

DMI COLLEGE OF ENGINEERING

III YEAR / V SEMESTER

CBM355 - MEDICAL IMAGING SYSTEM

IMPORTANT TWO MARKS (UNIT-1)

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PART-A

1. Define Nature of Rays.

⇒ X-Rays are electromagnetic radiation located at the low wavelength end of the electromagnetic spectrum.

⇒ The X-Rays in the medical diagnostic region have wavelength of the order of 10^{-10} m

⇒ They propagate with speed of 3×10^{10} cm/s and are unaffected by electric and magnetic fields.

⇒ According to the quantum theory,

$$E = h\nu = h\frac{c}{\lambda}$$

h = Planck's constant = 6.32×10^{-34} Js

c = Velocity of Propagation of photons = 3×10^{10} cm/s

ν = Frequency of radiation

λ = wavelength

2. Write a short note on Medical imaging Systems

- ⇒ A medical Imaging system is a crucial tool used in the field of healthcare to visualize internal structures and organs of the human body.
- ⇒ It allows medical Professionals, such as radiologists and Physicians, to diagnose and monitor various medical conditions accurately.
- ⇒ Medical Imaging Plays a significant role in the early detection and treatment of diseases.

3. Define Tissue contrast.

- ⇒ Tissue contrast, in the context of medical imaging, refers to the visual distinction or difference in appearance between different types of tissues (or) structures within the human body.

EXAMPLE

- * X-Ray
- * Computed tomography (ct).

4. List out of the Ideal Requirement of x-Rays

- ⇒ Safe and accurate.
- ⇒ Small.
- ⇒ Easy to maneuver and Position
- ⇒ Simple to operate
- ⇒ Robust
- ⇒ Easily folded and stored
- ⇒ Stable, balanced and steady once the tube head has been positioned.

5. Define Bucky grid.

- ⇒ A Bucky grid, also known as grid or grid cassette, is an essential accessory used in X-Ray imaging to improve the quality of X-Ray image.
- ⇒ It is positioned between the Patient and the image receptor (such as X-Ray film or digital detector) and is particularly useful when imaging thicker body parts or when using high energy X-Ray beams.

6. Write a note on Purpose of a Bucky grid.

⇒ The Primary Purpose of a Bucky grid is to reduce the amount of the scattered radiation reaching the image receptor during X-Ray imaging.

⇒ Scattered Radiation degrades the image quality by reducing contrast and increasing the overall image fog (or) haze.

7. List out the two important characteristics of Bucky grid.

⇒ Grid Ratio

⇒ Grid frequency

GRID RATIO

⇒ The grid ratio is the ratio of the height of the lead strips to the distance between them.

Example

5:1, 6:1, 8:1, 10:1

- GRID FREQUENCY
- ⇒ The grid frequency refers to the number of lead strips per unit length.
 - ⇒ Grid frequency is typically expressed in lines per unit (LPI) or Lines Per continuous (LPC)

8. Define Digital Radiography and its advantages.

- ⇒ Digital Radiography is a form of x-Ray imaging, where digital x-Ray sensors are used instead of traditional photographic film.

ADVANTAGES

- ⇒ Immediate Image Preview and availability.
- ⇒ Elimination of costly film Processing steps
- ⇒ A wider dynamic range, which makes it more forgiving for over- and under exposure.

9. What are the classifications of digital Radiography

Digital Radiography

Direct Radiography

Direct detection

Indirect detection

Computed Radiograph

10. List out the types of digital Radiography detectors : 12

- ⇒ Discrete digital detectors
- ⇒ Storage Phosphors
- ⇒ Film scanning

11. Define Fluoscope.

- ⇒ Fluoscope is a medical imaging technique that uses x-rays to obtain real-time moving images of internal structures and organs within the body.
- ⇒ It is commonly used to visualize dynamic processes, such as the movement of organs, blood flow and the passage of contrast agents through the body.
- ⇒ the procedure involved the use of specialized x-ray machine called a Fluoscope

12. Define Digital Fluoroscopy.

⇒ Digital fluoroscopy is a modern medical imaging technique utilises digital technology to capture and display real-time x-ray images of internal structures and processes within the body.

⇒ It is an advancement over traditional fluoroscopy, which used an image intensities tube

13. Define Angiography

⇒ Angiography is a medical imaging technique used to visualize the blood vessels (arteries and veins) and their flow patterns within the body.

⇒ It is commonly used to diagnose and assess various vascular conditions and disease

⇒ Angiography provides detailed and precise images of the blood vessels, allowing medical professionals to detect blockages/narrowing, aneurysms and other abnormalities.

14. Write a short note on cine Angiography

⇒ Cine angiography also known as digital subtraction angiography (DSA) ... is a specialized types of angiography that provides real-time imaging of blood vessels using x-rays and digital technology.

⇒ It is an advancement over conventional angiography and offers several benefits including reduced radiation exposure and improved image quality.

15. Write a short note on Mammography

⇒ Mammography is a specialized medical imaging technique used to detect breast abnormalities, particularly breast cancer, in both men and women.

⇒ It involves the use of low-dose x-rays to create detailed images of the breast tissue.

16. List out the types of Grid ratio (Bucky grid)
- ⇒ Low - Ratio Grid (4:1 , 5:1)
 - ⇒ Medium Ratio grid (6:1 , 8:1)
 - ⇒ High - Ratio grid (10:1 , 12:1)
 - ⇒ Very - High Ratio grid (16:1 & above)
17. List out the advantages of digital fluoroscopy.
- ⇒ Improved Image Quality
 - ⇒ Dose Reduction
 - ⇒ Image Storage and Post - Processing
 - ⇒ Integration with other Imaging Modalities.
18. List out the advantage of discrete electronics.
- ⇒ High spatial resolution
 - ⇒ Fast image acquisition times
 - ⇒ Wide dynamic range
 - ⇒ It captures a broad range
 - ⇒ X-ray intensities accurately.

19. What are types of Bucky grids and advantages
of Disadvantage

⇒ Stationary grid

⇒ Moving grid (Bucky grid)

ADVANTAGES OF STATIONARY GRID

⇒ Simplicity

⇒ Durability

ADVANTAGE OF MOVING GRID

⇒ Reduced Grid lines.

⇒ Improved Image Quality

DISADVANTAGE OF STATIONARY GRID

⇒ Grid lines

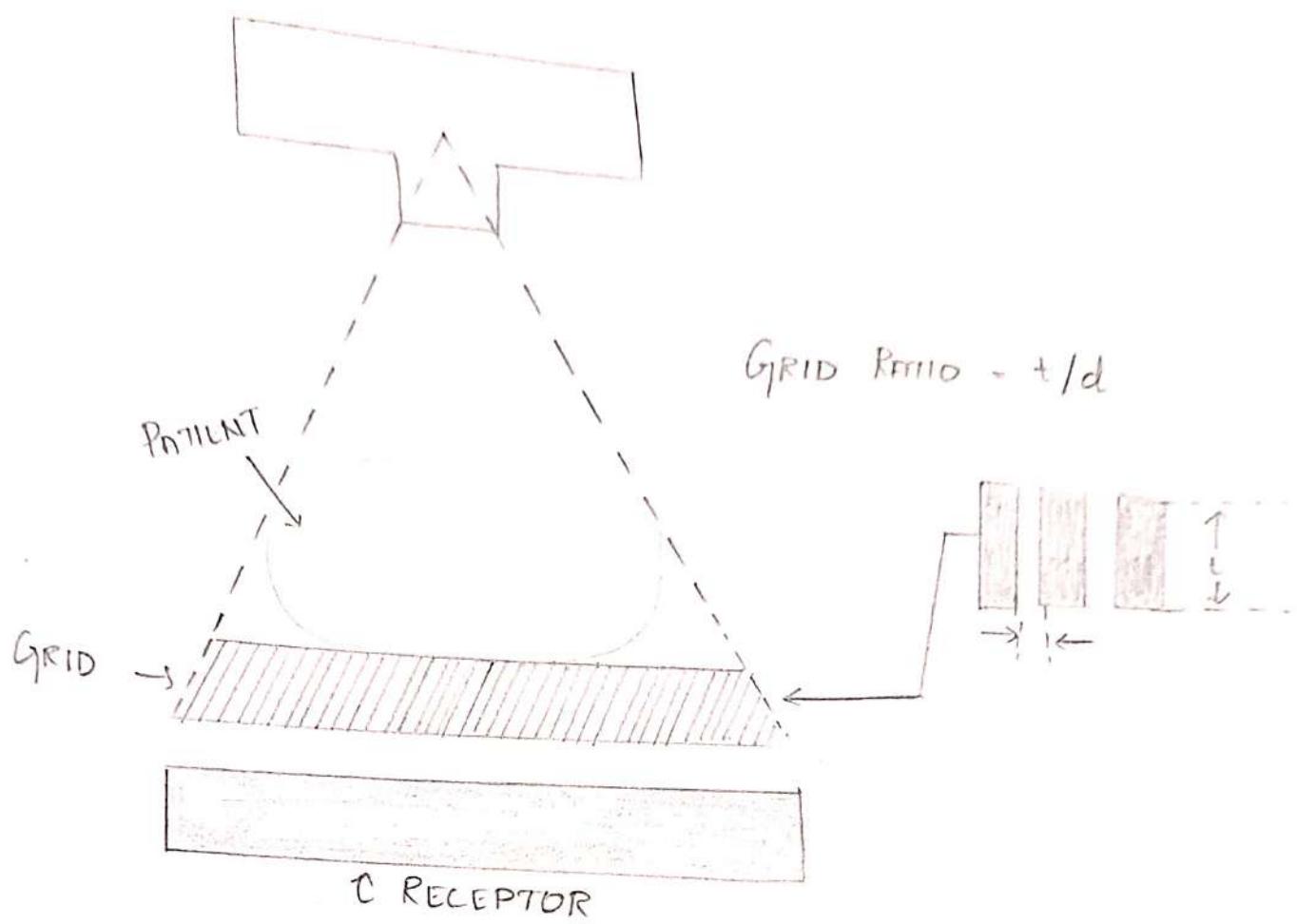
DISADVANTAGE OF MOVING GRID

⇒ Complexity

⇒ Potential for Mechanical Issues.

"ages 20.

Draw the grid ratio.



GRID RATIO

removal
mechanisms for heat

Point-B

1. Describe in detail about production of rays

X-rays:

→ Three types of rays emit continuously from a radium material. These rays are known as alpha rays (α rays), Beta rays (β rays) and gamma rays (γ -rays).

→ Gamma rays also known as X-rays.

→ The frequency of X-rays is approximately 10²⁰ Hz and its wavelength is approximately 10^{-10} meters.

→ X-rays are electromagnetic wave which are widely used in medical field and industries for inspection of human body or any other thing

→ Production Of X-rays:

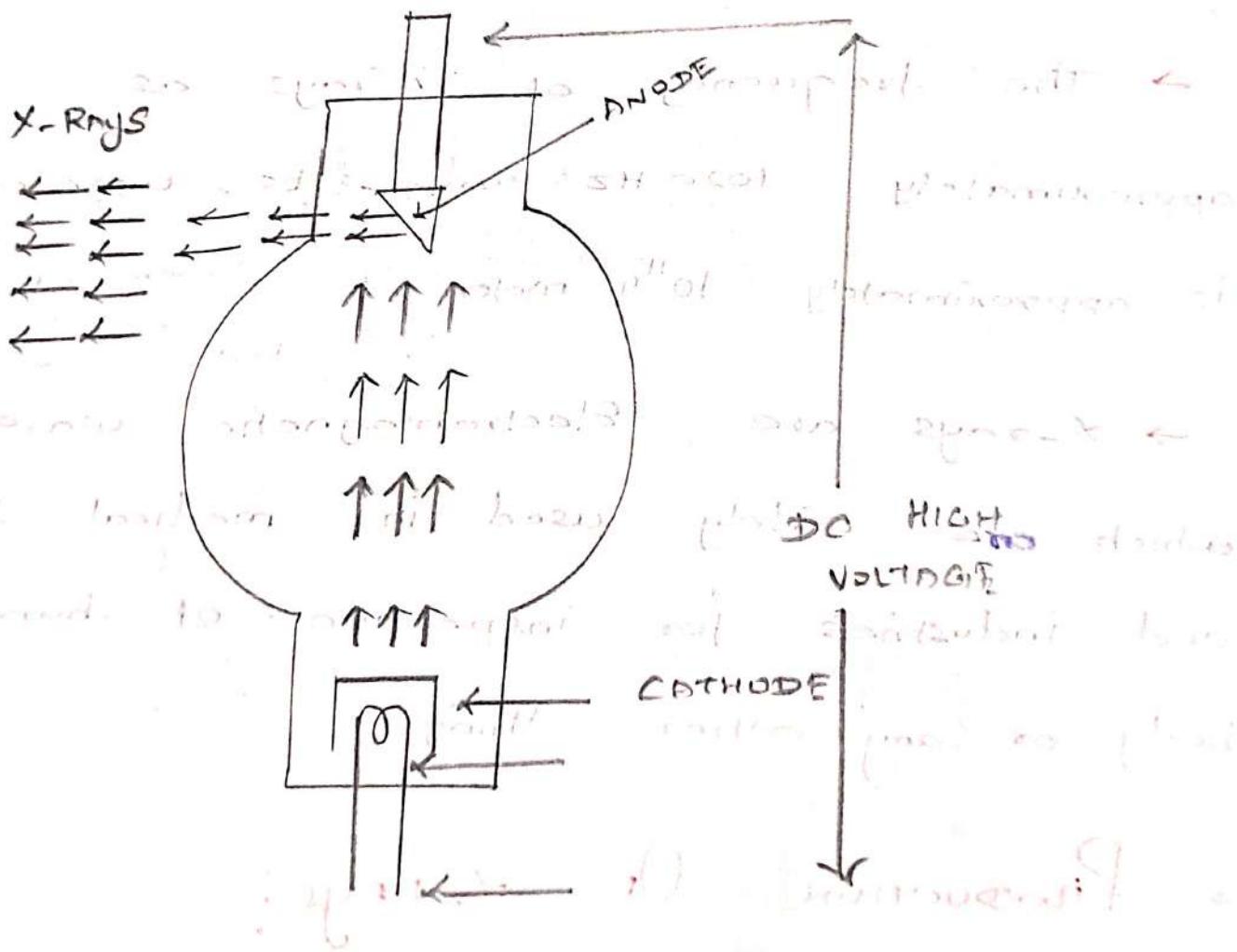
→ X-rays can be produced with the help of high vacuum tube with a cathode, anode and anode.

→ Vacuum tube is operated at very high voltage.

→ A special electron tube (vacuum tube) is used for production of X-rays.

→ Such a tube has a hot filament cathode, an anode made of a heavy metal.

→ Electron flow from the cathode to anode as in any diode tube. However a large DC voltage is used b/w cathode and anode of X-rays tube.



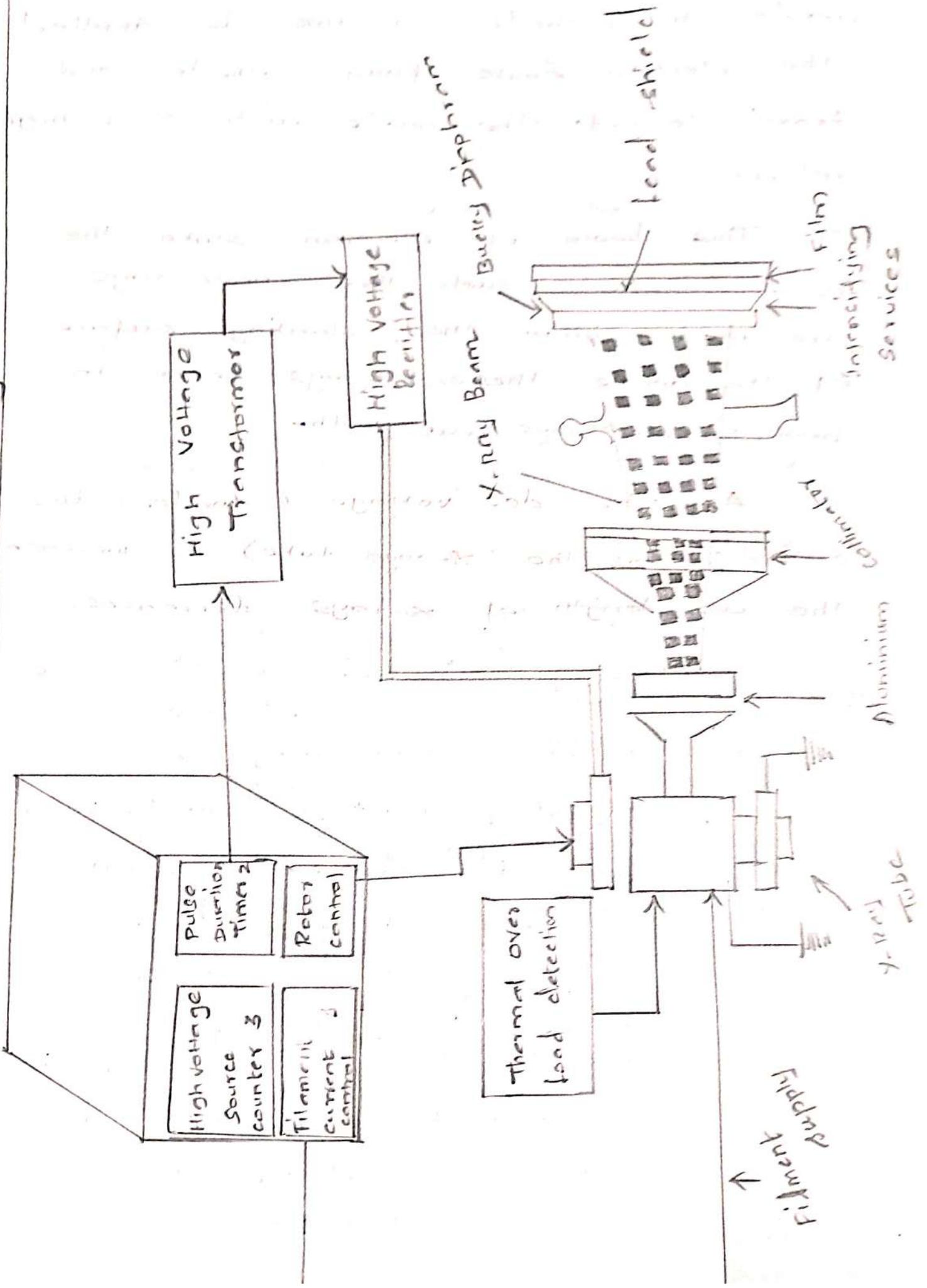
X-RAY TUBE

→ When heater is on and very high anode to cathode voltage is applied the electron emits from cathode and travel towards the anode with very high velocity.

→ This beam of electron strike the metal anode, such that new rays are made from the slanting surface of the anode these x-ray seem to bounce sideways out.

→ As the dc-voltage (anode-to-cathode of the x-ray tube) is increased, the wavelength of x-rays decreases.

2) Explain the Block Diagram Of X-ray in detail.



X-ray equipment consists of various components that work together to generate X-rays, capture the X-ray images, and ensure safety and accuracy during the imaging process.

(i) X-ray TUBE:

→ The X-ray tube is the heart of the X-ray machine, responsible for producing X-rays.

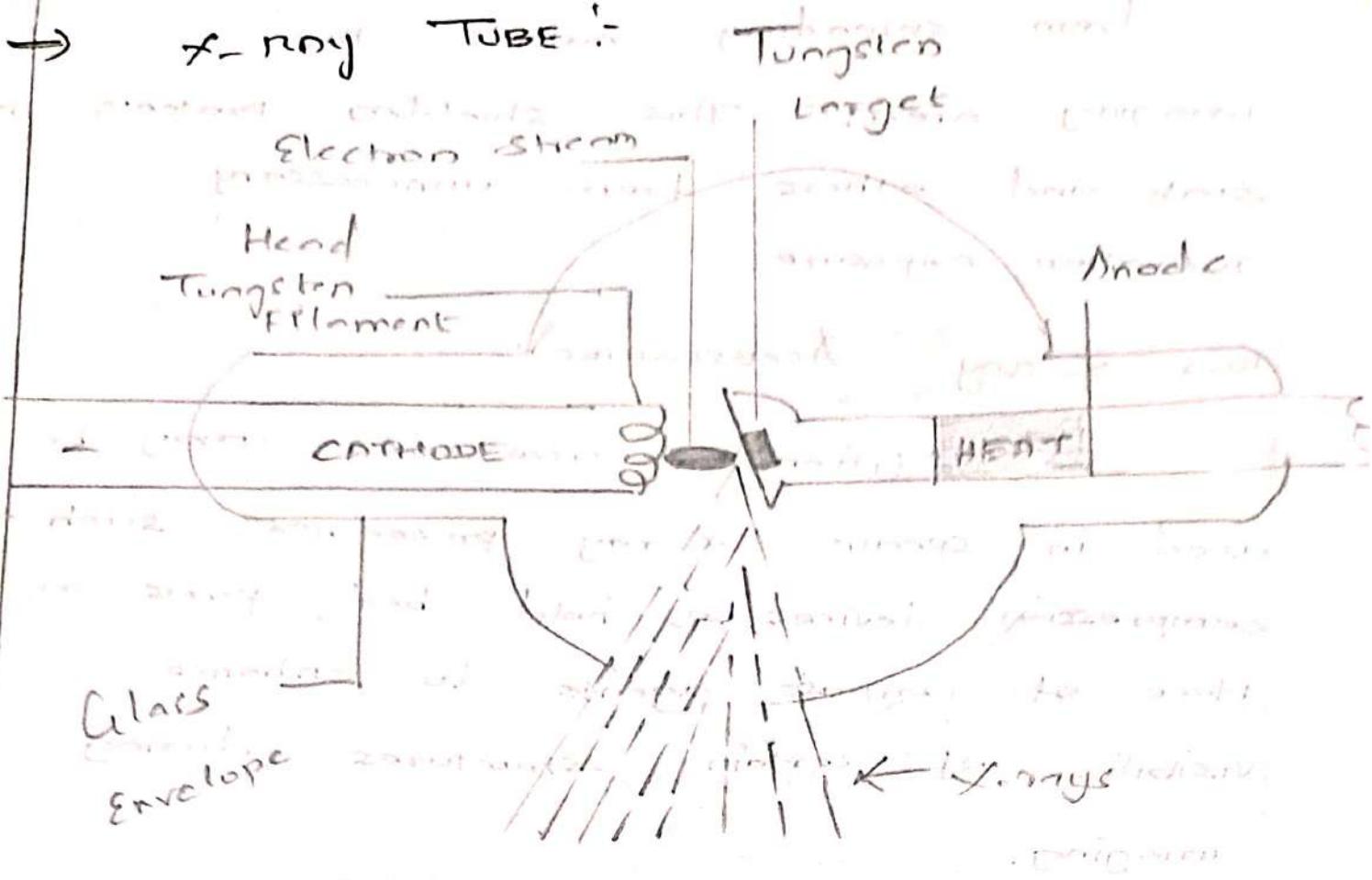
→ It consists of a vacuum-sealed glass or metal enclosure that houses a cathode and an anode.

→ When energized, the cathode emits a stream of electrons that are accelerated toward the anode.

→ During interaction between the electrons and the anode, produces X-rays.

(ii) COLLIMATOR:

→ The collimator is a device mounted near the X-ray tube that shapes and restricts the X-ray beam to a specific area of interest.



→ The X-ray tube is crucial component of X-ray equipment, responsible for producing X-rays, that are used for medical imaging, industrial testing, security screening and other applications.

→ It is a vacuum-sealed device that contains a cathode and an anode, where the X-ray generation process occurs.

Let's delve into the details of the X-ray tube.

1. cathode:

→ The cathode is the negative electrode of the x-ray tube. It consists of a filament made of tungsten or another refractory metal.

→ When an electric current passes through the filament, it heats up, causing the emission of electrons through a process called thermionic Emission.

→ The emitted electrons form an electron cloud around the filament.

2. Anode:

→ The Anode is the Positive electrode of the x-ray tube, placed opposite to the cathode.

→ It is typically made of a rotating disc or a stationary target made of tungsten, molybdenum or other metals with high atomic numbers.

→ The anode is usually encased in a metal block to dissipate the heat generated during x-ray production.

3. → X-ray Production Process :

→ When the x-ray machine is turned on, a high voltage is applied b/w the cathode and the anode.

→ The voltage causes the electrons from the cathode's electron cloud to accelerate rapidly toward the anode.

→ As the electrons strike the anode's target, they undergo a sudden deceleration, resulting in the emission of x-ray photons.

→ This phenomenon is known as Bremsstrahlung radiation (braking radiation).

