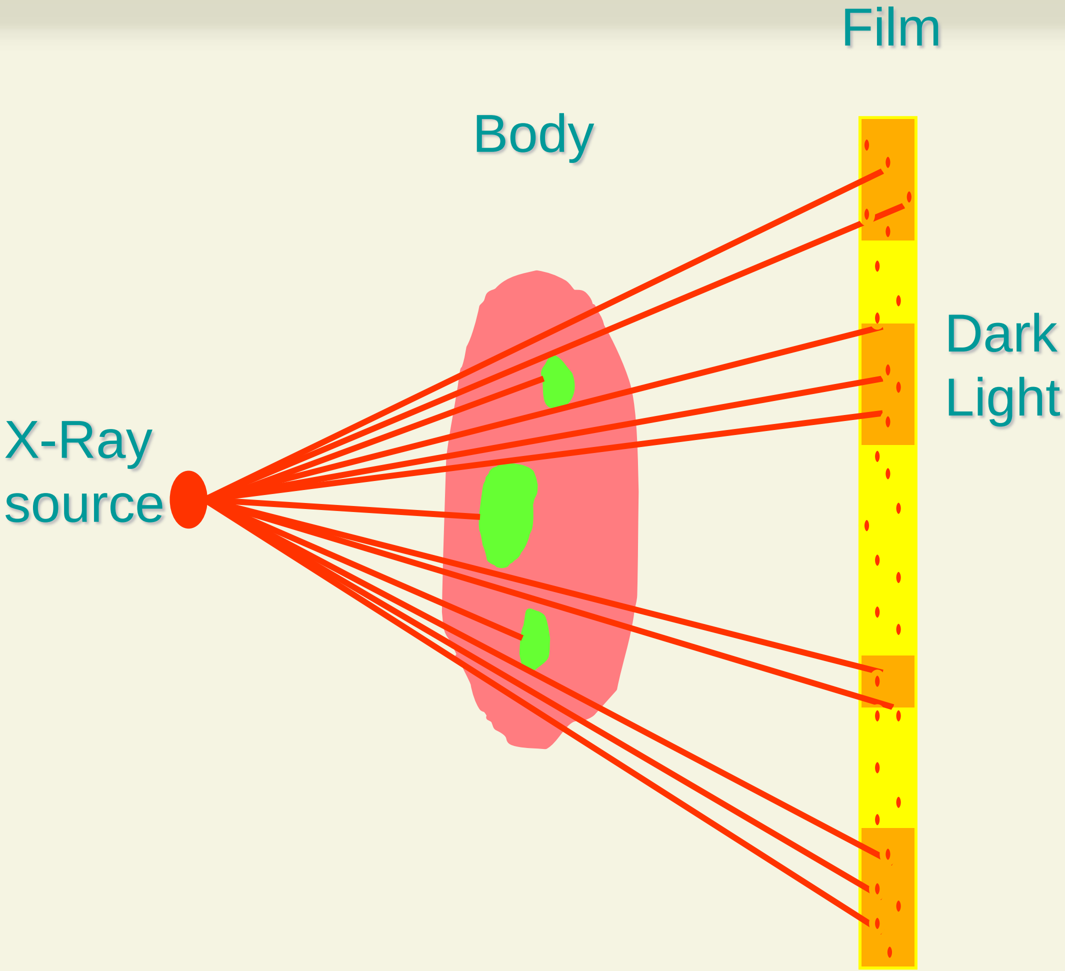
Images

- Analog radiography
  - Film based – still widely used
  - Fluorescent screens are used to convert x-rays into visible light that is then recorded on film
  - Screens are more efficient at stopping x-rays than the film.



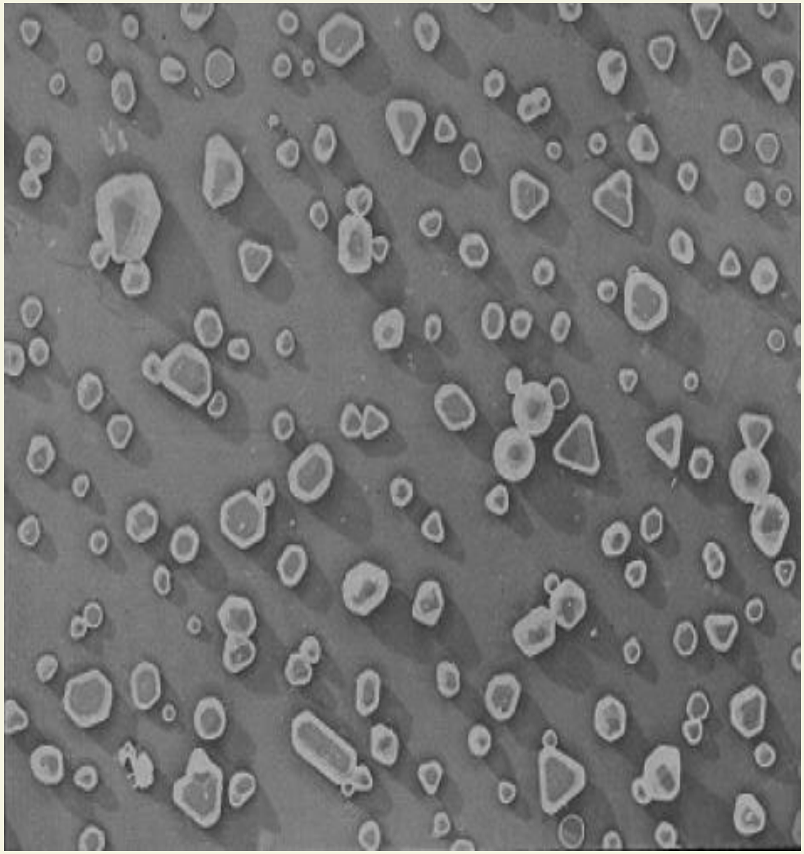
Analog Radiography





Film Badge

- A film badge consists of a photographic film with various filters
- The film is a gelatin mixture containing silver-halide grains (95% AgBr and 5% AgI) on a supporting material like mylar
  – Grain diameter is ~ 1mm



Film Badge

- The film is exposed by light by:
  1. An electron is released from Br^- and moves about the 1m diameter crystal
  2. The electron may be captured by a trap such as a crystal imperfection
  3. The trapped electron attracts mobile Ag^+ ions
  4. Additional Ag atoms are formed by repeated trapping
  5. These Ag atoms are called a **latent image center**
  6. The developing process effectively amplifies this process turning the grains with latent image centers into a visible silver deposit

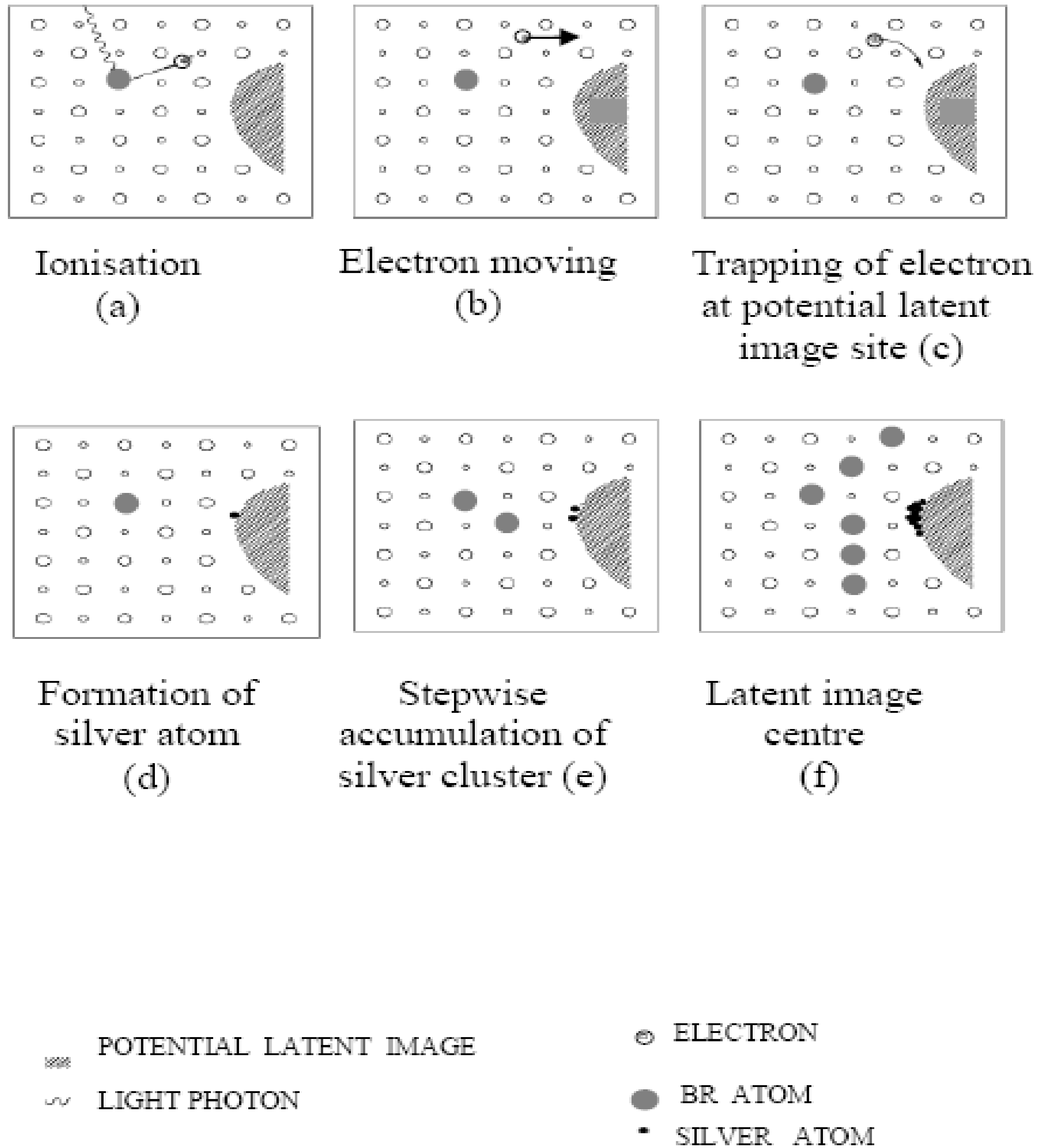


Fig. 2.7: Stages of latent image formation in a grain of an emulsion according to the Gurney-Mott Theory (Gurney and Mott 1938).

