17BEBME5E01 MEDICAL PHYSICS 3 0 0 3

UNIT I NON IONIZING RADIATION AND ITS MEDICAL APPLICATION 9

Non-ionizing Electromagnetic Radiation: Overview of non-ionizing radiation effects-Low Frequency Effects- Higher frequency effects. Physics of light, Measurement of light and its unit- limits of vision and color vision an overview, Thermography– Application

UNIT II SOUND IN MEDICINE 9

Physics of sound, Normal sound levels –ultrasound fundamentals – Generation of ultrasound (Ultrasound Transducer) - Interaction of Ultrasound with matter; Cavitations, Reflection, Transmission- Scanning systems – Artifacts- Ultrasound- Doppler-Double Doppler shift-Clinical Applications

UNIT III PRINCIPLES OF RADIOACTIVE NUCLIDES 9

Radioactive Decay – Spontaneous Emission – Isometric Transition – Gamma ray emission, alpha, beta, Positron decay, electron capture, Sources of Radioisotopes Natural and Artificial radioactivity, Radionuclide used in Medicine and Technology ,Decay series, Production of radionuclides – Cyclotron produced Radionuclide- Reactor produced Radio- nuclide-fission and electron Capture reaction, radionuclide Generator-Technetium generator.

UNIT IV INTERACTION OF RADIATION WITH MATTER 9

Interaction of charged particles with matter –Specific ionization, Linear energy transfer range, Bremsstrahlung, Annihilation, Interaction of X and Gamma radiation with matter- Photoelectric effect, Compton Scattering , Pair production, Attenuation of Gamma Radiation ,Interaction of neutron with matter and their clinical significance.

UNIT V BASIC RADIATION QUANTITIES 9

Introduction -exposure- Inverse square law-KERMA-Kerma and absorbed dose –stopping power - relationship between the dosimetric quantities - Bremsstrahlung radiation, Bragg’s curve- concept of LD 50- Stochastic and Non-stochastic effects, Different radiation Unit, Roentgen, gray, Sievert.

Total : 45

TEXT BOOKS:

S.NO.	Author(s) Name	Title of the book	Publisher	Year of publication
1	John R Cameran , James G Skofronick	Medical Physics	John-Wiley & Sons	1978
2	W.J.Meredith and J.B. Massey	Fundamental Physics of Radiology	Varghese Publishing house	1992

REFERENCES:

S.NO.	Author(s) Name	Title of the book	Publisher	Year of publication
1	P.Uma Devi, A.Nagarathnam , B S SatishRao	Intorduction to Radiation Biology	B.I ChurChill Livingstone pvt Ltd	2000
2	S.Webb	The Physics of Medical Imaging	Taylor and Francis	1988

3	J.P.Woodcock	Ultrasonic,Medical Physics Handbook series	Adam Hilger,Bristol	2002
4	Hylton B.Meire and Pat Farrant	Basic Ultrasound	John Wiley& Sons	1995

KARPAGAM ACADEMY OF HIGHER EDUCATION
(Established under section 3 of the UGC Act 1956)
COIMBATORE – 641021
MEDICAL PHYSICS
18BEBME5E01
LECTURE PLAN

TOTAL HOURS: 45

UNIT I - NON IONIZING RADIATION AND ITS MEDICAL APPLICATION

HOURS REQUIRED: 9

S.No	Topics	Hours
1.	Introduction	1
2.	Overview of non-ionizing radiation effects	1
3.	Low Frequency Effects	1
4.	Higher frequency effects	1
5.	Physics of light	1
6.	Measurement of light and its unit	1
7.	Limits of vision and color vision an overview	1
8.	Thermography	1
9.	Application	1

UNIT II - SOUND IN MEDICINE

HOURS REQUIRED: 9

S.No	Topics	Hours
1.	Physics of sound	1
2.	Normal sound levels	1
3.	Ultrasound fundamentals	1
4.	Generation of ultrasound(Ultrasound Transducer)	1
5.	Interaction of Ultrasound with matter	1
6.	Cavitations, Reflection, Transmission	1
7.	Scanning systems – Artifacts	1
8.	Ultrasound- Doppler	1
9.	Double Doppler shift-Clinical Applications	1

UNIT III - PRINCIPLES OF RADIOACTIVE NUCLIDES

HOURS REQUIRED: 9

S.No	Topics	Hours
1.	Radioactive Decay , Spontaneous Emission	1
2.	Isometric Transition ,Gamma ray emission	1
3.	Alpha, beta, Positron decay ,electron capture	1
4.	Sources of Radioisotopes Natural and Artificial radioactivity	1
5.	Radionuclide used in Medicine and Technology	1
6.	Decay series, Production of radionuclides	1
7.	Cyclotron produced Radionuclide- Reactor produced Radio- nuclide	1
8.	Fission and electron Capture reaction	1
9.	Radionuclide Generator,Technetium generator	1

UNIT IV – INTERACTION OF RADIATION WITH MATTER

HOURS REQUIRED: 9

S.No	Topics	Hours
1.	Interaction of charged particles with matter	1
2.	Specific ionization, Linear energy transfer range	1
3.	Bremsstrahlung, Annihilation	1
4.	Interaction of X and Gamma radiation with matter	1
5.	Photoelectric effect	1
6.	Compton Scattering	1
7.	Pair production	1
8.	Attenuation of Gamma Radiation	1
9.	Interaction of neutron with matter and their clinical significance	1

UNIT V - BASIC RADIATION QUANTITIES

HOURS REQUIRED: 9

S.No	Topics	Hours
1.	Introduction	1
2.	exposure- Inverse square law-KERMA-	1
3.	Kerma and absorbed dose	1
4.	stopping power	1
5.	relationship between the dosimetric quantities	1
6.	Bremsstrahlung radiation	1
7.	Bragg's curve, concept of LD 50	1
8.	Stochastic and Non-stochastic effects	1
9.	Different radiation Unit, Roentgen, gray, Sievert	1

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4	Hylton B.Meire and Pat Farrant	Basic Ultrasound	John Wiley& Sons	1995

WEBSITES:

1. www.nptel.ac.in
2. www.ocwmit.edu

STAFF

HoD 20/6/2019

UNIT 1
NON IONIZING RADIATION AND ITS MEDICAL APPLICATION

OVERVIEW OF NON-IONIZING RADIATION EFFECTS

- If electromagnetic radiation is incident on the human body then it will be absorbed in discrete amounts or quanta.
- This amount may be sufficient for ionization of atoms to occur. The equation $E = h\nu$, where h is Planck's constant (6.624×10^{-34} J s), gives the relationship between the energy E of the radiation and the frequency ν.
- Quantized radiation absorption is an important concept where we are dealing with ionizing radiation, but it becomes less important where lower-energy radiations are concerned.
- Table 1 lists some of the major components of the electromagnetic spectrum and the associated energies and frequencies. An energy of about 10 eV is required for ionization of an atom to occur. Because the human body is at a temperature of 37 ◦C (310 K), i.e. normal body temperature, all the atoms will be moving around and the associated thermal energy is given by kT , where k is Boltzmann's constant ($k = 1.38 \times 10-23$ J deg^{-1}) and T is the temperature.
- This is about 0.03 eV. It corresponds to a frequency of 7×10^{12} Hz, which is in the infrared part of the spectrum.
- At lower frequencies than the infrared the quantized energy states are so close together that absorption is normally considered as a continuum.
- In this region we do not normally consider absorption by single atomic events but by a continuous energy loss.
- There is a grey area between the 0.03 eV thermal energy and the 10 eV required for ionization of atoms. Single-photon events may occur in this region.
- Table 2 lists some of the possible types of absorption that may occur in this region. All of these interactions might occur and be of biological significance in the infrared (IR) to ultraviolet (UV) part of the spectrum.

Table 1 Principal components of the electromagnetic spectrum and associated wave and energy parameters.

Components	Wavelength in air (m)	Frequency (Hz)	eV
γ-radiation	1.3×10^{-13}	2.3×10^{21}	10^{7}
Ultraviolet	10^{-7}	3×10^{15}	13
Visible light	5×10^{-7}	6×10^{14}	2.6
Infrared	10^{-6}	3×10^{14}	1.3
Microwaves	10^{-2}	3×10^{10}	1.3×10^{-4}
Radio waves	10	3×10^{7}	1.3×10^{-7}

Table 2 Approximate activation energies for some possible biological interactions with radiation in the infrared to ultraviolet part of the spectrum

Effect	eV	Frequency (GHz)
Ionization	10	2.4×10^6
Covalent-bond disruption	5	1.2×10^6
Photoconduction	1-4	$(2.4\text{-}9.6)\times10^5$
Dielectric relaxation of proteins	0.4	9.6×10^4
Dielectric relaxation of water	0.2	4.8×10^4
Hydrogen bond disruption	0.1-0.2	$(2\text{-}5)\times10^4$
Thermal energy	0.03	7.2×10^3

- Most of the electromagnetic radiations to which we are exposed are of lower energy than the 0.03 eV thermal energy level.
- Some examples are given in Table 3 Most of these radiations are most likely to be absorbed in tissue as heat.
- There is a very large difference between the total amount of heat involved in the absorption of ionizing and non-ionizing radiations

- It might seem that the electromagnetic radiations given in table 3 are most unlikely to cause significant biological interactions. However, it is possible that absorption by many photons might raise energy levels sufficiently to disrupt molecular structures.
- The whole area of hazards from electromagnetic fields is a controversial one, and one that is very poorly understood.
- The three most important interactions between electromagnetic fields and tissue are electrolysis, neural stimulation and heating.
- There are other interactions such as the proton and molecular resonances which occur in a DC magnetic field but these are not thought to cause any significant biological effects.

Table 3. Some sources of electromagnetic fields

Source	Frequency range	Intensity range
Lightning	1 Hz–1 kHz	10 kV m^{-1}
Home appliances	50–60 Hz	250 V m−1 max.
Microwave ovens	2.45 GHz	50 W m−2 max.
High-voltage cables	50–60 Hz	>10 kV m−1
Portable phones	500 MHz typical	>1 W m−2

1.1 LOW-FREQUENCY EFFECTS: 0.1 Hz–100 kHz

1.1.1 Properties of tissue

- Biological tissue contains free charge carriers so that it is meaningful to consider it as an electrical conductor and to describe it in terms of conductivity.
- Bound charges are also present in tissue so that dielectric properties also exist and can be expected to give rise to displacement currents when an electric field is applied.

These properties might arise as electronic or nuclear polarization in a non-polar material, as a relative displacement of negative and positive ions when these are present. These effects may be described in terms of a relative permittivity (dielectric constant).

- In addition to the above two passive electrical properties, biological tissue contains mechanisms for the active transport of ions.
- This is an important mechanism in neural function and also in membrane absorption processes, such as those which occur in the gastro-intestinal tract.
- Conductivity is the dominant factor when relatively low-frequency (less than 100 kHz) electric fields are applied to tissue.

Frequency-dependent effects

- The electrical properties of a material can be characterized by an electrical conductivity σ and permittivity ε.
- If a potential V is applied between the opposite faces of a unit cube of the material (see figure 1) then a conduction current I_c and displacement current I_d will flow, where

$$I_c = V\sigma \qquad I_d = \frac{dV}{dt}\varepsilon\varepsilon_0$$

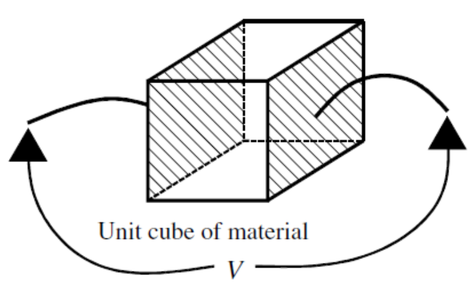


Figure 1 Potential V applied to a unit cube of material with conductivity σ and permittivity ε.

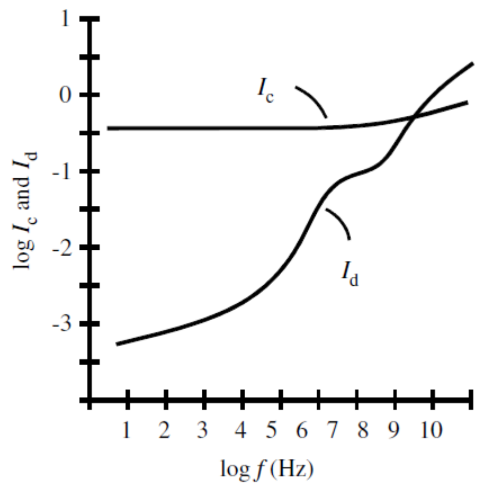


Figure 2 The change in conduction current Ic and displacement current Id for a typical tissue.

where ε_0 is the dielectric permittivity of free space with the value 8.854×10−12 Fm^{-1}. If V is sinusoidally varying then I_d is given by

$$I_d = V\, 2\pi f\, \varepsilon\varepsilon_0$$

where f is the frequency of the sinusoidal potential.

- Both conductivity and permittivity vary widely between different biological tissues but figure 2 shows a typical frequency variation of Ic and I_d for soft biological tissue.
- Ic increases only slowly with increasing frequency and indeed at frequencies up to 100 kHz conductivity is almost constant.
- Id increases much more rapidly with increasing frequency and above about 10^7 Hz the displacement current exceeds the conduction current. Permittivity decreases with increasing frequency and there are, in general, three regions where rapid changes take place.

Resistivity of various biological tissues

- There are many discrepancies in the reported values for tissue resistivity, but this is not surprising view of the great difficulties in making measurements in vivo and the problems of preserving tissue for measurement in vitro.
- Table 4 gives typical values for a range of biological materials at body temperature (resistivity can be expected to fall by 1–2% $^{\circ}C^{-1}$).

- Many tissues contain well-defined long fibres, skeletal muscle being the best example, so that it might also be expected that conductivity would be different in the longitudinal and transverse directions.

- This is indeed the case, and it has been shown that the transverse resistivity may be 10 times greater than the longitudinal resistivity.

Table 4. The electrical resistivity of a range of tissues.

Tissue	Resistivity (m)	Frequency (kHz)
CSF	0.650	1–30
Blood	1.46–1.76	1–100
Fat	20	1–100
Bone	>40	1–100
Lung: inspired expired	17.0 8.0	100 100

1.1.2 Neural effects

- If low-frequency currents are passed between a pair of electrodes placed on the skin then a current can be found at which sensation occurs.
- In general, this threshold of sensation rises with increasing frequency of applied current, as shown in figure 3 three fairly distinct types of sensation occur as frequency increases.

1. At very low frequencies (below 0.1 Hz) individual cycles can be discerned and a ‘stinging sensation’ occurs underneath the electrodes. The major effect is thought to be electrolysis at the electrode/tissue interface where small ulcers can form with currents as low as 100 μA.
2. At frequencies above 10 Hz, electrolysis effects appear to be reversible and the dominant biological effect is that of neural stimulation.
    - If the electrodes are placed over a large nerve trunk such as the ulnar or median, then the first sensation arises from the most rapidly conducting sensory fibres.
    - If the amplitude of the current is increased, then more slowly conducting fibres are stimulated and motor contractions occur. Stimulation over a nerve trunk arises as a result of depolarization at a node of Ranvier.
    - However, when the current is delivered through relatively distant surface electrodes only a very small fraction of the current will pass into a particular node of Ranvier.
    - It is therefore to be expected that the threshold shown in figure 3 will fall as the electrodes are moved closer to a nerve trunk.

    .
3. At frequencies above about 10 kHz the current necessary to cause neural stimulation is such that heating of the tissue is the more important biological effect.

Displacement currents are usually negligible within the range 10–100 kHz and therefore the I 2R losses are dominant.

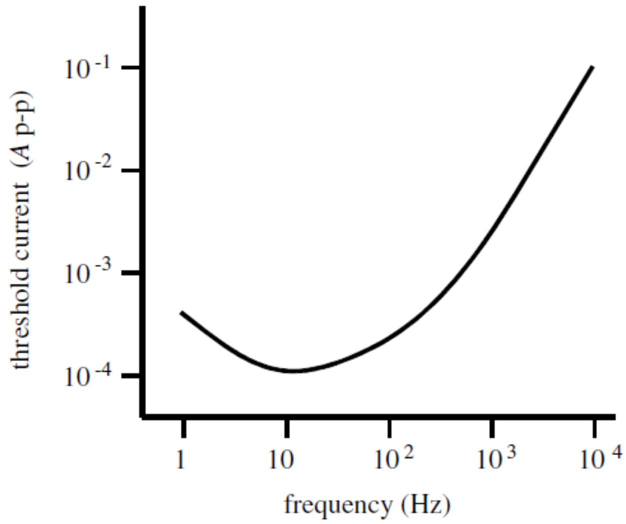


Figure 3 Threshold of sensation as a function of frequency for an electric current applied between 5 mm wide band electrodes encircling the base of two adjacent fingers. (Result from one normal subject.)

The major biological effects within our frequency range of interest are therefore electrolysis, neural stimulation and heating. In figure 3 the threshold sensation is given in terms of the total current which is passed between a pair of surface electrodes. The threshold will depend upon the electrode area as there is ample evidence to show that current density rather than current is the important parameter.