→ Additionally, when the high-speed electrons interact with the atoms in the anode's target material, they can knock out inner-shell electrons, leaving vacancies in the atomic structure.

→ When outer-shell electrons fill these vacancies, characteristic x-rays are emitted.

→ These characteristic x-rays have specific energies related to the atomic

structure of the anode's target material and are used in x-ray spectroscopy for material analysis.

4. → Focal spot:

- The area on the anode's target where the electrons strike is known as the focal spot.
- The size of the focal spot determines the spatial resolution of the x-ray image.
- A smaller focal spot produces higher resolution images, but it also limits the amount of x-ray energy that can be emitted, leading to longer exposure times.
- Larger focal spots are used for procedures where higher x-ray intensity is required but with slightly reduced spatial resolution.

5. → Cooling Mechanism:

- The x-ray tube generates a significant amount of heat during x-ray production.
- To prevent overheating, the x-ray tube is equipped with a cooling system, typically consisting of a rotating anode or oil cooling.

→ The rotating anode design allows the anode to spin rapidly, distributing the heat more evenly, while oil cooling uses a heat exchanger to dissipate the heat.

6. → Housing And Vacuum :-

→ The entire x-ray tube is enclosed in a protective housing that is designed to shield users and patients from unnecessary x-ray exposure.

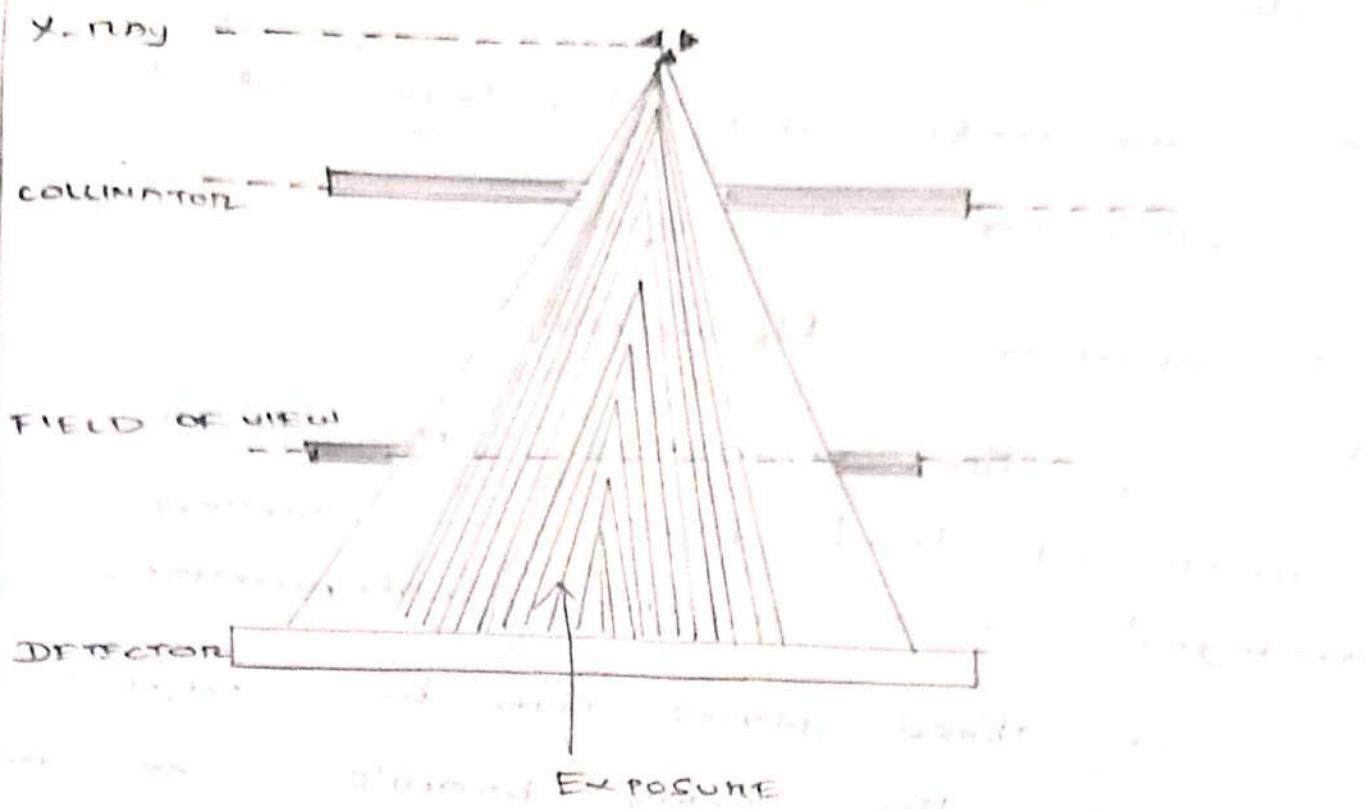
→ The tube is also maintained under a vacuum to minimize electron scattering and to facilitate the efficient production of x-rays.

→ X-ray tubes are available in various designs and configurations to suit different imaging needs.

→ Their performance and durability are essential factors in determining the quality and longevity of the x-ray equipment.

→ In addition to the basic components mentioned above, certain optional features may be included.

⇒ COLLIMATOR:

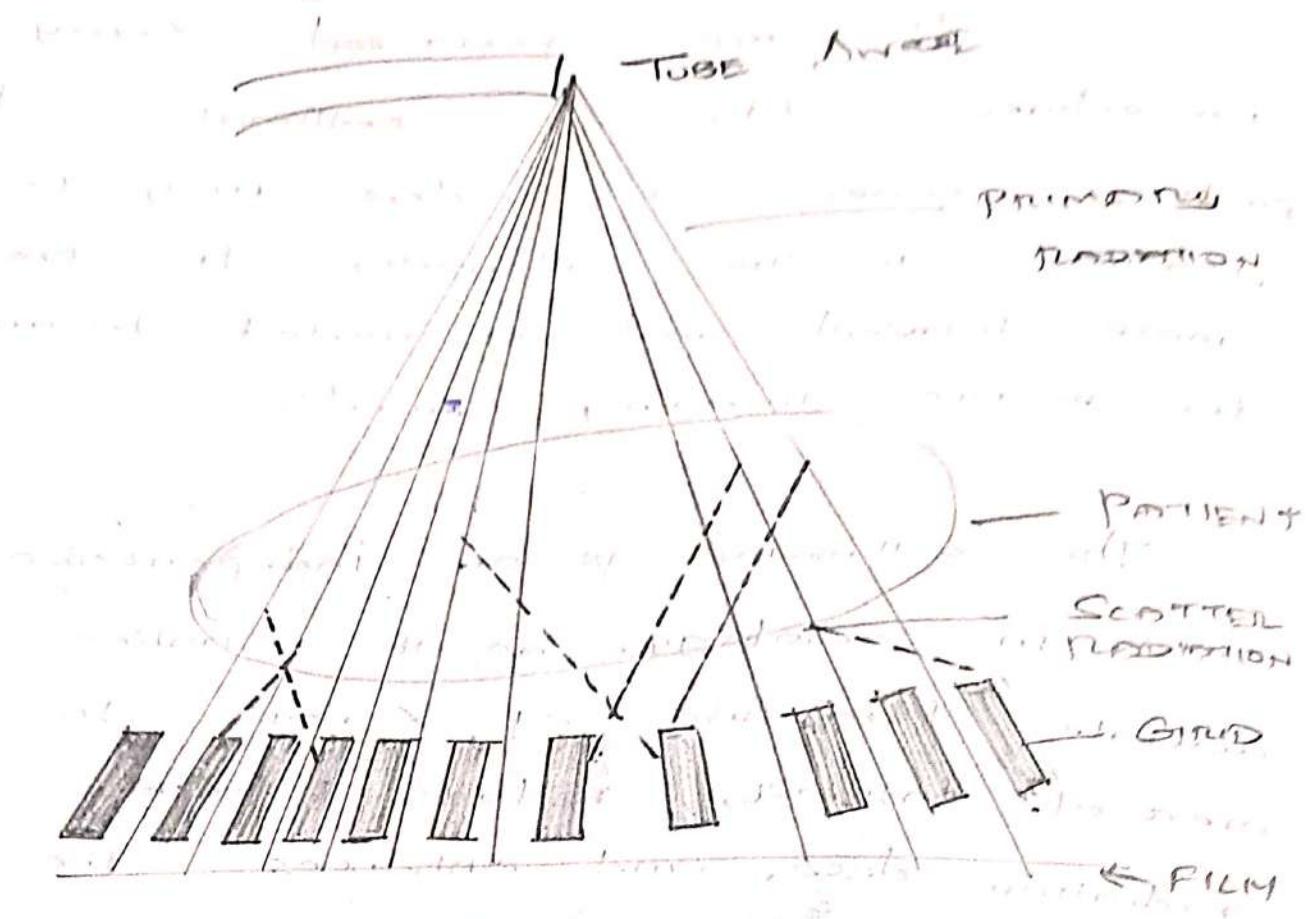


→ A collimator is an essential component in X-ray equipment used to shape and limit the X-ray beam to a specific field size.

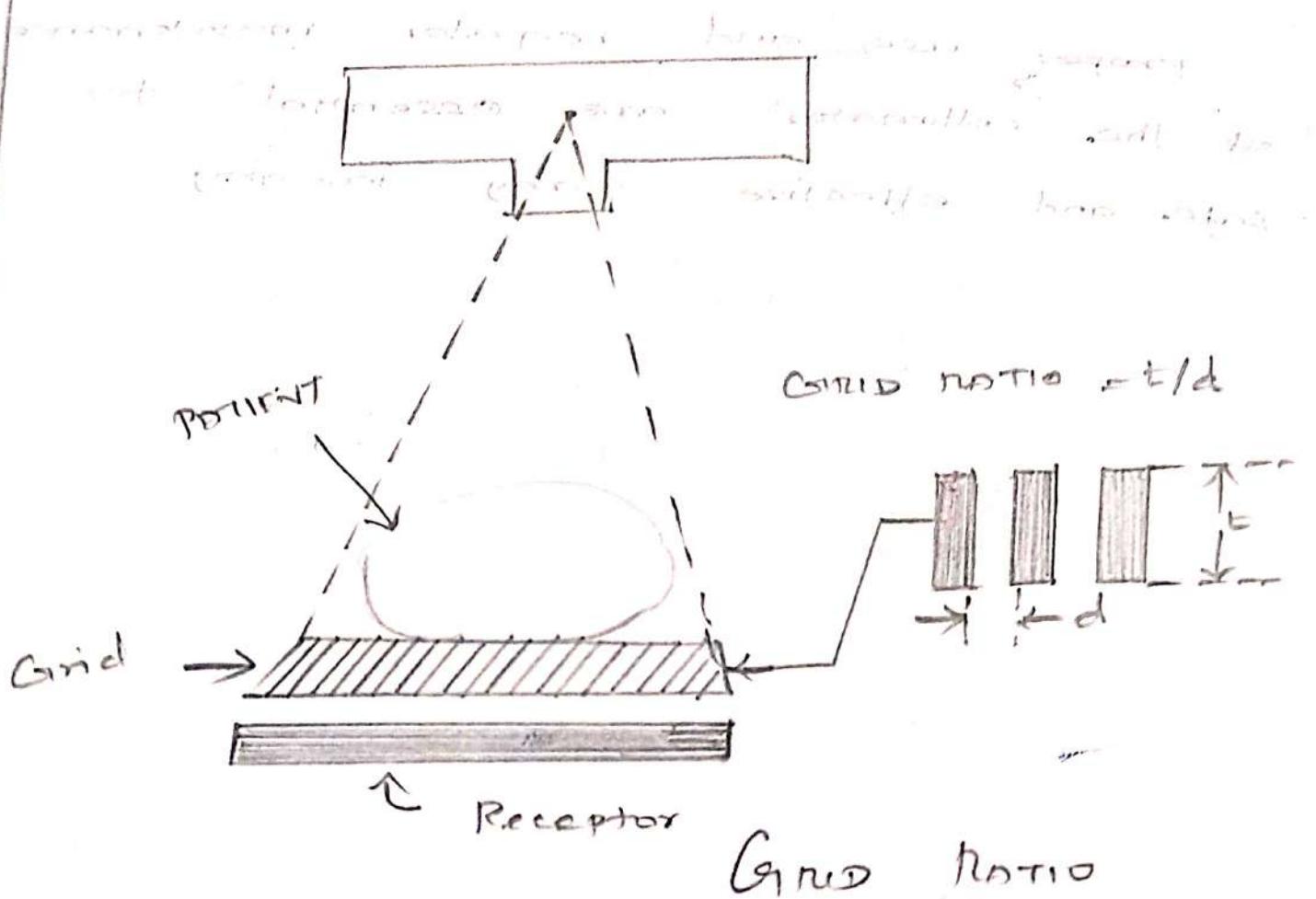
→ Its primary function is to control the size and direction of the X-ray beam, ensuring that only the area of interest is exposed to X-rays while minimizing unnecessary radiation exposure to surrounding tissues and organs.

→ Collimator play a crucial role in optimizing image quality & radiation safety.

→ Buckey Grid :



Grid Function



DMI COLLEGE OF ENGINEERING

MEDICAL IMAGING SYSTEM

IMPORTANT 2 MARKS (UNIT-II)

PART-A

1. What are the limitations of using conventional X-Rays?

- ⇒ There are two main limitations of using conventional X-Rays to examine internal structures of the body.
- ⇒ The super-imposition of the three-dimensional information onto a single plane makes diagnosis confusing and often difficult.
- ⇒ The photographic film usually used for making radiographs has a limited dynamic range and X-Ray absorption relative to their surroundings will cause sufficient contrast differences on the film to be distinguished by the eye.

2. Define tomography.

⇒ Tomography is a term derived from the Greek word 'tomas' meaning 'to write a slice or section.'

3. Define conventional tomography.

⇒ conventional tomography was development to reduce the super-imposition effect of simple radiography.

⇒ X-ray tube and photographic film are moved in synchronisation so that one plane of the patient under examination remains in focus, while all other planes are blurred.

4. Define Pneumo - encephalography.

⇒ With CT images, radiologists could easily visualize the ventricles of the brain and reservoirs of the cerebro-spinal fluid.

⇒ this capability made obsolete a rather unpleasant procedure known as Pneumo - encephalography.

How to calculate
CT image.
⇒ FOX
characteristics

From the
line of

How to calculate the tissue attenuation characteristics of CT image.

⇒ For a monochromatic κ -ray beam, the tissue attenuation characteristics can be described by

$$I_t = I_0 e^{-\mu x}$$

I_0 = Incident radiation intensity

I_t = Transmitting intensity

x = Thickness of tissue

μ = characteristic attenuation co-efficient of tissue.

6. Express the relationship between the linear attenuation coefficient and the corresponding Hounsfield unit.

⇒ The relationship between the linear attenuation coefficient and the corresponding Hounsfield unit is

$$H = \frac{\mu - \mu_{\text{water}}}{\mu_{\text{water}}} \times 1000$$

μ_{water} = attenuation coefficient in water.

H are also denoted by CT numbers.

7. Define slope of the straight line in ct .

⇒ The measured ct values and the known μ -values of these substances are employed in a ct number scale, and the ratio of difference of the ct values to the corresponding difference of the values is given by the slope of the straight line.

$$\frac{I}{K} = \frac{\text{CT}_{\text{plex}} - \text{CT}_{\text{H}_2\text{O}}}{\mu_{\text{plex}} - \mu_{\text{H}_2\text{O}}}$$

where

$$\mu_{\text{plex}} - \mu_{\text{H}_2\text{O}} = 0.029 \text{ cm}^{-1}$$

$$\mu_{\text{H}_2\text{O}} = 0.197 \text{ cm}^{-1} \text{ at } 66 \text{ keV}$$

$$K = 1.9 \times 10^{-4} \text{ cm}^{-1} / \text{ct value}$$

The μ value for various tissues can thus be computed by simply multiplying the measured ct value by K .

8. List four Sub Systems of computer tomography.

- ⇒ Planning System
- ⇒ Processing unit
- ⇒ Viewing Part
- ⇒ Storage unit

9. List the generations of CT.

- ⇒ First generation (Parallel Beam Geometry)
- ⇒ Second generation (Fan Beam, Multiple Detectors)
- ⇒ Third generation (Fan Beam, Rotating Detectors)
- ⇒ Fourth generation (Fan Beam, Fixed Detector)
- ⇒ Fifth generation (Scanning Electron Beam)

10. What are the two types of X-Ray tubes?

⇒ oil cooled fixed anode line - focus

continuous tube

⇒ Rotating anode air cooled
pulsed x-ray tube as source.

5. Define ultra fast CT scanning?

ultra fast CT scanning refers to a medical imaging technique that uses computed tomography (CT) technology to create detailed cross-sectional images of the body at an extremely rapid rate.

This type of CT scan captures images in a matter of seconds or even milliseconds, allowing for high-resolution imaging of organs, blood vessels, and tissues with minimal motion artifacts.

1b. Applications (or) where the ultrafast CT scanning is used?

ultra-fast CT scanning is often used for diagnosing conditions that require real-time imaging such as cardiac studies (or) trauma assessments.

17. List Image Reconstruction techniques.

Two types of Image reconstruction

techniques are followed, they are

→ Basic projection method

→ Iterative method,

→ analytical method (two-dimensional Fourier reconstruction technique).

18. Define Basic projection method ?

It is a simple and direct method.

In this method each of the measured profiles is projected back over the image area at the same angle from which it was taken. At the same time, each projection contributes not only to the points that originally formed the profile, but also to all the other points in its path.

→ Basic projection is analogous to a graphic reconstruction.

11. \rightarrow types of detectors in CT:-

(i) \rightarrow Xenon detector

(ii) \rightarrow Scintillator - photo-multiplication detector

(iii) Scintillation detector.

12. What is Meant by Computed tomography?

Computed tomography (CT) is a medical imaging technique that uses X-ray technology and advanced computer processing to create detailed cross-sectional images of the body. These images are known as 'slices' and provide valuable information about internal structures.

In computed tomography, the picture is made by viewing the patient via X-ray imaging from numerous angles, by mathematically reconstructing the detailed structures and displaying the reconstructed image on a visible monitor.

13. Define Viewing system in CT

Viewing system presents the information in visual form and includes other manipulative aids to assist diagnosis.

14. Define spiral CT Scanning ?

→ This is a scanning technique in which the X-ray tube rotates continuously around the patient while the patient is continuously translated through the fan beam. The focal spot therefore traces a helix around the patient.

→ The projection data thus obtained allow for reconstruction of multiple contiguous images. This operation is often referred to as helix, spiral, volume (or) three-dimensional CT Scanning.

Define Iterative method;

This technique iteratively refines the image reconstruction process, gradually improving image quality by repeatedly estimating and updating the image until convergence.

20. Define Analytical Method / Two-dimensional

Fourier reconstruction technique / convolution.

current commercial scanners use a mathematical technique known as convolution (or) filtering.

This technique employs a spatial filter to remove the blurring artifacts.

This is achieved by convolving the shadow function with a filter so that each point in the projection has a negative value instead of 0, at every point other

than its proper place in the projection.

21) Define Convolution kernel?

The blurring effect is counteracted in the convolution process by means of a weighting of the scan profiles. The nature and degree of the weighting is determined by the "convolution kernel" where in the convolution has an effect on the image structures.

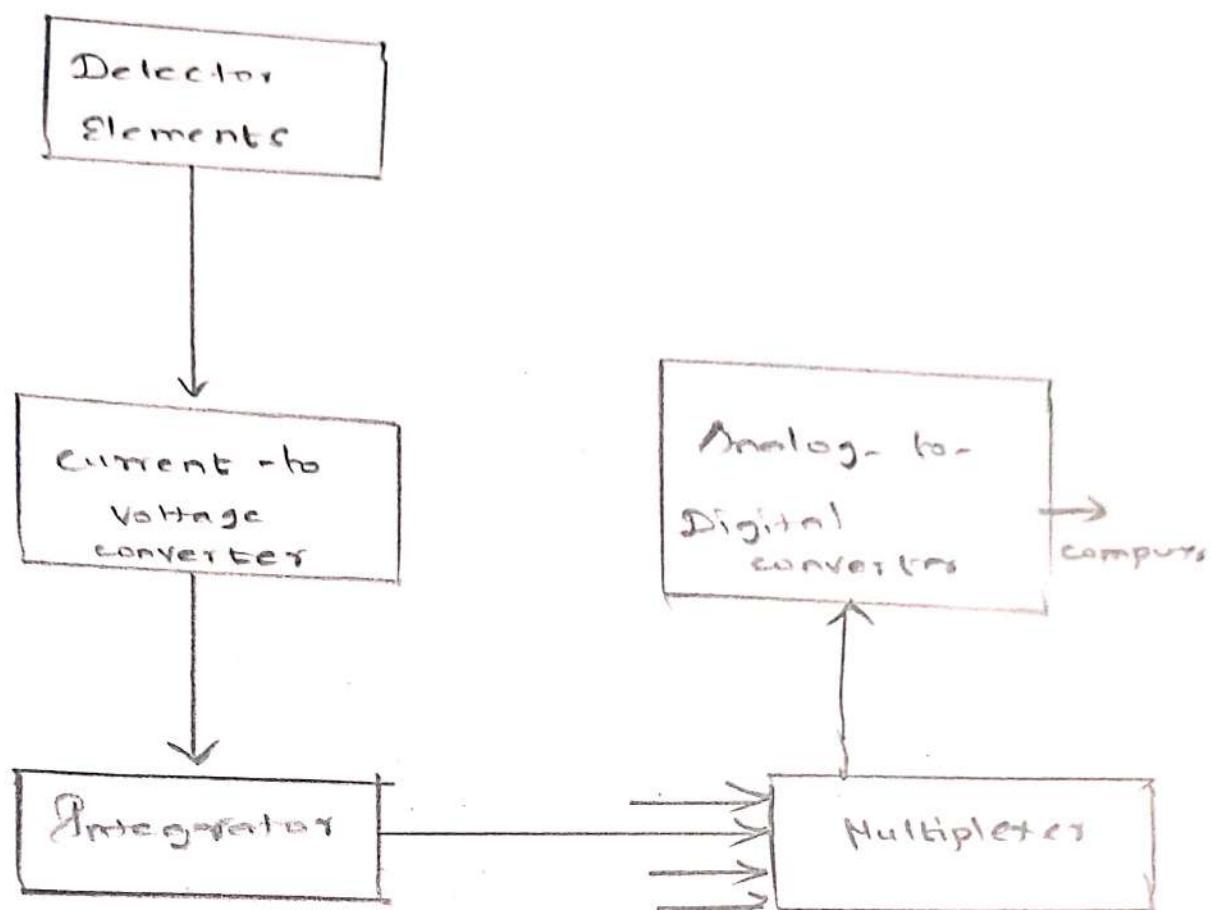
22) Define "smoothing effect" and "cupping effect"

The "smoothing effect" → is the aim of producing a more uniform image structure

The "smoothing" convolution kernel reduces images of noise and such errors which for ex can occur with motion artifacts.

The convolution kernels for the head take account of the bones forming the outer housing of the head, in such a way that ~~the~~ is called "cupping" effect is suppressed.

CT scanner.



1) Explain the principles of Tomography.

Principles Of Tomography:

In principle, computed tomography

involves the determination of attenuation characteristics for each small volume of tissue in the patient slice, which constitute the transmitted radiation intensity recorded from various irradiation directions.

The tissue attenuation characteristics that actually compose the CT image.