- Silver atoms at latent image centers

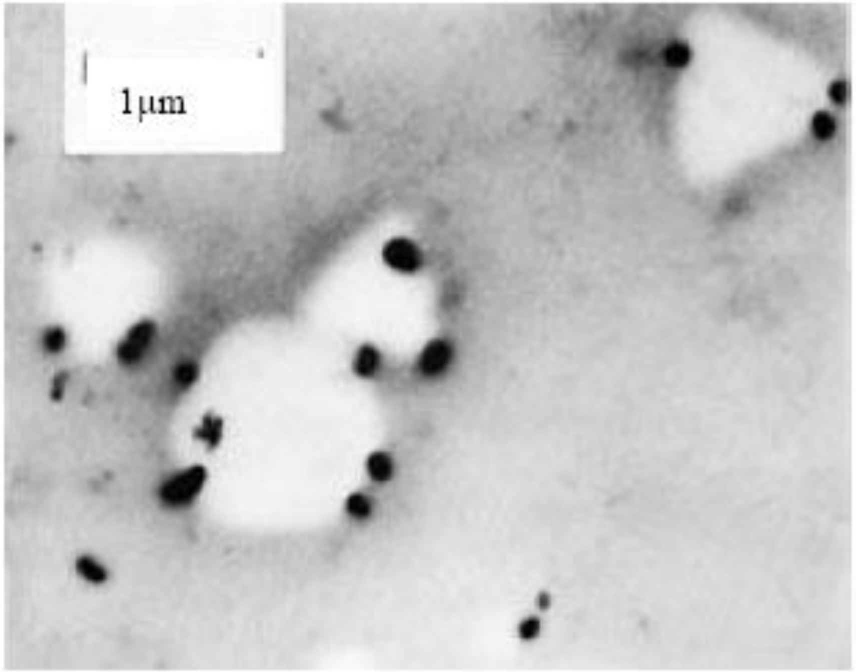
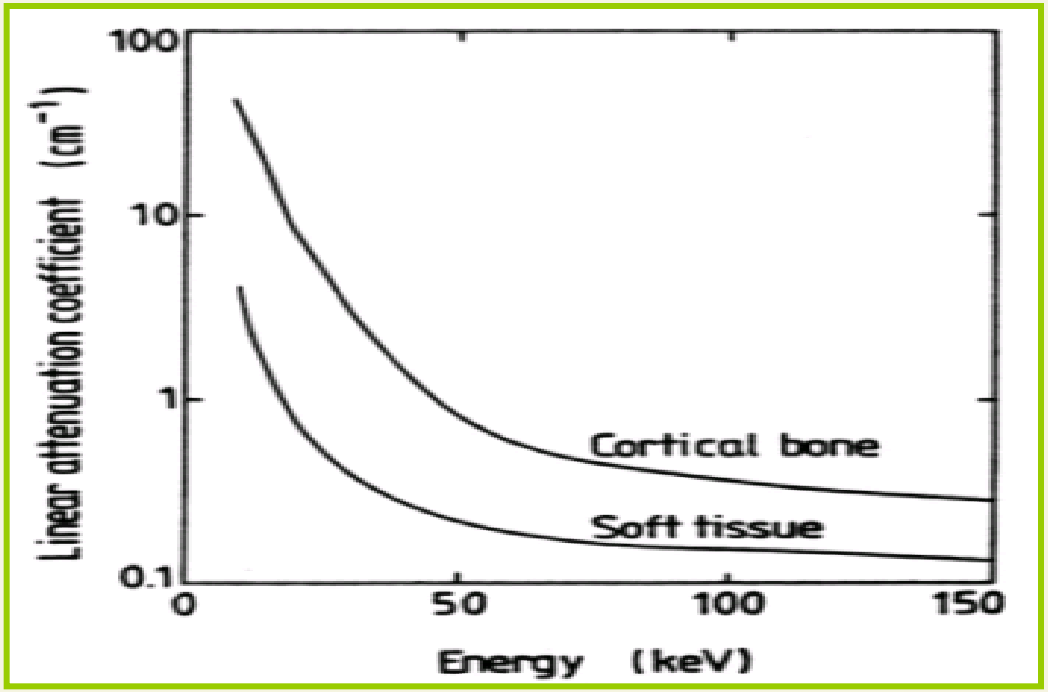


Fig. 2.8: Electron micrograph of exposed, partially developed and fixed silver-halide grains, showing the initiation of the development at localized sites on the grains, (Kodak 1999).

X-rays

- For bone tissue, the linear attenuation coefficient is much greater than that for soft body tissue.



Medical applications of X ray

- ❑ Imaging

Transition x ray through human body used in

- Dental radiography
- Fluoroscopy
- Computed tomography (CT)

- ❑ X and gamma rays are used in radiation therapy for cancer treatment.

Medical applications of X ray

- ❑ Imaging

Transition x ray through human body used in

- Dental radiography
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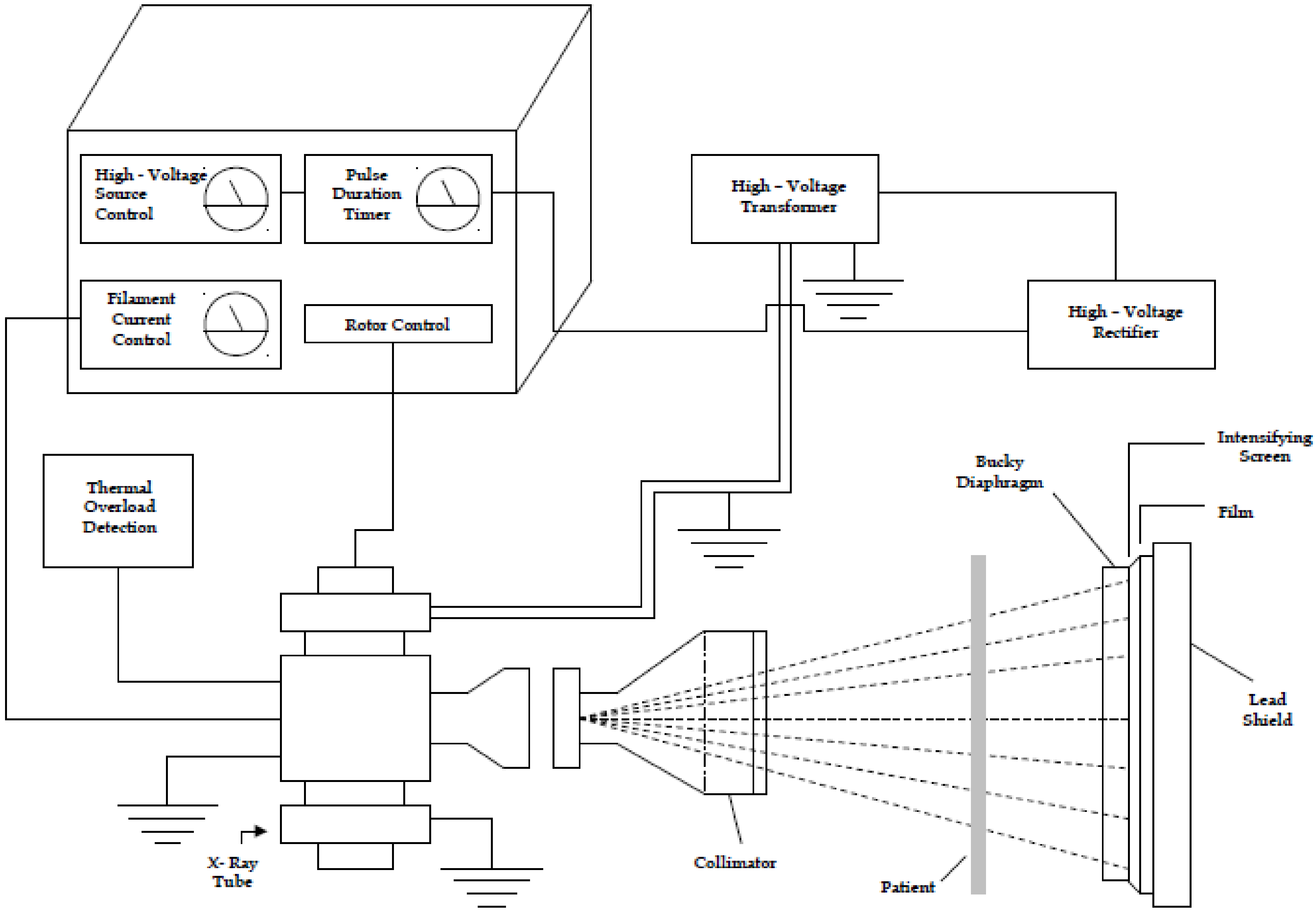
- ❑ X and gamma rays are used in radiation therapy for cancer treatment.

X rays Properties

1. X-rays travel in straight lines.
2. X-rays cannot be deflected by electric field or magnetic field.
3. X-rays have a high penetrating power.
4. Photographic film is blackened by X-rays.
5. Fluorescent materials glow when X-rays are directed at them.
6. Photoelectric emission can be produced by X-rays.
7. Ionization of a gas results when an X-ray beam is passed through it.