1.1.3 Cardiac stimulation: fibrillation

- Electromedical equipment is a possible source of hazard to the patient. In many cases the patient is directly connected to the equipment so that in cases of a fault electrical current may flow through the patient.
- The response of the body to low-frequency alternating current depends on the frequency and the current density.
- Low-frequency current (up to 1 kHz) which includes the main commercial supply frequencies (50 Hz and 60 Hz) can cause:

a) prolonged tetanic contraction of skeletal and respiratory muscles;
b) arrest of respiration by interference with the muscles that control breathing;
c) heart failure due to ventricular fibrillation (VF).

- In calculating current through the body, it is useful to model the body as a resistor network. The skin can have a resistance as high as 1 M (dry skin) falling to 1 k (damp skin). Internally, the body resistance is about 50 . Internal conduction occurs mainly through muscular pathways. Ohm’s law can be used to calculate the current.

- For example, for a person with damp skin touching both terminals of a constant voltage 240 V source (or one terminal and ground in the case of mains supply), the current would be given by I = V/R = 240/2050 = 117 mA, which is enough to cause ventricular fibrillation (VF).

Indirect cardiac stimulation

- Most accidental contact with electrical circuits occurs via the skin surface. The threshold of current perception is about 1 mA, when a tingling sensation is felt.
- At 5 mA, sensory nerves are stimulated. Above 10 mA, it becomes increasingly difficult to let go of the conductor due to muscle contraction.
- At high levels the sustained muscle contraction prevents the victim from releasing their grip. When the surface current reaches about 70–100 mA the co-ordinated electrical control of the heart may be affected, causing ventricular fibrillation (VF).

- The fibrillation may continue after the current is removed and will result in death after a few minutes if it persists.
- Larger currents of several amperes may cause respiratory paralysis and burns due to heating effects.
- The whole of the myocardium contracts at once producing cardiac arrest.
- However, when the current stops the heart will not fibrillate, but will return to normal co-ordinated pumping.
- This is due to the cells in the heart all being in an identical state of contraction. This is the principle behind the defibrillator where the application of a large current for a very short time will stop ventricular fibrillation.

Figure 4 shows how the let-go level varies with frequency. The VF threshold varies in a similar way; currents well above 1 kHz, as used in diathermy, do not stimulate muscles and the heating effect becomes dominant. IEC 601-1 limits the AC leakage current from equipment in normal use to 0.1 mA.

Direct cardiac stimulation

- Currents of less than 1 mA, although below the level of perception for surface currents, are very dangerous if they pass internally in the body in the region of the heart.
- They can result in ventricular fibrillation and loss of pumping action of the heart.

Currents can enter the heart via pacemaker leads or via fluid-filled catheters used for pressure monitoring. The smallest current that can produce VF, when applied directly to the ventricles, is about 50 μA.

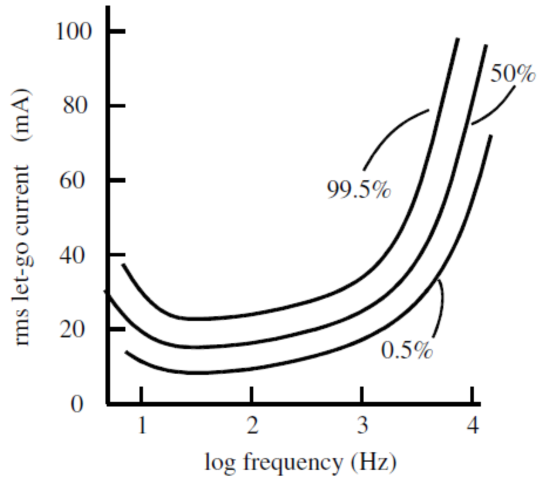


Figure 4. Percentage of adult males who can 'let go' as a function of frequency and curren

Ventricular fibrillation

- VF occurs when heart muscle cells coming out of their refractory period are electrically stimulated by the fibrillating current and depolarize, while at the same instant other cells, still being in the refractory period, are unaffected.
- The cells depolarizing at the wrong time propagate an impulse causing other cells to depolarize at the wrong time.
- Thus, the timing is upset and the heart muscles contract in an unco-ordinated fashion.
- The heart is unable to pump blood and the blood pressure drops.
- Death will occur in a few minutes due to lack of oxygen supply to the brain. To stop fibrillation, the heart cells must be electrically co-ordinated by use of a defibrillator.
- The threshold at which VF occurs is dependent on the current density through the heart, regardless of the actual current.

1.2 HIGHER FREQUENCIES: >100 kHz

1.2.1 Surgical diathermy/electrosurgery:

- Surgical diathermy/electrosurgery is a technique that is widely used by surgeons. The technique uses an electric arc struck between a needle and tissue in order to cut the tissue.

The arc, which has a temperature in excess of 1000 ◦C, disrupts the cells in front of the needle so that the tissue parts as if cut by a knife; with suitable conditions of electric power the cut surfaces do not bleed at all. If blood vessels are cut these may continue to bleed and current has to be applied specifically to the cut ends of the vessel by applying a blunt electrode and passing the diathermy current for a second, or two or by gripping the end of the bleeding vessel with artery forceps and passing diathermy current from the forceps into the tissue until the blood has

- coagulated sufficiently to stop any further bleeding. Diathermy can therefore be used both for cutting and coagulation.
- The current from the 'live' or 'active' electrode spreads out in the patient's body to travel to the
- 'indifferent', 'plate' or 'patient' electrode which is a large electrode in intimate contact with the patient's body. Only at points of high current density, i.e. in the immediate vicinity of the active electrode, will coagulation take place; further away the current density is too small to have any effect.
- Although electricity from the mains supply would be capable of stopping bleeding, the amount of
- current needed (a few hundred milliamperes) would cause such intense muscle activation that it would be impossible for the surgeon to work and would be likely to cause the patient's heart to stop. The current used must therefore be at a sufficiently high frequency that it can pass through tissue without activating the muscles. A curve showing the relationship between the minimum perceptible current in the finger and the frequency of the current was given in figure 3

Diathermy equipment

- Diathermy machines operate in the radio-frequency (RF) range of the spectrum, typically 0.4–3 MHz. Diathermy works by heating body tissues to very high temperatures.
- The current densities at the active electrode can be 10 A cm^{-2}. The total power input can be about 200 W.
- An RF current follows the path of least resistance to ground. This would normally be via the plate (also called dispersive) electrode. However, if the patient is connected to the ground via the table or any attached leads from monitoring equipment, the current will flow out through these.
- The current density will be high at these points of contact, and will result in surface burns (50 mA cm^{-2} will cause reddening of the skin; 150 mA cm^{-2} will cause burns).
- Even if the operating table is insulated from earth, it can form a capacitor with the surrounding metal of the operating theatre due to its size, allowing current to flow. Inductive or capacitive coupling can also be formed between electrical leads, providing other routes to ground.

1.2.2 Heating effects

- If the whole body or even a major part of the body is exposed to an intense electromagnetic field then the heating produced might be significant. The body normally maintains a stable deep-body temperature within relatively narrow limits (37.4±1 ◦C) even though the environmental temperature may fluctuate widely.
- Blood perfusion has an important role in maintaining deep-body temperature. The rate of blood flow in the skin is an important factor influencing the internal thermal conductance

of the body: the higher the blood flow and hence, the thermal conductance, the greater is the rate of transfer of metabolic heat from the tissues to the skin for a given temperature difference.

- Blood flowing through veins just below the skin plays an important part in controlling heat transfer
- Exposure to electromagnetic (EM) fields can cause significant changes in total body temperature.
- Consider the cylindrical geometry shown in **figure 5** which represents a body which is 30 cm in diameter and 1 m long (L). We will assume a resistivity (ρ) of 5 m for the tissue. The resistance (R) between the top and bottom will be given by ρL/A where A is the cross-sectional area. R = 70.7 . For a field of 1 V m^{-1} (in the tissue) the current will be 14.1 mA. The power dissipated is 14.1 mW which is negligible compared to the basal metabolic rate.

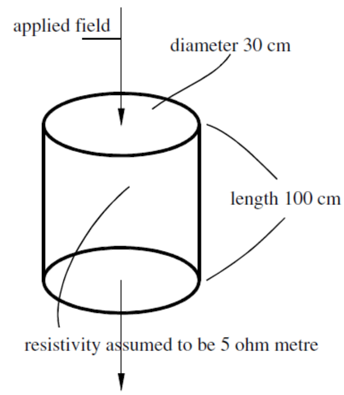


Figure 5. The body modelled as a cylinder of tissue.

- For a field of 1 kV m^{-1}, the current will be 14.1 A and the power 14.1 kW, which is very significant. The power density is 20 W cm^{-2} over the input surface or 200 mW cm^{-3} over the whole volume. In the above case we assumed that the quoted field density was the volts per metre produced in tissue.
- However, in many cases the field is quoted as volts per metre in air. There is a large difference between these two cases. A field of 100 V m^{-1} in air may only give rise to a field of 10^{-5} V m^{-1} in tissue.

PHYSICS OF LIGHT

The nature of light

- The nature of light itself is much more difficult to understand than that of sound. Newton, in the 17th Century, was convinced that light was comprised of tiny mass-less particles, whereas Huygens, working at the same time, argued that it must be a wave of some sort. We now know that light exhibits properties of both particulate and wave motion, but it was not until the beginning of the 19th Century that the wave properties of light were finally established.

- The major problem then was that we could only understand vibration when a mechanical Medium was available to vibrate.
- It was known that light propagated through space and that therefore, unlike sound, no current mechanical theory could describe its motion.
- Maxwell derived the mathematical theories of electromagnetic waves, and demonstrated that light exhibited the properties expected of electromagnetic radiation.
- The wavelength of electromagnetic radiation has no theoretical bound, but we are most familiar with the range from about 10−14 m to about 108 m, as illustrated in figure 6.

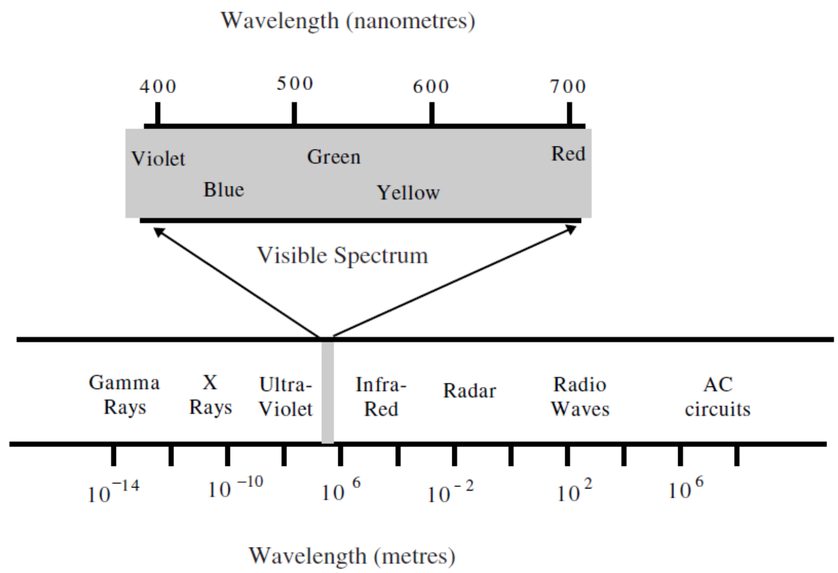


Figure 6. The electromagnetic spectrum.

We use electromagnetic radiation over this whole spectrum in various applications of medical physics, and many of them are covered in other chapters of this book. Visible light occupies only a narrow band from about 400–700 nm. For comparison, the wavelength of sound in the audible range (20 Hz to 20 kHz) in air is 17 m to 17 mm.

Speed of light

The speed at which light travels in a vacuum is approximately 3 × 108 m s−1, or 186 000 miles per second. Its speed in a transparent medium is always less than this, and the ratio of the speed in vacuum to that in the medium is known as its index of refraction, n,

$$n = \text{index of refraction} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \frac{c}{v}.$$

The indices of refraction of some common media are listed in table 4.

Medium	Index of refraction
Air	1.0003
Water	1.3
Glass	1.5

For most practical purposes the speed of sound in air is taken as the same as that in vacuum.

Refraction and reflection at a boundary

- When light travels from one medium into another its frequency cannot change but its velocity must. The wavelength changes to accommodate the change in velocity. At a fixed frequency, wavelength is proportional to speed and therefore the ratio of the wavelength in vacuum to the wavelength in a medium is also equal to the index of refraction.
- The angle through which the light is refracted can be calculated from simple geometry, and the relationship between the angle of incidence and the angle of refraction is determined by Snell's law.

Snell's law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2.$$

Figure 7 is a little misleading because it implies that all of the light that reaches the boundary is refracted and continues into the second medium. This is not true, and some percentage of the incident light is reflected away from the surface.

- The reflected light, which has been omitted from the figure for clarity, leaves at an angle which is simply the reflection of the incident angle in the normal to the boundary plane.
- The relative intensities of the incident, reflected and refracted light depend on the properties of the media and on the angle of incidence.

A consequence of Snell's law is that a spherical boundary will focus parallel light rays onto a single point. This property is the basis of the geometrical optics of the eye, and of our design of corrective optical devices for defective vision. Two portions of spherical boundaries, as represented by a simple biconvex lens, will also focus parallel incident light rays to a point (see figure 8).

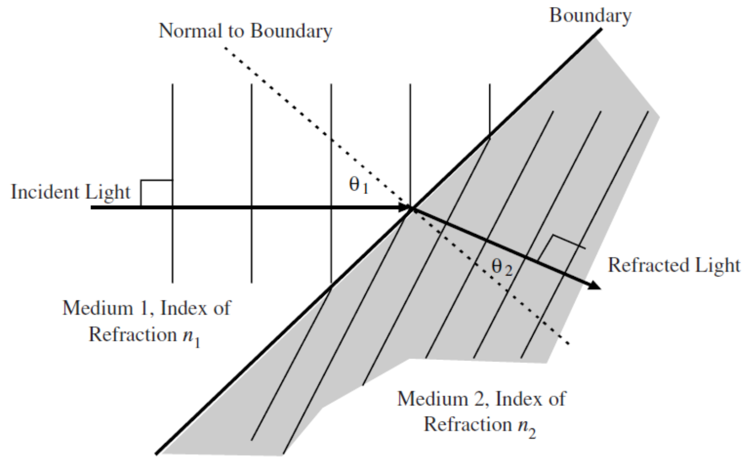


Figure 7. Refraction of light at a boundary between media, n2 > n1.

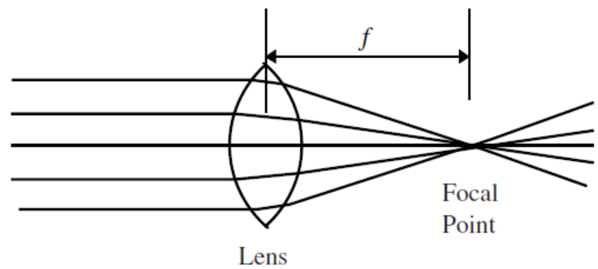


Figure 8. Focusing of light by a biconvex lens.

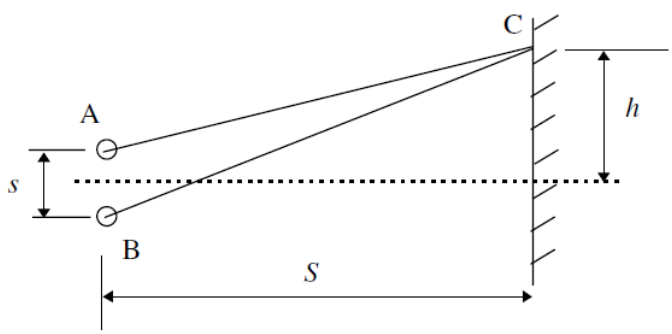


Figure 9. Conditions for constructive and destructive interference.

If the index of refraction of the material of a thin lens is n2 and that of the surrounding medium is n1, the focal length, f , of the lens is given by

$$\frac{1}{f} = \left(\frac{n_2 - n_1}{n_1}\right)\left(\frac{1}{R_a} - \frac{1}{R_b}\right)$$

where Ra is the radius of curvature of the first surface of the lens and Rb is that of the second surface, measured from the same side of the lens. This equation is known as the lens-makers' equation.

Diffraction

- In the preceding section we have looked at how light rays from two slits interfere. The width of each slit is taken to be infinitesimal, so that each represents a line source.
- By considering a real slit of finite width as an aggregation of very much thinner slits we can develop an expression for the intensity of the light falling on a screen as a function of position along the screen. Once again we find that there are fringes of light.
- The central fringe is the brightest, and the brightness of each successive fringe moving away from the centre is less than that of the previous one.
- The spreading of the light from the slit is called diffraction, and the pattern of fringes on the screen is the diffraction pattern.
- The width of the bright central fringe can be taken as a measure of the diffraction. The half-angle, θ, at which the beam appears to diverge can be approximated by the relationship

$$\theta = \sin^{-1}\left(\frac{\lambda}{w}\right)$$

Where λ is the incident wavelength and w is the width of the slit.

Complete diffraction occurs when the width of the slit approaches the wavelength of the incident wave.