For a monochromatic X-ray beam, the tissue attenuation characteristics can be described by:

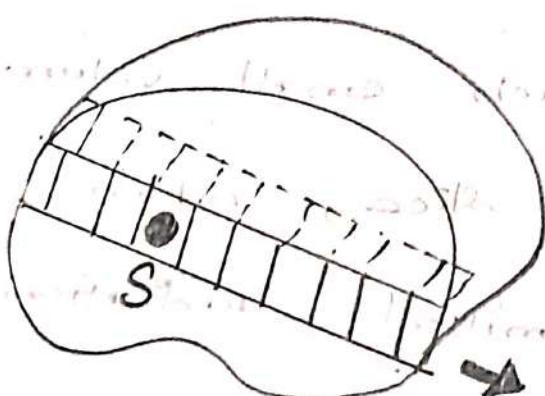
$$I_t = I_0 e^{-\mu x}$$

where, I_0 = incident radiation intensity

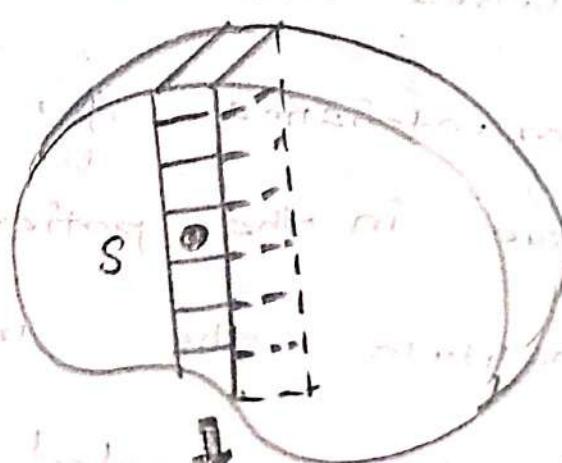
I_t = Transmitted Intensity

x = Thickness of tissue

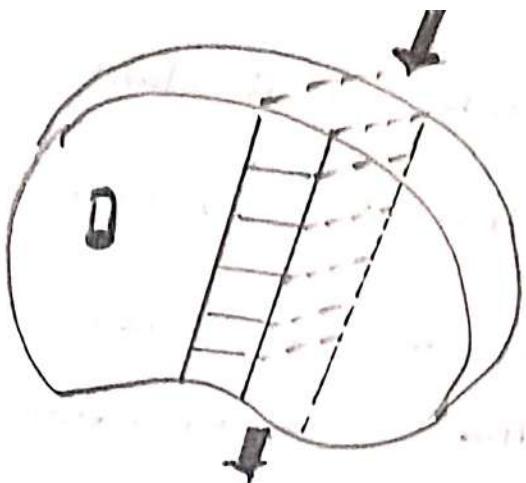
μ = characteristic attenuation coefficient of tissue



(a)



(b)



(C)

X-rays incident on patient from different directions. They are attenuated by different amounts, as indicated by the different transmitted X-ray intensities.

If a slice of heterogeneous tissue is irradiated as shown in the above figure, we divide the slice into volume elements or voxels. Each voxel having its own attenuation coefficient; it is obvious that the sum of the voxel attenuation coefficients for each X-ray beam direction can be determined from the experimentally measured beam intensities for the given voxel width.

However, each individual voxel attenuation coefficient remains unknown.

computed tomography uses the knowledge of the attenuation coefficients sums derived from X-ray intensity measurements made at all the various irradiation directions to calculate the attenuation coefficients of each individual voxel to form the CT image.

The principles of tomography in CT imaging involves the following key steps:

→ X-ray Source and Detectors:

A CT scanner consists of an X-ray tube and a detector array. The X-ray tube emits a narrow beam of X-rays, while the detector array measures the intensity of the X-rays after they pass through the body.

However, the measured signal contains both scattered and unscattered signals.

→ Rotation:

→ The patient lies on a motorized table that can move through the CT scanner. Simultaneously, the "x-ray tube and detector array" are mounted on a rotating gantry.

→ During the scan, the gantry rotates

around the patient, capturing x-ray data from multiple angles.

→ Data Acquisition:

→ As the gantry rotates, the x-ray tube emits x-ray beams through the body at various angles.

→ The detector array measures the intensity of the x-rays beams, through the body at various after they

pass through the body.

→ These measurements, called

projection data, are collected for each angle.

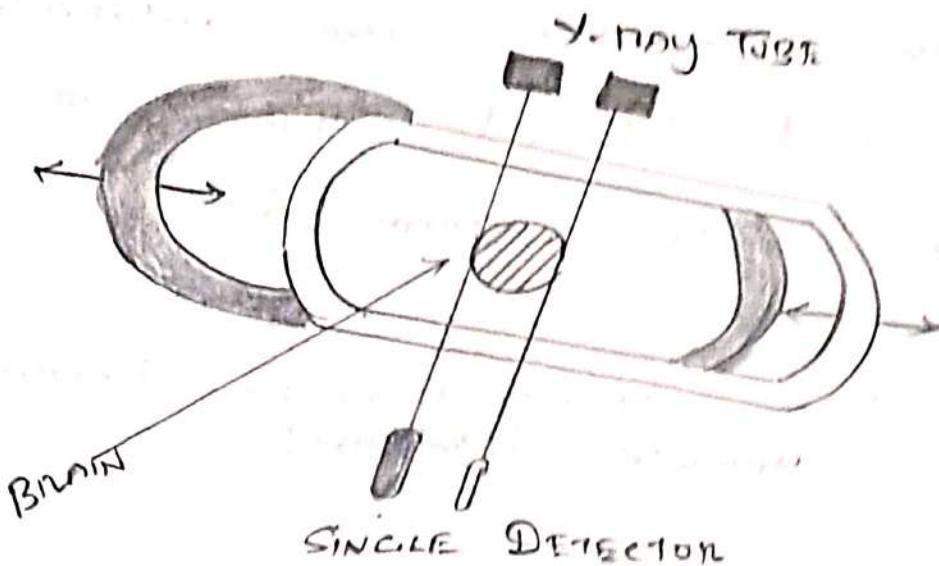
Explain all the generations of CT with next diagram

CT GENERATIONS:

Computed tomography (CT) scanners have evolved over time, with each generation introducing improvements in

image quality, speed and capabilities.

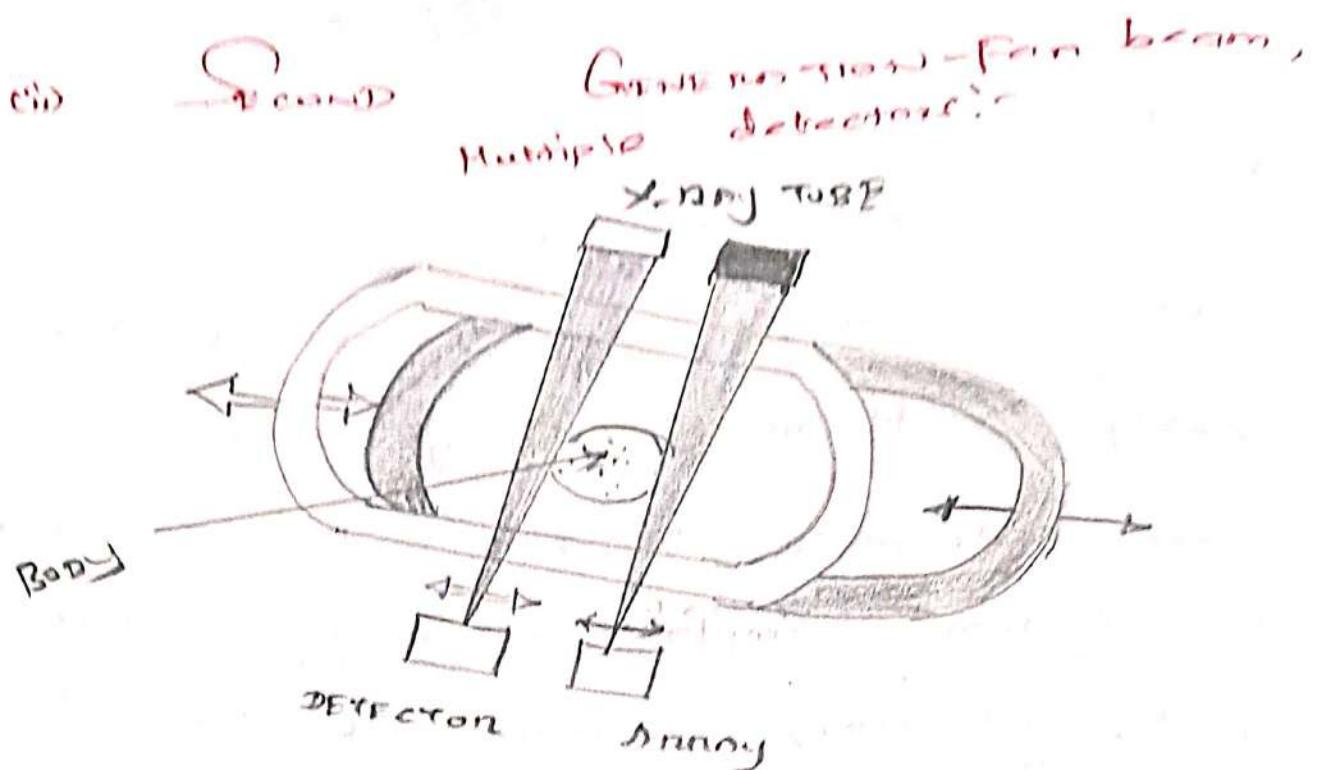
First Generation - Parallel Beam Geometry.



(a) Scanning arrangement of the early CT Machines. They made a linear traverse before taking a 1° rotation. The system employed single source and single-detector system. It took long measuring times.

- The first Generation CT Scanner, introduced in the 1970s, was based on the concept of computed tomography.
- It utilized a single X-ray source and a single detector to acquire a single slice of data.
- The X-ray tube and detector assembly would rotate 180 degrees around the patient to collect data from various

angle. The generation were slow and had limited applications due to single slice acquisition.



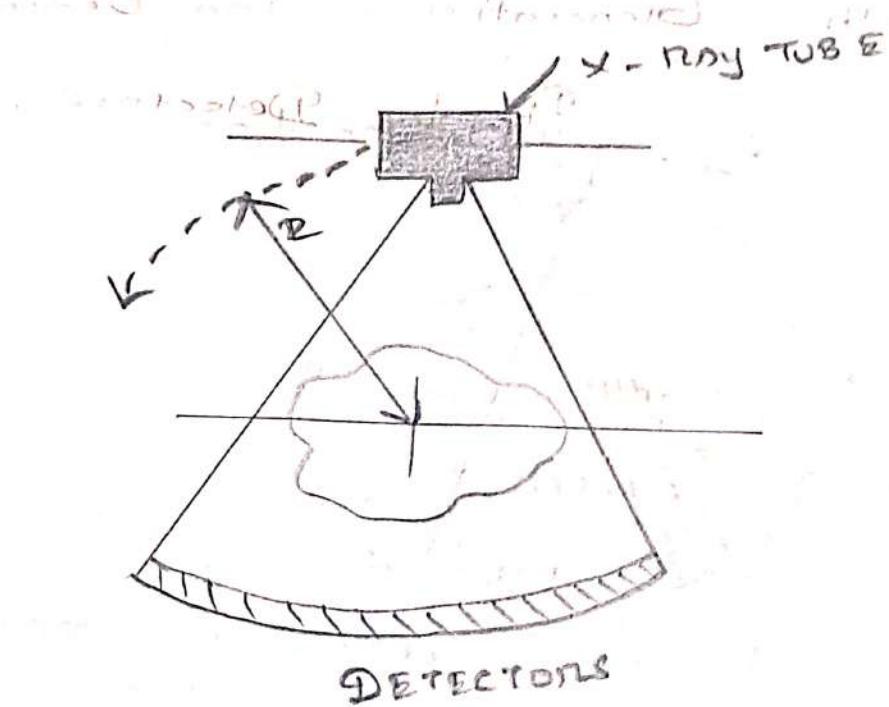
(b) Using a fan-shaped beam and an array of detectors, large steps can be taken and the scanning processes speeded up.

→ Second generation CT scanners, developed in the late 1970s and early 1980s, improved upon the first generation by using multiple detectors in an array. This allows for faster scanning and reduces artifacts. The detectors are arranged in a circular pattern around the patient's body, allowing for a faster scan time. The detectors are also more sensitive than the first generation, providing better image quality. The use of multiple detectors also allows for better resolution and contrast, making it easier to see small details in the image. The second generation CT scanners also have better noise reduction, which makes the images clearer and more accurate. The use of a fan-shaped beam instead of a single line of X-rays also reduces the dose of radiation to the patient, making it safer. The second generation CT scanners are used in a variety of medical applications, including diagnosis of diseases such as cancer, heart disease, and stroke. They are also used in surgery to help plan operations and guide instruments during procedures. The second generation CT scanners are an important tool in modern medicine, providing valuable information that can help save lives.

- This allowed for faster data acquisition and reduced scan times.
- These scanners were capable of acquiring multiple slices in a single rotation, increasing efficiency.

(iii) Third Generation :- - Fan Beam,

Rotating Detectors :



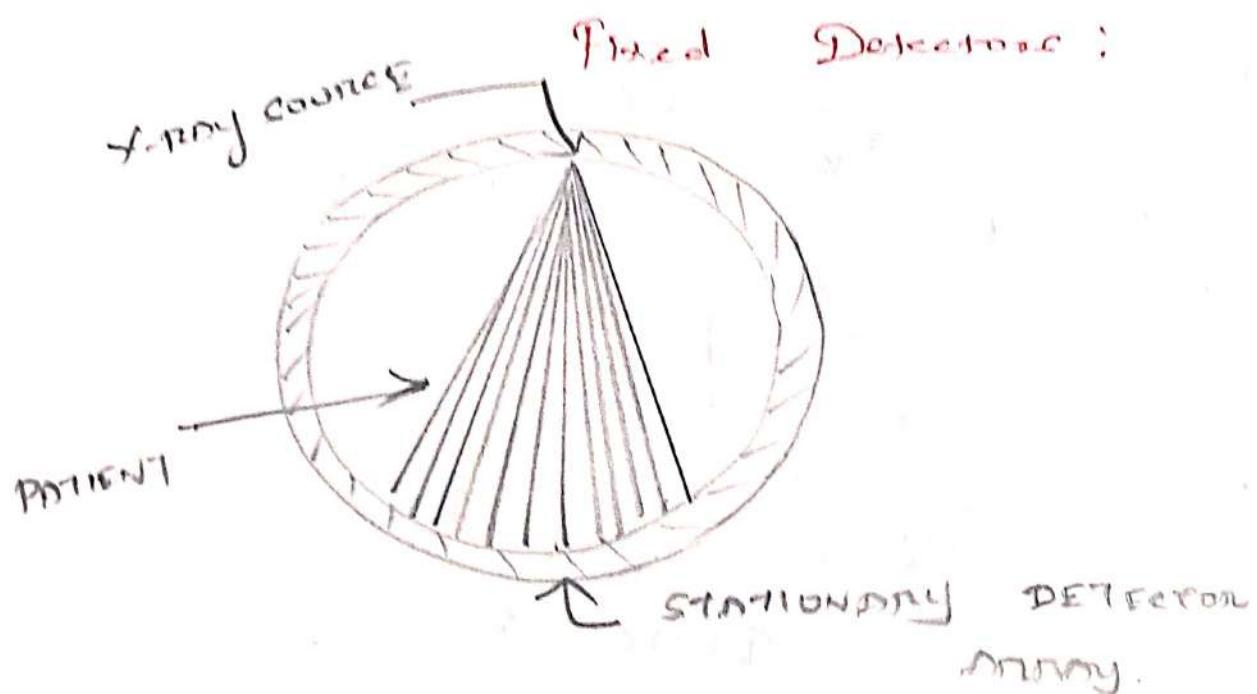
- (c) If the fan beam is large, no transverse motion is needed, only rotational movement of the scanning frame is required, thus offering considerable

Third Generation CT Scanners, introduced in the mid-1980s featured a

a larger portion of the patient to body.

→ The design is further improved to speed and efficiency, reducing the time required for a full-body scan.

(iv) Fourth Generation - Fan Beam,



(v). The X-ray tube rotates while detectors remain stationary. This arrangement overcomes many problems of pure rotational systems.

→ Fourth generation CT scanners, developed in the late 1980s and early 1990s, introduced a rotating X-ray tube with a ring of detectors surrounding the patient.

→ This design eliminated the need for the entire detector assembly to move during scans, leading to faster and more reliable data acquisition.

(C) FIFTH GENERATION (MULTISLICE CT) / -

Scanning with Electron beam,

→ The fifth generation of CT scanners, which emerged in the late 1990s and early 2000s, brought about a significant advancement, the ability to acquire multiple slices of data simultaneously.

→ This was achieved by using an array of detectors and wider X-ray beam.

→ For ex: a 16-slice or "scanner" could capture 16 slices per rotation,

greatly enhancing the speed and

image quality of general

→ The fact does not affect

resolution limit of mechanical CT

scanners makes phase resolution imaging

of the beating heart possible only

through manipulations involving ECG

triggering.

→ The acquisition of all the cardiac

phases within a single cardiac cycle can

only be realized using a data acquisition

system which does not contain any

moving mechanical parts.

Such a system is the Electron

beam tomography (EBT) scanner.

Explanation about X-ray Source & collimation
Source & And Collimation

In CT scanners, the highest image quality, free from disturbing blurring effects, is obtained with the aid of pulsed X-ray radiation.

→ During rotation, high voltage energy is applied at all times. A grid inside the tube prevents the electron current from striking the anode except when desired, allowing the electrons to be emitted in bursts.

→ As the gantry rotates, an electric signal is generated at certain positions of the rotating system.

→ Each pulse contains on the fly arrays for a short period of time. Since the beam is on for only short periods of time, the motion of the patient during the measurement has to be minimized to ensure that the resolution does not get degraded.

→ For producing a "fan beam", a collimator is incorporated b/w the X-ray tube and the patient.

→ A filter inside the collimator housing shapes the beam intensity.

→ Actually, in body scanners, there are two filters, one for bodies and the other for heads which are automatically selected by the computer. These filters produce an intensity variation which, when coupled with the roughly round shape of the patient, significantly reduce the requirements on the dynamic range of the array electronics.

X-ray TUBE:
→ The fan of X-rays extends beyond the patient diameter so that X-rays which are not attenuated can enter the detector. The intensity of these non-attenuated X-rays is measured in order to correct for variations in the array tube bank.

Two main types of X-ray tubes have been utilized for computed tomography.

→ The first is an oil-cooled fixed anode line-focus continuous tube.

which was principally used in first & 2nd generation CT scanners. They utilized a tungsten target with a target angle of about 20 degrees. The line focus

provided by a 2x16 mm aperture.

→ The second type of tube used in the low generations of the scanner is the rotating anode air-cooled pulsed X-ray source.

↓
These tubes have a higher power capability for exposure times in the 2-20 second range. The powers requirements of these tubes are generally variable within 100-160kV.

→ Typical power requirement of these tubes are 120kW to 200-500mA producing X-rays with an energy spectrum ranging from approximately 30-120keV.

→ Most systems have two possible focal spot sizes, approximately 0.5x1.5 mm & 1.0 to 2.5 mm.

→ A collimator assembly is used to control the width of the imaged slice.

→ All modern systems use high frequency generators, typically operating

→ with the production of X-ray in the X-ray tube being an inefficient process most of the power delivered to the tube results in heating up of the anode tube. A heat exchanger on the rotating X-ray tube is used to cool the tube.

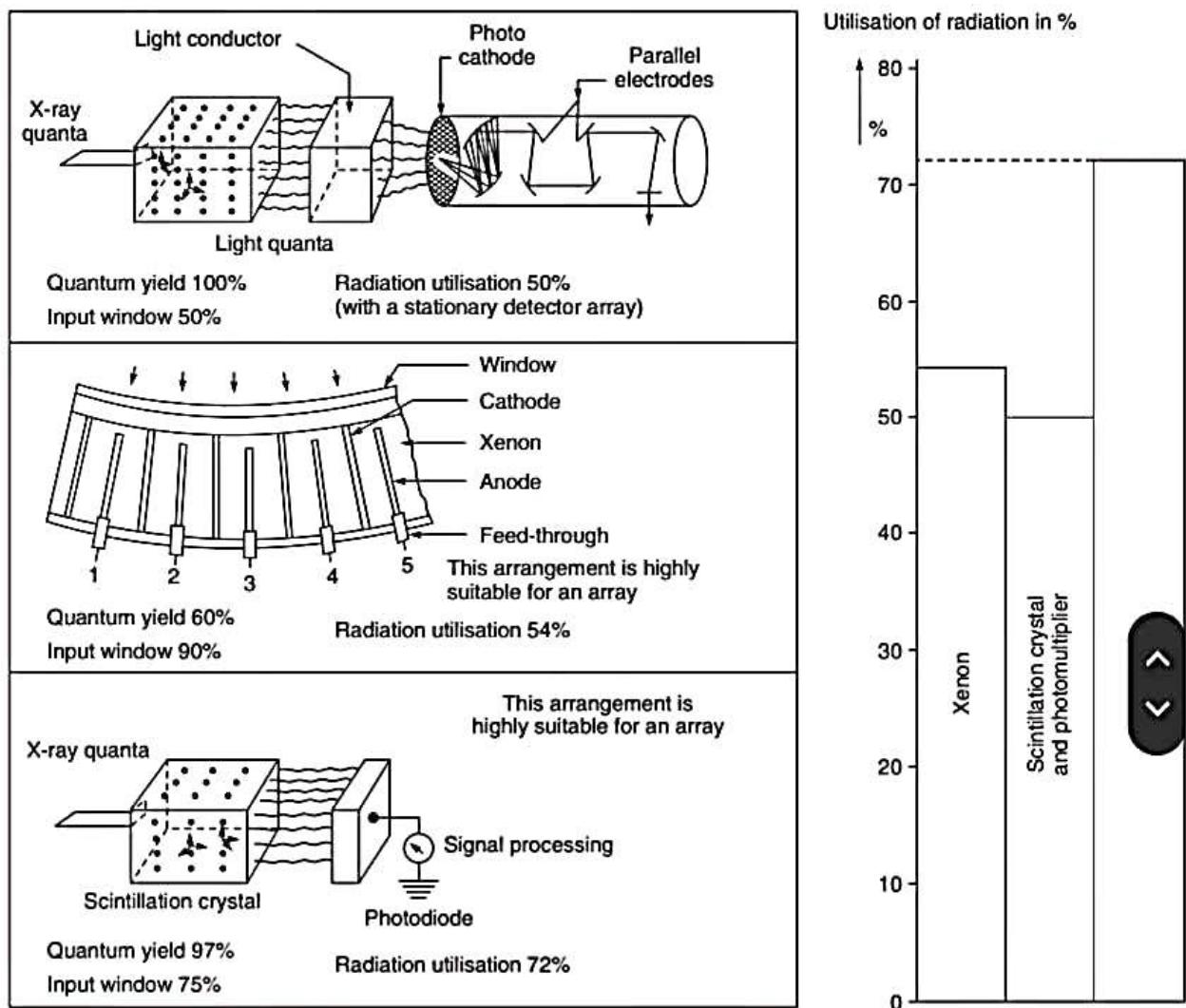
→ spiral scanning especially places heavy demands on the heat storage capacity and cooling rate of the X-ray tube. A new array tube has been developed based on the liquid - metal filled spiral - groove bearings which allow very high continuous power, has been developed to meet this requirements.

→ New applications such as CT angiography have become possible with these developments.

4) Explain all the types of detectors in CT -

- Xenon detectors
- scintillator photo-multiplic.
- scintillare detector

Scintillation crystal
and photomultiplier



► Fig. 20.9 Three types of detectors used in computer tomography (Courtesy: M/s Siemens, W. Germany)

The detector volume is separated into several hundred elements or cells. In a typical scanner, these cells subtend the 42 cm maximum patient diameter. There are 511 data cells and 12 reference cells for simultaneous data collection per view. The detector cells are defined by thin tungsten plates. Every other plate is connected to a common 500 V power supply. The alternate plates are collector plates and are individually connected to electronic amplifiers. X-rays which enter the gas volume between the plates interact with xenon, thus producing positive ions and negative electrons. The positive voltage accelerates the ions to the collector plate and produces an electric current in the amplifier. The resulting current through the electrode is a measure of the incident X-ray intensity.

The xenon detector is inherently a stable detector. Since the detector operates in an ionization mode rather than a proportional mode, small changes in voltage and temperature produce no measurable change in detector output. This is vastly different from photo-multiplier tubes which require almost continual calibration. The main advantages of xenon gas detectors are that they can be packed closely and that they are inexpensive. The entrance width can be as small as 1 mm. In the fixed detectors-rotating source scanners, the detectors do not have to be packed closely. Therefore, scintillation detectors are employed as opposed to ionization gas chambers. Most scintillation detectors are made of sodium iodide, bismuth germanate and cesium iodide crystals. The crystals transform the kinetic energy of the secondary electrons into flashes of light which can be detected by a photo-multiplier.

The scintillator-photo-multiplier detectors suffer from the disadvantage that the smallest commercially available photo-multiplier tube has a diameter of 12 mm. Consequently, they are employed only in translation-rotation and stationary detector arrays.