Block Diagram of an X – Ray Machine



Radiography and Fluoroscopy

S. No.	Radiography	Fluoroscopy
1	X – ray image is developed by photosensitive film	X – ray image is developed by photoelectric effect and fluorescence principle
2	High geometric resolution can be obtained	Fair resolution can be obtained
3	Wide range of contrast can be obtained	Contrast can be increased by introducing electronic image intensifier
4	Patient is not exposed to X – rays during examination of the X – ray image	Patient is exposed to X – rays during examination of the X – ray image

5	Patient dose is low	Patient dose is high
6	Permanent record is available	Permanent record can be made by inserting video tape recorder
7	Image can be obtained after developing the film and the examination cannot be made before developing the film	Immediately image can be seen and examination can be finished within a short time
8	Movement of organs cannot be observed	Movement of organs can be observed (Real time experiment)
9	Efficiency is more	Efficiency is lesser in direct fluoroscopy, can be increased with modern systems

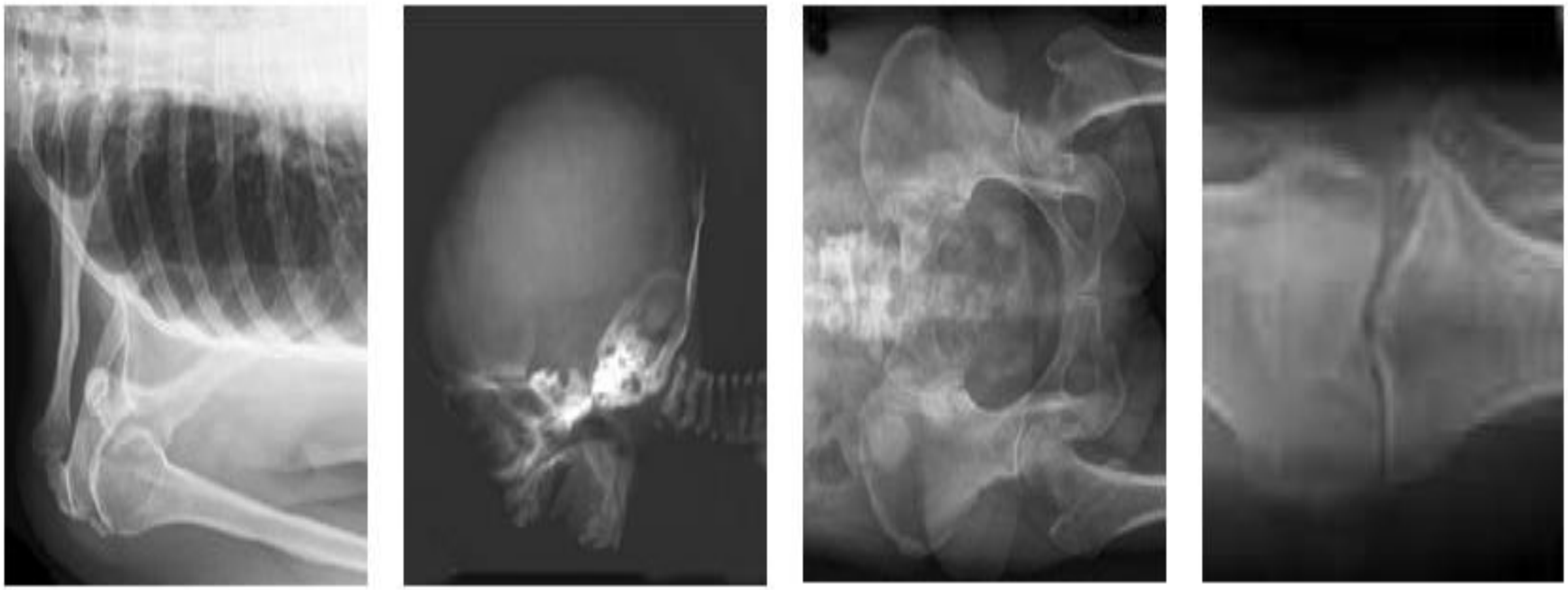
X-Ray Radiography Benefits:

1. Noninvasive, quick, and painless.
2. Support medical and surgical treatment planning.
3. Guide medical personnel as they insert catheters or stents inside the body to treat tumors, or remove blood clots.

X-Ray Radiography Risks

1.Exposure to ionizing radiation, this increase the possibility of developing cancer later in life.

2.Tissue effects such as cataracts, skin reddening, and hair loss, which occur at relatively high levels of radiation exposure.



Shoulder Head Pelvis Knee

Examples of X-ray images

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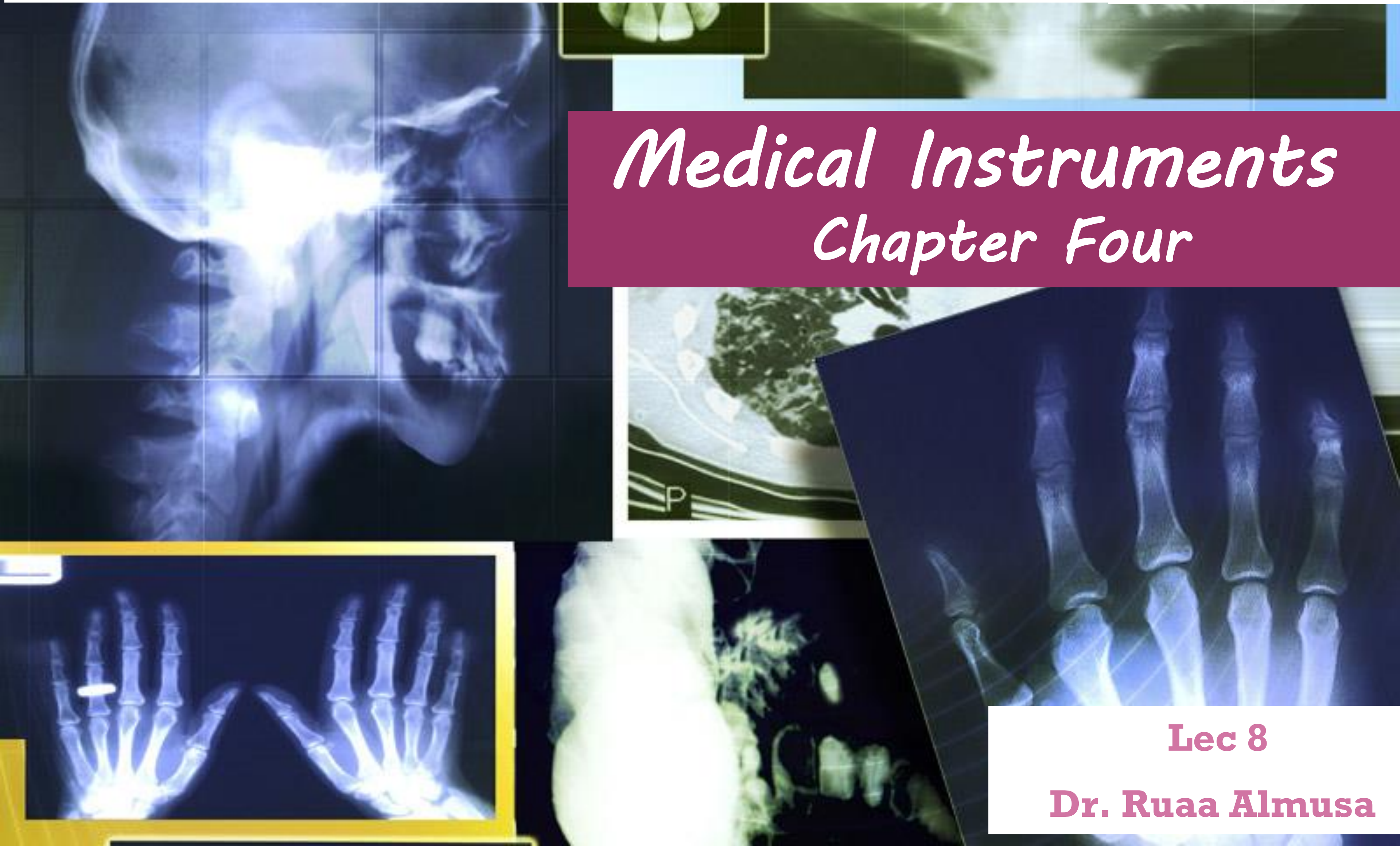
Medical Instruments
Chapter Four



Lec 8

Dr. Ruaa Almusa

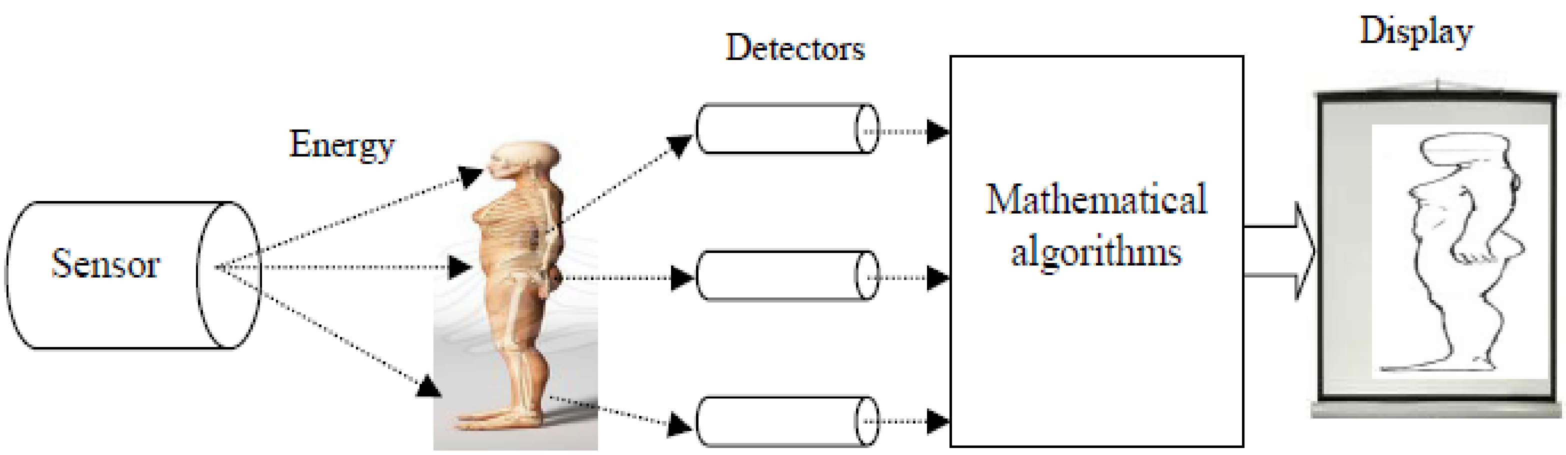
Chapter four Medical Imaging Techniques

Imaging Techniques

Is the determination of the identity of a possible disease or disorder, the basic **principles** of all imaging techniques are **same**. A beam of wave passes through the body/area under diagnosis, transmits or reflects back the radiation which will be captured by a detector and processed to get an image pattern. The type of wave differs for different modalities.