MEASUREMENT OF LIGHT AND ITS UNIT

Light measurement is done with two different set of units. These set of units are:

1. Radiometry Unit
2. Photometry Unit.

Radiometry units deal with measuring light power at all wavelengths. Photometry units deal with measurement of light wavelength. Photometry is important for measurement of illumination (lighting).

Radiometry measures and units are given in the following table

Sl no	Quantity	S.I Unit
1	Radiant energy	Joule **(J)**
2	Radiant flux	Watt **(W)**

3	Spectral power	Watt per meter **(W/m)**
4	Radiant Intensity	Watt per Steradians **(W/Sr)**
5	Spectral Intensity	Watt per Steradians per meter **(W/Sr/m)**
6	Radiance	Watt per steradian per square meter **($W/Sr/m^2$)**
7	Spectral radiance	Watt per steradian per meter cube **($W/Sr/m^3$)** or **($W/Sr/m^2/Hz$)**
8	Irradiance	Watt per square meter **(W/m^2)**
9	Spectral Irradiance	Watt per meter cube **(W/m^3)** or **($W/m^2/Hz$)**
10	Radiance exitance / Radiant emittance	Watt per square meter
11	Spectral radiant exitance/ Spectral radiant emittance	Watt per meter cube **(W/ m^3)** or Watt per square meter per hertz **($W/m^2/Hz$)**
12	Radiosity	Watt per square meter **(W/m^2)**
13	Radiant exposure	Joule per square meter **(J/m^2)**
14	Radiant energy	Joule per meter cube **(J/m^3)**

Following are the Photometry measures and units:

Sl no	Quantity	S.I unit
1	Luminous energy	Lumen second **(lm s)**
2	Luminous Flux	Lumen **(lm)**
3	Luminous Intensity	Candela **(Cd)**
4	Luminance	Candela per meter square **(Cd/m^2)**
5	illuminance	lux **(lx)**
6	Luminous emittance	lux **(lx)**
7	Luminous exposure	lux second **(lx s)**
8	Luminous energy density	Lumen second per meter cube **($lm\ s\ /m^3$)**
9	Luminous efficacy	Lumen per Watt **(lm / W)**

How to Measure Light?

Measurement of light depends on the fact that what characteristic of light we want to measure.

The Various characteristics of light are:

1. Light intensity
2. Speed of light
3. Flux

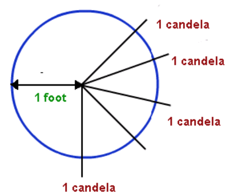
4. Luminous intensity
5. Luminous efficiency etc.

Many units are defined for measurement of light. For example candela, lumen, lux, and many more. If we are interested in measuring the Luminous Intensity we use the unit Candela.

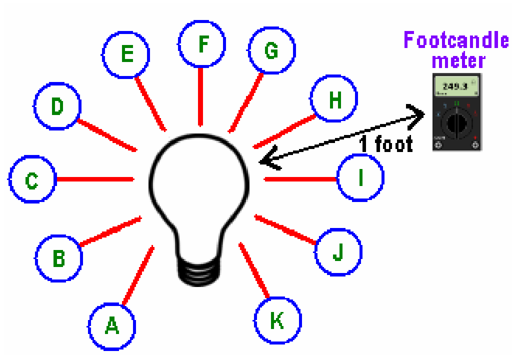
Luminous Intensity is the measure of wavelength-weighted power emitted by a light source in a particular direction per unit solid angle.

Similarly based on the light characteristics the units are used which are as below:

Candela is defined as the luminous intensity of 1/s 600,00 meter square of projected space of a black body radiator which is operating at solidification temperature of platinum under 101,325 N/m^2 of pressure.



Foot Candle is the amount of light incident on a square foot of a object's surface which is one foot distant from the point source of light.



End Foot Candle is used for focused light beam measurements only. It is the focal light beam measurement between two points separated at a distance of one foot.

Lumen is a unit for luminous flux. It is the measure of total light output of a bulb. End lumen is based on spot of light measurement only. End lumen is the measurement of light between two points at a distance of one foot.

Lux is measure of illuminance of an objects surface. Light intensity measured on a surfaceplane at a particular position is called illuminance.

1 Lux = 1 lumen/m^2.

As the visibility is related to human viewer, photometric data considers the varying sensitivity of human eye for varying wavelengths of visible light. Plotting the sensitivity of human eye with human eye results into a bell shaped curve. This curve is called as eye sensitivity curve or spectral luminous efficiency curve or function. To measure lumens, depending on where the light wavelengths fall on the eye sensitivity curve these wavelengths are given less or more weight.

For two different light sources with same radiant flux incident on different portions of the curve will have different

Lumen measurements: Consider two light sources, both with 1 W of radiant flux and one source emits a green light at **555 nm** and other emit blue light at **480 nm**. As the curve shows, the green light appears more bright the blue light even when the total energy of two lights is same. Blue light at 480 nm wavelength will have 68 lumens and green light with 555 nm will measure 683 lumens.

Lumen Measurement
lumen measurement **may be of two types:**

1. Photometric
2. Radiometric.

Photometry measures only the Visible wavelengths of light whereas **Radiometry** measures measures all the wavelengths both visible and invisible spectrum of a light source. **Luminous Flux** is the total light energy that a light source emits across wavelengths (visible) of light. This flux is measured in terms of **Lumen**.

How to Measure Light Output

Light output is an informal term used to describe the amount of light a source produces and how the light is distributed. Photometrics is the formal term which describes the quantity and distribution of light by a source. Most commonly used specification for calculating the light output or luminous flux of a light source is lumen output. A lumen is a unit that measures the total emitted light by a light source.

The relation between Lumen and Candela is:

$$1 \text{ Lumen} = 1 \text{ Candela} \times 1 \text{ steradian.}$$

LIMITS OF VISION

Visual acuity

- If the angle between two light rays passing through the optical centre is too small, we will not be able to distinguish between them with respect to location.
- The minimum angle at which resolution is just possible is called the visual angle, and the inverse of the visual angle, measured in minutes of arc, is our visual acuity.

- The most commonly applied test of visual acuity has been the Snellen chart. One version of this chart consists of a series of 11 rows of letters, progressively smaller from the top. When it is viewed from a distance of 20 ft the letters on the eighth line are just distinguishable by a person of good vision: the distinguishing characteristics of the letters on this line form a visual angle of 1 min of arc at 20 ft.
- A person with 20/20 vision can read the letters of the eighth line at 20 ft. The lines above the eighth are marked with greater distances, again at which they are just discernible by the person with good vision.
- A person with 20/40 vision can read at 20 ft the line (in fact the fifth) that with good vision is readable at 40 ft. Note that the visual acuity expressed as a ratio is dimensionless, and the distances could equally well be expressed in metres or any other unit.
- Many Snellen charts are now marked in metres and 6/6 vision (recorded at 6 m) is the equivalent of 20/20 when measured in feet.
- If the colours on the Snellen chart are reversed, so that the letters are white and the background is black, our measured acuity is very much lower.

- Under ideal conditions a person with excellent vision might achieve a visual acuity of two, implying that their visual angle of resolution is 0.5 min.
- It is interesting to investigate the absolute limits of visual acuity based on the geometry and spatial distribution of cones on the retina.
- Our most acute vision occurs when light is focused on the fovea. Each of the cones in this region has its own communication line down the optic nerve, and we can distinguish between the activities of two adjacent cones.
- This tells us the spatial resolution available at the retina, and gives an upper bound on our visual acuity.
- For the normal eye the optical centre is about 17 mm in front of the retina, and the cones are 2 μm apart. This implies that the maximum visual angle is about 0.4 min, and the upper bound on visual acuity is 2.5. It would seem, then, that those of us with the best visual acuity are limited by the density of the cones.

Visual sensitivity

- What is the lower threshold of light energy required to stimulate the visual process? This problem was investigated very successfully by Hecht in the middle part of this century. He devised several ingenious and well-controlled experiments to measure the sensitivity of the eye.
- As discussed earlier, the rods are much more sensitive than the cones. In terms of luminance, the cones do not function below about 0.001 cd m^{-2}, and our vision is entirely dependent on the rods.
- The optimal sensitivity of the rods is to light at a wavelength of about 510 nm. Hecht directed light at this wavelength at an area of high rod concentration (away from the fovea). He demonstrated that, for a number of observers, the average threshold was about 100 photons arriving at the cornea.
- He further calculated that only about 48% of these would arrive at the retina: 4% would be reflected at the cornea, 50% of those remaining would be absorbed in the media within the eye. Of the 48% getting through, 20% would be absorbed by the rhodopsin to create a visual stimulus (the remainder would either have been absorbed by the neural

components before reaching the photoreceptors or would miss the rods entirely and be absorbed by the black pigment behind).

- In total then, only about 10% of the light arriving at the retina, or about ten photons, actually generates the visual stimulus. This is a very small amount of energy, and once again it can be demonstrated that little could be done to improve our visual sensitivity without a very major re-design.

A great incentive for the exploration of the limits of vision, with respect to both acuity and sensitivity, was the development of the television. Much of the literature in the middle part of the 20th Century has immediate application in this field.

COLOR VISION

- It has already been stated that our colour vision is associated with the cones. Colour is a psychophysical property of light, in that it is associated with visual perception.
- There are two attributes of a light wave that we would expect to govern our perception of it.
- The first is the wavelength, and the second is the intensity.
- When we mix light together, we would further expect the spectral composition of the resulting combination to be important.
- This effectively gives three parameters that we might use to describe a colour. In addition, we might anticipate that the duration of exposure to the light might also be important, and indeed we have already discussed the processes of light- and dark-adaptation, which obviously depend on time of exposure to the stimulus.
- Putting aside the time element, the remaining three parameters have been represented by Munsell as a double cone, as illustrated in figure 10.

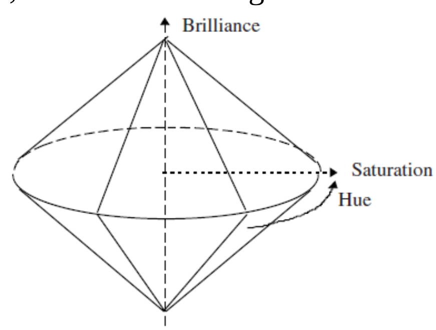


Figure 10 . Munsell’s colour description in terms of brilliance, saturation and hue.

- The vertical axis represents the intensity of the colour.
- The circumferential coordinate represents the hue: it is dependent on the wavelength, and is what we would normally think of as the determinant of colour.
- The horizontal axes define the saturation of the colour, and reflect the spectral composition.
- At the outer extreme the light is of only one pure colour, and at the inner extreme all wavelengths are present.
- The vertical axis represents brilliance, which is a property of intensity.

- At the bottom there is no light, and the colour is black. At the top all wavelengths are present at maximum intensity, and the resulting colour is white.
- All other points on the vertical axis represent shades of grey.
- Although this particular representation might be useful to aid our understanding of the qualities of colour, it is less useful in predicting the outcome of combining different colours. The rules of combination are not simple.

Pre-dating the Munsell description is the Young–Helmholtz trichromatic theory. Young originally observed that all colours could be made up from three primary ones: his chosen primaries were red, green and blue.

- He postulated that the eye contained three different types of nerve receptor, and that the brain made up composite colours by combination of signals.
- Helmholtz did not initially accept Young's theory, because he was aware that some colours could not apparently be produced from pure monochromatic (single wavelength) primaries. He later realized that the receptors might not be 'pure' in that they might have overlapping spectral response curves, and that this could explain the discrepancies in experimental results.

Essentially the trichromatic theory uses the 'concentration' of three colours as a mathematical basis rather than three parameters such as brilliance, saturation and hue.

- Simple rules for the combination of colours using addition and subtraction can readily be developed on this basis.
- The choice of primaries for a trichromatic combination is arbitrary, and any three 'independent' colours will serve the purpose.
- Suppose that we take red, green and blue as the primaries. The Young–Helmholtz theory suggests that we can write any colour, C, of intensity c as a linear sum of the three primaries,

$$\mathbf{cC \equiv rR + gG + bB}$$

- The intensities of the colours (c, r, g and b) can be measured in any standard photometric units, such as lumens. The total light flux must be the sum of the components, and so $c = r + g + b$.
- A standard colour-matching experiment is to project a spot of a colour, cC, at a particular intensity onto a screen, and to focus on one spot next to it three filtered beams producing each of the three primary colours.
- By adjusting the intensities of the three primaries, we expect to be able to produce a match of the original colour. For many colours this is true, but it turns out that there are some colours that cannot be matched in this way, the basis of Helmholtz's early rejection of Young's trichromatic theory.
- A saturated blue–green is one example of a colour that cannot be produced by a combination of red, green and blue light. What is possible, however, is to refocus the red beam so that it falls onto the original blue–green spot, and then to match the resulting colour with a combination of blue and green.
- Although we have been unable to demonstrate that we can satisfy the trichromatic equation as written, we have been able to satisfy the following:

$$\mathbf{cC + rR \equiv gG + bB.}$$

In principle the two equations are identical, except that we have to accommodate the notion of a negative coefficient of a colour in the trichromatic equation.

Chromaticity diagrams

- Chromaticity diagrams provide a two-dimensional representation of a colour. The parameter that is sacrificed is brightness.
- It is assumed that the basic determinants of colour are the relative intensities of the three chosen primaries. We can write the trichromatic equation in terms of relative intensities if we assume that one unit of colour is produced by a particular relative mixture of the primaries, irrespective of their absolute magnitudes.

In this case a relative form of the trichromatic equation can be written;

$$C = \frac{r}{r+g+b}R + \frac{g}{r+g+b}G + \frac{b}{r+g+b}B.$$

- Changing each of the intensities by the same factor will produce the same colour. The three coefficients are not independent: any one of them can be obtained by subtracting the sum of the other two from unity.
- This means that we can choose any pair of the coefficients as the independent variables and represent the colour as a point in a single plane. The resulting graph is called a chromaticity diagram.
- If we choose red and green primaries as the independents, we obtain the diagram illustrated in figure 11. All colours can be represented on this diagram, each occupying a point in the plane.
- We should recognize that some colours will not lie within the triangle shown because negative coefficients would be required to produce them.
- Straight lines on the chromaticity diagram have special properties: all colours on a straight line can be represented as a linear combination of the two monochromatic colours at its extremes.

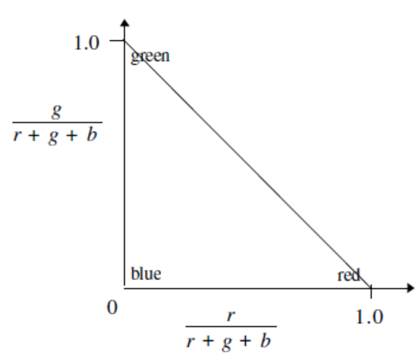


Figure 11. Chromaticity diagram based on red, green and blue primaries.

The triangular envelope formed by the connection with straight lines of points on a chromaticity diagram defines all of the colours that can be produced using an additive combination of the colours represented by the points.

- This has immediate application in the fields of television, cinema and colour printing. The choice of primaries determines the range of colours available.
- Deficiencies in colour vision can be identified by the pattern of lines connecting different colours that an individual cannot distinguish from one another.

THERMOGRAPHY– APPLICATION

Infrared thermography (IRT), **thermal imaging**, and **thermal video** are examples of infrared imaging science. Thermographic cameras usually detect radiation in the long-infrared range of the electromagnetic spectrum (roughly 9,000–14,000 nanometers or 9–14 µm) and produce images of that radiation, called **thermograms**. Since infrared radiation is emitted by all objects with a temperature above absolute zero according to the black body radiation law, thermography makes it possible to see one's environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature; therefore, thermography allows one to see variations in temperature. When viewed through a thermal imaging camera, warm objects stand out well against cooler backgrounds; humans and other warm-blooded animals become easily visible against the environment, day or night. As a result, thermography is particularly useful to the military and other users of surveillance cameras.

Some physiological changes in human beings and other warm-blooded animals can also be monitored with thermal imaging during clinical diagnostics. Thermography is used in allergy detection and veterinary medicine. It is also used for breast screening, though primarily by alternative practitioners as it is considerably less accurate and specific than competing techniques. Government and airport personnel used thermography to detect suspected swine flu cases during the 2009 pandemic.

Thermography has a long history, although its use has increased dramatically with the commercial and industrial applications of the past fifty years. Firefighters use thermography to see through smoke, to find persons, and to localize the base of a fire. Maintenance technicians use thermography to locate overheating joints and sections of power lines, which are a sign of impending failure. Building construction technicians can see thermal signatures that indicate heat leaks in faulty thermal insulation and can use the results to improve the efficiency of heating and air-conditioning units.

The appearance and operation of a modern thermographic camera is often similar to a camcorder. Often the live thermogram reveals temperature variations so clearly that a photograph is not necessary for analysis.