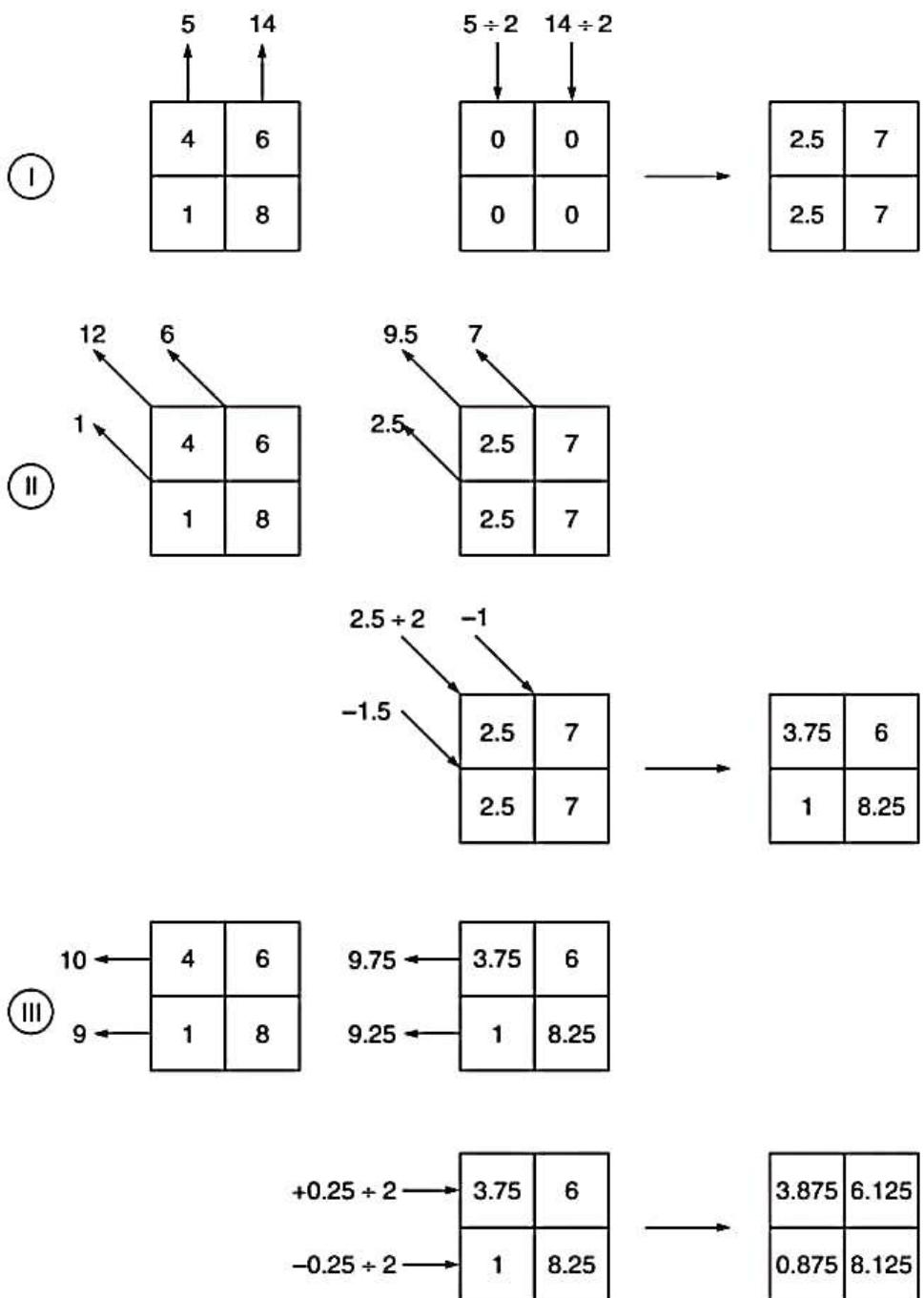
Siemens employs the SCINTILLARC detector system comprising scintillation crystals and photo-diodes in their SOMATOM machines. In this system, 520 CsI crystals, assembled with photo-diodes, are arranged on a 42° arc. In the radiation entrance plane, the detectors have very small dimensions of only 1.2 mm × 13.5 mm, thus permitting a good resolution. Owing to the fine-grid like separation of the scattered radiation collimator, high percentages (75%) of the X-ray quanta actually reach the detectors. Also, about 97% of the incident quanta can be converted into an electrical signal.

Many modern scanners use solid state detectors such as single crystal CdWO₄ or ceremic Gd₂O₂S, with photo-diodes which have some inherent advantages such as a higher efficiency in detecting X-ray photons. One of the next developments to be expected is the use of multi-array detectors, i.e. a number of parallel rings of solid state detectors. This will allow for faster volume scanning.

5) Explain about the Image reconstruction techniques.

→ Iterative method

→ Back projection Method



► Fig. 20.11 Principle of iterative reconstruction method

The information received by the computer from the scanning gantry needs to be processed for reconstructing the pictures. The data from the gantry contains information on the following parameters:

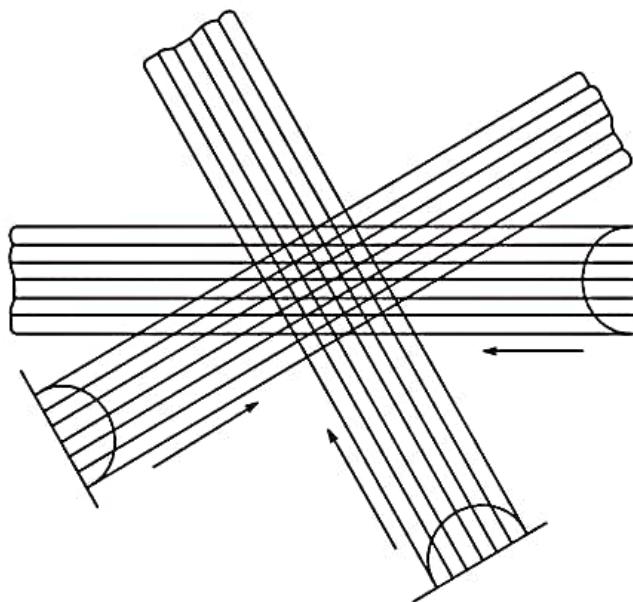
- Positional information, such as which traverse is being performed and how far the scanning frame is along its traverse;
- Absorption information including the values of attenuation coefficient from the detectors;

- Reference information that is obtained from the reference detector that monitors the X-ray output; and
- Calibration information that is obtained at the end of each traverse.

The first stage of computation is to analyse and convert all the collected data into a set of profiles, normally 180 or more. However, the main part consists of processing the profiles to convert the information which can be displayed as a picture and then be used for diagnosis. In general, the reconstruction methods can be classified into the following three major techniques:

- Back projection, which is analogous to a graphic reconstruction;
- Iterative methods, which implement some form of algebraic solution; and
- Analytical methods, where an exact formula is used. Two of these are filtered-back projection, which incorporates the convolution of the data and Fourier filtering of the image, and the two-dimensional Fourier reconstruction technique.

The method of back projection without any further processing is simple and direct. In this method each of the measured profiles is projected back over the image area at the same angle from which it was taken. At the same time, each projection contributes not only to the points that originally formed the profile, but also to all the other points in its path. This technique in fact produces 'starred' images (Fig. 20.12(a)) and blurring, which makes it totally unsuitable for providing pictures of adequate clarity for medical diagnosis.

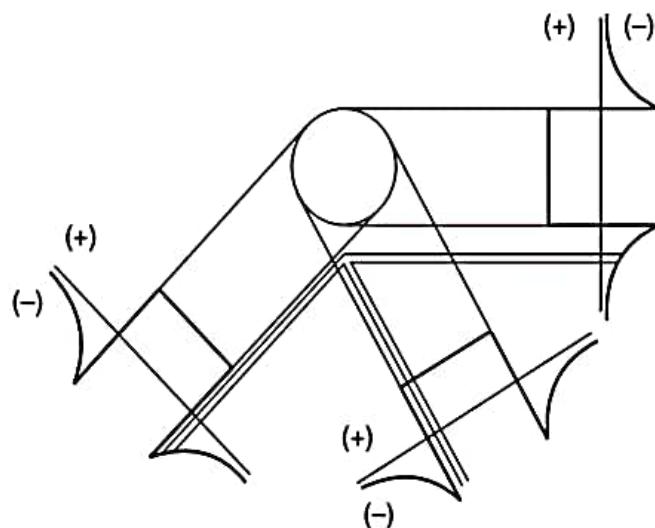


► Fig. 20.12(a) By adding the back projections produced by the shadow functions, the back-projected rays are added to the reconstructed image as artefacts or unwanted points. The original circular structure is transformed into a star shaped display

The earlier brain scanners used the iterative technique which took a succession of back projections correcting at each stage until an accurate reconstruction was achieved. The method requires several steps to modify the original profiles into a set of profiles which can be projected

back to give an unblurred picture. The technique, however, tends to require long computation time.

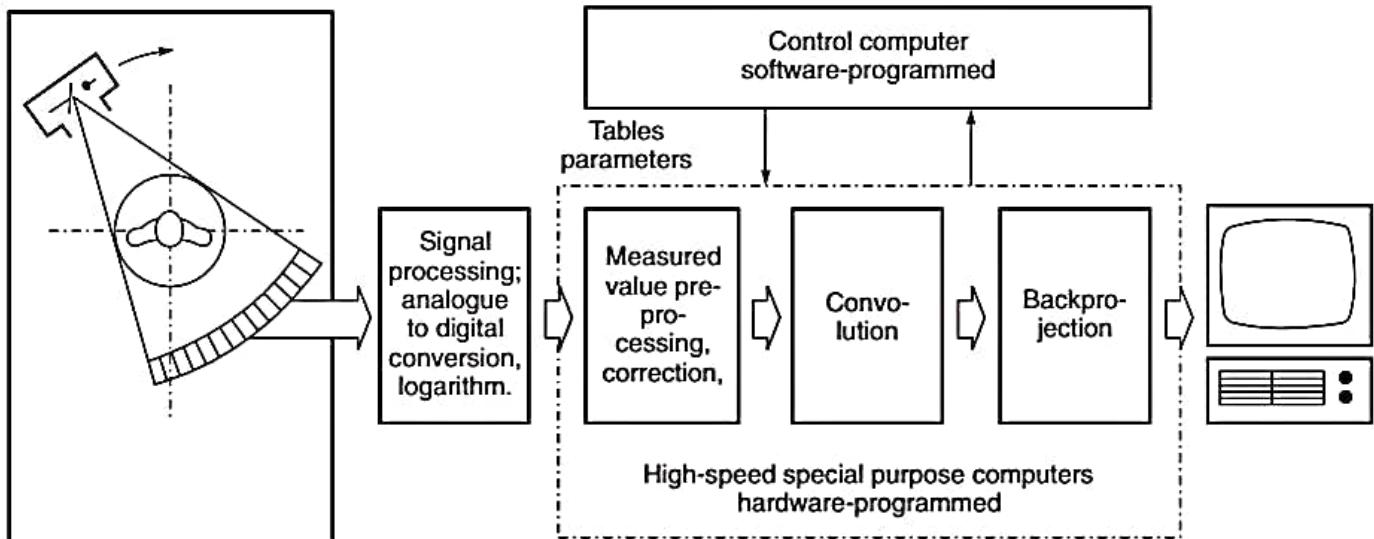
Current commercial scanners use a mathematical technique known as convolution (Fig. 20.12(b)) or filtering. This technique employs a spatial filter to remove the blurring artifacts. This is achieved by convolving the shadow function with a filter so that each point in the projection has a negative value instead of 0, at every point other than its proper place in the projection. The resulting profiles



► Fig. 20.12(b) *Filtered back projection technique of eliminating the unwanted cusp like tails of the projection. The projection data are convolved (filtered) with a suitable processing function before back projection. The filter function has negative side lobes surrounding a positive core, so that in summing the filtered back projections, positive and negative contribution cancel outside the central core, and the reconstructed image resembles the original object*

are then back-projected and added. Thus, the negative portion of each shadow function cancels out image artifacts that would otherwise be caused by other functions. Mathematically, the method of fast Fourier transform offers a powerful tool in making the required computations and special purpose high speed computers are now available to meet this requirement. The use of this method enables pictures to be reconstructed within a few seconds. Figure 20.13 shows a block diagram image reconstruction computer, used in CT scanners.

In principle, the blurring effect is counteracted in the convolution process by means of a weighing of the scan profiles. The nature and degree of the weighing is determined by the 'convolution kernel', wherein the convolution has an effect on the image structures. Thus, for example, it can be edge-enhancing, so that the bone/soft part interfaces within the skull are particularly clearly emphasized or it can have a 'smoothing effect' with the aim of producing a more uniform image structure. The 'smoothing' convolution kernel reduces image noise and such errors which, for example, can occur with motion artifacts. However, the details are more poorly resolved. The convolution kernels for the head take account of the bones forming the outer housing of the head, in such a way that the so-called 'cupping' effect is suppressed. Gilbert et al. (1981)



► Fig. 20.13 Block diagram of the image computer. The synchronous reconstruction of the image permits the representation of the tomogram on the video monitor immediately upon completion of the scan (Courtesy: Siemens, Germany)

review several computer software and special purpose digital hardware implementations of different forms of algorithms, either proposed or actually implemented in commercial or research CT scanners.

Computer Systems: The computer system plays a central role in CT scanning because without it, there would be no image computation and formation. The computer controls X-ray generation, gantry and table motion, data acquisition, image formation, display and storage. Usually, the CT computer system includes a microcomputer for control functions, an array processor and video memory to enable viewing of the reconstructed images. The image can be viewed on a console and a hard copy can be made on a multi-format camera. Figure 20.14 illustrates a typical computer system employed in a CT scanner. It uses twelve independent processors connected by a 40 Mbyte/s multibus configuration. A multiple array processor is used to achieve the computational speed of 200 Mflops (million floating-point operations per second). The reconstruction time from such a configuration is approximately five seconds to produce an image on a 1024×1024 pixel display. A multiuser and multi-tasking environment is provided by a simplified UNIX operating system.

≡

UNIT-III - Magnetic Resonance Imaging

Two Nuclei

1. Define Larmor Frequency.

The precession (or) wobbling of the magnetic ~~field~~ moment about the applied magnetic field with a resonant angular frequency, ω_0 called Larmor frequency.

$$\omega_0 = \gamma B_0$$

2. Derive Planck's Equation.

The excitation energy E is given by the Planck's Equation

$$E = h\nu_0$$

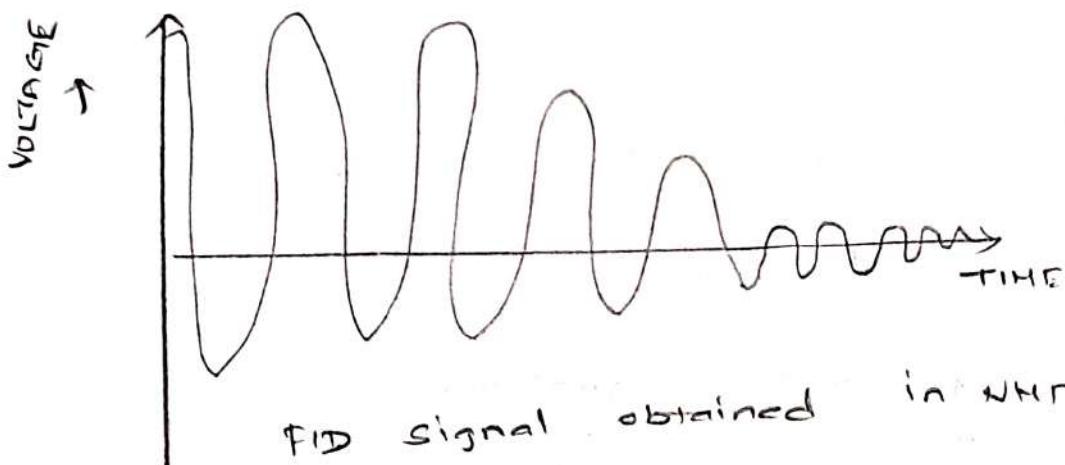
where ν_0 is the Planck's constant divided by 2π .

3. Define FID:

FID \rightarrow Free Induction Decay

The excited proton tends to return (∞) to its lower-energy state with spontaneous decay and re-emission of energy at a later time 't' in the form of radio wave.

photons. This decay is exponential in nature, "Free Induction Decay" signal, that is the fundamental form of the nuclear signal obtainable from an NMR system.



FID signal obtained in NMR

ii. Derive the expression for the amplitude for decaying signal.

The amplitude of the signal decays in an exponential fashion with time T , i.e.,

$$A = A_0 e^{-t/T_2}$$

where $T_2 \rightarrow$ is the characteristic (or) average decay time for the process.

$1/T_2 \rightarrow$ decay constant

The resultant signal amplitude with both decay processes contributing to the observed

observed decay of the signal would be

$$A = A_0 e^{-t/\tau_1}, e^{-t/\tau_2}$$

Q. List two relaxation Mechanisms associated with excited nuclear spins.

- (i) Relaxation Time τ_1 (spin-lattice relaxation)
 - (a) Longitudinal relaxation process
- (ii) Relaxation Time τ_2 (spin-spin relaxation)
 - (b) Transverse relaxation.

Q. List the important properties of Electromagnetic waves?

- (i) → speed
- (ii) → Amplitude
- (iii) → phase
- (iv) → orientation (polarization)
- (v) → waves in matter.

Q. What is meant by "Zeeman effect"?

When atomic nuclei with non-zero spin are placed in this field, they experience the "zeeman Effect" which causes their Energy levels to split into two states commonly referred to as "up" and "down" states.

8. Define flip angle?

The angle by which the nuclear spins are tilted away from the equilibrium position is known as the "flip angle".

9. Define Rotation.

Rotation refers to the circular (or) angular motion of an object around an axis (or) point.

10. Define precession.

Precession is a type of rotational motion where the orientation of an objects axis itself rotates.

What is the role of Relaxation process in MRI (or) NMR.

- Relaxation process play a crucial role in MRI.
- In imaging, variations in the relaxation time among different biological tissue types provide the key contrast mechanism for anatomical discrimination.

→ It is a powerful mechanism for the detection of pathology.

12. Important parameters \Rightarrow using in NMR / MRI?
A relaxation time T_1 & T_2 Notes

It makes NMR imaging a unique, versatile & powerful technique in medical imaging.

13. Express the equation for Fourier transformation of the FID?

The Fourier transformation $f(\omega)$ of a function of time $f(t)$ is given by

$$f(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt$$

where $\omega \rightarrow$ is the angular frequency

$$\omega = 2\pi\nu \text{ and } i = \sqrt{-1}$$

$f(t) \rightarrow$ free induction decay

$f(\omega) \rightarrow$ Zonal spectrum.

14) List two Methods for Measuring the signal.

(i) continuous wave method

(ii) pulse method

15. Express Bloch Equation.

$$\frac{dM}{dt} = \gamma H_0 B - \left[\frac{(H_{xi} + H_{zj})}{T_2} \right] - \left[\frac{(M_z - M_0)}{T_1} \right]$$

where

$\gamma \rightarrow$ gyromagnetic ratio

1b Define Bloch Equation:

The Bloch equation gives a phenomenological description of the time dependence of nuclear magnetization $M(t)$ in the presence of an applied magnetic field $B(t)$.

1c) List Various NMR Imaging Methods.

(i) sequential - point Method

(ii) sequential - line Method

(iii) sequential plane Measurement

(iv) simultaneous Measurement

24/18 Define Zeugmatoigraphy (01)

Back projection Zeugmatoigraphy

Zeugmatoigraphy is based on the fact that the two-dimensional spatial variation (or) image of a physical property of an object can be reconstructed from a series of one-dimensional projections of the parameter that are recorded at different orientations relative to the sample.

19. Define saturation recovery and Inversion recovery:-

→ Saturation Recovery :

In saturation recovery pulse sequence a series of 90 degree pulses is applied with an inter-pulse spacing & data acquisition period longer than the decay time T_2 and same length as τ ,

→ Inversion Recovery :

An Inversion recovery sequence resembles the saturation recovery sequence

that T_1 variations in the sample can be exploited to achieve better contrast.

20. What are the two areas have dominated the field of research and intensive development.

(i) \rightarrow the extension and improvement in tissue differentiation.

(ii) \rightarrow the possibilities for shortening the required scan time.

21. Express the SNR of the RF signal?

The signal to noise ratio of the RF signal at the receiver depends in the following manner

$$SNR \propto k (\alpha/v_c)$$

where k \rightarrow Numerical constant

α \rightarrow coil magnetization factor

v_c \rightarrow coil volume

22. Common available coils.

- Body coils
- Head coils
- Surface coils
- Organ- enclosing coils.

23. List the two types of system magnet used?

- permanent magnet
- superconductive magnet (superconductors)

24. Define patient couch:

The patient couch for NMR imaging applications is made of a non-magnetic material to prevent disturbing the uniformity of the magnetic field in the scanning region.

25. List the aspects of NMR/MRI Imaging which could cause potential health hazard are:-

The three aspects of NMR imaging which could cause potential health hazard are.

- Heating due to RF power
- Static magnetic field

→ Electric current induction due to rapid change in magnetic field

26. what are the advantages of NMR Imaging system?

- cross-sectional images with any orientation are possible in NMR imaging systems.
- NMR imaging parameters are affected by chemical bonding and therefore, offers potential for physiological imaging.
- NMR uses no ionizing radiation and has minimal, if any hazards for operators of the machines and for patients.
- the alternative contrast mechanisms of NMR provide promising possibilities of new diagnostics for pathologies that are difficult or impossible with present techniques.

27. what does the shape of the pulse and gradient of the pulse depends on.

The characteristic of the slice will be determined by the shape of the pulse and the thickness of the slice will be determined by the width and gradient of the pulse.

2) Explain the fundamentals of Magnetic Resonance.
FUNDAMENTALS OF MAGNETIC RESONANCE:

Magnetic Resonance, often referred to as Nuclear magnetic Resonance (NMR) or Magnetic Resonance Imaging (MRI), is a powerful technique used in various scientific and medical applications.

1. Nuclei with spin:

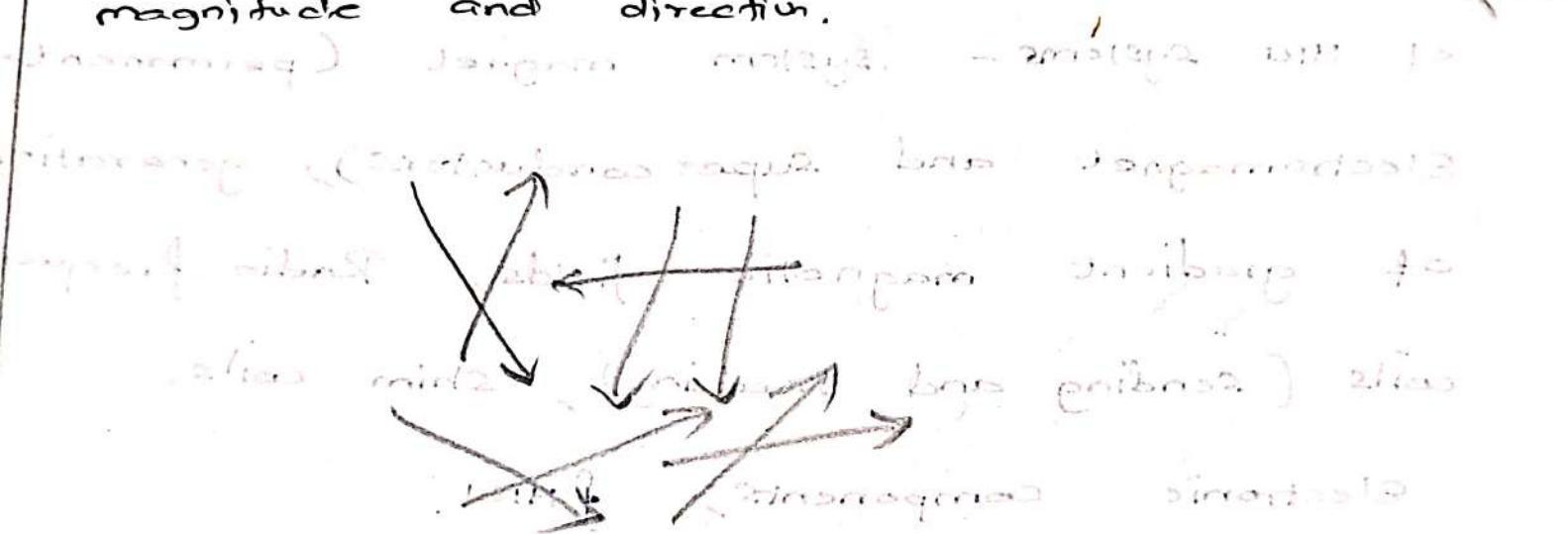
Magnetic resonance primarily involves the interaction of atomic nuclei with a magnetic field. Nuclei with a non-zero spin (e.g. hydrogen, carbon-13) respond to external magnetic fields.