The basic concept of a medical imaging system consists of a **sensor** or **source of energy** that can penetrate the human body, the energy pass through the body, they are absorbed or attenuated at differing levels, according to the density and atomic number of the different tissues, creating signals.

These signals are detected by special **detectors** compatible with the energy source, then mathematically employed to **create an image**.



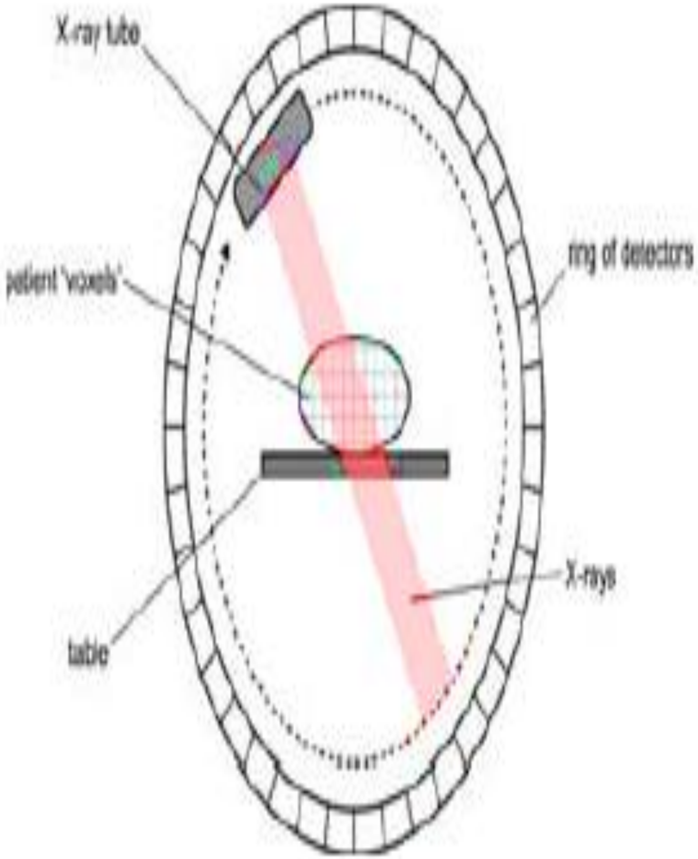
Concept of a medical imaging system

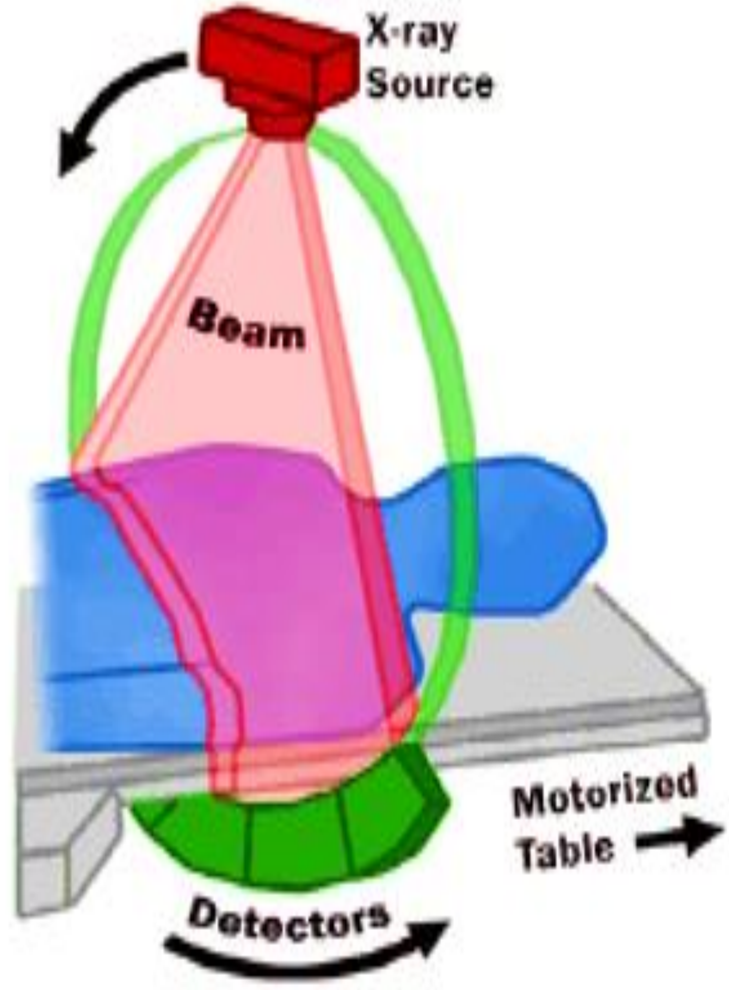
Computer Tomography (CT)

- Also called **Computerized Axial Tomography** or **Computer Transmission Tomography**.
- Measurements are taken from the transmitted X–rays through the body and contain information on all the contents of the body in the path of the X – ray beam, Using **multi directional scanning** of the object, multiple data are collected.

Computer Tomography Parts

1. X-ray equipment, computer, cathode ray tube display to produce images of cross sections of the human body and detector which measures the X-ray profile.
2. Inside the CT scanner, there is a rotating frame that has an X-ray tube on one side and the detector on the opposite side. A beam of X-ray is generated as a rotating frame spins the X-ray tube and detector around the patient.





X-ray CT imaging

2D CT

3D CT

4D CT

Example of CT scan

Computer Tomography Benefits

1. Non invasive, quick, and painless.
2. Good locative resolution.
3. Good view of veins.
4. Distinguished by small differences in physical density.
5. Avoids insertion of an arterial catheter and guidewire.

Computer Tomography Risks

1. Exposure to ionizing radiation, this increase the possibility of developing cancer later in life.
2. Cannot detect intra-luminal abnormalities.
3. Less contrast resolution where soft tissue contrast is low.

Computer Tomography

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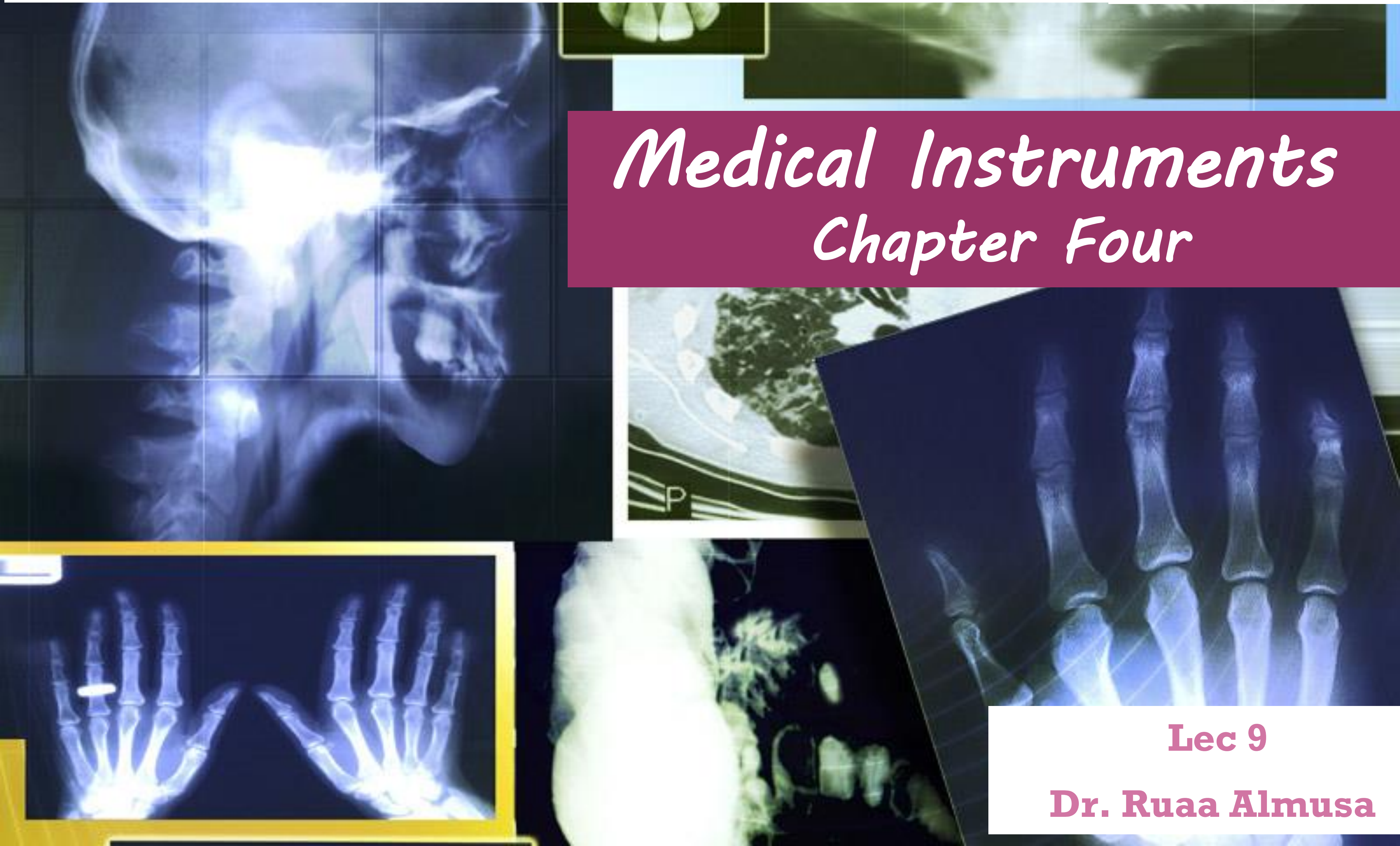

Medical Instruments

Chapter Four

Lec 9

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Chapter four Medical Imaging Techniques