Advantages of thermography

- It shows a visual picture so temperatures over a large area can be compared

- It is capable of catching moving targets in real time
- It can be used to find defects in shafts, pipes, and other metal or plastic parts
- It can be used to detect objects in dark areas
- It has some medical application, essentially in kinesiotherapy

Limitations and disadvantages of thermography

- Many models do not provide the irradiance measurements used to construct the output image; the loss of this information without a correct calibration for emissivity, distance, and ambient temperature and relative humidity entails that the resultant images are inherently incorrect measurements of temperature
- Images can be difficult to interpret accurately when based upon certain objects, specifically objects with erratic temperatures, although this problem is reduced in active thermal imaging
- Accurate temperature measurements are hindered by differing emissivities and reflections from other surfaces
- Most cameras have ±2% accuracy or worse in measurement of temperature and are not as accurate as contact methods
- Only able to directly detect surface temperatures

Applications

- Condition monitoring
- Digital infrared thermal imaging in health care
- Medical imaging
- Neuro musculo skeletal disorders.
- Thyroid gland abnormalities.
- Various other neoplastic, metabolic, and inflammatory conditions.
- Night vision and Targeting
- UAV Surveillance.
- Research
- Surveillance in security, law enforcement and defence

MEDICAL IMAGING Application

- Primarily used for breast imaging. There are three approaches: tele-thermography, contact thermography and dynamic angiothermography.
- These digital infrared imaging thermographic techniques are based on the principle that metabolic activity and vascular circulation in both pre-cancerous tissue and the area surrounding a developing breast cancer is almost always higher than in normal breast tissue.
- Cancerous tumors require an ever-increasing supply of nutrients and therefore increase circulation to their cells by holding open existing blood vessels, opening dormant vessels, and creating new ones (neo-angiogenesis theory).

Tele-thermography and contact thermography supporters claim this process results in an increase in regional surface temperatures of the breast, however there is little evidence that thermography is an accurate means of identifying breast tumours.

- Thermography is not approved for breast cancer screening in the United States or Canada, and medical authorities have issued warnings against thermography in both countries.
- Dynamic angiothermography utilizes thermal imaging but with important differences with the tele-thermography and contact thermography, that impact detection performance.
- First, the probes are improved over the previous liquid crystal plates; they include better spatial resolution, contrastive performance, and the image is formed more quickly.
- The more significant difference lies in identifying the thermal changes due to changes in vascular network to support the growth of the tumor/lesion.
- Instead of just recording the change in heat generated by the tumor, the image is now able to identify changes due to the vascularization of the mammary gland. It is currently used in combination with other techniques for diagnosis of breast cancer. This diagnostic method is a low cost one compared with other techniques.
- The angiothermography is not a test that substitutes for other tests, but stands in relation to them as a technique that gives additional information to clarify the clinical picture and improve the quality

Electronic and LC (liquid crystal) contact thermography

Also by contact measurement the temperatures of the skin can be recorded. There have been electronic thermometers (thermistor or thermo couple devices for punctual registration in use as well as plates including encapsuled LC (liquid cholesterol crystals)for two -dimensional area covering.

These devices are of historic interest and have been used as long as infrared cameras were extremely expensive and in early stages of development. They have a lot of disadvantages such as interfering with the measured object by contact.

Recently used infrared cameras for medical examinations:

- Together with the advanced microelectronic development infrared cameras recently achieve major advantages. While still the cooled MCT scanner must be called the gold standard, it is a slowly recording (1 Hz) and therefore not a real time imaging system.

- Modern scanners like the Jenoptik VarioScan HR (Fig. 7) have brilliant, clear, noise and pixel error free images with a high resolution and best stability, reproducibility, sensitivity (better than 30 mK) and avoidance of any thermal drift.

UNIT 2
SOUND IN MEDICINE

PHYSICS OF SOUND

Definition: Sound is defined by as "(a) Oscillation in pressure, stress, particle displacement, particle velocity, etc., propagated in a medium with internal forces (e.g., elastic or viscous), or the superposition of such propagated oscillation. (b) Auditory sensation evoked by the oscillation described in (a)."

Physics of sound

- Sound can propagate through compressible media such as air, water and solids as longitudinal waves and also as a transverse waves in solids.
- The sound waves are generated by a sound source, such as the vibrating diaphragm of a stereo speaker. The sound source creates vibrations in the surrounding medium.
- As the source continues to vibrate the medium, the vibrations propagate away from the source at the speed of sound, thus forming the sound wave.
- At a fixed distance from the source, the pressure, velocity, and displacement of the medium vary in time.

The behavior of sound propagation is generally affected by three things:

- A relationship between density and pressure. This relationship, affected by temperature, determines the speed of sound within the medium.
- The propagation is also affected by the motion of the medium itself. For example, sound moving through wind. Independent of the motion of sound through the medium, if the medium is moving, the sound is further transported.
- The viscosity of the medium also affects the motion of sound waves. It determines the rate at which sound is attenuated. For many media, such as air or water, attenuation due to viscosity is negligible.

When sound is moving through a medium that does not have constant physical properties, it may be refracted (either dispersed or focused).

The mechanical vibrations that can be interpreted as sound are able to travel through all forms of matter: gases, liquids, solids, and plasmas. The matter that supports the sound is called the medium. Sound cannot travel through a vacuum.

Longitudinal and transverse waves

- Sound is transmitted through gases, plasma, and liquids as longitudinal waves, also called compression waves. It requires a medium to propagate.
- Through solids, however, it can be transmitted as both longitudinal waves and transverse waves.
- Longitudinal sound waves are waves of alternating pressure deviations from the equilibrium pressure, causing local regions of compression and rarefaction, while transverse waves (in solids) are waves of alternating shear stress at right angle to the direction of propagation.

Sound waves may be "viewed" using parabolic mirrors and objects that produce sound.

The energy carried by an oscillating sound wave converts back and forth between the potential energy of the extra compression (in case of longitudinal waves) or lateral displacement strain (in case of transverse waves) of the matter, and the kinetic energy of the displacement velocity of particles of the medium.

Sound wave properties and characteristics

Sound waves are often simplified to a description in terms of sinusoidal plane waves, which are characterized by these generic properties:

- Frequency, or its inverse, the period
- Wavelength
- Wave number
- Amplitude
- Sound pressure
- Sound intensity
- Speed of sound
- Direction

Sound that is perceptible by humans has frequencies from about 20 Hz to 20,000 Hz. In air at standard temperature and pressure, the corresponding wavelengths of sound waves range from 17 m to 17 mm. Sometimes speed and direction are combined as a velocity vector; wave number and direction are combined as a wave vector.

Transverse waves, also known as shear waves, have the additional property, polarization, and are not a characteristic of sound waves.

Speed of sound

he speed of sound depends on the medium that the waves pass through, and is a fundamental property of the material. The first significant effort towards the measure of the speed of sound was made by Newton. He believed that the speed of sound in a particular substance was equal to the square root of the pressure acting on it (STP) divided by its density.

$$c = \sqrt{\frac{p}{\rho}}$$

This was later proven wrong when found to incorrectly derive the speed. French mathematician Laplace corrected the formula by deducing that the phenomenon of sound travelling is not isothermal, as believed by Newton, but adiabatic. He added another factor to the equation-gamma-and multiplied $\sqrt{\gamma}$ to $\sqrt{\frac{p}{\rho}}$, thus coming up with the equation $c = \sqrt{\gamma \cdot \frac{p}{\rho}}$.

Since $K = \gamma \cdot p$ the final equation came up to be $c = \sqrt{\frac{K}{\rho}}$ which is also known as the Newton-Laplace equation.

In this equation, K = elastic bulk modulus, c = velocity of sound, and ρ= density. Thus, the speed of sound is proportional to the square root of the ratio of the bulk modulus of the medium to its density.

NORMAL SOUND LEVELS

Table- Gives The Sound Pressure Levels Both In Pascals And In Decibels, Corresponding To Nine Circumstances.

- Damage To The Ear Occurs Immediately For Sound Levels Of About 160 Db. Normal Atmospheric Pressure Is About 105 Pa And 160 Db Is 2 × 103 Pa So That Damage Occurs At About 0.02 Atm. The Threshold Of Hearing Is The Other Extreme.
- This Pressure Represents 2 × 10−10 Atm; If We Were To Measure This Pressure With A Mercury Manometer Then The Mercury Level Would Only Change By 1.5 × 10−10 M.
- The Range Of Sound Levels Which Are Encountered In Normal Living Is Very Wide, Although There Has Been Increasing Pressure In Recent Years To Limit The Maximum Sound Levels To Which People Are Exposed.
- There Is No International Agreement On Standards For Occupational Exposure But Most Of The Developed Countries Have Adopted A Limit Of 90 Db For Continuous Exposure Over A Normal 8 H Working Day, With Higher Levels Allowed For Short Periods Of Time. In Some Countries The Level Is Set Below 90 Db.
- In A Room Where Hearing Tests Are Carried Out, The Background Noise Level Should Not Be Greater Than 40 Dba And A Level Below 30 Dba Is Preferred. Lower Noise Levels Are Needed If 'Free Field' Testing Is To Be Carried Out (See Iso 8253-2 For More Detailed Guidance).
- The Use Of Sound-Reducing Material In The Walls, Floor And Ceiling Of The Audiology Test Room Is Often Necessary.
- Noise-Reducing Headsets Are A Cheap Way Of Reducing The Background Noise Level For A Patient

Table 15.1. *Nine typical sound pressure levels, expressed on the dBA scale.*

Sound pressure ($N\ m^{-2} = Pa$)	Sound pressure level (dBA)	Circumstances
2×10^3	160	Mechanical damage to the ear perhaps caused by an explosion
2×10^2	140	Pain threshold, aircraft at take-off
2×10	120	Very loud music, discomfort, hearing loss after prolonged exposure
2×10^0	100	Factory noise, near pneumatic drill
2×10^{-1}	80	School classroom, loud radio, inside a car
2×10^{-2}	60	Level of normal speech
2×10^{-3}	40	Average living room
2×10^{-4}	20	Very quiet room
2×10^{-5}	0	Threshold of hearing

Ultrasound Fundamentals

- At audible frequencies, sound waves are capable of moving the eardrum, and thus giving rise to the sensation of hearing.
- At higher (ultrasonic) frequencies, the sound is not audible, but can be used to image materials and measure the velocity of moving objects. Sound waves are usually defined as a compressional disturbance travelling through a material.

This definition is actually too limiting, as any material which will support some shear (e.g. a solid or a liquid with non-zero viscosity) will support transverse waves as well as longitudinal (compressional) waves. However, the transverse waves are usually of much less importance than longitudinal waves in biological materials.

The classical wave equation was derived as

$$\frac{\partial^2 \psi}{\partial t^2} = c^2 \frac{\partial^2 \psi}{\partial x^2}$$

where $\psi(x, t)$ gives the displacement of an element of fluid initially at point x and where

$$c = \sqrt{\frac{B}{\rho}}.$$

c is the speed of the wave, B the bulk modulus of the medium and ρ the density.

In an ideal gas, where $(PV)^\gamma$ is constant, c is given by

$$c = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} \qquad (\gamma \cong 1.4 \text{ for air}).$$

We can answer one of the questions posed in the introduction straight away: ‘Why does inhaling helium make the pitch of the voice rise?’ ρ will be less for helium than for air and so, from the above equation, c will be higher than in air. Now for any transmitted wave $c = f\lambda$, where f is the frequency and λ the wavelength. The wavelength is fixed by the size of the vocal cavity and therefore frequency will increase in proportion to velocity.

Radiation pressure

A sound wave travelling through a medium exerts a static pressure on any interface across which there is a decrease in intensity along the direction of propagation. The mechanism is disputed, but the result can be used to measure the power output of ultrasound transducers.

Power = force × velocity,

so the transducer power can be found by using a force balance. A force of 6.7 × 10−4 N is generated by the complete absorption of the beam from a 1 W transducer in water, where the ultrasound velocity is 1500 m s^{-1}.

GENERATION OF ULTRASOUND (ULTRASOUND TRANSDUCER)

Ultrasound transducers:

- We are all familiar with the use of loudspeakers to generate audible sound. The most common type uses a stiff conical diaphragm as an approximation to a piston—the relationship between wavelength and loudspeaker size is left for the reader to explore.
- The driving force is the interaction between the magnetic field of a coil mounted on the cone and a fixed permanent magnet.

Table 2 gives the velocity of sound in some biological media, from which it can be calculated that the wavelength at 1 MHz is of the order of 1.5 mm in soft tissue. Acoustic impedance is the product of the density and velocity of the sound for the medium and is therefore very low for air.

	Acoustic impedance (kg m^{-2} s^{-1})	Velocity of sound (m s^{-1})
Air	0.0004×10^6	330
Water at 20 °C	1.48×10^6	1480
Soft tissue	1.63×10^6	1540
Muscle	1.70×10^6	1580
Bone	7.80×10^6	4080

Table 2. The acoustic impedance and velocity of sound for different media.

Ultrasound transducers are commonly made of piezoelectric materials. Quartz and tourmaline are naturally occurring piezoelectric materials, which change their shape when subjected to an electric field.

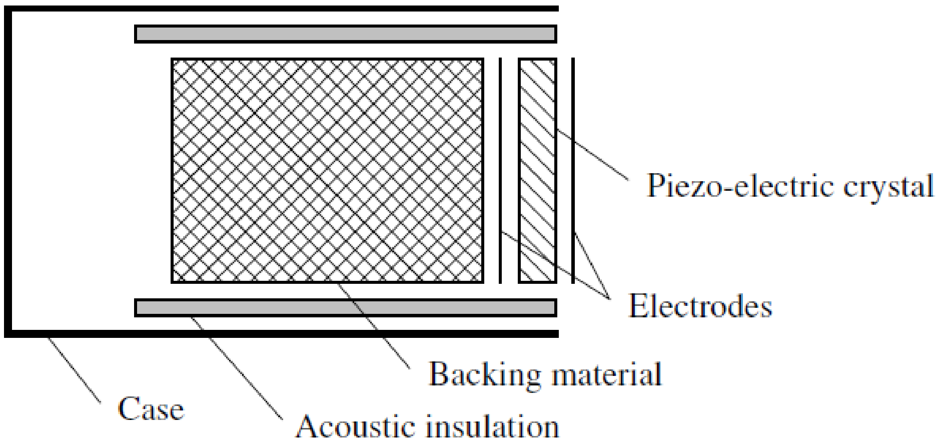
- The converse effect is also obtained: mechanical deformation of the crystal produces an electric field across it.
- Piezoelectric crystals are therefore suitable both for transmitting and receiving transducers.
- In practice, at frequencies which are used for medical diagnosis, an artificial material (lead titanium zirconate, PZT) is used. PZTs are ceramic ferroelectrics, which are hard, inert and impervious to water.
- The precise chemical composition will alter the physical and piezoelectric properties of the material, so different materials are chosen for different applications
- The frequency at which the transducer can be used is determined by the thickness of the crystal. A typical lead titanium zirconate (PZT) transducer operating at its fundamental resonant frequency would be half a wavelength thick (about 2 mm thick for a 1 MHz transducer).

Figure 1 shows the construction of a typical transducer. The electrodes are evaporated or sputtered onto each face of the transducer, and the backing material is chosen to give the required frequency characteristics.

- The backing material is usually designed to have the same acoustic impedance as the transducer, so that there is no reflection at the boundary, and to absorb ultrasound energy. A typical material is an epoxy resin loaded with tungsten powder and rubber powder, which might have an absorption coefficient of about 8 dB cm−1.

- If the ultrasound is to be transmitted as pulses, it is usual to use the same transducer as both transmitter and receiver.

- If the ultrasound is to be transmitted continuously, as is the case for continuous wave ultrasonic Doppler blood flow measurement, separate transmitting and receiving crystals are mounted side by side on backing blocks separated by an acoustic insulator.