→ Larmor Frequency:

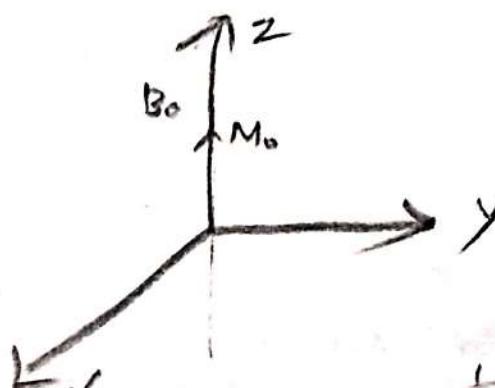
When placed in a magnetic field, nuclei precess about the field at a characteristic frequency known as the Larmor frequency. This frequency depends on the nucleus and the strength of the magnetic field.

Magnetic Moment

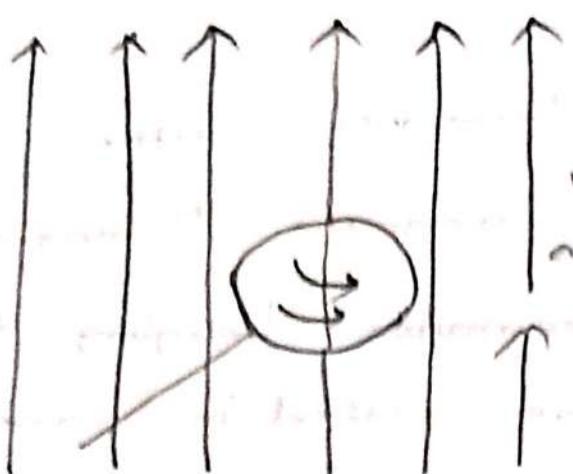
All materials contain nuclei that are either protons or neutrons or a combination of both. Nuclei containing an odd number of protons and neutrons, both in combination, possess a nuclear spin, and a magnetic moment which has both magnitude and direction.



Random alignment of magnetic moments of the nuclei making up the tissue, resulting in a zero net magnetisation



The application of External magnetic field field causes the nuclear magnetic moments to align themselves,



Precessing (or) wobbling

of the nucleus about
an applied magnetic
field B_0 , with a resonant
angular frequency ω_0

$W_{\text{eff}} = Y_B \omega_0$ (in Joules) for constant

Y_B : Magnetogyric ratio

→ RESONANCE

CONDITION: $B_0 = \text{static Magnetic field}$

Magnetic resonance occurs when an external radio frequency (RF) pulse is applied at the Larmor frequency, causing the nuclei to absorb energy and transition to higher energy state.

when a Nucleus with a magnetic moment is placed in a magnetic field, the energy of the nucleus is split into lower (parallel with the field) and higher (anti-parallel) energy levels.

The energy difference is such that a proton with specific frequency (ω_0) is necessary to excite a nucleus from the lower to the higher state.

The Excitation Energy E is given by

the Planck's Equation

$$E = h\omega_0$$

where h is a Planck's constant divided by 2π .

→ Relaxation:

→ After the RF pulse is turned off the excited nuclei return to their lower energy states, releasing energy in the form of RF signals.

→ This process involves two relaxation times: T_1 (spin-lattice relaxation) and T_2 (spin-spin relaxation).

Decay (FID):

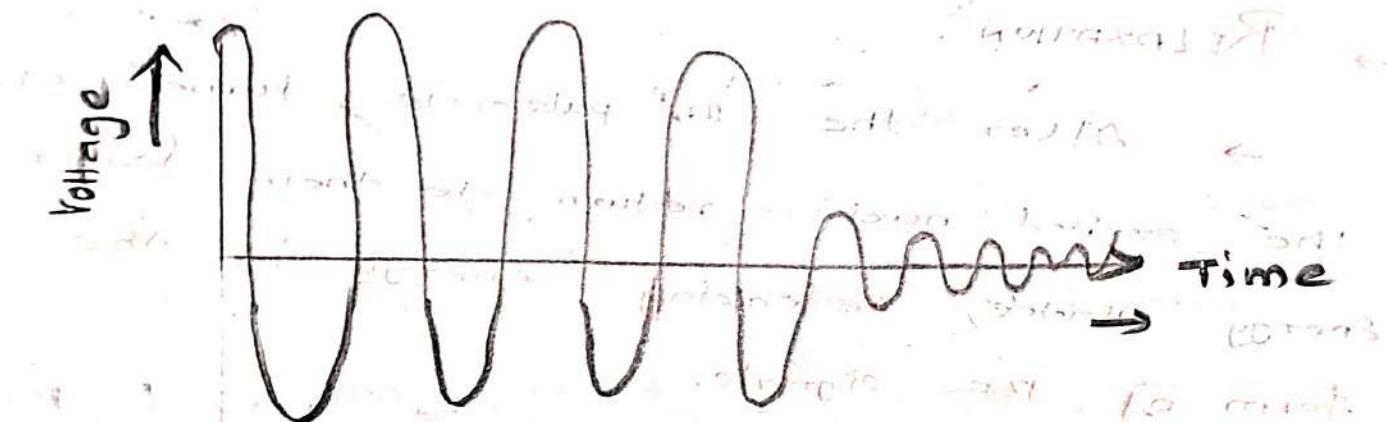
Free Induction Decay

At room temperature, there are more protons in a low energy state than in a high energy state.

In NMR at room temperature, there are more protons in a low energy state than in a high energy state.

The excited proton tends to return (or relax) to its low energy state with spontaneous decay and re-emissions of energy at a later time 't' in the form of radio wave photon.

→ This decay is exponential in nature and produces a "Free Induction Decay".



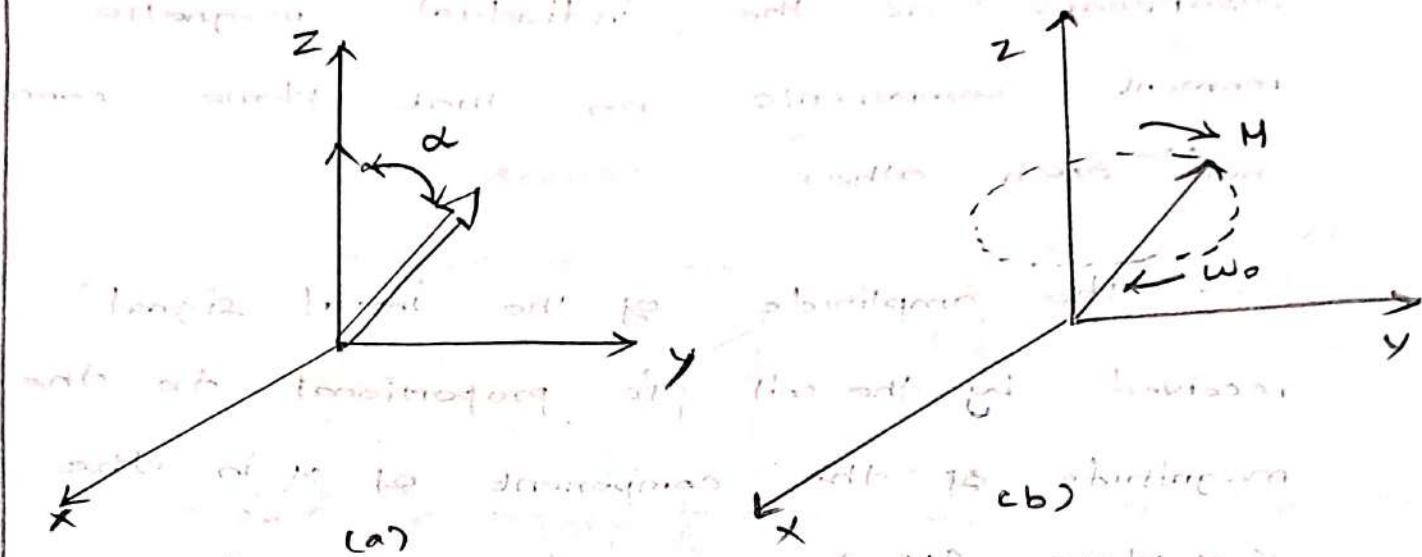
→ EXCITATION:

→ At the material (e.g. tissue) is now subjected to another magnetic field, say a bar magnet placed along the Y-axis,

this would cause net magnetization to shift slightly from the Z-axis (B_0)

magnetic field direction through an angle α .

→ The angle of rotation α depends on the amplitude but primarily on the length of the applied radio frequency pulse ($\alpha = kT$, where T is the pulse length in seconds and k is constant).



(a) The Magnetic Moment is flipped from its Equilibrium by the application of another magnetic field.

(b) It then precesses about the external field direction at a high angular frequency which is proportional to the field strength.

→ Emission:

When the rf pulse is turned off, the net tissue magnetization begins to swing back towards the z -axis (direction of B_0).

including producing
including an NMR signal in the receiver
coil placed perpendicular to the moving
magnetic vector.

→ The component of M in the $x-y$ plane
disappears as the individual magnetic
moment components on that plane cancel
out each other

→ The amplitude of the initial signal
received by the coil is proportional to the
magnitude of the component of m in the
 $x-y$ plane (M_{xy})

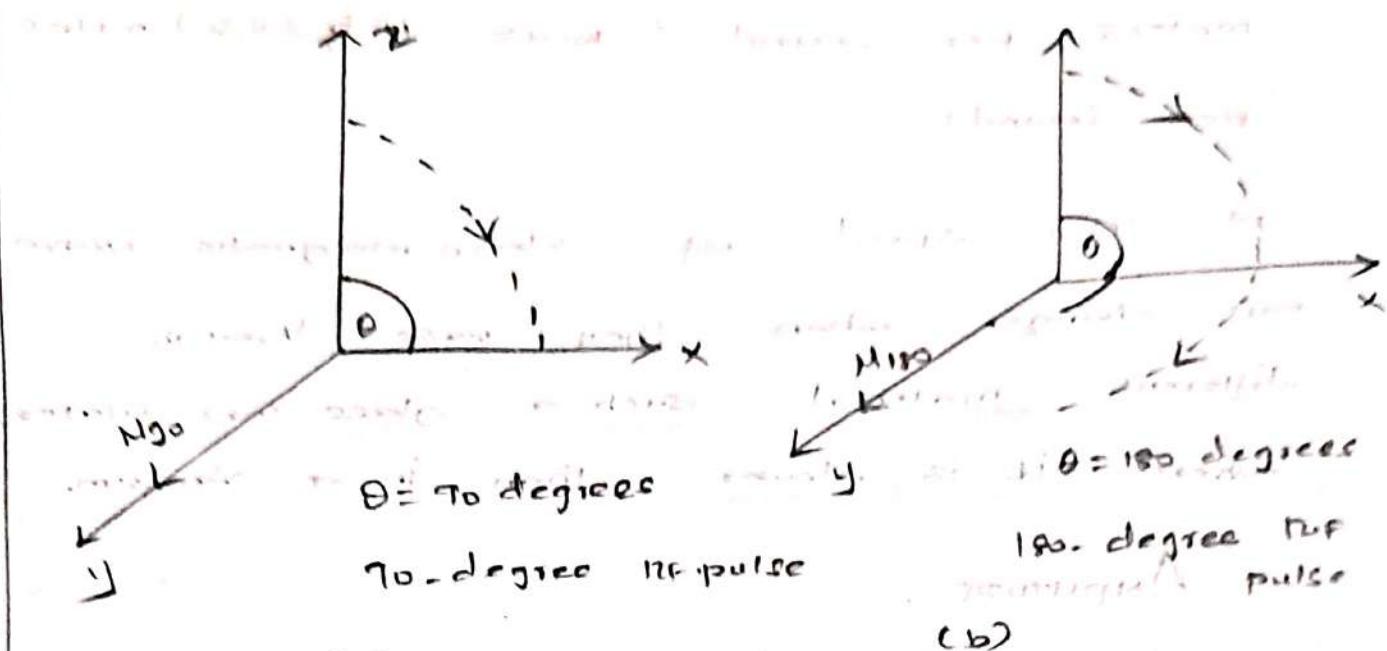
→ The amplitude of the signal decays
in an exponential fashion with time T

where

$$A = A_0 e^{-t/T_2}$$

$T_2 \rightarrow$ characteristic (or) average decay
time for the process and $1/T_2$ is the
decay constant

3.2 Stimulated



The radio frequency pulses needed to tip the magnetization vector through an angle of 90° , (b) 180° respectively are called 90 and 180 degree pulse

→ 2) Interaction Of Nuclei With Radio Frequency Wave

The interaction of nuclei with a static magnetic field and a radiofrequency wave is a fundamental concept in nuclear magnetic resonance (NMR) and Magnetic resonance imaging (MRI), where atomic nuclei in a sample are manipulated and detected using magnetic fields and RF waves.

→ Static Magnetic field (B_0):

In Nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI), a strong static magnetic field (B_0) is applied uniformly across the entire sample.

When atomic nuclei with nonzero spin (e.g. hydrogen nuclei or protons) are placed in this field, they experience the

Zeeman effect, which causes their energy levels to split into two states

commonly referred to as "up" and "down" states.

→ Larmor Precession:

→ In the presence of the static magnetic field (B_0), the nuclei begin to precess (or spin around the direction of the magnetic field).

→ The frequency at which they precess is called the Larmor frequency (ω_0), which is directly proportional to the strength of the magnetic field (B_0) and is unique to each type of nucleus.

→ The precession occurs because the magnetic field exerts a torque on the nuclear magnetic moments (resulting from nuclear spins) causing them to align with the field.

→ Radio Frequency (RF pulse)

→ To manipulate the nuclear spins and extract information, a radio frequency (RF) pulse is applied perpendicular to the static magnetic field (B_0) (or in the horizontal direction as shown).

→ the rf pulse is turned to match the Larmor frequency of the nuclei of interest, when it satisfies the resonance condition, it imparts energy to the nuclei.

→ Resonance and Flip Angle:

→ The resonance condition is critical as it causes the nuclear spins to absorb energy and transition from their lower energy state to the higher energy state.

→ the angle by which the nuclear spins are tilted away from the equilibrium position is known as the "flip angle",

and depends on the characteristics of the rf pulse.

→ Relaxation And Signal Emission:

→ After the rf pulse is turned off,

the excited nuclear spins gradually relax back to their lower energy state.

→ This relaxation process includes two mechanisms: T₁ (spin-lattice relaxation)

(spin-spin relaxation).

and T_2 (spin - spin relaxation)

→ As the spins relax, they emit RF signals, which are detected by the NMR and (or) MRI instrument

→ ROTATION AND PRECESSION

→ ROTATION:

→ Rotation refers to the circular (or)

angular motion of an object around an axis or point.

→ It involves a change in the orientation of the object in space.

→ Constant rate of rotation is called

Angular Velocity (ω) measures how quickly an object is rotating. It is usually expressed in radians per second (rad/s)

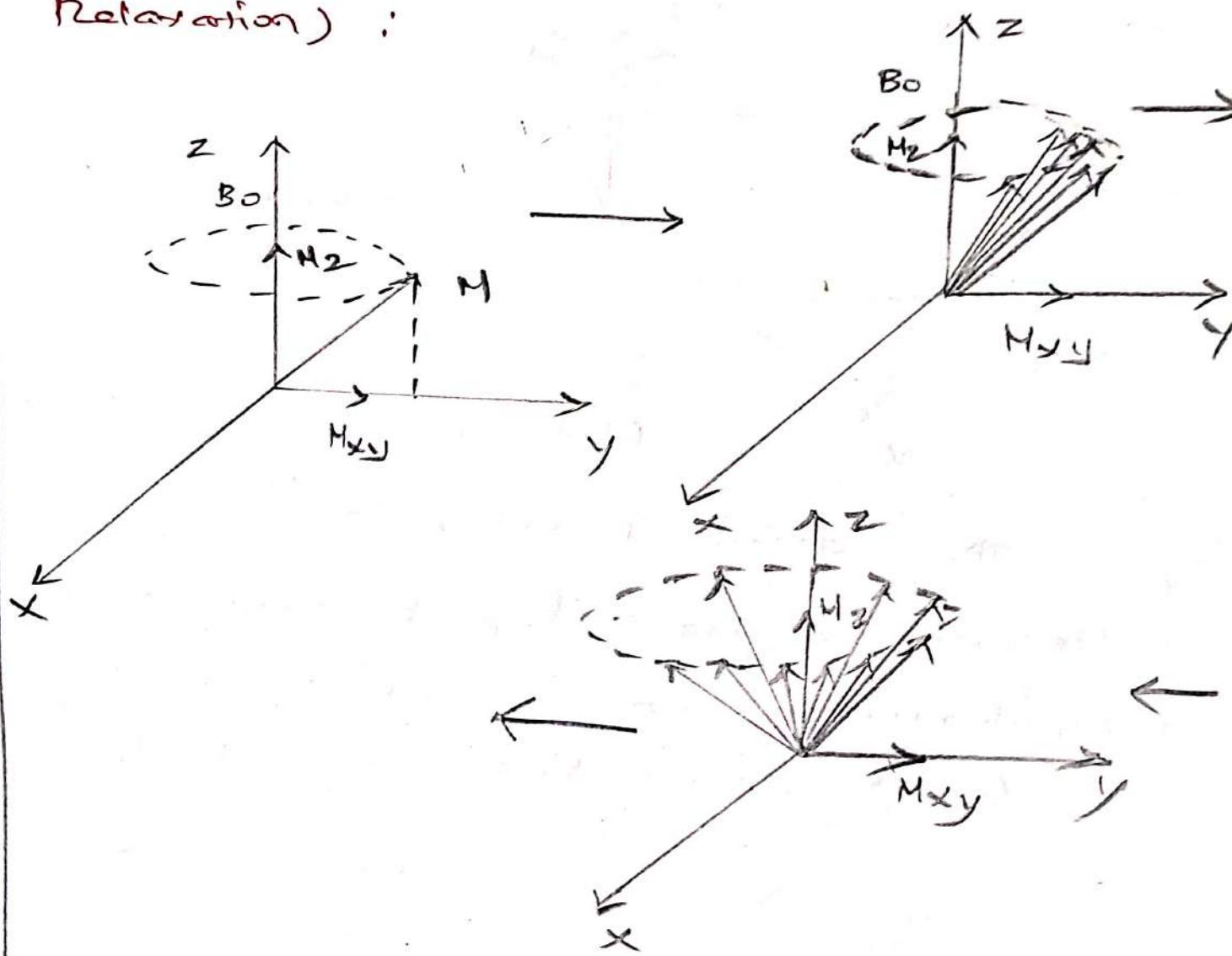
→ PRECESSION:

precession is a type of rotational motion where the orientation of an object's

axis itself rotates.

→ It often results from external torques (or) forces acting on a rotating objects, causing its axis to "wobble" or change direction over time.

3) Relaxation Processes T_1 (spin-lattice relaxation) and T_2 (spin-spin relaxation):

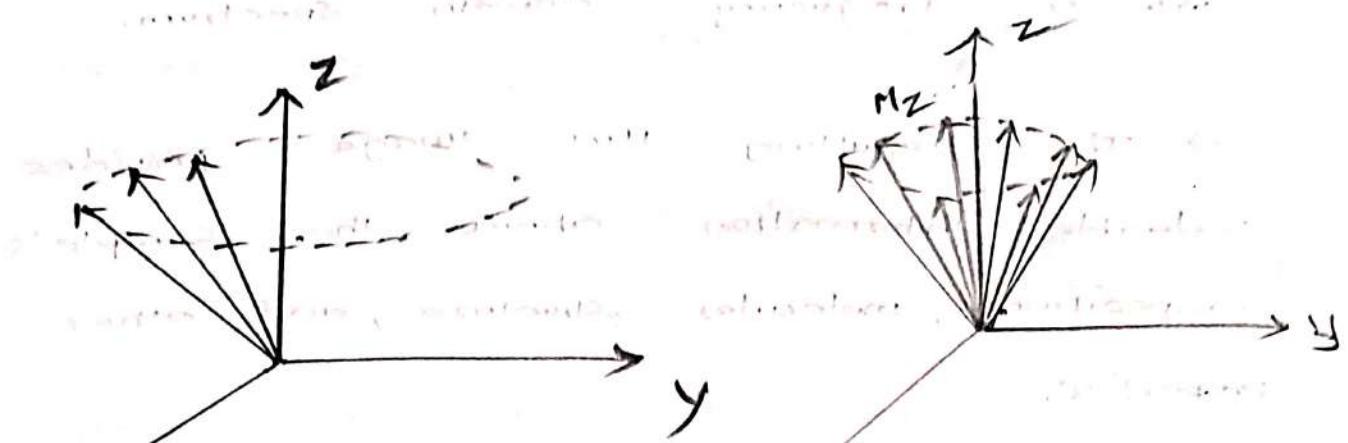


(a)

The decay of Magnetization

(b) The signals decays with time constant T_2

to give $x-y$ component

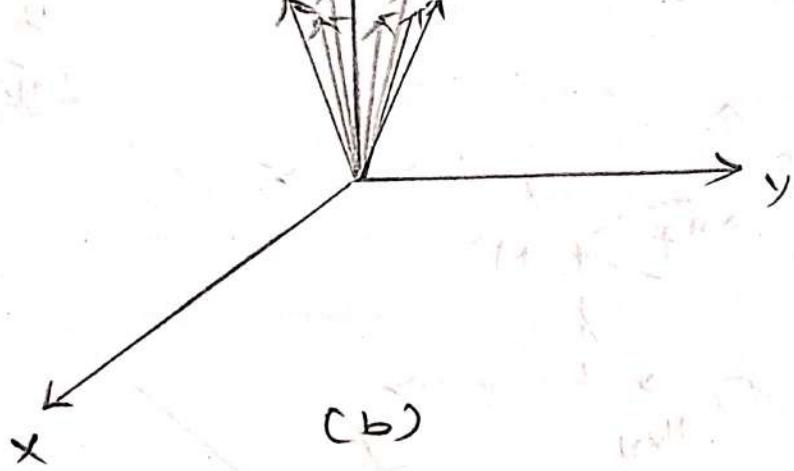


initial value) IT makes magnetization

angle θ_0 (initial)

time (acquisition)

angle θ_0 (acquisition)



(b)

The decay of the Magnetization

Recovery of the Magnetization to its

equilibrium position parallel to the
x-axis with a time constant T_1

The amplitude of this signal decays in an exponential fashion when time T_2

$$(1.e) A = A_0 e^{-t/T_2}$$

where,

$T_2 \rightarrow$ is the characteristic or average decay time for the process. $1/T_2$ is the decay constant

Simultaneously, with the de-phasing decay process, there is also a relaxation of the M_z component to the pre excitation or rest state M_0 .

This process is also exponential in nature with an average decay time T_1 .

If T_1 is sufficiently short, the resultant signal amplitude with both decay processes contributing to the observed decay of the signal would be.

$$(2.e) A = A_0 e^{-t/T_1} e^{-t/T_2}$$

It may be observed that the following two relaxation mechanisms are

associated with excited nuclear spins.

(i) → Relaxation time T_1 is referred to as the spin-lattice relaxation process as it characterizes the time for the perturbed nuclei to re-align themselves with the existing lattice structure of the host material. This is also called longitudinal relaxation as it is the time constant that describes the recovery of the z -component of \mathbf{M} to its equilibrium value M_0 which is along the direction of the magnetic field.

(ii) Relaxation time T_2 is called spin-spin relaxation as it indicates the time required for perturbed, in-phase spins to de-phase with respect to each other. It is also called the transverse relaxation process as it is related to the decay of the component of \mathbf{M} in the xy plane which is conventionally perpendicular to the z -axis or the direction of the applied magnetic field B_0 .

→ Transverse relaxation is faster than longitudinal relaxation so that the spin-spin relaxation time constant T_2 is always smaller than the spin-lattice relaxation time constant T_1 .

→ Both relaxation times (T_1 and T_2) are sensitive to the molecular structure and environments surrounding the nuclei.

→ Ex:- The value of T_2 tends to increase with increased nuclear motion from micro seconds in solids to seconds in liquids.

In biological systems, typical T_2 values for ^1H are 0.04 to 25 ms.

→ The value of T_1 decreases as the amount of motion that has spectral component near the resonant frequency increases.