Imaging Techniques

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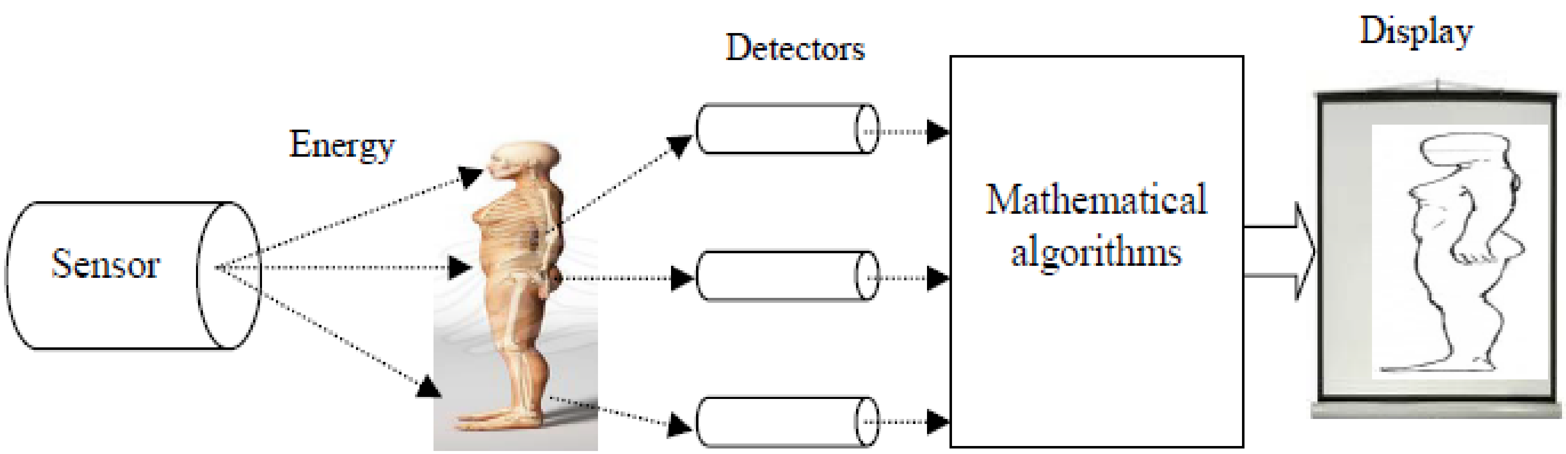

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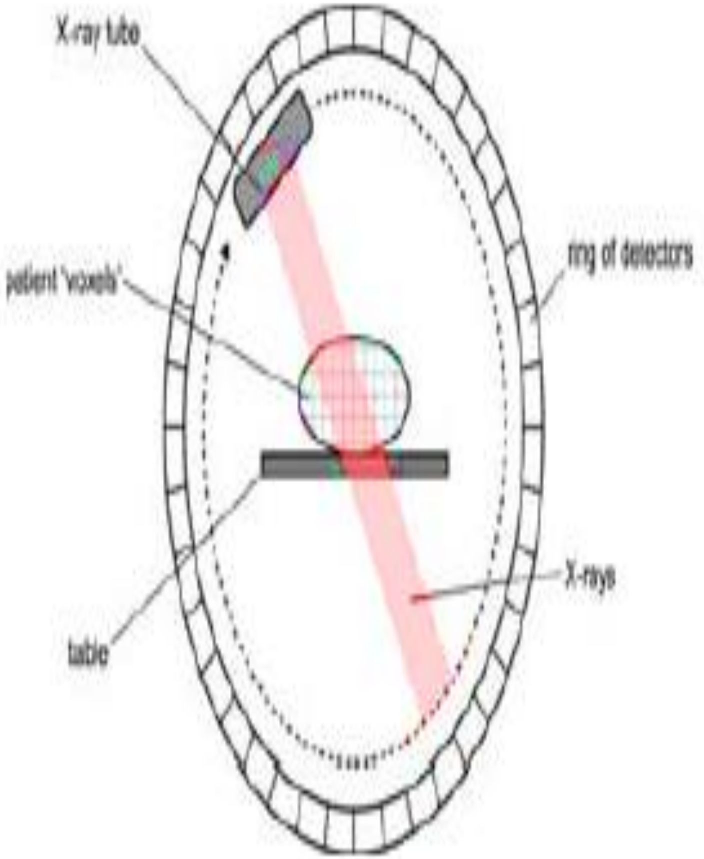

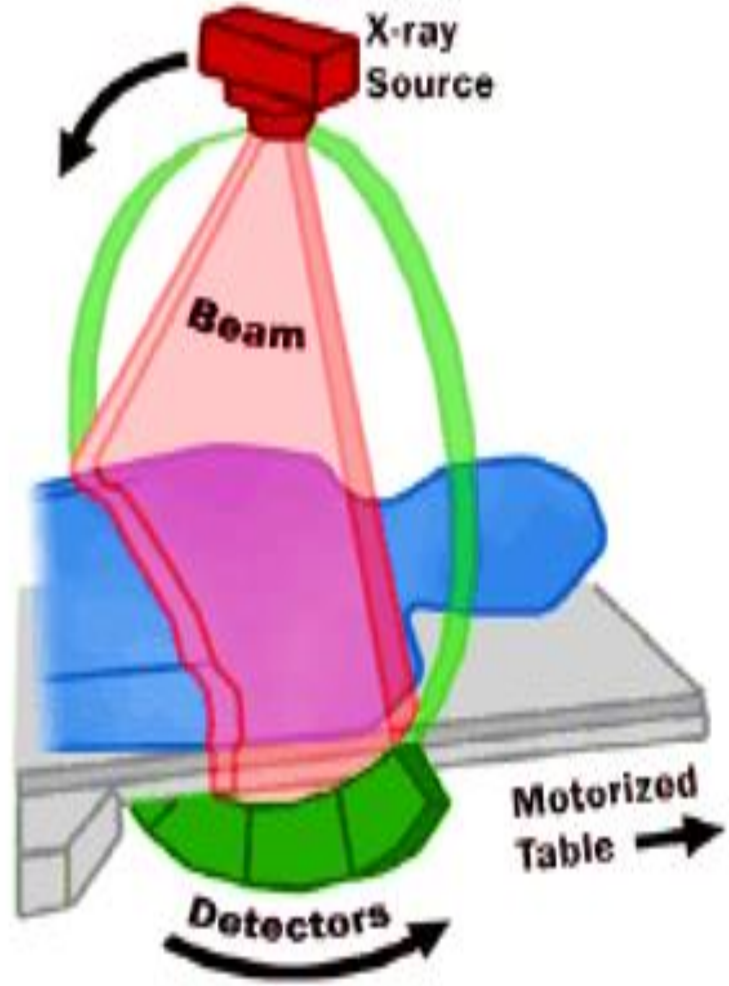

X-ray CT imaging

2D CT

3D CT

4D CT

Example of CT scan

COMPUTED TOMOGRAPHY SYSTEM COMPONENTS

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2. Inside the CT scanner, there is a rotating frame that has an X-ray tube on one side and the detector on the opposite side. A beam of X-ray is generated as a rotating frame spins the X-ray tube and detector around the

Generation of X-Rays

For medical imaging, x-rays are generated by an x-ray tube. In this device, a **metal filament** is heated until energetic electrons escape from the cathode surface into a vacuum. These electrons are then **accelerated** by an electric field, gaining kinetic energy while being attracted to a positive anode target.

The total amount of **energy** acquired by the electron in the accelerating electric field is **equal to** the product of the potential (peak kilovoltage, kVp) multiplying by the unit of electrical charge, possessing units of **electron volts** (kilo electron volts, keV). The amount of charge generated by the x-ray tube per unit time has units of electrical current (milliamperes, mA), and the product of voltage and current is the amount of power (watts) delivered by the tube.

- When the electrons collide with the target, most of their energy is dissipated into heat but a small fraction (<1%) is converted into several forms of electromagnetic radiation.
- In typical clinical operation, an x-ray tube delivers on the order of 2×10^{11} x-rays per second to the patient.

Detection of X-Rays

Detection of x-rays is accomplished by the use of special materials that convert the high energies (tens of keV) of the x-ray quantum into lower energy forms, such as optical photons or electron-hole pairs, which have energies of a few electron volts.

The detector materials, such as phosphors, scintillating ceramics, or pressurized xenon gas produce an electrical current or voltage.

Electronic amplifiers condition this signal, and an analog-to-digital converter converts it into a digital number.

Computer Tomography Benefits

1. Non invasive, quick, and painless.
2. Good locative resolution.
3. Good view of veins.
4. Distinguished by small differences in physical density.
5. Avoids insertion of an arterial catheter and guidewire.