INTERACTION OF ULTRASOUND WITH MATTER- CAVITATIONS, REFLECTION, TRANSMISSION

CAVITATION

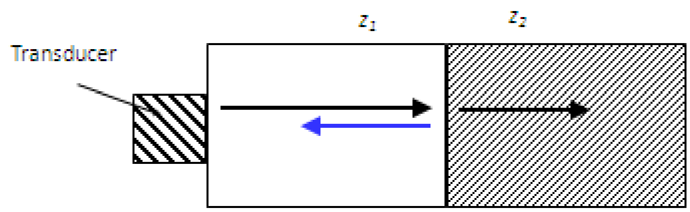
- Ultrasound can produce direct physical effects in liquids by a second effect known as cavitation.
- This term is used to refer to a range of complex phenomena that involve the creation, oscillation, growth and collapse of bubbles within a medium (see for example Leighton, 1994, 1998).
- The cavitation behaviour can be broadly classified into one of two categories: non-inertial cavitation or inertial cavitation.
- The exact behaviour will depend on the frequency, pressure amplitude, bubble radius and environment.
- When an existing bubble is exposed to an ultrasonic field the acoustic pressure acts as a driving force that drives the bubble and results in the bubble radius varying. The bubble behaves as an oscillator with a stiffness and inertia.
- The stiffness is provided by the gas within the bubble; when the gas is compressed it provides a force that resists the compression.
- The inertia is mainly provided by the liquid surrounding the bubble that moves with the bubble wall.
- As a result the bubble has a natural resonant frequency . For the case of a spherical air bubble of radius R_0 in water (assumed to be incompressible and inviscid) a simple calculation based on the linear oscillations gives

$$f_r R_0 \approx 3\,\mathrm{Hz\,m} \quad (R_0 \geqslant 10\,\mu\mathrm{m}).$$

REFLECTION

Reflection of Ultrasound Waves

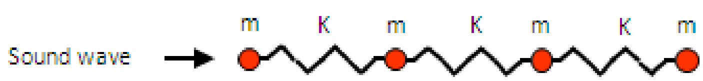
- When an ultrasound wave travelling through one type of tissue encounters an interface with a tissue with different acoustic impedance, *z*, some of its energy is reflected back towards the source of the wave, while the remainder is transmitted into the second tissue
- Reflections occur at tissue boundaries where there is a change in acoustic impedance



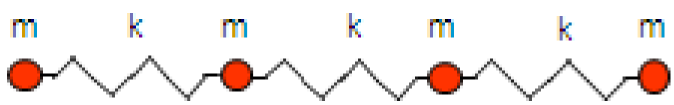
Acoustic Impedance (*z*)

- The acoustic impedance of a medium is a measure of the response of the particles of the medium to a wave of a given pressure
- The acoustic impedance of a medium is again determined by its density, ρ, and elasticity, *k* (stiffness)

  As with speed of sound, consider a row of masses (molecules) linked by springs

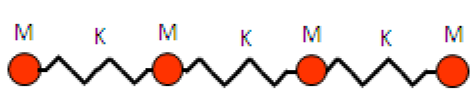


Small masses (m) model a material of low density linked by weak springs of low stiffness k



- A given pressure is applied momentarily to the first small mass m
- The mass is easily accelerated to the right and its movement encounters little opposing force from the weak spring k
- This material has low acoustic impedance, as particle movements are relatively large in response to a given applied pressure

Large masses (M) model a material of high density linked by springs of high stiffness K



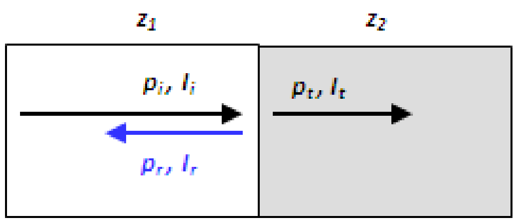
- In this case, the larger masses M accelerate less in response to the applied pressure
- Their movements are further resisted by the stiff springs
- This material has high acoustic impedance, as particle movements are relatively small in response to a given applied pressure

Can also be shown

Acoustic Impedance $z = \sqrt{\rho k}$

Acoustic Impedance $z = \rho c$

Amplitude Reflection Coefficient (r)



$$r = \frac{p_r}{p_i} = \frac{Z_2 - Z_1}{Z_1 + Z_2}$$

Intensity Reflection Coefficient (R)

$$R = \frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_1 + Z_2}\right)^2$$

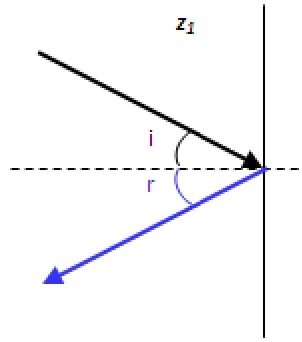
- Strength of reflection depends on the difference between the *Z* values of the two materials
- Ultrasound only possible when wave propagates through materials with similar acoustic impedances – only a small amount reflected and the rest transmitted
- Therefore, ultrasound not possible where air or bone interfaces are present

Intensity Transmission Coefficient (T)

$$\boxed{T = 1 - R}$$

Interface	R	T
Soft Tissue-Soft Tissue	0.01-0.02	0.98-0.99
Soft Tissue-Bone	0.40	0.60
Soft Tissue-Air	0.999	0.001

Reflection at an Angle



- For a flat, smooth surface the angle of reflection, r = the angle of incidence, i
- In the body surfaces are not usually smooth and flat, then r ≠ i

SCANNING SYSTEMS

Product description : General-purpose ultrasonic scanning systems provide two dimensional (2-D) images of most soft tissues without subjecting patients to ionizing radiation. These systems typically consist of a beam former, a central processing unit, a user interface (e.g., keyboard, control panel, trackball), several probes (transducers or scan heads), one or more video displays, some type of recording device, and a power system.

Health problem addressed : These devices are used primarily for abdominal and OB/GYN scanning. Some systems include additional transducers to facilitate more specialized diagnostic procedures, such as cardiac, vascular, endovaginal, endorectal, or small-parts (e.g., thyroid, breast, scrotum, prostate) scanning.

Principles of operation: Ultrasound refers to sound waves emitted at frequencies above the range of human hearing. For diagnostic imaging, frequencies ranging from 2 to 15 megahertz (MHz) are typically used. Ultrasonic probes contain one or more elements made of piezoelectric materials (materials that convert electrical energy into acoustic energy and vice versa). When the ultrasonic energy emitted from the probe is reflected from the tissue, the transducer receives some of these reflections and reconverts them into electrical signals. These signals are processed and converted into an image. Lower sound frequencies provide decreased resolution but greater tissue penetration, while higher frequencies improve resolution when deep penetration is not necessary

Operating steps : To perform ultrasonic imaging, a probe is either placed on the skin (after an acoustic coupling gel is applied) or inserted into a body cavity. Scanned structures can be measured by ultrasound technicians using digital calipers (i.e., cursors electronically superimposed over the scanned cross-sectional image that calculate the size of the scanned structure). The caliper system can also be used by technicians to plot and measure the area, circumference, or volume of a structure. A data-entry keyboard permits information such as patient name, date, and type of study to be entered and displayed along with the scanned image.

Reported problems: Ultrasound diagnostic imaging appears to be risk-free when used properly. Ultrasound transducers should be handled carefully to avoid damage. Electromechanical problems, such as cracks in piezoelectric elements, can alter beam width and/or spatial pulse length, thereby affecting lateral and axial resolution. Errors in distance measurements can cause incorrect calculations.

ARTIFACTS

- Artifacts can be defined as any structure in an ultrasound image that does not have a corresponding anatomic tissue structure.
- Artifacts may be classified into four main categories: missing structures, degraded images, falsely perceived objects, and structures with a misregistered location.

1. MISSING STRUCTURES

- Missing Structures occur for several reasons and can be related to the resolution of the ultrasound image. Resolution is defined as the ability to distinguish between two distinct structures that are in close proximity. Lateral resolution, or the ability to distinguish between two objects in a horizontal plane, is related to the width of band of the ultrasound beam.
- If two structures are closer together than the width of the lateral resolution, they will appear as a single image; in essence the display is missing images. The best lateral resolution occurs at the focal zone, where the near field meets the far field and where the beam width is the narrowest. (figures 1, 2) .
- Determination of the size of a structure in the horizontal plane incorporating two beams is never as good as measurements made in the vertical plane or down a single beam (axial resolution).

Figure 1: Resolution

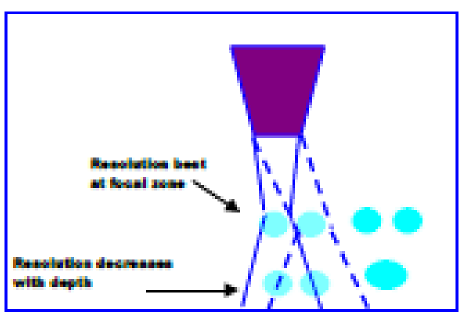
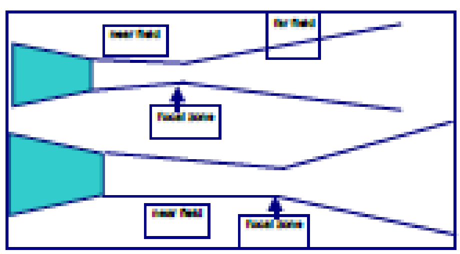


Figure 2: Focal zone



Acoustic shadowing may also create missing images. It occurs when the ultrasound beam reaches a strong reflector. This reflector decreases the beam intensity to distal structures, essentially blocking the beam to that area. Therefore, any image that lies deep to the strongly reflecting item cannot be seen.

2.DEGRADED IMAGES

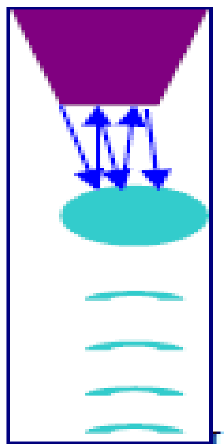
- An image of imperfect or poor quality is referred to as degraded and is often due to artifact phenomena. ***Reverberations*** are a type of image degradation.
- They are secondary reflections that occur along the path of a sound pulse and are a result of the ultrasound “bouncing” in between the structure and another reflecting surface.

- Reverberations appear as parallel yet irregular lines extending from the object away from the transducer. They occur when either the near side of the object, a second object, or the transducer itself functions as another reflecting surface.

- The repeated journeys traveled by the same beam produce additional signals that are interpreted as the same object at twice the distance from the primary target.

- Therefore, a reverberation is two or more equally spaced echo signals at increasing depths, twice the distance as the original signal (figure 4).

Figure 4 reverberations



3.FALSELY PERCEIVED OBJECTS

- **Falsely perceived objects** may occur as a result of *refraction*. Refracted ultrasound waves are beams that have been deflected from their original uniform path and occur as a result of the waves passing through a medium with a different acoustic impedance.

- The transducer assumes the reflected signal originated from the initial scan line and the image is displayed as such. A mirror image can also be created as a result of the ultrasound wave bouncing in between the near and the far side of the structure before returning to the transducer, similar to a reverberation.

- This mirrored image is always located on a straight line between the transducer and the artifact as is always deeper than the true reflector. A common place of occurrence for this is the descending aorta and is often referred to as a double-barrel aorta. This artifact is believed to be caused by the aorta-lung interface.

4.MISREGISTERED LOCATIONS

- **Range ambiguity** results in the display of the correct structures in the wrong location. It occurs with high pulse repetition frequency. With a high PRF a second pulse is sent out before the first Doppler signal along the same scan line is received.

- Therefore the machine is unable to recognize the returning signal as originating from the first or second or even a subsequent pulse. This results in deep structures appearing closer to the transducer than their true location. When an unexpected object is observed in a cardiac chamber, it is often due to range ambiguity.

Side Lobes : Although the main ultrasound beam is central, multiple beams are projected out from the transducer in a diverging manner. These beams are referred to as side lobes and can result in images being placed in the wrong location on the displayed image.

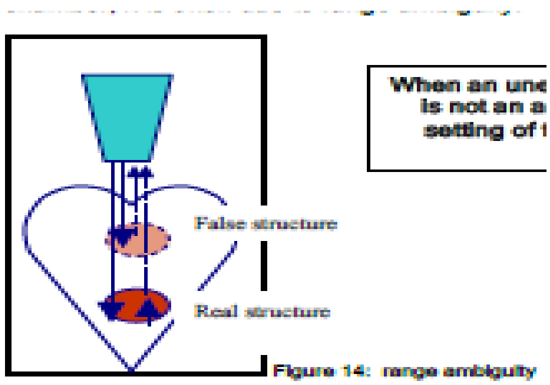
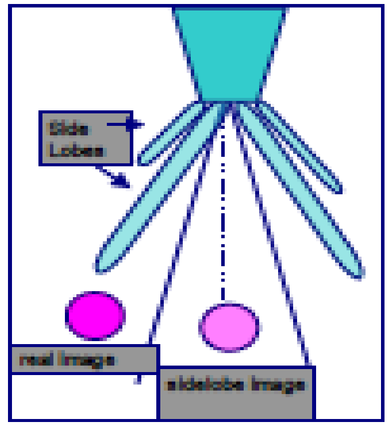


Figure 14: range ambiguity

Figure 15: sidelobe



DOPPLER-DOUBLE DOPPLER SHIFT

Doppler effect

The **Doppler effect** (or **Doppler shift**) is the change in frequency of a wave (or other periodic event) for an observer moving relative to its source

In classical physics, where the speeds of source and the receiver relative to the medium are lower than the velocity of waves in the medium, the relationship between observed frequency f and emitted frequency f_0 is given by

$$f = \left(\frac{c + v_\mathrm{r}}{c + v_\mathrm{s}}\right) f_0$$

where

c is the velocity of waves in the medium;
v_r is the velocity of the receiver relative to the medium; positive if the receiver is moving towards the source (and negative in the other direction);
v_s is the velocity of the source relative to the medium; positive if the source is moving away from the receiver (and negative in the other direction).

The frequency is decreased if either is moving away from the other.

- In medical ultrasound the Doppler effect is used to measure the velocity of blood in blood vessels, especially arteries to determine if a stenosis is present.
- The Doppler equation is modified when used for medical ultrasound to take into account the pulse-echo cycle, as each part produces a Doppler shift
- The transmitted pulse interacting with a moving reflector results in a Doppler shift with the transducer acting as the stationary source.
- The reflector then acts as a moving source, generating an echo which returns to the transducer, now acting as a stationary receiver (refer figure 2).

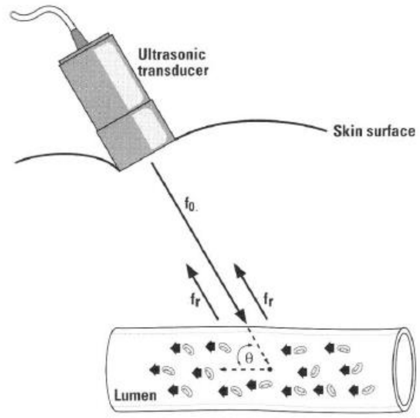


Figure 2: pictorial representation of Doppler signals being detected from within a vessel

To take into account the double Doppler shift, a factor of two figures in the equation:

$$f_d = \frac{f_t 2u \cos\theta}{c}$$

The Doppler shift increases with transmitted frequency, increasing velocity of blood cells and with a decreased angle of approach. The goal is to determine the velocity of blood within the vessel so the equation is rewritten as:

$$u = \frac{f_d c}{f_t 2 \cos\theta}$$

- To accurately determine the Doppler frequency shift, the transmitted frequency must be known and constant so that it can be compared to the returning signal.
- Identifying and maintaining the transmitted frequency would appear to be relatively straightforward; however most modern transducers are capable of transmitting many different frequencies.
- The different manufacturers of ultrasound machines achieve the transmision of different frequencies through the application of two technologies:
- **Defined frequency technology**: defined frequency technology lets the operator choose the specified frequency transmitted by the receiver and the whole ultrasound beam operates at the same frequency. A 4MHz to 7MHz transducer will send and receive all of the ultrasound beam at either 4MHz, 5MHz, 6MHz or 7MHz.
- **Broadband technology**: Broadband transducers use a pre-defined range of frequencies to form an ultrasound image. A 4MHz to 7MHz broadband transducer will send and receive some of the ultrasound beam at 4MHz, 5MHz, 6MHz and 7MHz.
- It should be noted that the utilisation of multiple frequencies creates a number of problems for calculating the Doppler shift and corresponding velocities in Doppler imaging.

- The processing required to calculate numerous velocities and accurately depict the individual Doppler shift for each transmitted frequency is too complex to allow real-time imaging.
- As a result, rather than using a range of frequencies to determine the Doppler shift only one centre frequency is used as the transmitted frequency. For example, a 4MHz to 7.5MHz transducer used for B-mode imaging will use 5MHz as the Doppler centre frequency.
- The centre frequency will usually be lower than the highest frequency available on the transducer because the best Doppler signal is usually obtained using a lower centre frequency.

ULTRASOUND CLINICAL APPLICATIONS

Abdominal Application

The Abdominal Imaging is performed for the following clinical evaluations:

(1) To detect abdominal organ abnormalities.

(2) To determine the size, contour, and pattern of the abdominal venous structure.

(3) To characterize an obstruction.

(4) To determine blood flow patterns and velocities.

Target	Abdominal Organs Arteries Veins
Approach	Abdominal
Patient	Adult Neonatal Pediatric

Peripheral Vessel Application

The Peripheral Vessel Application is performed for the following clinical evaluations:

(1) To determine the contour, size, and patterns of the peripheral vascular structure.

(2) To characterize obstructions.

(3) To determine blood flow patterns and velocities.

Target	Arteries Veins
Approach	Neck Extremities: Upper & Lower
Patient	Adult Pediatric

- Clinical applications for peripheral vessels include vein mapping and sclerotherapy. Ultrasound is well recognized as a test modality for evaluating the veins of the upper and lower extremities.
- Compression B-Mode ultrasound techniques are used to assess the presence or absence of a thrombosis within the vessel lumen. Doppler spectral analysis and Color Flow Mapping techniques are used to assess the competency of venous valves, as well as the presence of an obstruction within the vessel.

A brief explanation of the vein mapping and sclerotherapy applications follows:

Vein Mapping - One common use of Duplex ultrasound (B-Mode, Doppler and Color Flow Mapping) is to "map" superficial veins that are to be used as "conduit" vessels in arterial bypass procedures. These bypass procedures include "Lower Extremity Arterial Bypass Grafts" and "Coronary Artery Bypass Grafts". The "Vein Mapping" technique includes B-Mode scanning of the vein to evaluate its anatomic location, vessel wall thickness, presence or absence of a thrombosis, and the vessel diameter. Doppler and Color Flow Mapping are used to assess venous patency, as well as valve competency. B-Mode ultrasound is then used to guide the marking of the vein's location throughout the course of the vessel on the patient's skin. The markings are usually left on the patient's skin until the time of surgery, so that the surgeon can visualize the location of the vein.