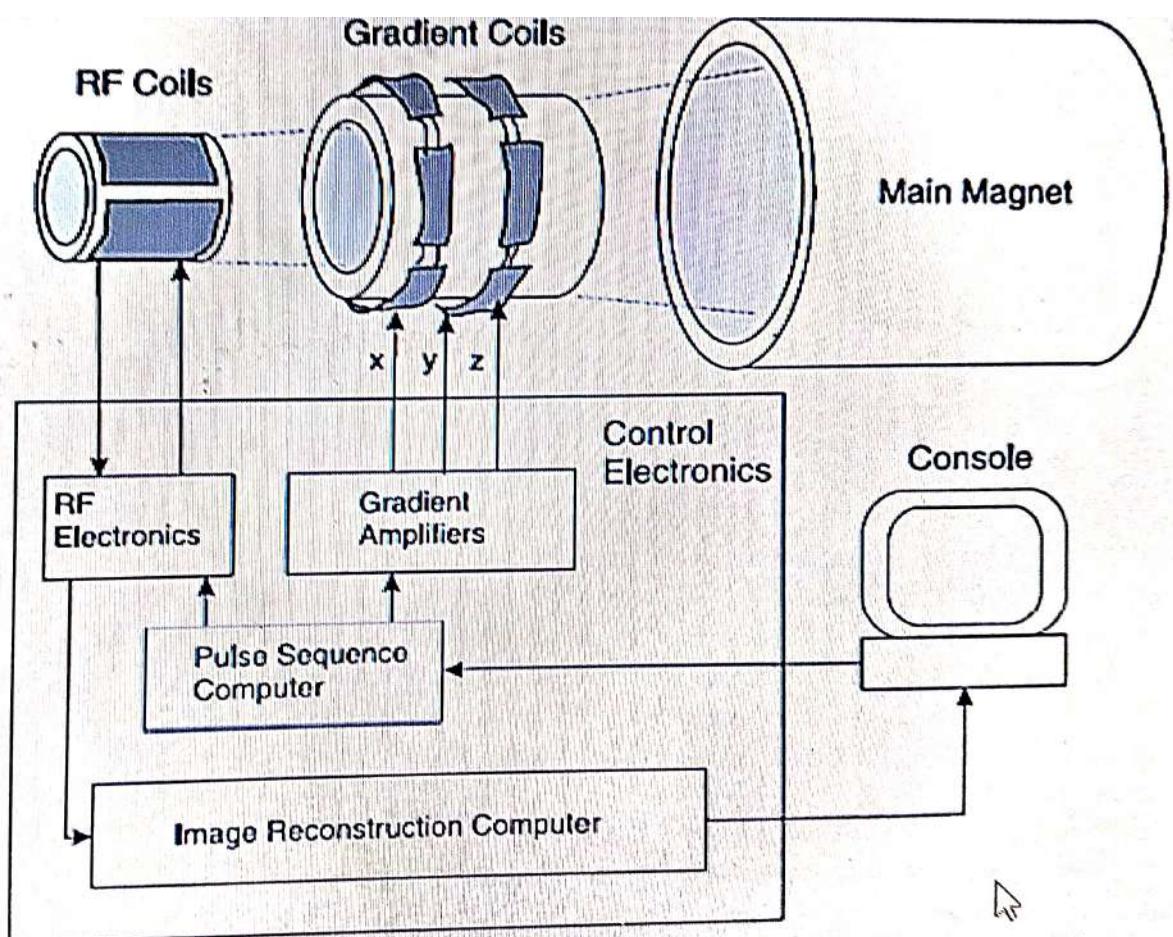
→ T_1 can vary milli-seconds in liquids to months in solids.

Block diagram approach of NMR System

The basic concepts of NMR imaging system are shown in the below figure. These are.

- A Magnet, which provides a strong uniform, steady, Magnetic field B_0
- An RF Transmitter, which delivers radio frequency magnetic field to the sample.
- A gradient system, which provides time-varying magnetic field controlled spatial non-uniformity.
- A detection system, which yields the output signal
- An Imager system; including the computer which reconstructs and displays the images.

The imaging sequencing in the system is provided by a computer, functions such as gates and envelopes for the NMR / MRI pulses, blanking for the pre-amplifier and rf power amplifier and voltage

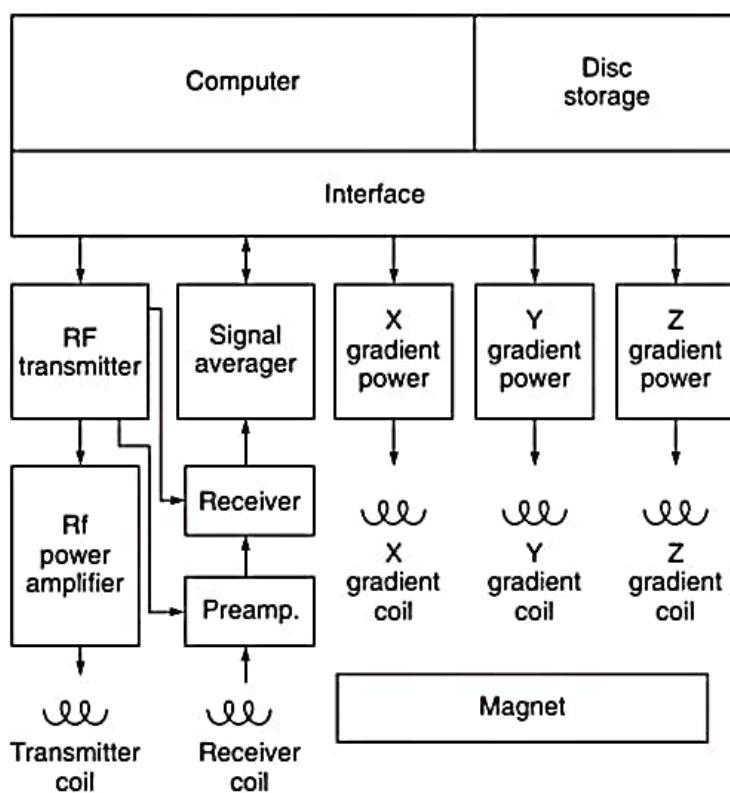


MRI systems: The main

► 22.3 BASIC NMR COMPONENTS

The basic components of an NMR imaging system are shown in Fig. 22.19. These are:

- A *magnet*, which provides a strong uniform, steady, magnet field B_0 ;
- An *RF transmitter*, which delivers radio-frequency magnetic field to the sample;
- A *gradient system*, which produces time-varying magnetic fields of controlled spatial non-uniformity;
- A *detection system*, which yields the output signal; and
- An *imager system*, including the computer, which reconstructs and displays the images.



► Fig. 22.19 Sub-systems of a typical NMR imaging system

The imaging sequencing in the system is provided by a computer. Functions such as gates and envelopes for the NMR pulses, blanking for the pre-amplifier and RF power amplifier and voltage waveforms for the gradient magnetic fields are all under software control.

The computer also performs the various data processing tasks including the Fourier transformation, image reconstruction, data filtering, image display and storage. Therefore, the computer must

Explain the system magnet used in NMR.

- permanent magnet
- Electromagnet
- Superconductors

have sufficient memory and speed to handle large image arrays and data processing, in addition to interfacing facilities.

The Magnet: In magnetic resonance tomography, the base field must be extremely uniform in space and constant in time as its purpose is to align the nuclear magnets parallel to each other in the volume to be examined. Also, the signal-to-noise ratio increases approximately linearly with the magnetic field strength of the basic field, therefore, it must be as large as possible. Four factors characterize the performance of the magnets used in MR systems; viz., field strength, temporal stability, homogeneity and bore size. The effect of the magnetic field strength has been elaborated earlier. The temporal stability is important since instabilities of the field adversely affect resolution. The gross nonhomogeneities result in image distortion while the bore diameter limits the size of the dimension of the specimen that can be imaged.

Such a magnetic field can be produced by means of four different ways, viz., permanent magnets, electromagnets, resistive magnets and super-conducting magnets.

In case of the permanent magnet, the patient is placed in the gap between a pair of permanently magnetized pole faces. Permanent magnet materials normally used in MRI scanners include high carbon iron alloys such as alnico or neodymium iron (alloy of neodymium, boron and iron) and ceramics such as barium ferrite. Although permanent magnets have the advantages of producing a relatively small fringing field and do not require power supplies, they tend to be very heavy (up to 100 tons) and produce relatively low fields of the order of 0.3 T or less.

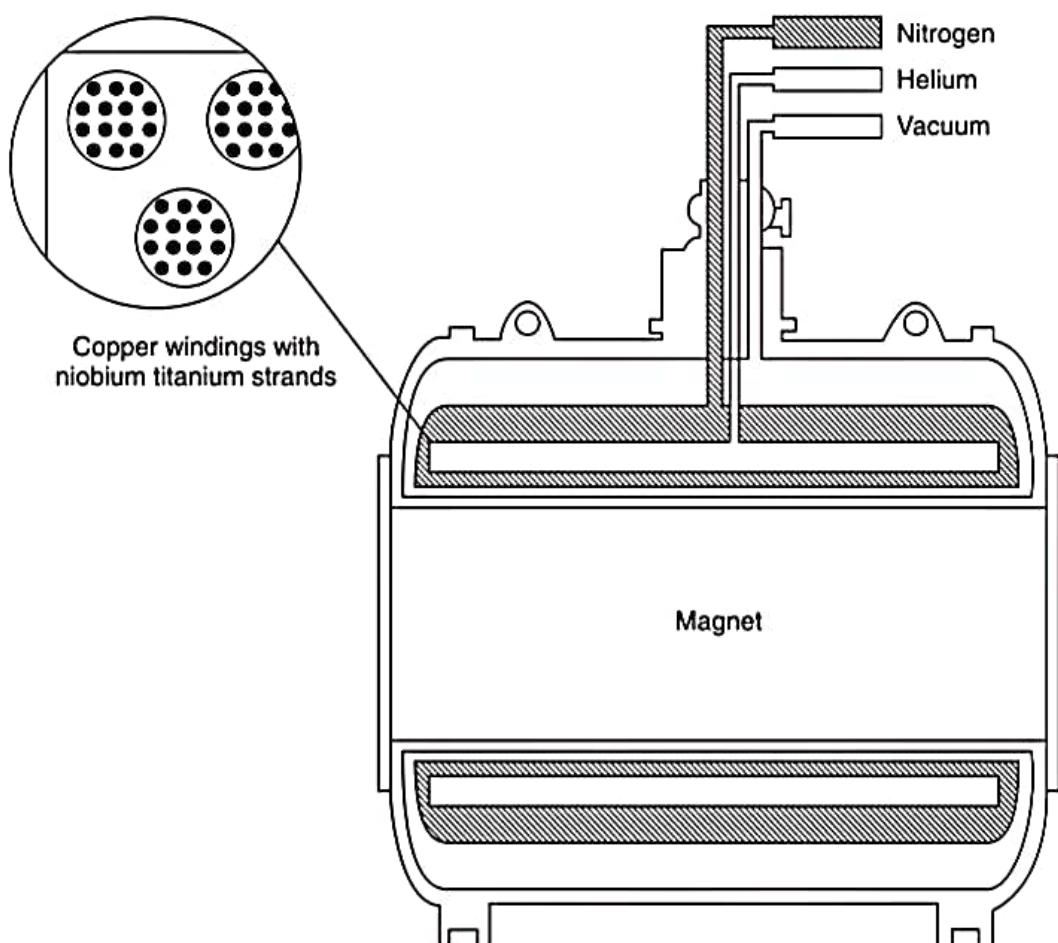
Electromagnets make use of soft magnetic materials such as pole faces which become magnetized only when electric current is passed through the coils wound around them. Electromagnets obviously require external electrical power supply.

On cost considerations, the earlier NMR imaging systems were equipped with resistive magnets. Resistive magnets make use of large current-carrying coils of aluminium strips or copper tubes. In these magnets, the electrical power requirement increases proportionately to the square of the field strength which becomes prohibitively high as the field strength increases. Moreover, the total power in the coils is converted into heat which must be dissipated by liquid cooling. For instance, at 0.2 T, the power requirement is nearly 70 kW (Oppelt, 1984) and a substantial increase of field strength above 0.2 T in resistive magnets is thus technically limited. At present, resistive magnets are seldom used except for very low field strength applications, generally limited to 0.02 to 0.06 T.

Most of the modern NMR machines utilize superconductive magnets. These magnets utilize the property of certain materials, which lose their electrical resistance fully below a specific temperature. The commonly used superconducting material is Nb Ti (Niobium Titanium) alloy for which the transition temperature lies at 9 K (-264°C). In order to prevent superconductivity from being destroyed by an external magnetic field or the current passing through the conductors, these conductors must be cooled down to temperatures significantly below this point, at least to half of the transition temperature. Therefore, superconductive magnet coils are cooled with liquid helium which boils at a temperature of 4.2 K (-269°C). The helium container with its superconductive windings is enclosed in a vacuum to keep the evaporation rate low. Internal shields cooled with liquid nitrogen prevent heating due to radiated heat passing through the vacuum vessel.

In a superconducting magnet, connection to a current supply is only necessary for energizing up to the required field strength. After this, the coils are short-circuited and require no further

electrical energy. The magnetic field is temporarily stable. Due to evaporation of the liquid helium and liquid nitrogen, the monthly topping of helium and weekly topping of nitrogen is necessary. The evaporation rate in the earlier scanners was about 0.5 l/h for liquid helium and 2 l/h for liquid nitrogen. At present, many magnets now make use of cryogenic refrigerators that reduce or eliminate the need for refilling the liquid helium reservoir. Figure 22.20 shows a schematic diagram of the superconducting magnet. Because of their capability to achieving very strong and stable magnetic field strengths without any continuous power consumption, superconducting magnets have become the most widely used and preferred source of the main magnetic fields for MRI scanners.



► Fig. 22.20 Schematic drawing of the superconducting magnet

Superconductive magnetic resonance magnets with an open internal diameter of 1 m, as is desirable for whole body examinations, are now produced for field strengths of upto 2 T. In a typical 1.5 T magnetic field, the current required by the superconducting coils is of the order of 200 amp. The diameter of the coils is about 1.3 m and total length of the wire could be 65 kms. The magnet is operated in the persistent mode, i.e. once the current is established, the terminals may be connected together, and a constant persistent current will flow indefinitely so long as the temperature of the coils is maintained below the superconducting transition temperature.

b) Explain the generations of gradients Magnetic field in detail.

Gradient System for Spatial Coding:Spatial distribution information can be obtained by using the fact that the resonance frequency depends on the magnetic field strength. By varying the field in a known manner through the specimen volume, it is possible to select the region of the specimen from which the information is derived on the basis of the frequency of the signal. The strength of the signal at each frequency can be interpreted as the density of the hydrogen nuclei in the plane

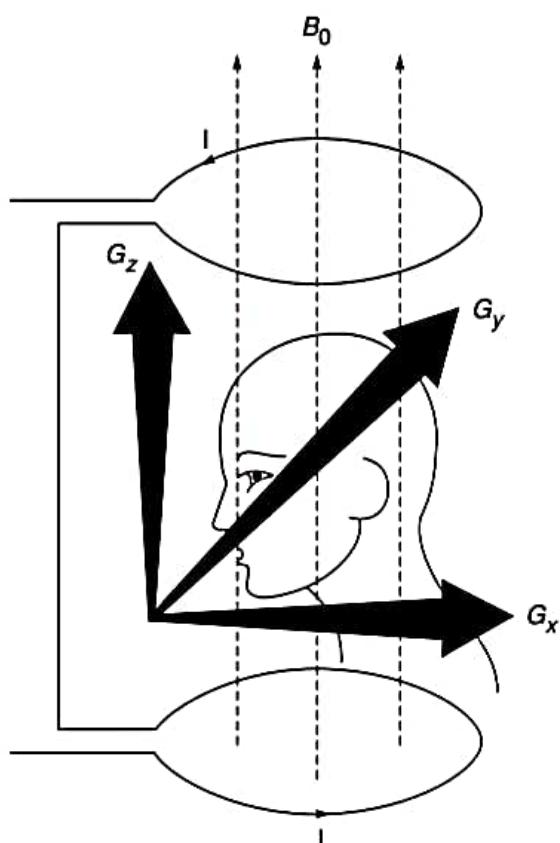
within the object where the magnetic field corresponds to that frequency. NMR imaging methods exploit this property by way of carefully controlled, well-defined gradients to modulate the NMR signal in a known manner such that the spatial information can later be decoded and plotted as an image. Typically, the gradients are chosen with linear spatial dependence so that the NMR frequency spectrum directly corresponds to the position or even one or more spatial co-ordinate axes. The imaging methods differ mainly in the nature of the gradient time dependence (static, continuously time-depended or pulsed), and in the type of NMR pulse sequence employed.

The concept of obtaining spatial information and therefore images was given by Lauterbur (1973). He made a major advancement by super-imposing a linear magnetic field gradient on the uniform magnetic field applied to the object to be imaged. When this is done, the resonance frequencies of the precessing nuclei will depend primarily on the positions along the direction of the magnetic gradient. This produces a one-dimensional projection of the structure of the three-dimensional object. By taking a series of these projections at different gradient orientations, a two or even three-dimensional image can be produced.

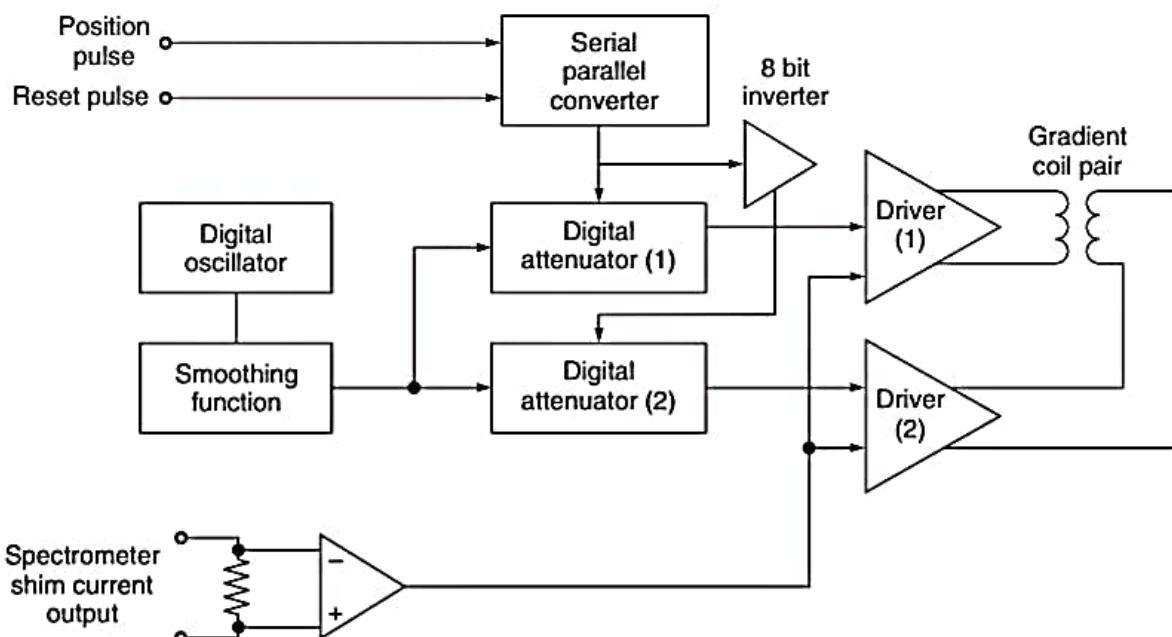
There are various methods for selecting a slice, but the 'selective excitation' method is currently the most widely used method throughout the world. This method covers only the area on which radio wave pulses of the same frequency as the resonant frequency are applied, since the resonant frequency changes in the same direction if a uniform static field and a gradient magnetic field changing linearly in the vertical direction of the layer in question, are impressed simultaneously. *The characteristic of the slice will be determined by the shape of the pulse and the thickness of the slice will be determined by the width and gradient of the pulse.*

In NMR systems, for spatially resolving the signals emitted by the object, the initially homogeneous magnetic field B_0 is overlaid in all three spatial dimensions, X, Y, Z with small linear magnetic fields-gradient fields G. These gradient fields are represented in Fig. 22.22 by arrows of increasing thickness to illustrate the linear increase in magnetic field strength. These gradient fields are produced with the aid of current carrying coils and can be switched on or off as desired, both during the application of the RF energy and also in any phase of the measuring procedure.

The principle of the use of gradient field for selecting plane a is shown in Fig. 22.23. As described earlier, elsewhere, in the sensitive point method, alternating gradients are utilized. The purpose of alternating gradients is to provide a discrete but movable time variant (or sensitive) plane so that various locations may be sensed without the need to move the physical components of the sample or magnet system. With pairs of field coils and alternating complementary gradients, one can position a sensitive plane under magnetic and



► Fig. 22.22 Arrangement of the field gradients



➤ Fig. 22.24 Block diagram of gradient control system. Each X, Y and Z coil pair has its own control circuit (Redrawn after Fitzsimmons, 1982)

The output of the attenuators is then voltage-amplified by two op amps prior to the driven circuits.

Current control requires through the shim coil that the control used to adjust the static field gradients be available for setting the DC levels upon which the alternating gradients are superimposed. An op amp serves the differential voltage drop across a dummy load (having the same resistance as the shim coil) and produces an output which is then DC coupled to the drivers.

The high current drivers use a conventional design with a single op amp providing the input to a driver and a complimentary pair of power transistors to provide a sufficient current to the gradient coil.

In typical scanners, gradient coils have an electric resistance of about 1Ω and an inductance of 1 mH . The gradient fields are required to be switched from 0 to 10 mT/m in about 0.5 ms . The current switches from 0 to about 100 A in this interval. The power dissipation during the switching interval is about 20 kW . This places very strong demands on the power supply and it is often necessary to use water cooling to prevent overheating of the gradient coils.

The demand on the power supply is quite high since the X and Y gradient drivers operate in the $4\text{-}6\text{ A}$ range. Since there are two drivers for each dimension, the total requirement is at least 20 A . The Z driver requires much less current due to the coil geometry and positions with respect to the major fields.

The software requirements pertain only to re-setting a particular gradient and then send an appropriate number of pulses to the gradient control interface. This simply requires that a register be loaded with a number corresponding to the desired plane location and that a countdown is executed outputting a pulse on each decrement of the register. In the program, the entire series of plane settings are stored in memory, so that each time the program is called by the user, it loads

UNIT-8

NUCLEAR IMAGING

QUESTION BANK

1. Define Radio-isotope.

→ Radio-isotopes are unstable variants of chemical elements that emit radiation as they decay.

→ Radio-isotopes are used in medicine both for therapeutic as well as diagnostic applications.

2. What is meant by "Tracers"?

In diagnostic practice, a small amount of radioactive chemicals called 'tracers' (or radio-pharmaceuticals) are injected into an arm vein or administered through ingestion (or) inhalation.

3. What are the three different forms that radioactive emissions take place

Radioactive emissions take place in the following three different forms

→ Alpha Emissions

→ Beta Emissions

produce radiation.

There are four types of radioactive decay that produce radiation.

→ β^+ (positron decay)

→ β^- decay (negatron)

→ Electron capture

→ Isomeric Transition

5. Express that half-life of a radioactive isotope

The half-life of a radioactive isotope is given by

$$t^{1/2} = 0.693/\lambda$$

where

$\lambda \rightarrow$ decay constant for a particular radioactive isotope

6. Define unit of radioactivity?

→ The unit of radioactivity is curie and is abbreviated as Ci or ci

→ This was originally defined to represent the

disintegration rate of one gram of radium, but it is now used as the standard unit of measurement for the activity of any substance.

→ The curie represents a very high degree of activity.

Q. List the three modes that gamma rays lose Energy.

upon interaction with matter, gamma rays lose energy by three modes.

(i) the photo-electric effect transfers all the energy of the gamma rays to an electron in an inner orbit of an atom of the absorber.

(ii) The compton effect occurs when a gamma ray and an electron make an elastic collision.

(iii) when a high energy gamma ray is annihilated interaction with the nucleus of a heavy atom, pair production of a positron and an electron results.

8. List the methods used for exact measurement.

Better methods are available for an exact measurement of the activity. They are

- (i) Ionization chamber
- (ii) Geiger Muller counter
- (iii) proportional counter
- (iv) semiconductor detectors
- (v) solid state detector

9. Define scintillators?

A scintillator is a crystalline substance which produces minute flashes of light in the visible (or near ultraviolet range) when it absorbs ionizing radiation.

10. What is meant by scintillation counter.

→ The light flashes are of very short duration and are detected by using a photo-multiplication tube which produces a pulse for each particle.

→ A scintillator along with the photo-multiplication tube is known as a scintillation counter.

11) State the advantages of solid state detector over gamma rays.

Solid state detectors are highly sensitive to gamma rays because of the high atomic number of Cadmium (48) and Telluride (52). The limited thickness of solid state detectors makes them superior to NaI(Tl) detectors with respect to gamma ray detection sensitivity.

12. Define pulse height analyser?

In order to sort out the pulses of different amplitudes and to count them, electronic circuits are employed. The instrument which accomplishes this is called a 'pulse height analyser'. These analysers are either single or multiple - channel instruments.

What is meant by window width?

The pulses with amplitudes between two triggering levels are counted. This difference in two levels is called the window width (or) channel width (or) acceptance slit and is analogous to monochromators in optical spectrometry.

- 14) what is meant by anti-coincidence circuit.
- Schmitt trigger circuit are followed by an anti-coincidence circuit. This circuit gives an output pulse when there is an impulse in only one of the input channels. It cancels all the pulses which trigger both the schmitt triggers.
- 15) what is meant by multi-channel pulse height analysers.