Computer Tomography Risks

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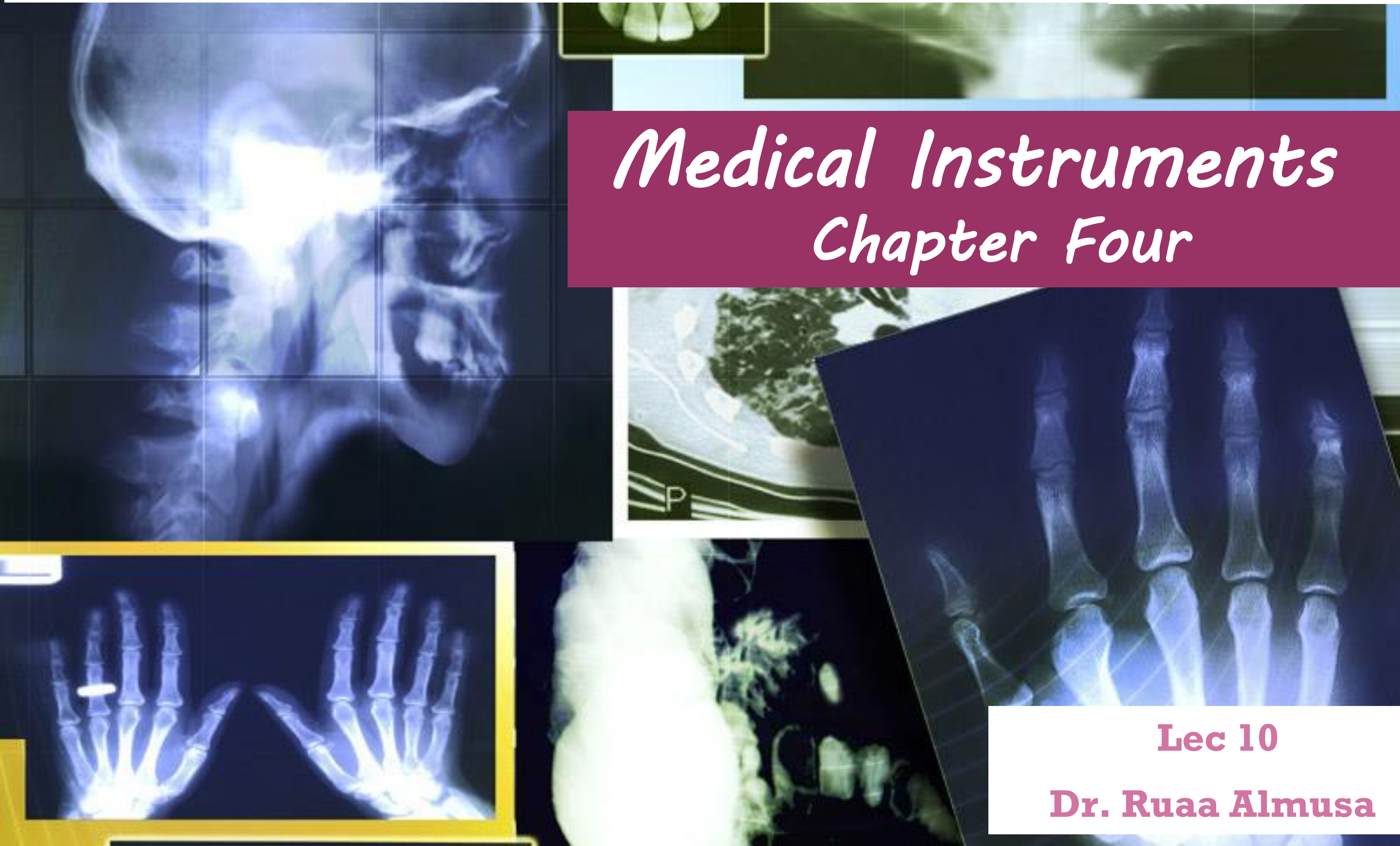

Medical Instruments

Chapter Four

Lec 10

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Chapter four Medical Imaging Techniques

The Hounsfield units

All the CT scanners programmed such that water appears dark on the image, its attenuation value in Hounsfield unit (HU) is 0, from this **central point** HU range from +1000 HU to the -1000 HU

Air = −1,000 HU or less (black)
Fat = −5 to −50 HU (dark gray)
Water = 0 H U (gray)

Soft tissue = +40 to +80 HU (light gray)
Calcium (stone) = +100 to +400 HU (gray white)
Cortical bone = +1,000 HU (white)

Contrast CT

In contrast CT, a fluid containing **iodine** (dense mineral) is injected intravenously, contrast is routinely employed during chest abdomen and pelvis CT, it help to identify abnormal structure that may be differentiated from other normal structures. contrast is help to detect primary or metastatic cancer, infection or vascular malformation.


A
Siloam

3D & 4D CT Scan Images

Software provided in CT scanners allows for the conversion of axial images into images in any other plane desire, 3D pictures utilizing shading techniques to create the appearance of 3D are sometimes helpful when evaluating facial bone fractures and the fractures of the hip before reconstruction surgery.

Four-dimensional CT (4DCT) is record multiple images over time. It allows playback of the scan as a video, so that physiological processes can be observed and internal movement can be tracked. The name is derived from the addition of time (as the fourth dimension) to traditional 3D computed tomography. Alternatively, a particular process, such as respiration, may be considered the fourth dimension.


A
R
P
L
Standard
Head First Supine

Radiography	CT Scan
X-ray machines uses for scanning the effected body part like fracture, bones dislocation, lungs infections, pneumonia and tumors.	CT scan process is a kind of advanced x-ray machines, which provide the much detailed structure of the affected body part and even more clear images of the internal tissues and organs.

Radiography	CT Scan
• Invented By Wilhelm Rontgen in 1895.	• Invented By Godfrey Hounsfield and Allan Cormack in 1972.
• Internal organs injuries details are not clearly visible.	• produce deep and high-quality images and images appear on the computer screen which is more powerful and clear.

Radiography	CT Scan
• Inexpensive • Doesn’t allowed to quantify the density.	• Expensive • CT allows to quantify radiographic density through measuring HU. • Is preferred when more anatomic details is required.

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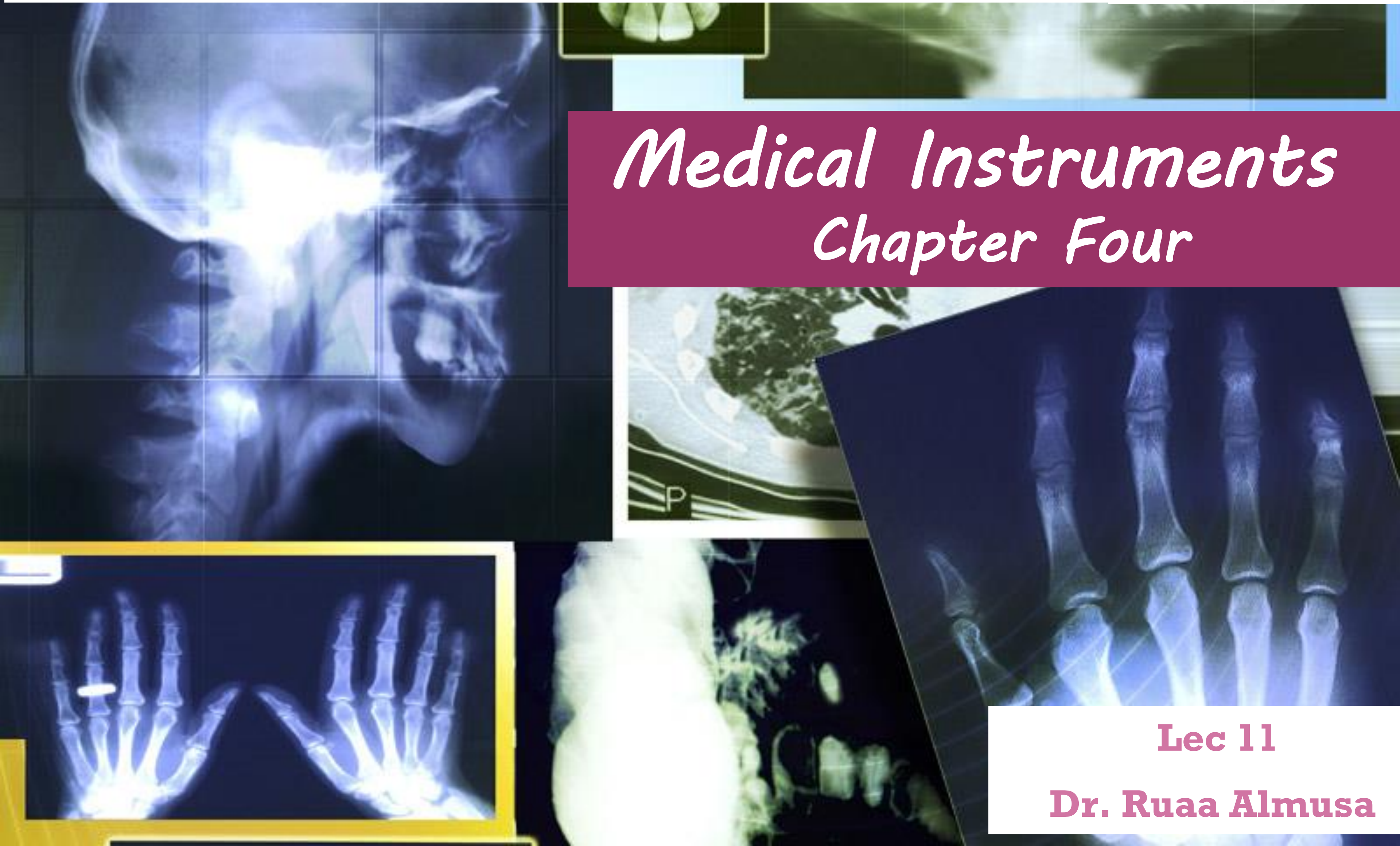

Medical Instruments

Chapter Four

Lec 11

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Chapter four
Medical Imaging Techniques