Sclerotherapy - Physicians who treat varicose veins using sclerotherapy commonly use Duplex ultrasound (B-Mode, Doppler and Color Flow Mapping) techniques to evaluate the patient's venous system prior to sclerotherapy treatment. When performing sclerotherapy treatment, physicians use the B-Mode ultrasound to guide the placement of the needle in the vein, as well as to visualize the introduction of the sclerosing agent into the vein. Duplex ultrasound is used to evaluate the condition of the treated vein(s) immediately after treatment, and on follow-up visits.

Small Organs (Parts) Application

The Small Organs Application is performed to visualize, evaluate and detect the following:

Target	Thyroid Gland Testicles Breast
Approach	Neck Scrotal Sac Breast
Patient	Adult Neonatal Pediatric

Urologic Application

The Urologic Application is performed to evaluate the following:

(1) Prostate Gland abnormalities.

(2) Testicle abnormalities.

(3) Penis Artery Blood Flow.

Target	Prostate Testicles Penis
Approach	Transrectal Scrotal Sac Penis
Patient	Adult Pediatric

Cardiological Application

The Cardiological Application is performed for the following clinical evaluations:

(1) To search and determine eventual anomalies in the heart.

(2) To determine the contour, size, and patterns of cardiac structures.

(3) To determine blood flow patterns and velocities.

Target	Heart Aorta
Approach	Thorax
Patient	Adult Pediatric

UNIT III

PRINCIPLES OF RADIOACTIVE NUCLIDES

RADIOACTIVE DECAY

Radioactive decay, also known as **nuclear decay** or **radioactivity**, is the process by which a nucleus of an unstable atom loses energy by emitting radiation. A material that spontaneously emits such radiation — which includes alpha particles, beta particles, gamma rays and conversion electrons — is considered **radioactive**.

- There are many different types of radioactive decay . A decay, or loss of energy from the nucleus, results when an atom with one type of nucleus, called the *parent radionuclide* (or *parent radioisotope*), transforms into an atom with a nucleus in a different state, or with a nucleus containing a different number of protons and neutrons. The product is called the *daughter nuclide*.
- In some decays, the parent and the daughter nuclides are different chemical elements, and thus the decay process results in the creation of an atom of a different element. This is known as a nuclear transmutation.

The first decay processes to be discovered were alpha decay, beta decay, and gamma decay.

- **Alpha decay** occurs when the nucleus ejects an alpha particle (helium nucleus). This is the most common process of emitting nucleons, but in rarer types of decays, nuclei can eject protons, or in the case of cluster decay specific nuclei of other elements.
- **Beta decay** occurs when the nucleus emits an electron or positron and a neutrino, in a process that changes a proton to a neutron or the other way about. The nucleus may capture an orbiting electron, causing a proton to convert into a neutron in a process called electron capture. All of these processes result in a well-defined nuclear transmutation.
- By contrast, there are radioactive decay processes that do not result in a nuclear transmutation. The energy of an excited nucleus may be emitted as a gamma ray in a process called **gamma decay,** or be used to eject an orbital electron by its interaction with the excited nucleus, in a process called internal conversion.

Types of Decay

Early researchers found that an electric or magnetic field could split radioactive emissions into three types of beams. The rays were given the names alpha, beta, and gamma, in order of their ability to penetrate matter.

While alpha decay was observed only in heavier elements of atomic number 52 (tellurium) and greater, the other two types of decay were produced by all of the elements. Lead, atomic number 82, is the heaviest element to have any isotopes stable (to the limit of measurement) to radioactive decay.

Radioactive decay is seen in all isotopes of all elements of atomic number 83 (bismuth) or greater. Bismuth, however, is only very slightly radioactive.

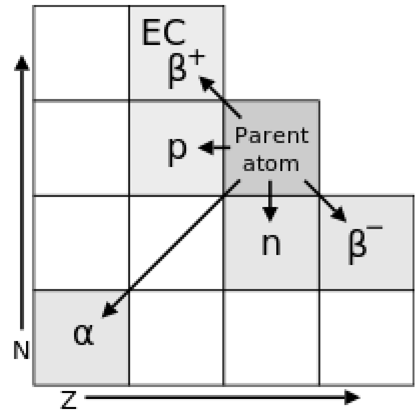


Figure 1. Transition diagram for decay modes of a radionuclide, with neutron number *N* and atomic number *Z* (shown are α, $\beta^{\pm}$, p^{+}, and n^{0} emissions, EC denotes electron capture).

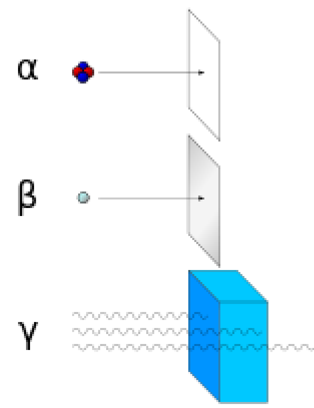


Figure 2.Alpha particles may be completely stopped by a sheet of paper, beta particles by aluminium shielding. Gamma rays can only be reduced by much more substantial mass, such as a very thick layer of lead

SPONTANEOUS EMISSION & ISOMETRIC TRANSITION

SPONTANEOUS EMISSION :

Spontaneous emission is the process by which a quantum system such as an atom, molecule, nano crystal or nucleus in an excited state undergoes a transition to a state with a lower energy (e.g., the ground state) and emits quanta of energy.

If a light source ('the atom') is in the excited state with energy E_2, it may spontaneously decay to a lower lying level (e.g., the ground state) with energy E_1, releasing the difference in energy between the two states as a photon. The photon will have angular frequency ω and energy $\hbar\omega$ (= $h\nu$, where h is the Planck constant and ν is the frequency):

$$E_2 - E_1 = \hbar\omega,$$

where $\hbar$ is the reduced Planck constant. The phase of the photon in spontaneous emission is random as is the direction in which the photon propagates. This is not true for stimulated emission. An energy level diagram illustrating process of spontaneous emission the is shown below:

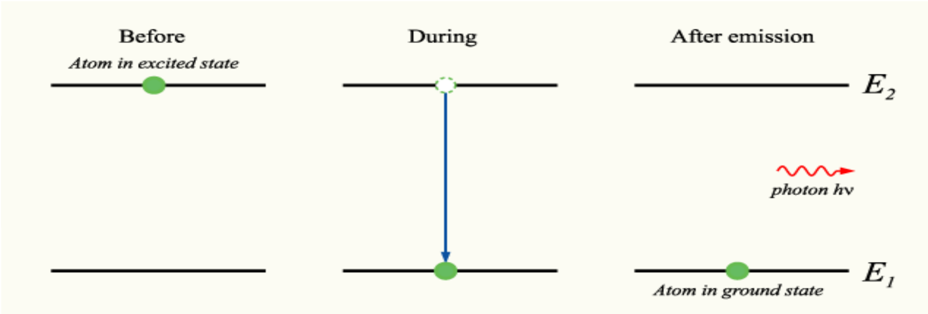


Figure 3. process of spontaneous emission

If the number of light sources in the excited state at time t is given by $N(t)$, the rate at which N decays is:

$$\frac{\partial N(t)}{\partial t} = -A_{21} N(t),$$

where A_{21} is the rate of spontaneous emission. In the rate-equation A_{21} is a proportionality constant for this particular transition in this particular light source. The constant is referred to as the *Einstein A coefficient*, and has units s^{-1}. The above equation can be solved to give:

$$N(t) = N(0)e^{-A_{21}t} = N(0)e^{-\Gamma_{rad}t},$$

where $N(0)$ is the initial number of light sources in the excited state, t is the time and Γ_{rad} is the radiactive decay rate of the transition. The number of excited states N thus decays exponentially with time, similar to radioactive decay. After one lifetime, the number of excited states decays to 36.8% of its original value ($\frac{1}{e}$-time). The radiative decay rate Γ_{rad} is inversely proportional to the lifetime τ_{21}:

$$A_{21} = \Gamma_{21} = \frac{1}{\tau_{21}}.$$

ISOMETRIC TRANSITION:

As mentioned earlier, radioactive decay often forms a progeny nucleus in an energetic ("excited") state. The nucleus descends from its excited to its most stable ("ground") energy state by one or more isomeric transitions. Often these transitions occur by emission of electromagnetic radiation termed γ rays. γ rays and x rays occupy the same region of the electromagnetic energy spectrum, and they are differentiated only by their origin: x rays result from electron interactions outside the nucleus, whereas γ rays result from nuclear transitions.

No radioactive nuclide decays solely by an isomeric transition. Isomeric transitions are always preceded by either electron capture or emission of an α or β(+or–) particle.

Sometimes one or more of the excited states of a progeny nuclide may exist for a finite lifetime. An excited state is termed a *metastable state* if its half-life exceeds 10^{-6} seconds.

For example, the decay scheme for ^{99}Mo shown to the right exhibits a metastable energy state, ^{99m}Tc, that has a half-life of 6 hours. Nuclides emit γ rays with characteristic energies. For example, photons of 142 and 140 keV are emitted by 99mTc, and photons of 1.17 and 1.33 MeV are released during negatron decay of ^{60}Co. In the latter case, the photons are released during cascade isomeric transitions of progeny ^{60}Ni nuclei from excited states to the ground energy state.
An isomeric transition can also occur by interaction of the nucleus with an electron in one of the electron shells. This process is known as internal conversion (IC). When IC happens, the electron is ejected with kinetic energy E_k equal to the energy $E\gamma$ released by the nucleus, reduced by the binding energy E_b of the electron.

$$E_k = E\gamma - E_b$$

The ejected electron is accompanied by x rays and Auger electrons as the extranuclear structure of the atom resumes a stable configuration. The internal conversion coefficient for an electron shell is the ratio of the number of conversion electrons from the shell compared with the number of γ rays emitted by the nucleus. The probability of internal conversion increases rapidly with increasing Z and with the lifetime of the excited state of the nucleus.

GAMMA RAY EMISSION, ALPHA RAY EMISSION & BETA RAY EMISSION

GAMMA RAY EMISSION:

- **Gamma decay** is the process by which the nucleus of an atom emits a high energy photon, that is, extremely short-wavelength electromagnetic radiation.
- Gamma decay is analogous to the emission of light (usually visible light) by decay in the orbits of the electrons surrounding the nucleus.
- In each case the energy states, and the wavelengths of the emitted radiation, are governed by the laws of quantum mechanics.
- But while the electron orbits have relatively low energy, the nuclear states have much higher energy.

Radioactive decay (gamma decay)

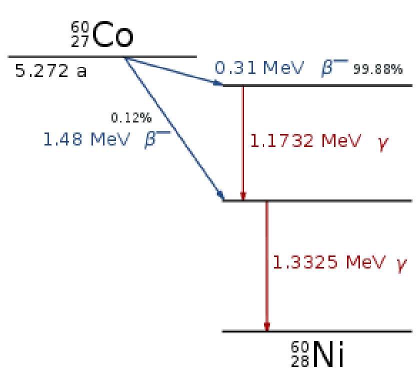


Figure 4. Decay scheme of ^{60}Co:

An example of gamma ray production follows:

First ^{60}Co decays to excited ^{60}Ni by beta decay emission of an electron of 0.31 MeV. Then the excited ^{60}Ni decays to the ground state by emitting gamma rays in succession of 1.17 MeV followed by 1.33 MeV. This path is followed 99.88% of the time:

$$^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni}^{*} + e^{-} + \bar{\nu}_e + \gamma + 1.17\ \mathrm{MeV}$$

ALPHA RAY EMISSION:

- **Alpha decay** or **α-decay** is a type of radioactive decay in which an atomic nucleus emits an alpha particle (helium nucleus) and thereby transforms or 'decays' into an atom with a mass number that is reduced by four and an atomic number that is reduced by two.
- An alpha particle is identical to the nucleus of a helium-4 atom, which consists of two protons and two neutrons. For example, uranium-238 decays to form thorium-234

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + \alpha$$

Or

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

- Both mass number and atomic number are conserved: the mass number is 238 on the left side and (234 + 4) on the right side and the atomic number is 92 on the left side and (90 + 2) on the right side.
- Alpha particles have a charge +2, but as a nuclear equation describes a nuclear reaction without considering the electrons, a convention that does not imply that the nuclei necessarily occur in neutral atoms, the charge is not usually shown.
- Alpha decay typically occurs in the heaviest nuclides. Theoretically, it can occur only in nuclei somewhat heavier than nickel (element 28),
- In practice, this mode of decay has only been observed in nuclides considerably heavier than nickel, with the lightest known alpha emitter being the lightest isotopes (mass numbers 106–110) of tellurium (element 52).
- Alpha decay is by far the most common form of cluster decay, where the parent atom ejects a defined daughter collection of nucleons, leaving another defined product behind.
- It is the most common form because of the combined extremely high binding energy and relatively small mass of the alpha particle.

BETA RAY EMISSION:

- In nuclear physics, **beta decay** (*β*-decay) is a type of radioactive decay in which a proton is transformed into a neutron, or vice versa, inside an atomic nucleus.
- This process allows the atom to move closer to the optimal ratio of protons and neutrons. As a result of this transformation, the nucleus emits a detectable beta particle, which is an electron or positron.
- Beta decay is mediated by the weak force. There are two types of beta decay, known as *beta minus* and *beta plus*. In beta minus (β^{-}) decay a neutron is lost and a proton

appears and the process produces an electron and electron antineutrino, while in beta plus (β^+) decay a proton is lost and a neutron appears and the process produces a positron and electron neutrino; β^+ decay is thus also known as positron emission.

An example of electron emission (β^- decay) is the decay of carbon-14 into nitrogen-14

$$^{14}C_6 \rightarrow {}^{14}N_7 + e^- + \nu_e$$

- In this form of decay, the original element becomes a new chemical element in a process known as nuclear transmutation. This new element has an unchanged mass number *A*, but an atomic number *Z* that is increased by one.
- As in all nuclear decays, the decaying element (in this case $^{14}C_6$) is known as the *parent nuclide* while the resulting element (in this case $^{14}N_7$) is known as the *daughter nuclide*. The emitted electron or positron is known as a beta particle.

POSITRON DECAY:

- **Positron emission** or **beta plus decay** (β^+ decay) is a particular type of radioactive decay and a subtype of beta decay, in which aproton inside a radionuclide nucleus is converted into a neutron while releasing a positron and an electron neutrino (ν_e).
- Positron emission is mediated by the weak force. The positron is a type of beta particle (β^+), the other beta particle being the electron (β^-) emitted from the β^- decay of a nucleus.
- An example of positron emission (β^+ decay) is shown with magnesium-23 decaying into sodium-23:

$$^{23}Mg_{12} \rightarrow {}^{23}Na_{11} + e^+ + \nu_e$$

- Because positron emission decreases proton number relative to neutron number, positron decay happens typically in large "proton-rich" radionuclides.
- Positron decay results in nuclear transmutation,changing an atom of a chemical element into an atom of an element with an atomic number that is less by one unit.
- Positron emission should not be confused with electron emission or beta minus decay (β^- decay), which occurs when a neutron turns into a proton and the nucleus emits an electron and an antineutrino.
- Electron capture (sometimes called inverse beta decay) is also occasionally classified as a type of beta decay. In some ways, electron capture can be regarded as an equivalent to positron emission, since capture of an electron results in the same transmutation as emission of a positron.
- Electron capture occurs when electrons are available and requires less energy difference between parent and daughter, so occurs much more often in smaller atoms than positron emission does. Electron capture always competes with positron emission where the latter is seen, and in addition, occurs as the only type of beta decay in proton-rich nuclei when there is not enough decay energy to support positron emission.

Emission Mechanism

- Inside protons and neutrons, there are fundamental particles called quarks. The two most common types of quarks are up quarks, which have a charge of $+^{2}/_{3}$, and down quarks, with a $-^{1}/_{3}$ charge.

- Quarks arrange themselves in sets of three such that they make protons and neutrons. In a proton, whose charge is +1, there are two up quarks and one down quark. Neutrons, with no charge, have one up quark and two down quarks.
- Via the weak interaction, quarks can change flavor from down to up, resulting in electron emission. Positron emission happens when an up quark changes into a down quark.
- Nuclei which decay by positron emission may also decay by electron capture. For low-energy decays, electron capture is energetically favored by $2m_ec^2 = 1.022$ MeV, since the final state has an electron removed rather than a positron added. As the energy of the decay goes up, so does the branching ratio towards positron emission. However, if the energy difference is less than $2m_ec^2$, then positron emission cannot occur and electron capture is the sole decay mode.

ELECTRON CAPTURE:

- **Electron capture** (**K-electron capture**, also **K-capture**, or **L-electron capture**, **L-capture**) is a process in which the proton-rich nucleus of an electrically neutral atom absorbs an inner atomic electron, usually from the K or L electron shell.
- This process thereby changes a nuclear proton to a neutron and simultaneously causes the emission of an electron neutrino.

$$p + e^- \rightarrow n + \nu_e$$

- The daughter nuclide, if it is in an excited state, then transitions to its ground state. Usually, a gamma ray is emitted during this transition, but nuclear de-excitation may also take place by internal conversion.