Multi-channel pulse height analysers are often used to measure a spectrum of nuclear energies and may contain several separate channels, each of which acts as a single-channel instrument for a different voltage span (or) window width.

16. Define gamma camera.

Gamma cameras are used to produce images of the radiation generated by radio-pharmaceuticals within a patient's body in order to examine organ anatomy and function, and to visualize bone abnormalities.

a. Define PET.

PET → positron Emission tomography (PET scanner)

positron Emission tomography is an imaging modality for obtaining *in vivo* cross-sectional images of positron-emitting isotopes that determines demonstrated biological function, physiology (or) pathology.

b. principle of Define SPECT.

SPECT - single photon - emission computed tomography

It is a nuclear medicine technique used to create a three-dimensional representation of the distribution of an administered radioactive pharmaceutical.

SPECT camera detect only radio-nuclides that produce a cascaded emission of single photons.

1) Explain in detail about Gamma camera

- Block diagram
- Its principle of operation
- detail about collimation
- X-ray tube.

2) Explain in detail about the principle's of SPECT

- Block diagram
- principle of operation

3) Explain in detail about principle's of PET

- Block diagram
- principle of operation of PET

21.7 THE GAMMA CAMERA

Gamma cameras are used to produce images of the radiation generated by radio-pharmaceuticals within a patient's body in order to examine organ anatomy and function, and to visualize bone abnormalities. The wide variety of radiopharmaceuticals and procedures used allows for evaluation of almost every organ system. In addition to producing a conventional planar image (a two-dimensional image of the three-dimensional radio-pharmaceutical distribution within a patient's body), most stationary gamma camera systems can also produce whole-body images (single head-to-toe skeletal profiles) and tomographic images (cross-sectional slices of the body acquired at various angles around the patient and displayed as a computer-reconstructed image).

The gamma camera was developed by Anger (1958). He used a large circular area of thin scintillation crystal and an array of closely packed photo-multiplier tubes to amplify and locate the gamma ray interactions in the crystal and to display the scintillations instantly on a cathode ray tube. The camera could then be used to study the rapidly changing distribution of activity, after which dynamic studies could be performed.

The gamma camera is a stationary imaging device as opposed to the rectilinear scanner in which the detector is made to move over the organ of interest. In the case of the gamma camera, the whole organ under study is viewed during the entire period of data collection. This enables fast dynamic function studies of various organs to be carried out conveniently.

Modern-day gamma cameras constitute extremely complex electronic equipment, consisting of the following functional components (Fig. 21.8).

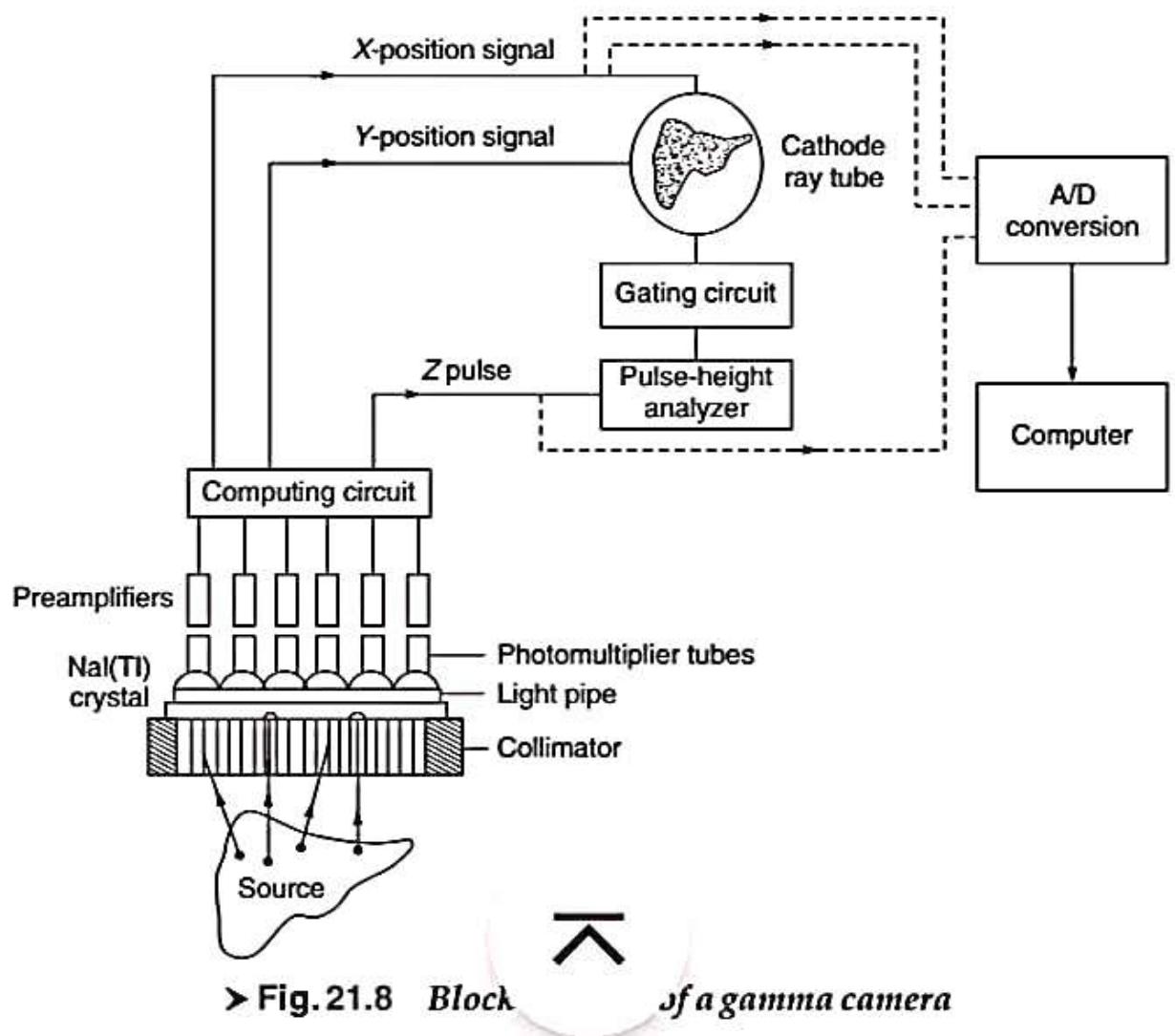
Detector: This consists of a Collimator, crystal, photo-multiplier tubes, position localization circuitry.

Camera Electronics: This includes correction circuitry, energy analysis circuitry, counting circuit, image display and image recording device.

Briefly, the function of gamma camera is as follows:

When a photon of the radiation leaves the patient's body, it passes through the collimator and interacts with a crystal wherein its energy is converted into light. The light from the crystal is received by photo-multiplier tubes and converted into an electrical signal. The electrical signal passes through the position localization circuitry whose output consists of X and Y positional signals, and a Z or energy signal. The X, Y and Z signals are processed by special correction circuits which compensate for errors in the detection and localization of photon.

The Z or energy signal is then analysed in the pulse height analyser circuit to determine if the detected photon is within a user-specified energy range; if it is registered in the counter. The X and Y



► Fig. 21.8 Block diagram of a gamma camera

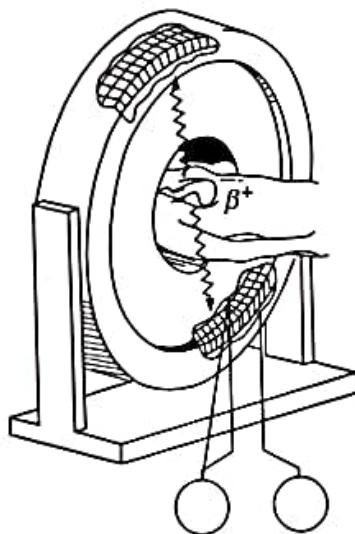
► 21.9 EMISSION COMPUTED TOMOGRAPHY (ECT)

Radio-nuclide tomography refers to the display of the distribution of radioactivity in a single plane or slice through the patient, just as X-ray-computed tomography attempts to display the distribution of density in a similar slice. In this technique, the three-dimensional distribution of radio-nuclide concentrations in the organ are estimated using two-dimensional projectional views acquired at many different angles about the patient. With the introduction of X-ray computed tomography and digital signal processing techniques, algorithms have become available that permit an accurate reconstruction of radio-pharmaceutical images, resulting in the development of several emission computed tomographic (ECT) systems.

For its working, ECT, depends on the measurement of an *in vivo* biochemical process, i.e. the accumulation of a radio-pharmaceutical within the body whereas transmission CT attempts to measure a physical parameter, i.e. the attenuation coefficient of X-rays. With ECT, gamma rays that are absorbed within the body before reaching the detector, or scattered within the organ and then detected, result in measurement errors that generally require compensation during reconstruction.

Emission computed tomography, provides *in vivo* three-dimensional maps of a pharmaceutical labelled with a gamma ray emitting radio-nuclide. The three-dimensional distribution of radio-nuclide concentrations are estimated from a set of two-dimensional projectional images acquired at many different angles about the patient. Several of the reconstruction algorithms are derived from the mathematical approaches used for transmission computed tomography. However, appropriate modifications have to be made to account for attenuation and photon scatter within the patient.

Emission computed tomography has developed in two complementary directions based on the type of radiation that is detected. One approach, positron emission tomography (PET), consists of the detection of annihilation coincidence radiation from positron emitter such as C-11, N-13, O-15, and F-18. When a positron (i.e., a positively charged electron) is emitted within tissue, it rapidly loses its kinetic energy in the same way that beta rays (electrons) lose their energy. The distance that the positron travels from the emission site depends on its initial energy, and typically has a range between 1 and 3 millimeters. After slowing down, the positron interacts with an electron, and both are annihilated, resulting in the emission of two 511 keV photons. To conserve momentum, the two annihilation photons are emitted in very nearly opposite directions (180°). Typically, one or more rings of discrete scintillators are used to detect the two photons (Fig. 21.12). Fast coincidence timing circuits minimize the detection of randomly occurring single events. Furthermore, collimation within the plane is not required since the emission



► Fig. 21.12 Principle of PET scanner (after Jaszczak, 1988)

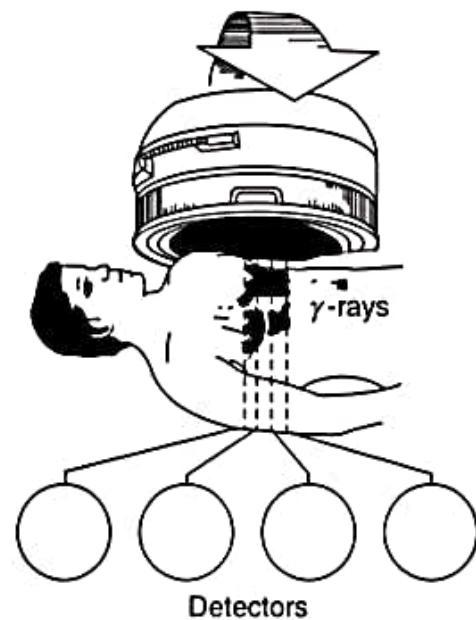
point essentially lies on a line determined by the two crystals that detected the two coincident photons. Collimation is usually required, however, perpendicularly to the transverse plane.

The second approach to emission computed tomography involves the detection of gamma rays emitted singly by the radio-nuclidic tracer. This approach, referred to as single photon emission computed tomography (SPECT) requires collimation within the transverse plane as well as in the perpendicular direction. SPECT uses conventional radionuclides such as Tc-99m (140 keV gamma photon) and TI-201 that are routinely used in all nuclear medicine departments.

SPECT detectors typically consist of Na(Tl) scintillators mounted in a specially designed gantry. The system illustrated in Fig. 21.13 uses a conventional scintillation, or gamma camera that rotates about the patient to obtain a set of projectional views over 360°. These views are then used to reconstruct the regional radio-pharmaceutical concentrations within the body. Since the gamma camera obtains two-dimensional images, the entire organ of interest can be imaged with a single rotation of the camera about the patient. Although presently most SPECT systems are based on the Anger camera approach, discrete detector devices have also been developed.

There are several techniques describing reconstruction algorithms. The two broad approaches to image reconstruction consist of: 1) iterative techniques where an initial trial solution is successively modified, and 2) direct analytical methods using an equation that relates the measured projections and the source distribution. There has been interest in developing iterative algorithms based on the use of prior information and the statistical nature of the measurement process [Levitin and Herman, 1987]. However, currently most commercial ECT systems use the analytical technique of back projecting the filtered projections. This technique is illustrated in Chapter 20 on computer tomography.

Although there are a few clinical applications where SPECT and PET provide similar diagnostic information, in general the applications tend to be different. These differences primarily result from the characteristics of the radio-nuclides that are used.



► Fig. 21.13 Principle of camera based SPECT

4) Explain about radioisotope in detail.

→ alpha emission

→ Beta Emission

→ Gamma Emission

→ Discuss all the 4 Four types of radioactive decay.

→ Positron decay

→ Negatron

→ Electron capture

→ Isomeric transition

→ discuss all the types of time decay of radio isotopes.

► 21.2 PHYSICS OF RADIOACTIVITY

From the theory of atomic structure, it is known that some elements are naturally unstable and exhibit natural radioactivity. On the other hand, elements can be made radioactive by bombarding them with high-energy charged particles or neutrons, which are produced by either a cyclotron or a nuclear reactor. This process will alter the ratio of photons to neutrons in the atoms, thus creating a new unstable nucleus which could undergo radioactive decay. The extra neutron disintegrates and in the process, releases energy in the form of gamma radiation.

Radioactive emissions take place in the following three different forms:

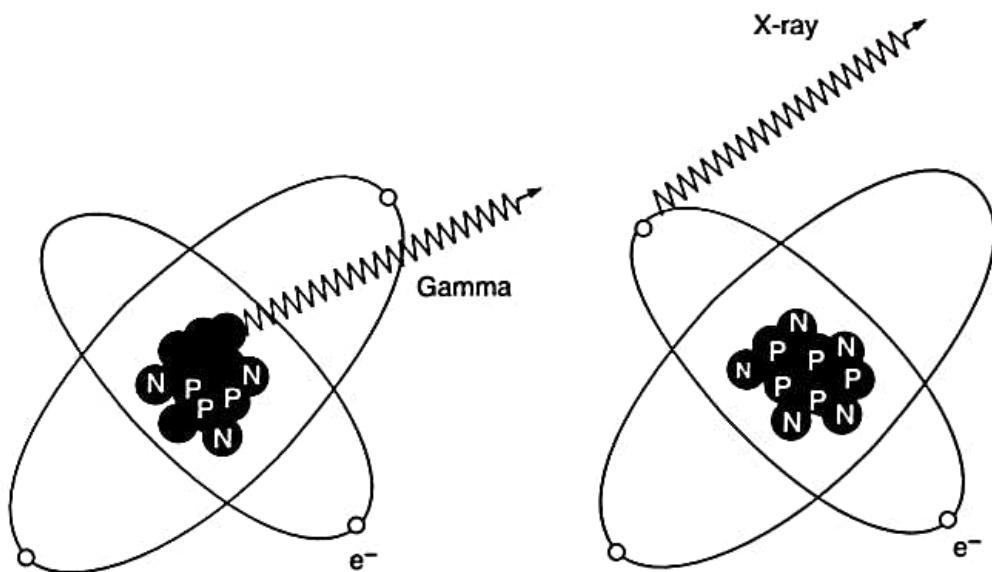
Alpha Emissions: Alpha particles are composed of the two protons and two neutrons. They are least penetrating and can be stopped or absorbed by air. They are most harmful to the human tissue.

Beta Emissions: Beta particles are positively or negatively charged, high speed particles originating in the nucleus. They are not as harmful to tissue as alpha particles, because they are less ionizing, but are much more harmful than gamma rays.

Gamma Emissions: Like X-rays, Gamma particles constitute electromagnetic radiation that travels at the speed of light. They differ from X-rays only in their origin (Fig. 21.1). X-rays originate in the orbital electrons of an atom, whereas gamma rays originate in the nucleus. They are caused by unstable nucleus. X-rays and gamma rays are also called 'photons' or packets of energy. As they have no mass, they have the greatest penetrating capability. Gamma rays are of primary interest in nuclear imaging systems.

The energies of alpha and beta particles and gamma radiations are expressed in terms of the electron volt. One electron volt signifies the energy that an electron would acquire, if it were accelerated through a potential difference of one volt. Radioactive emissions have energies of the order of thousands or millions of electron volts. Alpha emission is characteristic of the heavier radioactive elements such as thorium, uranium, etc. The energy of alpha particles is generally high and lies in the range 2 to 10 MeV (millions electron volt). Due to the larger ionizing power of alpha particles, they can be distinguished from beta and gamma radiations on the basis of the pulse amplitude that they produce on a detector. Beta emissions have an energy range 0–3 MeV.





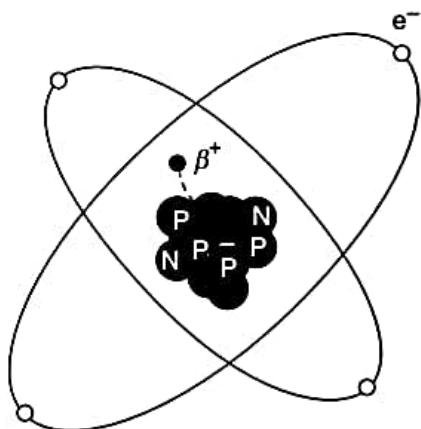
► Fig. 21.1 Difference between X-ray and gamma emissions

There are four types of radioactive decay that produce radiation (Fig 21.2). These are:

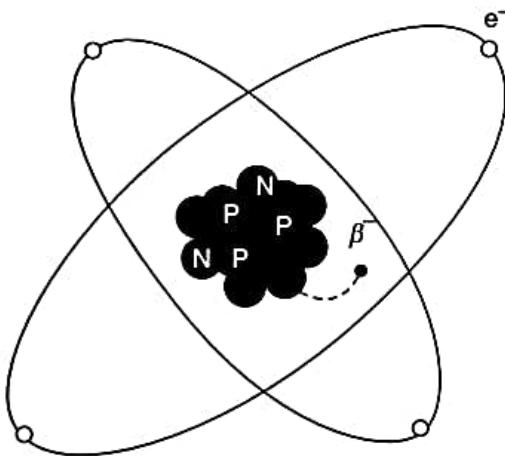
- β^+ (*Positron Decay*): In this, the nucleus is unstable because there are more protons than neutrons. For the atom to become stable, it must reduce the number of protons contained in its nucleus by emission of a positively charged particle. This is called positron decay (Fig. 21.2a). It occurs in man-made radioactive materials, wherein protons are added to the nucleus through bombardment using a 'cyclotron'. Cyclotrons are part of expensive equipment and are not typically available in the hospital.
- β^- *Decay (Sometimes called Negatron)*: In this the nucleus is unstable because there is an excess of neutrons. This negatively charged particle, which is an electron with a high kinetic energy, is emitted from the nucleus. This is called (-) decay. Many of the radio-nuclides used in nuclear medicine decay by the emission of a (-) particle, which in turn, triggers gamma emission (Fig. 21.2(b)).
- In *Electron Capture*: In this the nucleus captures an orbital electron from one of the surrounding energy shells. The captured electron then combines with a proton to form a neutron. During this process, energy in the form of photons or gamma rays is emitted from the nucleus, and X-rays are emitted from the electron orbits (Fig. 21.2(c)).
- *Isomeric Transition*: Sometimes, when a nucleus in an excited state begins the decay process to become more stable, it goes through more than one stage of decay. The intermediate stage is called the 'metastable' state. A nuclide in a metastable state eventually decays to a stable atom, through a process called isomeric transition (Fig. 21.2(d)). This type of decay is very important in nuclear medicine because it is the process by which Tc-99m decays. 'm' here means 'metastable'.

21.2.1 Time Decay of Radioactive Isotopes

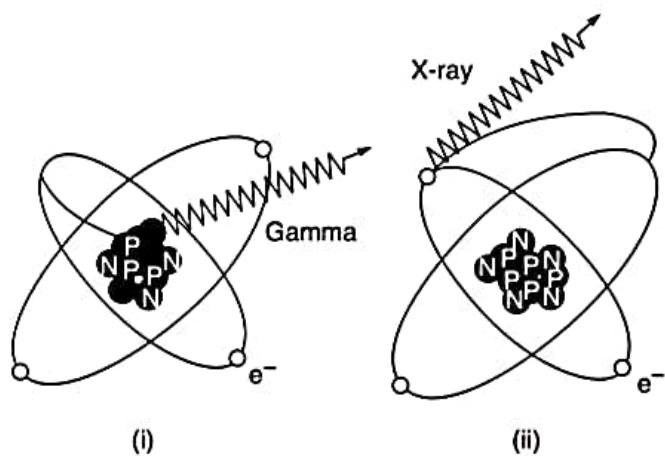
Each radioactive isotope is characterized not only by the type and energy of radiations emitted, but also by the characteristic life-time of the isotope. This is most conveniently designated by the



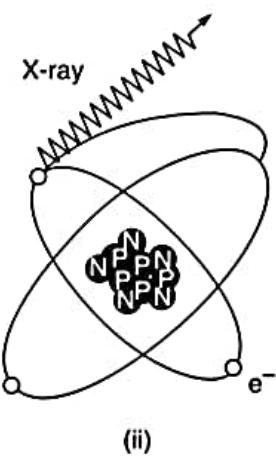
(a) Positron decay (β^+)



(b) β^- decay

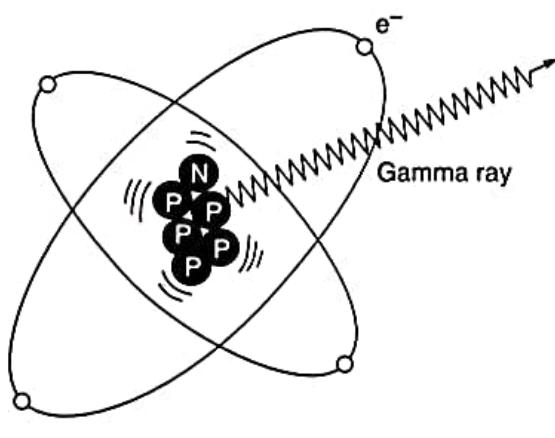


(i)



(ii)

(c) Electron capture



(d) Isomeric transition

► Fig. 21.2 Radioactive decay (i) emission of gamma radiation (ii) emission of X-radiation

half-life or half-period of the isotope. The half-period of a radioactive isotope is the time required for half of the initial stock of atoms to decay. Thus, after one-half period has elapsed, the total activity of any single radioactive isotope will have fallen to half its initial value; after two half-periods, the activity will be one-quarter its initial value and so on. After 6.6 half-periods, the activity will be 1% of the initial activity.

The half-life of a radioactive isotope is given by

$$t^{1/2} = 0.693/\lambda$$

where λ is the decay constant for a particular radio-isotope. In practice, the disintegration rates are determined by counting the number of disintegrations over a certain time t'' and finding the ratio of the number of disintegrations to the time t_m .



5) Explain about the detectors used in Nuclear Imaging

- Radiation detectors
- Ionization chambers.
- Block diagram of Ionization chamber
- Scintillation detectors
- Semiconductor detector
- solid state detectors

► 21.3 RADIATION DETECTORS

Depending upon the radiation emitted by the radio isotope of the radiopharmaceutical, a suitable detector is selected and operated under optimum conditions. Several methods are available for detection and measurement of radiation from radio-nuclides. The choice of a particular method depends upon the nature of the radiation and the energy of the particle involved.

If the radiation falls on a photographic plate, it would cause darkening when developed after exposure. The photographic method is useful for measuring the total exposure to radiation of workers, who are provided with film badges. Better methods are available for an exact measurement of the activity. These methods are the use of: (i) ionization chamber, (ii) Geiger Muller Counter, (iii) Proportional Counter, (iv) semiconductor detectors, and (vi) solid state detectors. Described below are the popular types of radiation detection methods used in modern nuclear imaging equipment.