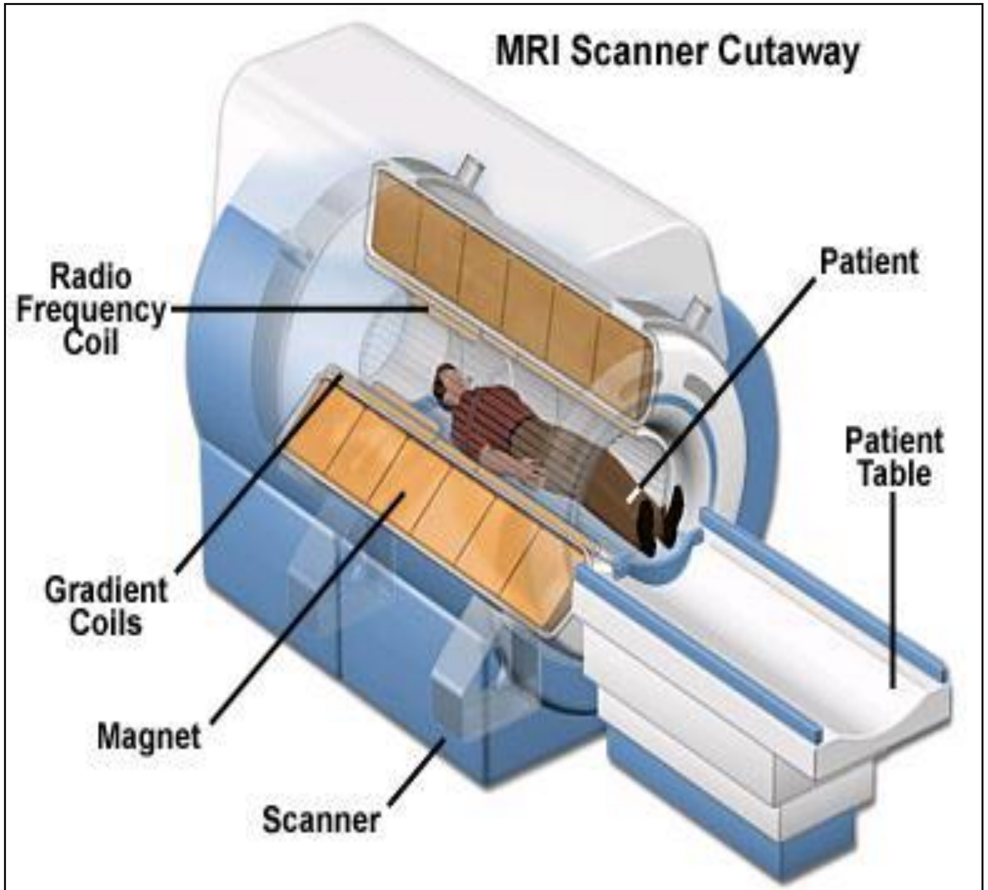
Magnetic Resonance Imaging (MRI)

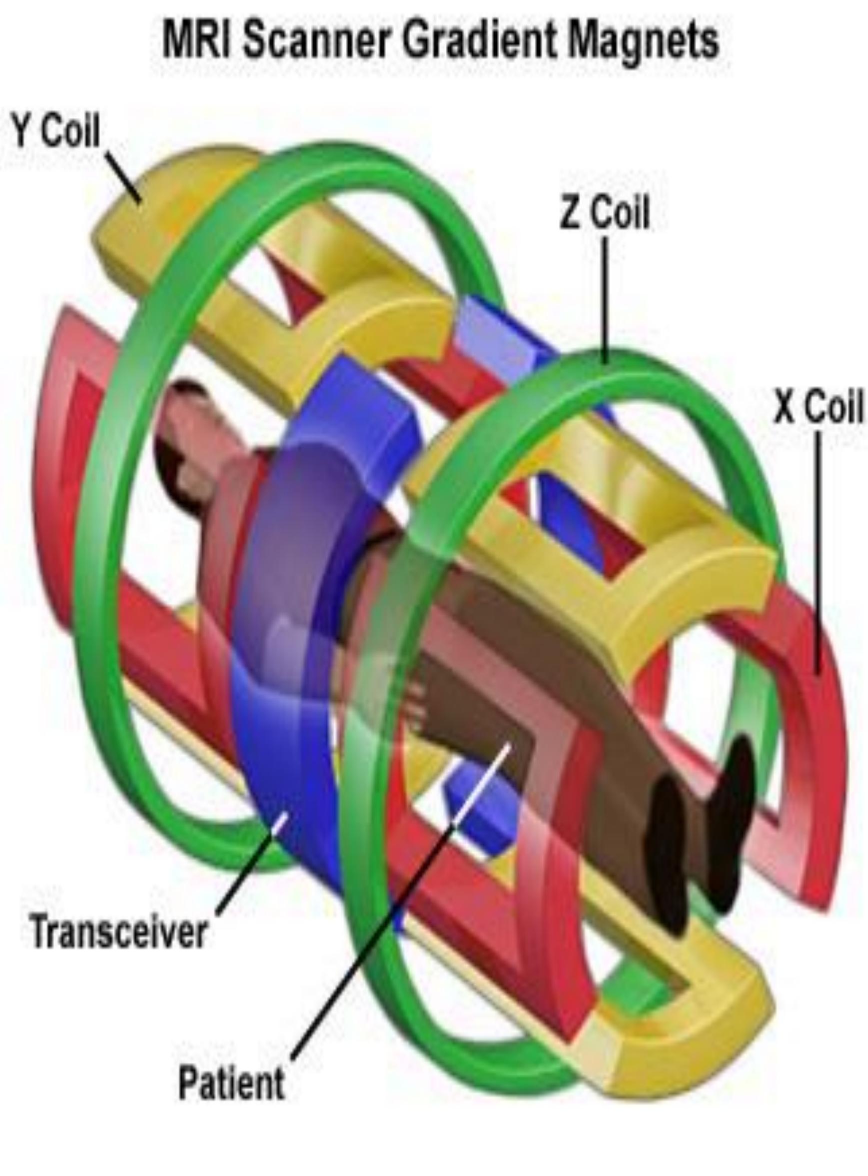
MRI is a powerful diagnostic technique for soft tissues, tendons and ligaments. MRI system implies strong and uniform **magnetic field** together with **radiofrequency waves**. MRI machine is also termed as **Nuclear Magnetic Resonance (NMR)**.

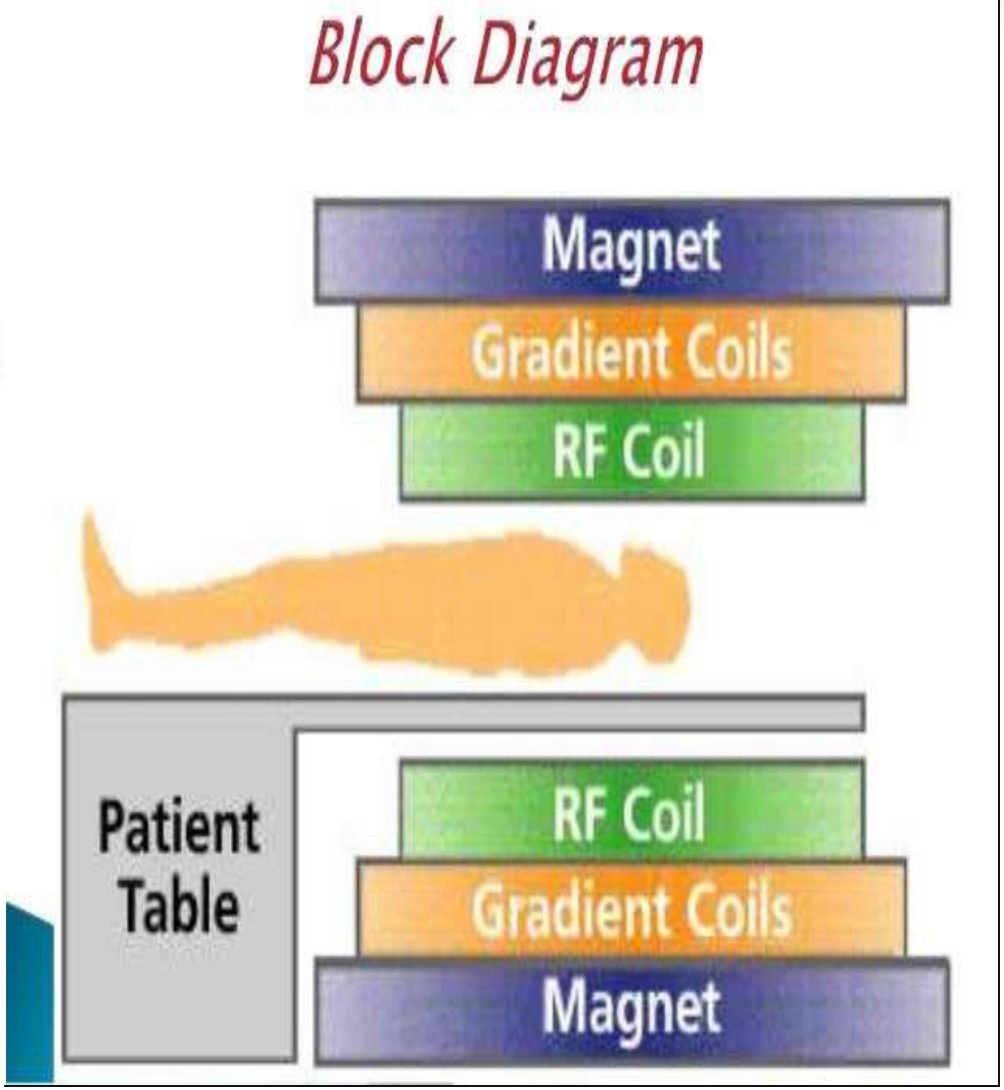
MRI Machine

The main parts of the machine are:

- Radio Frequency Coils
- Gradient Coils
- Magnet
- Scanner




MRI Scanner Gradient Magnets
Y Coil
Z Coil
X Coil
Transceiver
Patient


Block Diagram
Magnet
Gradient Coils
RF Coil
Patient Table
RF Coil
Gradient Coils
Magnet

WHO CAN'T HAVE AN MRI SCAN

- A cardiac pacemaker
- Certain clips in head from brain operations
- A cochlear implant
- A metallic foreign body in your eye
- Had surgery in the last 8 weeks
- pregnant
- People who get nervous in small places

MRI work principle

MRI makes use of the magnetic properties of **Hydrogen** nucleus (**single proton**) present in water molecules, and therefore in all body tissues.