Following capture of an inner electron from the atom, an outer electron replaces the electron that was captured and one or more characteristic X-ray photons is emitted in this process.

- Electron capture sometimes also results in the Auger effect, where an electron is ejected from the atom's electron shell due to interactions between the atom's electrons in the process of seeking a lower energy electron state.
- Following electron capture, the atomic number is reduced by one, the neutron number is increased by one, and there is no change in atomic mass.
- Simple electron capture results in a neutral atom, since the loss of the electron in the electron shell is balanced by a loss of positive nuclear charge. However, a positive atomic ion may result from further Auger electron emission.

Electron capture is an example of weak interaction, one of the four fundamental forces.

- Electron capture is the primary decay mode for isotopes with a relative superabundance of protons in the nucleus, but with insufficient energy difference between the isotope and its prospective daughter (the isobar with one less positive charge) for the nuclide to decay by emitting a positron.
- Electron capture is always an alternate decay mode for radioactive isotopes that do not have sufficient energy to decay by positron emission. It is sometimes called **inverse beta decay**, though this term can also refer to the interaction of an electron antineutrino with a proton.

- If the energy difference between the parent atom and the daughter atom is less than 1.022 MeV, positron emission is forbidden as not enough decay energy is available to allow it, and thus electron capture is the sole decay mode.
- For example, rubidium-83 (37 protons, 46 neutrons) will decay to krypton-83 (36 protons, 47 neutrons) solely by electron capture (the energy difference, or decay energy, is about 0.9 MeV).

A free proton cannot normally be changed to a free neutron by this process; the proton and neutron must be part of a larger nucleus.

Reaction Details

$^{26}Al_{13} + e^{-} \rightarrow {}^{26}Mg_{12} + \nu_e$
$^{59}Ni_{28} + e^{-} \rightarrow {}^{59}Co_{27} + \nu_e$
$^{40}K_{19} + e^{-} \rightarrow {}^{40}Ar_{18} + \nu_e$

- The electron that is captured is one of the atom's own electrons, and not a new, incoming electron, as might be suggested by the way the above reactions are written.
- Radioactive isotopes that decay by pure electron capture can be inhibited from radioactive decay if they are fully ionized ("stripped" is sometimes used to describe such ions).
- It is hypothesized that such elements, if formed by the r-process in exploding supernovae, are ejected fully ionized and so do not undergo radioactive decay as long as they do not encounter electrons in outer space. Anomalies in elemental distributions are thought to be partly a result of this effect on electron capture.
- Inverse decays can also be induced by full ionisation; for instance, ^{163}Ho decays into ^{163}Dy by electron capture; however, a fully ionised ^{163}Dy decays into a bound state of ^{163}Ho by the process of bound-state β^{-} decay.

SOURCES OF RADIOISOTOPES NATURAL AND ARTIFICIAL RADIOACTIVITY

ORIGIN: NATURAL

- Naturally occurring radionuclides fall into three categories: primordial radionuclides, secondary radionuclides, and cosmogenic radionuclides.
- Primordial radionuclides, such asuranium and thorium, originate mainly from the interior of stars, and exist in present time since their half-lives are so long they have not yet completely decayed.
- Secondary radionuclides are radiogenic isotopes derived from the decay of primordial radionuclides. T
- hey have shorter half-lives than primordial radionuclides. Cosmogenic isotopes, such as carbon-14, are present because they are continually being formed in the atmosphere due to cosmic rays.

SYNTHETIC

Synthetic radionuclides are artificially produced by human activity using nuclear reactors, particle accelerators or radionuclide generators:

- Radioisotopes produced with nuclear reactors exploit the high flux of neutrons present. These neutrons activate elements placed within the reactor. A typical product from a nuclear reactor is thallium-201 and iridium-192. The elements that have a large propensity to take up the neutrons in the reactor are said to have a high neutron cross-section.
- Particle accelerators such as cyclotrons accelerate particles to bombard a target to produce radionuclides. Cyclotrons accelerate protons at a target to produce positron-emitting radionuclides, e.g., fluorine-18.
- Radionuclide generators contain a parent radionuclide that decays to produce a radioactive daughter. The parent is usually produced in a nuclear reactor. A typical example is the technetium-99m generator used in nuclear medicine. The parent produced in the reactor is molybdenum-99.
- Radionuclides are produced as an unavoidable side-effect of nuclear and thermonuclear explosions.

Trace radionuclides are those that occur in tiny amounts in nature either due to inherent rarity or due to half-lives that are significantly shorter than the age of the Earth.

RADIONUCLIDE USED IN MEDICINE AND TECHNOLOGY

Radionuclide used in Medicine and Technology:

- Nuclear medicine uses radiation to provide diagnostic information about the functioning of a person's specific organs, or to treat them. Diagnostic procedures using radioisotopes are now routine.

- Radiotherapy can be used to treat some medical conditions, especially cancer, using radiation to weaken or destroy particular targeted cells.

- Tens of millions of nuclear medicine procedures are performed each year, and demand for radioisotopes is increasing rapidly.

- Sterilisation of medical equipment is also an important use of radioisotopes.

Nuclear medicine

- This is a branch of medicine that uses radiation to provide information about the functioning of a person's specific organs or to treat disease. In most cases, the information is used by physicians to make a quick, accurate diagnosis of the patient's illness.

- The thyroid, bones, heart, liver and many other organs can be easily imaged, and disorders in their function revealed. In some cases radiation can be used to treat diseased organs, or tumours. Five Nobel Laureates have been intimately involved with the use of radioactive tracers in medicine.

- Over 10,000 hospitals worldwide use radioisotopes in medicine, and about 90% of the procedures are for diagnosis. The most common radioisotope used in diagnosis is technetium-99, with some 40-45 million procedures per year (16.7 million in USA in 2012, 550,000 in Australia), accounting for 80% of all nuclear medicine procedures worldwide.

- In developed countries (26% of world population) the frequency of diagnostic nuclear medicine is 1.9% per year, and the frequency of therapy with radioisotopes is about one tenth of this. In the USA there are over 20 million nuclear medicine procedures per year among 311 million people, and in Europe about 10 million among 500 million people. In Australia there are about 560,000 per year among 21 million people, 470,000 of these using reactor isotopes. The use of radiopharmaceuticals in diagnosis is growing at over 10% per year.

- The global radioisotope market was valued at $4.8 billion in 2012, with medical radioisotopes accounting for about 80% of this, and is poised to reach about $8 billion by 2017. North America is the dominant market for diagnostic radioisotopes with close to half of the market share, while Europe accounts for about 20%.

- Nuclear medicine was developed in the 1950s by physicians with an endocrine emphasis, initially using iodine-131 to diagnose and then treat thyroid disease. In recent years specialists have also come from radiology, as dual CT/PET procedures have become established.

- Computed X-ray tomography (CT) scans and nuclear medicine contribute 36% of the total radiation exposure and 75% of the medical exposure to the US population, according to a US National Council on Radiation Protection & Measurements report in 2009.

- The report showed that Americans' average total yearly radiation exposure had increased from 3.6 millisievert to 6.2 mSv per year since the early 1980s, due to medical-related procedures. (Industrial radiation exposure, including that from nuclear power plants, is less than 0.1% of overall public radiation exposure.)

- An important nuclear medicine procedure is Magnetic Resonance Imaging (MRI), which uses powerful magnets and radio waves to create cross-sectional images of organs and internal structures in the body. It does not use radioisotopes or ionizing radiation, but relies on nuclear magnetic resonance of hydrogen.

Diagnostic techniques in nuclear medicine

- Diagnostic techniques in nuclear medicine use radioactive tracers which emit gamma rays from within the body. These tracers are generally short-lived isotopes linked to chemical compounds which permit specific physiological processes to be scrutinised.
- They can be given by injection, inhalation or orally. The first type are where single photons are detected by a gamma camera which can view organs from many different angles.
- The camera builds up an image from the points from which radiation is emitted; this image is enhanced by a computer and viewed by a physician on a monitor for indications of abnormal conditions.
- A more recent development is Positron Emission Tomography (PET) which is a more precise and sophisticated technique using isotopes produced in a cyclotron.

- A positron-emitting radionuclide is introduced, usually by injection, and accumulates in the target tissue. As it decays it emits a positron, which promptly combines with a nearby electron resulting in the simultaneous emission of two identifiable gamma rays in opposite directions.

- These are detected by a PET camera and give very precise indication of their origin. PET's most important clinical role is in oncology, with fluorine-18 as the tracer, since it has proven to be the most accurate non-invasive method of detecting and evaluating most cancers. It is also well used in cardiac and brain imaging.
- New procedures combine PET with computed X-ray tomography (CT) scans to give co-registration of the two images (PETCT), enabling 30% better diagnosis than with traditional gamma camera alone.
- It is a very powerful and significant tool which provides unique information on a wide variety of diseases from dementia to cardiovascular disease and cancer (oncology).
- Positioning of the radiation source within the body makes the fundamental difference between nuclear medicine imaging and other imaging techniques such as x-rays. Gamma imaging by either method described provides a view of the position and concentration of the radioisotope within the body.
- Organ malfunction can be indicated if the isotope is either partially taken up in the organ (cold spot), or taken up in excess (hot spot). If a series of images is taken over a period of time, an unusual pattern or rate of isotope movement could indicate malfunction in the organ.
- A distinct advantage of nuclear imaging over x-ray techniques is that both bone and soft tissue can be imaged very successfully. This has led to its common use in developed countries where the probability of anyone having such a test is about one in two and rising.

The mean effective dose is 4.6 mSv per diagnostic procedure.

Biochemical analysis

- It is very easy to detect the presence or absence of some radioactive materials even when they exist in very low concentrations.
- Radioisotopes can therefore be used to label molecules of biological samples *in vitro* (out of the body). Pathologists have devised hundreds of tests to determine the constituents of blood, serum, urine, hormones, antigens and many drugs by means of associated radioisotopes.
- These procedures are known as radioimmuno-assays and, although the biochemistry is complex, kits manufactured for laboratory use are very easy to use and give accurate results.
- In Europe some 15 million of these *in vitro* analyses are undertaken each year.

Sterilising

- Gamma irradiation is widely used for sterilising medical products and supplies such as syringes, gloves, clothing and instruments, many of which would be damaged by heat sterilisation. Cobalt-60 is the main isotope used, since it is an energetic gamma emitter.
- Large-scale irradiation facilities for gamma sterilisation are in many countries. Smaller gamma irradiators, often with Cs-137, are used for treating blood for transfusions and for other medical applications.

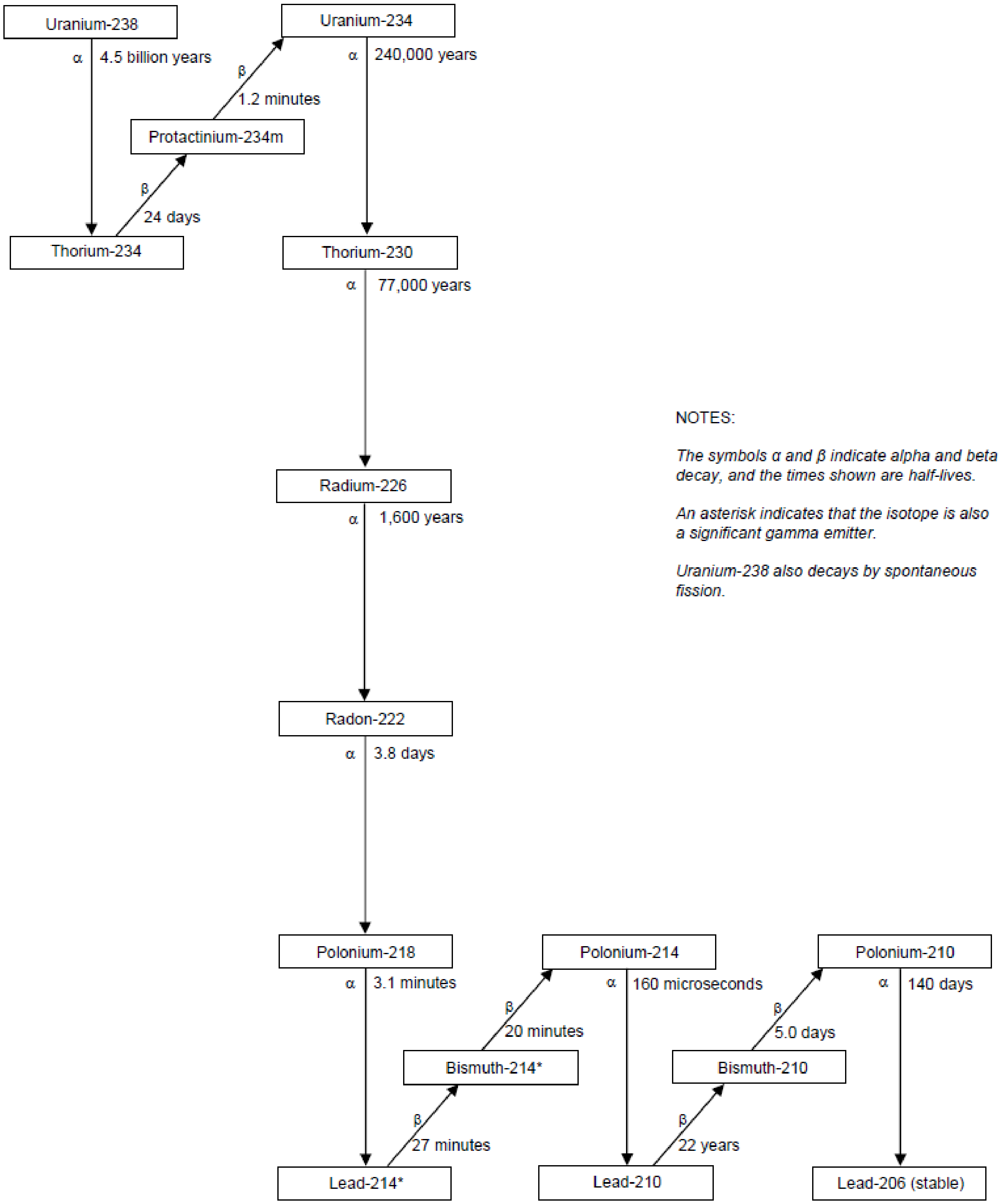
DECAY SERIES

- Uranium, radium, and thorium occur in three natural decay series, headed by uranium-238, thorium-232, and uranium-235, respectively.
- In nature, the radionuclides in these three series are approximately in a state of secular equilibrium, in which the activities of all radionuclides within each series are nearly equal.
- Two conditions are necessary for secular equilibrium.
    1. First, the parent radionuclide must have a half-life much longer than that of any other radionuclide in the series.
    2. Second, a sufficiently long period of time must have elapsed.

- The radionuclides of the uranium-238, thorium-232, and uranium-235 decay series are shown in Figures N.1, N.2, and N.3, along with the major mode of radioactive decay for each.
- Radioactive decay occurs when an unstable (radioactive) isotope transforms to a more stable isotope, generally by emitting a subatomic particle such as an alpha or beta particle.
- Radionuclides that give rise to alpha and beta particles are shown in these figures, as are those that emit significant gamma radiation.
- Of the two conditions noted above for secular equilibrium, the first is generally met for the uranium-238,thorium-232 and uranium-235 decay series in naturally occurring ores.
- While the second condition may not be met for all ores or other deposits of uranium and thorium (given the extremely long half-lives for the radionuclides involved and the geological changes that occur over similar time scales), it is reasonable to assume secular equilibrium for naturally occurring ores to estimate the concentrations of the various daughter radionuclides that accompany the parent.
- In some situations, it may be necessary to add the radiological risk identified for a given radionuclide to that of its parent radionuclide to properly represent the total risk. For example, the radiological risk for thorium-232 is comprised of the risk for thorium-232 plus the risk for radium-228.

- Decay series information should be used together with the information in these fact sheets to ensure that the radiological risks associated with uranium, radium, and thorium are properly estimated and represented.

Figure 5. Natural Decay Series: Uranium-238



NOTES:

The symbols α and β indicate alpha and beta decay, and the times shown are half-lives.

An asterisk indicates that the isotope is also a significant gamma emitter.

Uranium-238 also decays by spontaneous fission.