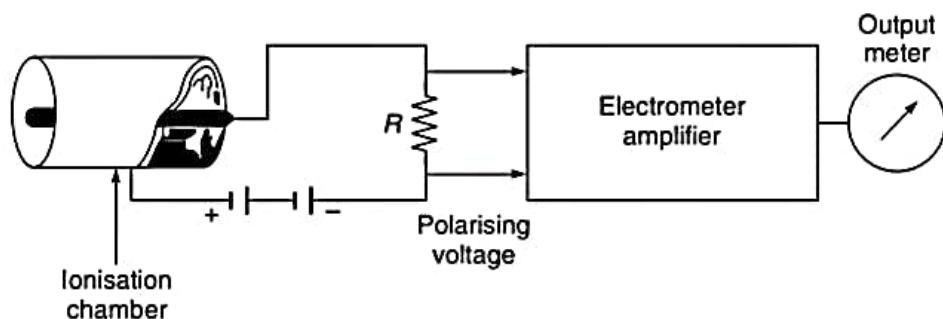
21.3.1 Ionization Chamber

The fact that the interaction of radioactivity with matter gives rise to ionization makes it possible to detect and measure the radiation. When an atom is ionized, it forms an ion pair. If the electrons are attracted towards a positively charged electrode and the positive ions to a negatively charged

electrode, a current would flow in an external circuit. The magnitude of the current would be proportional to the amount of radioactivity present between the electrodes. This is the principle of the ionizing chamber.

An ionization chamber consists of a chamber which is filled with gas and is provided with two electrodes. A material with a very high insulation resistance such as polytetrafluoroethylene is used as the insulation between the inner and outer electrodes of the ion chamber. A potential difference of a few hundred volts is applied between the two electrodes. The radioactive source is placed inside or very close to the chamber. The charged particles moving through the gas undergo inelastic collisions to form ion pairs. The voltage placed across the electrodes is sufficiently high to collect all the ion pairs. The chamber current will then be proportional to the amount of radioactivity in the sample. Ionization chambers are operated either in the counting mode, in which they respond separately to each ionizing current, or in an integrating mode involving collection of ionization current over a relatively long period.

Figure 21.3 shows an arrangement for measuring the ionizing current. The current is usually of the order of 10^{-10} A or less. It is measured by using a very high input impedance voltmeter.



► Fig. 21.3 Schematic diagram for measuring ionising current using DC ionising chamber

The magnitude of the voltage signal produced can be estimated from the fact that the charge associated with the 100,000 ion pairs produced by a single alpha particle traversing approximately 1 cm in air, would be around 3×10^{-14} coulomb. If this average charge is made to pass through a resistance of $3 \times 10^{10} \Omega$ in 1 s, a difference of approximately 1 mV potential would develop across the high resistance. This voltage is a function of the rate of ionization in the chamber.

Liquid samples are usually counted by putting them in ampoules and placing the ampoules inside the chamber. Gaseous compounds containing radioactive sources may be introduced directly into the chamber. Portable ionization chambers are also used to monitor personnel radiation doses.

21.3.2 Scintillation Detector

A scintillator is a crystalline substance which produces minute flashes of light in the visible or near ultraviolet range, when it absorbs ionizing radiation. In such cases, the number of fluorescent photons is proportional to the energy of the radioactive particle. The flashes occur due to the recombination and de-excitation of ions and excited atoms produced along the path of the radiation.

The light flashes are of very short duration and are detected by using a photo-multiplier tube, which produces a pulse for each particle. A scintillator along with the photo-multiplier tube is known as a scintillation counter.

Gamma radiations cannot be detected directly in a scintillating material, because gamma rays possess no charge or mass. The gamma ray energy must be converted into kinetic energy of electrons present in the scintillating material. Thus the conversion power of the scintillating material will be proportional to the number of electrons (electron density) available for interaction with the gamma rays. Because of its high electron density, high atomic number and high scintillating yield, the scintillating material which is generally used as gamma ray detector, is a crystal of sodium iodide activated with about 0.5% of thallium iodide. For counting beta particles, scintillator crystals of anthracene are employed. Since the crystal is hygroscopic in nature, it is usually mounted in a hermetically sealed aluminium container having a glass window on the side, which is in contact with the face of the photo-multiplier.

The detector must be able to absorb a high proportion of the incident radiation and convert this energy rapidly into suitable electronic signals. Presently, thallium-activated sodium-iodide NaI(Tl) scintillation crystal is used in all commercial cameras. Sodium iodide is the most versatile of all the phosphors. It has a high density that allows enough radiation to be absorbed and a high atomic number which favours photo-electric interaction. Thus a signal is generated which represents the full energy of the incident gamma ray. The activator or impurity (thallium) is necessary to provide sufficient luminescence centres. Conversion efficiency, i.e. the ratio of light output to incident photon energy, is typically 10% for 140 keV radiation. Thus a 140 keV gamma ray absorbed in the crystal produces about 4200 light photons (in the blue-green region of the spectrum where each light photon has an energy of around 3 eV). The decay time of this light flash has a half-life of approximately 0.2 ms, sufficiently fast for most clinical applications.

21.3.3 Semiconductor Detectors

There has been a great deal of development work on semiconductor radiation detectors. These detectors can be made very small and robust. Silicon and germanium crystals have been employed mainly for counting alpha and beta particles. They function in a manner similar to that of the gas ionization chamber. On absorption of radiation in the crystal, electrons and positive holes are formed, which move towards opposite electrodes under the influence of applied potential. The resulting current is proportional to the energy of the ionizing radiation.

The advantage of the semiconductor detector comes from the low energy (3 to 3.5 eV) required to produce an electron-hole pair relative to that of a gas (30 to 35 eV to produce one ion pair) or scintillation detector (200 to 300 eV to produce one photoelectron). However, its small energy gap makes it necessary to operate lithium-drifted silicon or germanium detectors at a low temperature (at the liquid nitrogen boiling point of 77°K) in order to reduce the leakage current.

21.3.4 Solid State Detectors

Solid state detectors can be made in miniature form and can be utilized as in-vivo probes for clinical and experimental applications in medicine. One such example is that of silicon and

UNIT-V

RADIATION THERAPY AND RADIATION SAFETY

QUESTION BANK

1. Define Radiation therapy.

Radiation therapy is a medical treatment that uses high-energy radiation, such as x-rays or protons, to target and destroy or shrink cancer cells and tumors.

2. List the Methods to treat cancer:

→ surgery

→ chemotherapy

→ radiation therapy.

3. Define Betatron.

Betatron device was used for cancer treatment in the 1950s. The betatron produced high-energy x-ray beams as well as several electron beams of various energies.

→ Some betatron units provided x-ray and electron energies as high as 45 MeV.

4. Define the term "linear accelerator".

The term "linear accelerator" applies to the part of the system wherein electrons are accelerated to required level of energy.

5. Mention the components of "linear Accelerator".

The linear accelerator machine is comprised of three major components

(a) gantry and stand

(b) treatment couch

(c) control console.

6. what is the role of the accelerators in linear accelerator?

The heart of the radiotherapy linear accelerator machine is the accelerator.

All the accelerators have four major components.

→ the modulator

→ the Electron gun.

→ RF power source

→ the accelerator guide.

7) define the function of the modulator.

The primary function of the modulator circuit is to supply high voltage pulses to the microwave generator. It steps up the 8/p main three-phase power supply to about 50kV prior to its rectification to DC.

8) what are the function Methods used for mounting the accelerator.

- accelerator inline w/ treatment beam
- Electron accelerator parallel to axis of rotation of gantry.

9) define SRS.

SRS stands for stereotactic radiosurgery, which is a specialized form of radiation therapy used to treat tumors and other medical conditions in a highly precise manner.

10) define SRT.

SRT stands for stereotactic radiation therapy, which is a precise and focused form of radiation therapy used to treat tumors and certain medical conditions. It delivers highly

targeted radiation to the tumor while minimizing exposure to surrounding healthy tissue.

11) List other recent techniques in radiation therapy:

- Stereotactic Radio surgery (SRS)
- Stereotactic Body radiation therapy (SBRT)
- Intensity - Modulated radiation therapy (IMRT)
- Image - Guided Radiation therapy (IGRT)
- Particle therapy
- ART (Adaptive radiation therapy)
- FLASH therapy

12) Define cyber knife

Cyber knife is a robotic radiosurgery system that delivers highly precise and targeted radiation therapy to treat tumors and other medical conditions.

13. Define dosimeter.

A dosimeter is a device used to measure and monitor an individual's exposure to ionizing radiation, providing data on the amount of radiation received over a specific period.

14. Define thermo luminescent dosimeter.

A TLD is a type of dosimeter that measures an individual's exposure to ionizing radiation by detecting and quantifying the light emitted when certain materials, typically crystals, are heated after radiation exposure.

15. Define Electronic dosimeter:

An electronic dosimeter is a compact digital device used to measure and monitor an individual's exposure to ionizing radiation in real time, providing instant readings and dose information.

16. Define radiation protection principles.

The fundamental principle of radiation protection is "ALARA", which stands for "As Low As Reasonably Achievable". This principle emphasizes minimizing radiation exposures to the lowest possible level while still achieving benefits from radiation-related activities, such as medical procedures or industrial processes.

14) 3D CRT ?

3D CRT stands for three-dimensional conformal radiation therapy.

It is a radiation therapy technique that uses computerized planning and imaging to precisely shape and target radiation beams to match the shape of the tumor.

15) Define IMRT, IGRT

IMRT → Intensity Modulated Radiation Therapy

IGRT → Image - Guided Radiation Therapy

Point 1B

1. Explain in detail about linear accelerator
in
→ Block diagram
→ The Accelerator
→ The modulators
→ Electron Gun
→ RF power source
→ Accelerator wave Guide
→ Methods of mounting line Accelerator
→ Gantry
→ patient couch.

2. recent Trends in radiation therapy.

Explain about

- 3D CRT
→ IMRT
→ IGRT
→ Cyberknife

3) Explain about the types of dosimeters

- Radiation Monitoring Instruments dosimeters
- Film badges
- Thermo luminescent dosimeters
- Electronic dosimeters

b) Explain about the Radiation Protection in detail.

- Radiation protection principle
- Radiation protection in Medicine

Explain in detail about one & say

→ Draw the block diagram of one

→ Explain their blocks separately

→ Draw the block diagram of one

→ Explain their blocks separately

Accelerator Wave Guide: A charged particle travelling along the axis of a series of conducting tubes which are connected to an alternating voltage gets accelerated and acquires energy as it passes through each gap between the tubes. A system using a radio frequency supply and medium atomic number particles formed the basis of early linear accelerators. The technology was not found to be practical because the high velocity attained by the particles would require very long flight tubes when radio frequency was used. However, at microwave frequencies, it became possible to accelerate electrons to energies of several million electron volts.

In practice, the accelerator structure or wave guide is made up of a number of specially shaped, copper microwave resonant cavities that have been brazed together to form a single structure. The length of the accelerator wave guide will vary from about 30 cm to 2.5 m. depending on the final electron energy to be achieved and the type of structure utilized. A number of different accelerating structures have been employed in medical accelerators. While the shape of the individual resonant cavities and method of injecting the RF power into the accelerator guide will vary depending on the manufacturer, all accelerator structures are of two basic types: travelling wave (TW) or standing wave (SW).

However, the standing wave system accelerates the electrons in a field of constant amplitude, while the field in a travelling wave system is attenuated as it moves along the guide, the former will give a higher electron energy in the same length of guide for a given microwave power level. This means that where the length of the accelerating guide is a critical design factor, a standing wave system has a definite advantage. But this advantage is applicable only to accelerators operating at a lower MeV range. For energies above 4 MeV, the guide length becomes too long and therefore, the difference in accelerating wave guide length does not remain a decisive factor between the standing wave and travelling wave systems.

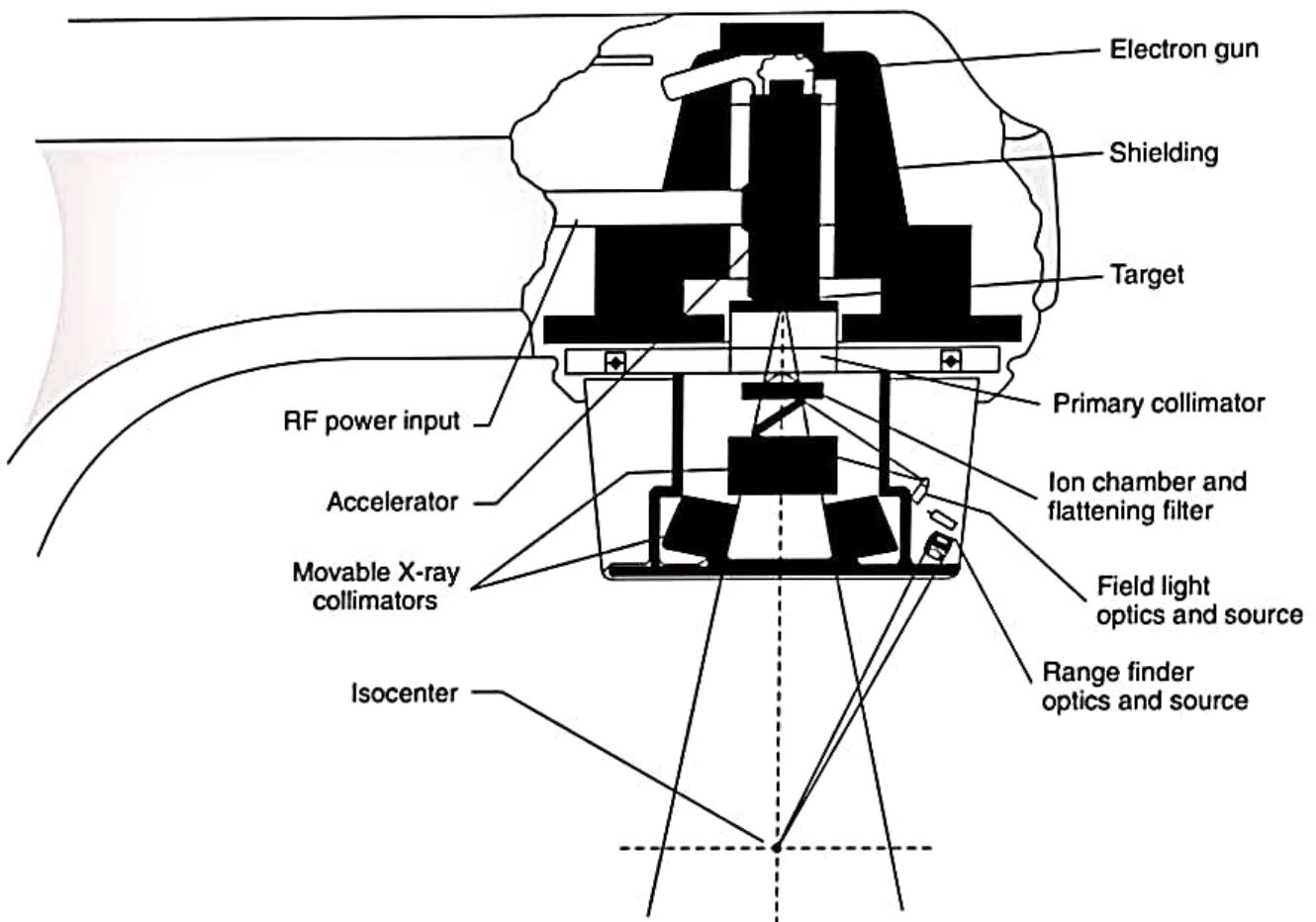
The accelerating electrons tend to diverge, partly by mutual repulsion but mainly, because the electric field in the wave guide structure has a radial component. They can be focused back onto their straight path by the use of a co-axial magnetic field, which is supplied by coils which themselves are co-axial with the accelerating wave guide. There are also additional coils which steer the electron beam in such a way that it emerges from the accelerator structure at the required position and direction.

Mechanical tolerances in the construction of accelerating guides are of the order of 0.01 mm. Both because of resistive losses in the guide walls and because some electrons may strike the structure, their accelerator guide will heat up in operation. Consequently, thermal expansion may result in significant changes in dimensions. A water cooling system for the wave guide is provided in the form of a water jacket through which temperature-controlled water is circulated at a pre-determined rate. The wave guide structure is typically 15 cm in outer diameter, with a length of one to three metres and a weight of several hundred kilograms.

Vacuum conditions need to be created in the accelerator wave guide so that the electrons being accelerated should not be deflected by collisions with gas atoms. For this purpose, an ion pump is used which has a working range of 10^{-3} to 10^{-8} torr.

Cooling System: The temperature of certain parts in the machine is critical for efficient operation. In particular, the temperature of the accelerating guide structure and the microwave valve has to be controlled because dimensional changes associated with thermal expansion will significantly change their characteristics. The X-ray target also needs to be cooled. A cooling system based on circulating water and operated using a thermostat is generally employed.

Treatment Head: The treatment head contains the X-ray target and filtering system, the beam monitor detectors and the beam defining system (Fig. 34.6).



► Fig. 34.6 Schematic of accelerator and collimator sub-systems

Once the electrons have been accelerated to the correct energy level, they either impinge on a metal target and produce X-rays through atomic collisions in the metal in the treatment head or can be used directly for treatment. After X-rays are produced in the target, they emerge in a forward directed lobe whose intensity distribution must be flattened for clinical use. This is accomplished by interposing a circularly symmetric-shaped metal absorber, called a flattening filter in the path of the X-rays. The filter is a cone-shaped device which differentially absorbs the radiation towards the beam centre, i.e. it substantially reduces the dose rate at the beam centre so as to give a uniform dose over the whole area of interest. If the electron beam is to be used for treatment, it will emerge from the vacuum system through a thin window into the treatment head, where it is monitored and, if necessary, scattered to give the required field coverage.

The collimation system is comprised of a primary collimator and two pairs of movable secondary collimators. The secondary collimators move approximately normal to the edge of the radiation field. The collimator system also contains a range finder and field defining light for determination of the target-skin distance and field size at the skin surface.

The photon beam flattening filter and two independent sealed transmission ion chambers, for measuring integrated dose and dose rate, are located above the movable collimators. The integrity of the dosimetry system is checked electronically before every treatment. Each ion chamber is designed to independently stop treatment when the desired integrated dose has been delivered. The ionization chamber also contains special electrode configurations to monitor beam symmetry in two orthogonal beam axes. The ionization chamber, in combination with other electronic circuitry, monitors beam energy.

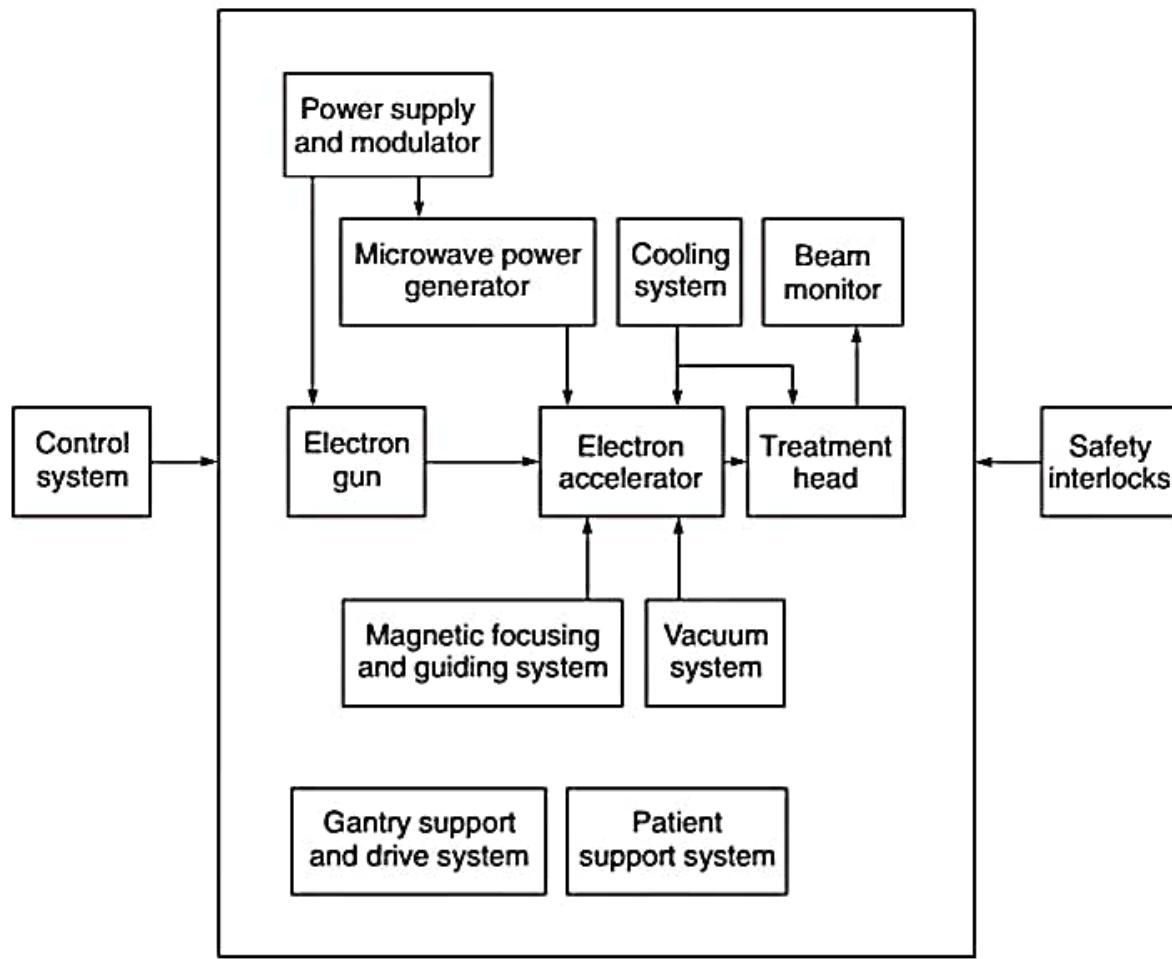
The control console is designed to control the operation of the machine. Treatment is controlled at the console through switch settings for the dose rate, the integrated dose to be delivered, treatment time duration, and stop angle and dose per degree for arc therapy. Lighted indicators show the status of equipment interlocks, and displays are provided for the dose rate, integrated doses for both dose channels, time, gantry angle, arc therapy and rotation direction (clockwise or counterclockwise) and operating mode, either fixed or arc therapy.

The treatment couch has four motions which are motorized with variable speed motors, and are controlled from a hand-held pendant connected to the treatment couch. The longitudinal and lateral motions of the treatment couch top can also be controlled via a manual over-ride. The couch top can be rotated 180° in order to position either end section.

The Accelerator: The heart of the radiotherapy linear accelerator machine is the accelerator. All accelerators have four major components: the modulator, electron gun, RF power source, and accelerator guide which are connected as shown in Fig. 34.5.

The electron accelerator is a wave guide structure which is energized at microwave frequency, most commonly at 3000 MHz. The microwave radiation is supplied in short pulses, a few microseconds long. These pulses are generated by supplying high voltage pulses of about 5 kV from the modulator to the microwave generator, which is most commonly a magnetron valve. In higher energy accelerators, a klystron valve is used as the microwave power source. The electron gun is also pulsed so that high velocity electrons are injected into the accelerating wave guide at the same time as it is energized. The electron gun and accelerating wave guide system have to be evacuated to a pressure such that the mean free path of electrons between atomic collisions is long compared with the electron path through the system.

Modulator: The primary function of the modulator circuit is to supply high voltage pulses to the microwave generator. It steps up the input mains three-phase power supply (380V-440V) to about 50 kV prior to its rectification to DC. Specialized circuitry within the modulator produces high-voltage pulses at the rate of a few hundred pulses per second to synchronously power the electron gun and RF power source. The modulator contains a thyratron which is a high-power switching device needed to direct the high-voltage pulses generated by the modulator to the electron gun and the RF power source. The pulse repetition frequency is determined by the pulse generator which controls the thyratron grid. The peak voltage, the peak power and the mean power required from this circuit are determined by the working conditions of the microwave generator. The dose rate



► Fig. 34.5 Sub-systems of a linear accelerator machine

from the accelerating guide is regulated by controlling the pulse repetition frequency. The pulse length used is typically 3-6 μs .

The modulator may be located either in the gantry or the gantry supporting stand, or in a separate cabinet that can be located at some distance from the accelerator. Electrical connections to the electron gun and the RF power source are made through high-voltage cables.

Electron Gun: The electron gun is pulsed by the modulator and injects pulses of electrons of a few micro-seconds duration into the accelerator guide at energies of about 15-40 keV. The electrons are subsequently accelerated in the accelerator guide to the required energy level. The electron gun can either be a diode device with direct or indirect heating of the cathode, or a triode device in which the grid can be used to obtain control of the injected electron current in the electron mode. All three designs are used in commercial accelerators. All electron guns employ either a heater or filament, which eventually burns out and requires replacement.

RF Power Source: The RF power source is either a magnetron or a klystron. Klystrons are generally used in high-energy accelerators and magnetrons in low- or medium-energy accelerators. These devices employ a number of RF cavities either in a circle (magnetron) or in a straight line (klystron). An electron beam from a cathode is used to excite RF power in these cavities. The amplified RF power is fed into a wave guide—a special hollow metallic tube used to transport microwaves, that is connected to the accelerator. The RF power source, also pulsed by the modulator, provides high-frequency electromagnetic waves (3000 MHz) that accelerate the electrons injected from the electron