What kinds of nuclei can be used for NMR

- Nucleus needs to have 2 properties:
  - Spin
  - charge
- Nuclei are made of protons and neutrons
  - Both have spin ½
  - Protons have charge
- Pairs of spins tend to cancel, so only atoms with an odd number of protons or neutrons have spin
  - Good MR nuclei are ^{1}H, ^{13}C, ^{19}F, ^{23}Na, ^{31}P

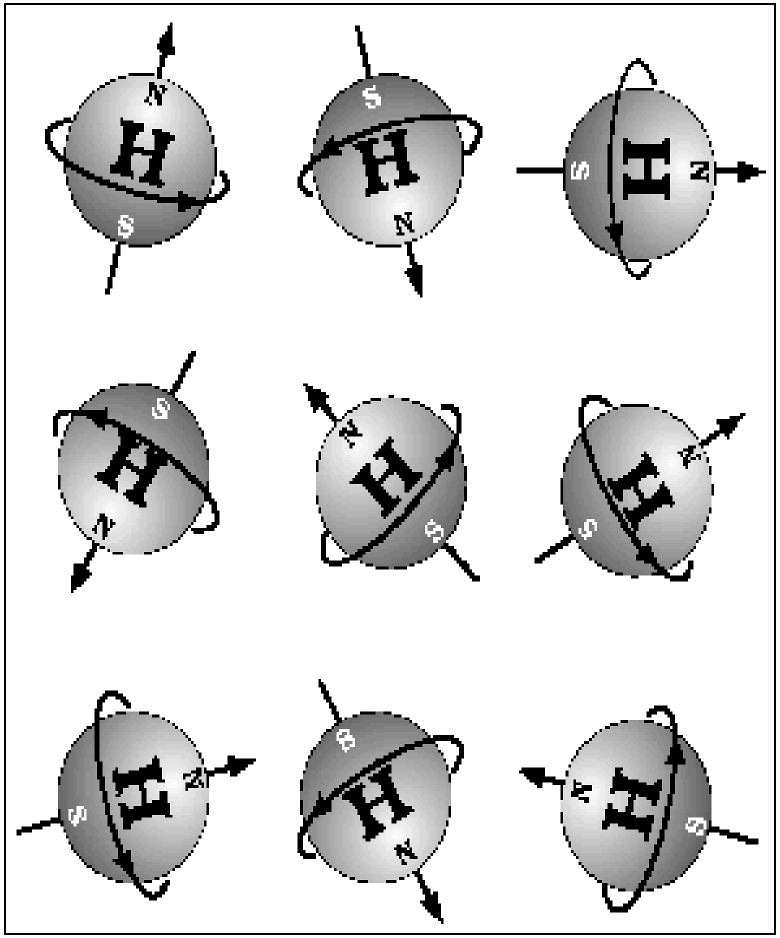
What kinds of nuclei can be used for NMR?

- Biological tissues are ^{12}C, ^{16}O, ^{1}H, and ^{14}N
- **Hydrogen** atom is the only major species that is MR sensitive
- Hydrogen is the most existence atom in the body
- The majority of hydrogen is in water (H_2O)
- Essentially all MRI is hydrogen (proton) imaging

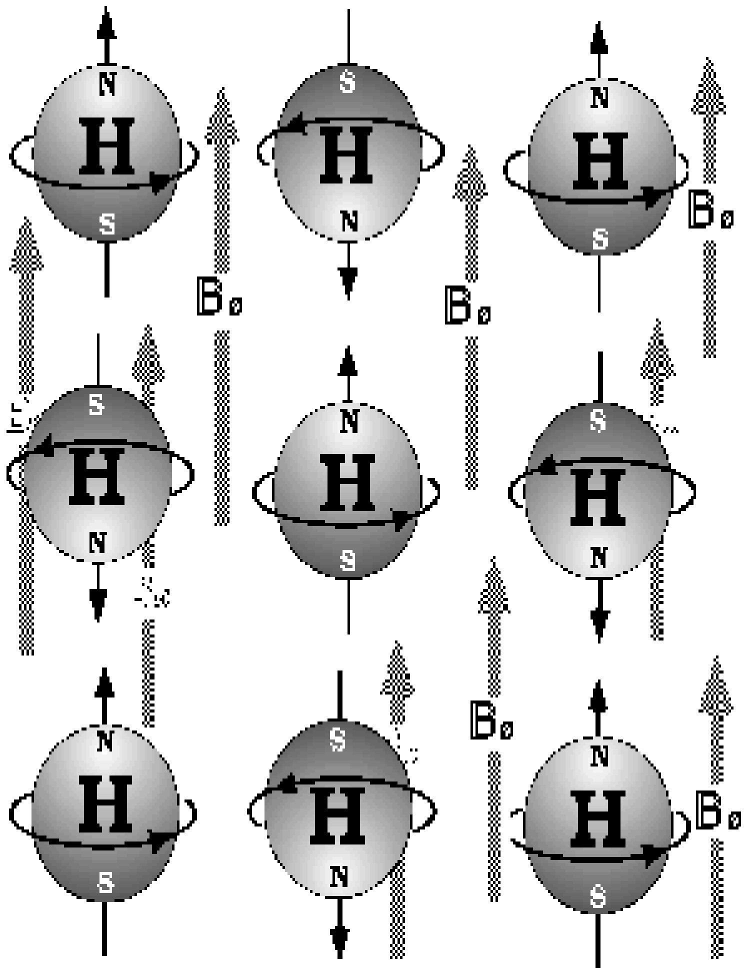
Hydrogen (H^+)

- ► Simplest element with atomic number of 1 and atomic weight of 1
- ►When in ionic state (H+), it is nothing but a proton.
- ►hydrogen has magnetic spin.
- ►MRI utilizes this magnetic spin property of protons of hydrogen to create images.

►The protons in body are spinning randomly, and. cancelling to each other by giving out net magnetization zero. That is our natural state.



►When a Magnetic field with strength: 0.3 – 7 T (2500 times more than earth’s magnetic field) applied the protons are lined up.

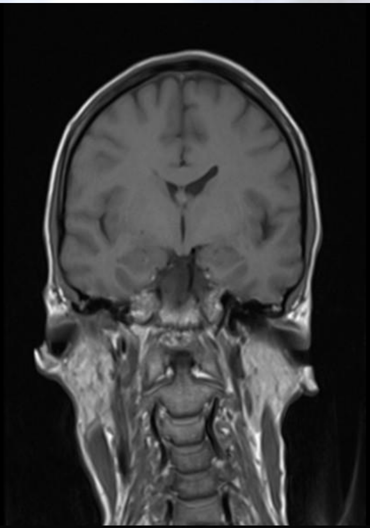


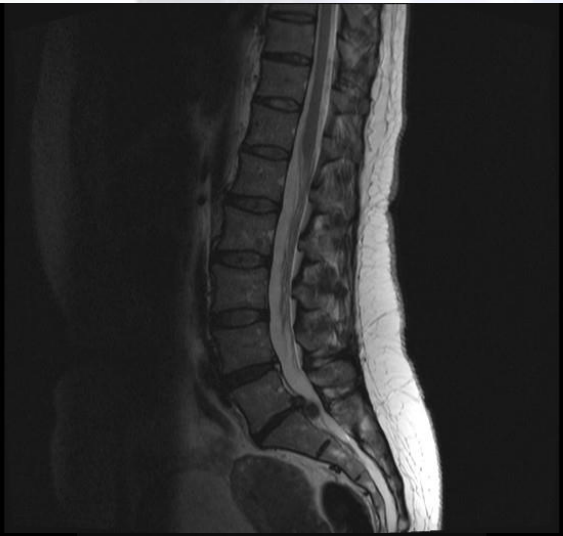
- Radio frequency pulses equal to frequency of hydrogen proton **(in resonance)** push the lined up protons (H+) to a higher energy level.

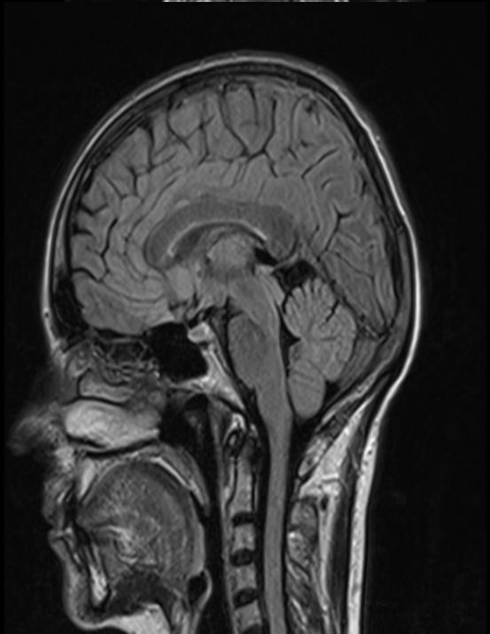
- Once the pulses stop the nuclei go back to their state induced by the magnet.

- The energy released by the nuclei create a signal.

- These radio waves are picked up by a computer where they are translated into an image.







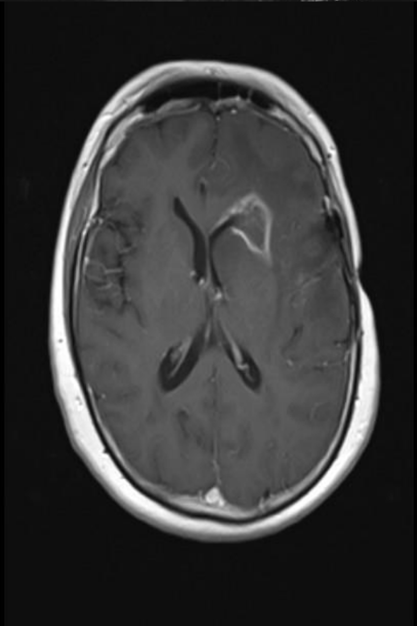


Image formation

Often, patients are injected with a contrast dye during the scan

- ✓ The dye will reach different tissues at different rates.
- ✓ The image being sent back to the computer will have different strengths depending on the level of contrast dye in the tissues.

ADVANTAGES OF MRI

1. The MRI does not use ionizing radiation, which is a comfort to patients.
2. the contrast dye has a very low chance of side effects.
3. ‘Slices’ images can be taken on many planes.
4. Better contrast resolution.
5. Many details without contrast dye (pregnancy allergy).
6. Noninvasive and painless.
7. Good soft tissue contrast.

DISADVANTAGES OF MRI

1. Claustrophobia. Patients are in a very enclosed space.
2. Weight and size. There are limitations to how big a patient can be.
3. Noise. The scanner is very noisy.
4. Keeping still. Patients have to keep very still for extended periods of time.
5. Sedation may be required for young children who can’t remain still.

6. Cost. A scanner is very, very expensive, therefore scanning is also costly.

7. Dangerous for patients with metallic devices placed within the body.

8. RF transmitters can cause severe burns if mishandled.

9. No real time information.

10. Cannot detect intra-luminal abnormalities.

11. Time consuming.

12. Not easily available (long waiting list).