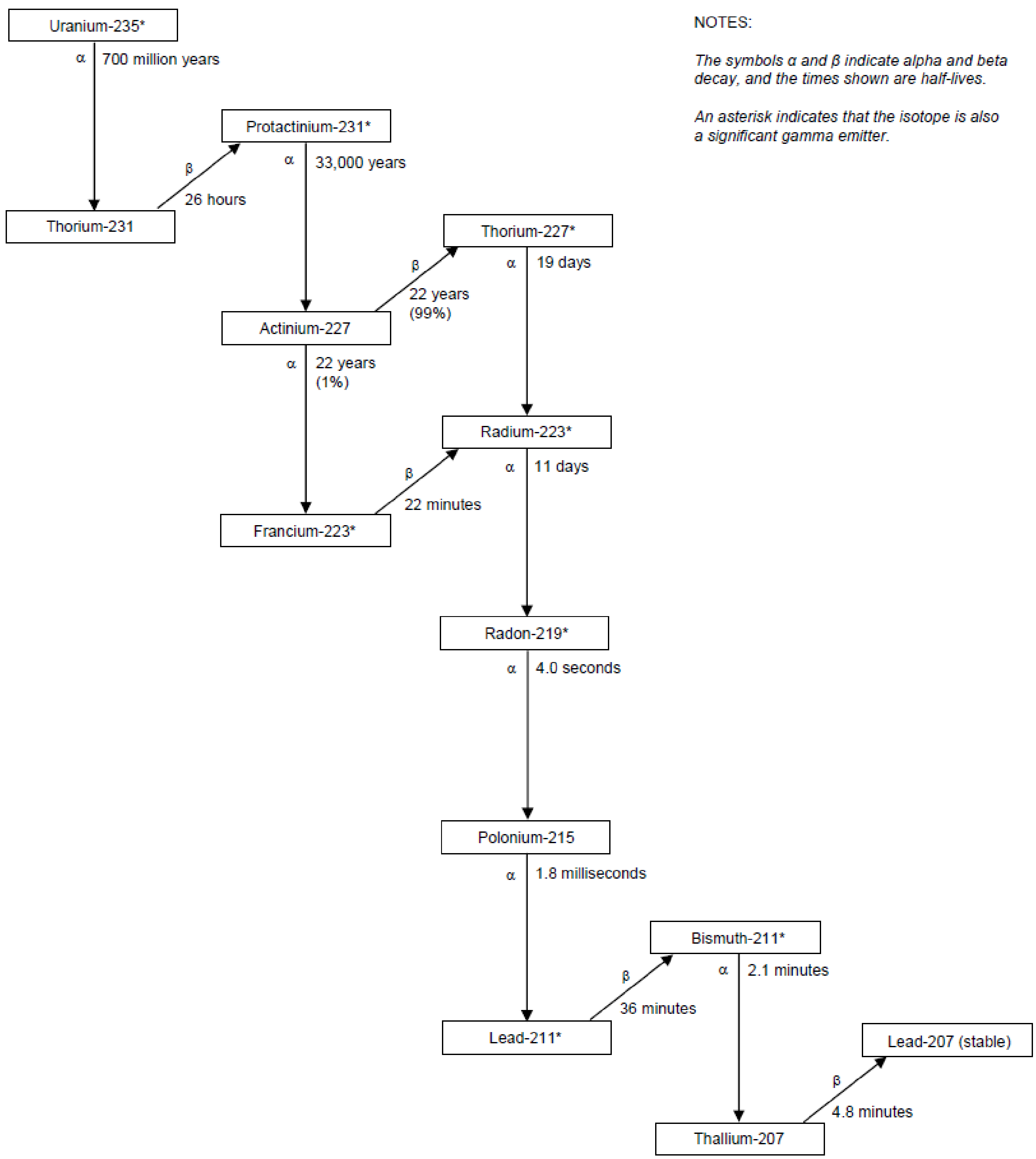


Figure 6. Natural Decay Series: Uranium-235

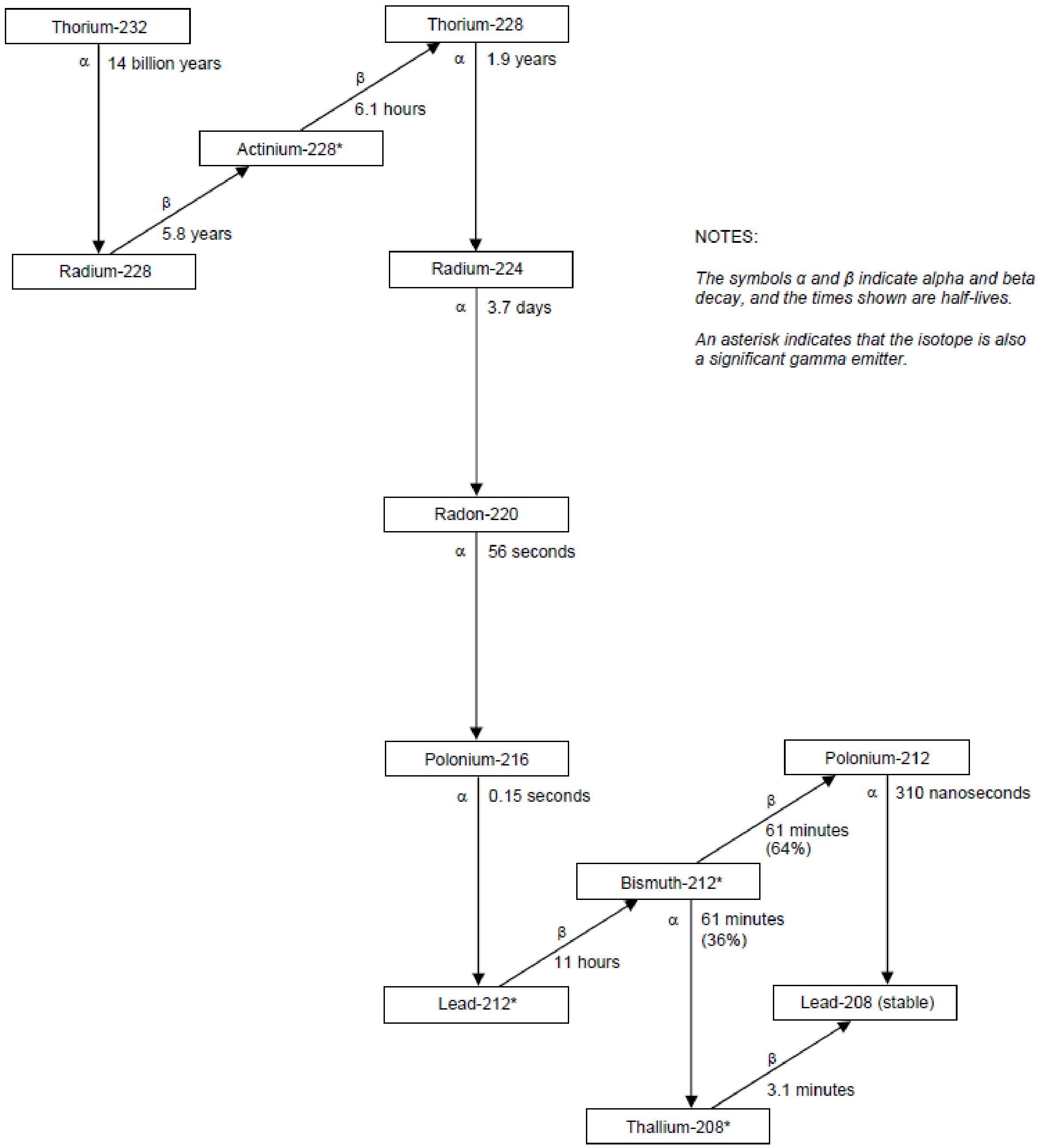


Figure 7. Natural Decay Series: Thorium-232

PRODUCTION OF RADIONUCLIDES:

CYCLOTRON -PRODUCED RADIONUCLIDE

Cyclotron Produced Radionuclides:

- Cyclotron produced radionuclides include all PET nuclides in common use such as fluorine F -18, oxygen O -15, nitrogen N -13 and carbon C -11, which are activated by proton irradiation.

Reaction Equations

- X (n, p) Y
- Means neutron, proton reaction
- X, the parent nucleus is bombarded with a neutron.
- The parent nucleus absorbs the particle and exists in an excited state.
- The parent nucleus promptly decays to the product nucleus (which is the positron emitter)

Examples of Reaction Equations

$$^{20}\mathbf{Ne}\ \mathbf{(d, a)}\ ^{18}\mathbf{F}$$

This means: A neon target is bombarded by deuterons (one proton, one neutron). The mass number increases by 2, the atomic number increases by 1. This is however, instantaneous.

The new species, decays with the emission of an alpha particle.The mass number therefore decreases by four, and the atomic number decreases by two, to Fluorine-18.

The nucleus of Fluorine-18 remains in an excited state. It decays by positron emission to Oxygen 18, with a 120 minute half life.

However, not all cyclotron produced radionuclides are positron emitters.

- An example of a typical cyclotron-produced radionuclide is ^{111}In, which is produced by irradiating ^{111}Cd with 12-MeV protons in a cyclotron. The nuclear reaction is written as follows:

$$^{111}\mathrm{Cd}(p, n)^{111}\mathrm{In}$$

- where ^{111}Cd is the target nuclide, the proton p is the irradiating particle, the neutron n is the emitted particle, and ^{111}In is the product radionuclide.
- In this case, a second nucleon may not be emitted, because there is not enough energy left after the emission of the first neutron.The excitation energy that is not sufficient to emit any more nucleons will be dissipated by g-ray emission.

As can be understood, radionuclides produced with atomic numbers differentfrom those of the target isotopes do not contain any stable (“cold,” or “carrier”) isotope detectable by ordinary analytical methods, and such preparations are called *carrier-free*.

- In practice, however, it is impossible to have these preparations without the presence of any stable isotopes. Another term for these preparations is *no-carrier-added* (NCA), meaning that no stable isotope has been added purposely to the preparations.
- The target material for irradiation must be pure and preferably monoisotopic or at least enriched isotopically to avoid the production of extraneous radionuclides.
- Because various isotopes of different elements may be produced in a target, it is necessary to isolate isotopes of a single element; this can be accomplished by appropriate chemical methods such as solvent extraction, precipitation, ion exchange, and distillation. Cyclotron-produced radionuclides are usually neutron deficient and therefore decay by

REACTOR-PRODUCED RADIONUCLIDES

- A variety of radionuclides is produced in nuclear reactors.A nuclear reactor is constructed with fuel rods made of fissile materials such as enriched 235U and 239Pu.These fuel nuclei undergo spontaneous fission with extremely low probability.
- *Fission* is defined as the breakup of a heavy nucleus into two fragments of approximately equal mass, accompanied by the emission of two to three neutrons with mean energies of about 1.5MeV.
- In each fission, there is a concomitant energy release of ~200 MeV that appears as heat and is usually removed by heat exchangers to produce electricity in the nuclear power plant.

Neutrons emitted in each fission can cause further fission of other fissionable nuclei in the fuel rod, provided the right conditions exist. This obviously will initiate a chain reaction, ultimately leading to a possible meltdown of the reactor core.

- This chain reaction must be controlled, which is in part accomplished by the proper size, shape, and mass of the fuel material and other complicated and ingenious engineering techniques.
- To maintain a selfsustained chain reaction, only one fission neutron is needed and excess neutrons (more than one) are removed by positioning cadmium rods, called *control rods*, in the reactor core (cadmium has a high probability of absorbing a thermal neutron).

- The fuel rods of fissile materials are interspersed in the reactor core with spaces in between. Neutrons emitted with a mean energy of 1.5MeV from the surface of the fuel rod have a low probability of interacting with other nuclei and therefore do not serve any useful purpose.
- It has been found, however, that neutrons with thermal energy (0.025 eV) interact with many other stable nuclei efficiently, producing various radionuclides.
- To make the high-energy neutrons, or so-called fast neutrons, more useful, they are thermalized or slowed down by interaction with low molecular weight materials, such as water, heavy water (D2O), beryllium, and graphite (C), which are distributed in the spaces between the fuel rods. These materials are called *moderators*.
- The flux, or intensity, of the thermal neutrons so obtained ranges from 1011 to 1014 neutrons/cm2 · sec, and they are useful in the production of many radionuclides.

- When a target element is inserted in the reactor core, a thermal neutron will interact with the target nucleus, with a definite probability of producing another nuclide. The probability of formation of a radionuclide by thermal neutrons varies from element to element. In the reactor, two types of interaction with thermal neutrons occur to produce various radionuclides: fission of heavy elements and neutron capture or (n, g) reaction.

FISSION AND ELECTRON CAPTURE REACTION

FISSION REACTION:

- When a target of heavy elements is inserted in the reactor core, heavy nuclei absorb thermal neutrons and undergo fission.
- Fissionable heavy elements are 235U, 239Pu, 237Np, 233U, 232Th, and many others having atomic numbers greater than 92.
- Fission of heavy elements may also be induced in a cyclotron by irradiation with high-energy charged particles, but fission probability depends on the type and energy of the irradiating particle.
- Nuclides produced by fission may range in atomic number from about 28 to nearly 65.These isotopes of different elements are separated by appropriate chemical procedures that involve precipitation, solvent extraction, ion exchange, chromatography, and distillation.
- The fission radionuclides are normally carrier-free or NCA, and therefore radionuclides of high specific activity are available from fission.The fission products are usually neutron rich and decay by b−-emission.
- Many clinically useful radionuclides such as 131I, 99Mo, 133Xe, and 137Cs are produced by fission of 235U.
- An example of thermal fission of 235U follows, showing a few representative radionuclides:

$$
\begin{aligned}
{}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{236}_{92}\mathrm{U} &\rightarrow {}^{131}_{53}\mathrm{I} + {}^{102}_{39}\mathrm{Y} + 3{}^{1}_{0}\mathrm{n} \\
&\rightarrow {}^{99}_{42}\mathrm{Mo} + {}^{135}_{50}\mathrm{Sn} + 2{}^{1}_{0}\mathrm{n} \\
&\rightarrow {}^{117}_{46}\mathrm{Pd} + {}^{117}_{46}\mathrm{Pd} + 2{}^{1}_{0}\mathrm{n} \\
&\rightarrow {}^{133}_{54}\mathrm{Xe} + {}^{101}_{38}\mathrm{Sr} + 2{}^{1}_{0}\mathrm{n} \\
&\rightarrow {}^{137}_{55}\mathrm{Cs} + {}^{97}_{37}\mathrm{Rb} + 2{}^{1}_{0}\mathrm{n} \\
&\rightarrow {}^{155}_{62}\mathrm{Sm} + {}^{78}_{30}\mathrm{Zn} + 3{}^{1}_{0}\mathrm{n} \\
&\rightarrow {}^{156}_{62}\mathrm{Sm} + {}^{77}_{30}\mathrm{Zn} + 3{}^{1}_{0}\mathrm{n}
\end{aligned}
$$

ELECTRON CAPTURE REACTION:

- Electron capture (K-electron capture, also K-capture, or L-electron capture, L-capture) is a process in which the proton-rich nucleus of an electrically neutral atom absorbs an inner atomic electron, usually from the K or L electron shell.

- This process thereby changes a nuclear proton to a neutron and simultaneously causes the emission of an electron neutrino.

Reaction Details:

Examples:

$^{26}Al_{13} + e^- \rightarrow {}^{26}Mg_{12} + \nu e$
$^{59}Ni_{28} + e^- \rightarrow {}^{59}Co_{27} + \nu e$
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- Radioactive isotopes that decay by pure electron capture can be inhibited from radioactive decay if they are fully ionized ("stripped" is sometimes used to describe such ions).
- It is hypothesized that such elements, if formed by the r-process in exploding supernovae, are ejected fully ionized and so do not undergo radioactive decay as long as they do not encounter electrons in outer space.
- Anomalies in elemental distributions are thought to be partly a result of this effect on electron capture. Inverse decays can also be induced by full ionisation; for instance, ^{163}Ho decays into ^{163}Dy by electron capture; however, a fully ionised ^{163}Dy decays into a bound state of ^{163}Ho by the process of bound-state β^- decay.
- Chemical bonds can also affect the rate of electron capture to a small degree (in general, less than 1%) depending on the proximity of electrons to the nucleus.
- For example in ^{7}Be, a difference of 0.9% has been observed between half-lives in metallic and insulating environments. This relatively large effect is due to the fact that beryllium is a small atom whose valence electrons are close to the nucleus.

RADIONUCLIDE GENERATOR-TECHNETIUM GENERATOR

RADIONUCLIDE GENERATOR

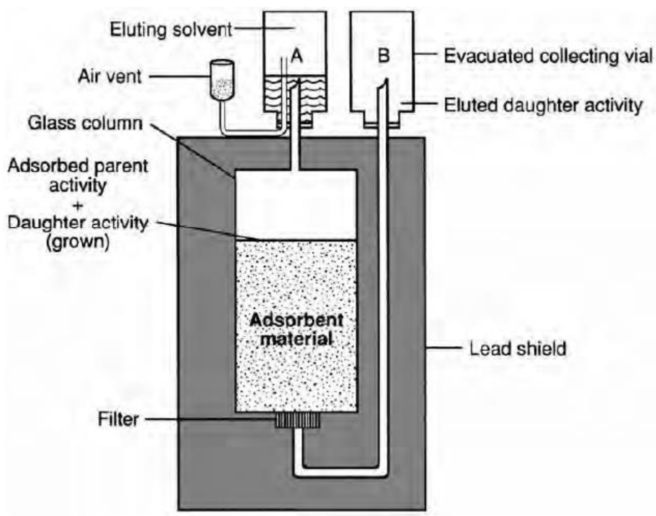
- Radionuclide generators provide the convenient sources of short-lived radionuclides that are very useful clinically.
- The basic requirements for a generator are that *a parent radionuclide has a longer half-life than that of the daughter*, and the daughter can be easily separated from the parent.
- In a generator, a long-lived parent radionuclide is allowed to decay to its shortlived daughter radionuclide, and the latter is then chemically separated.
- The importance of radionuclide generators lies in the fact that they are easily transportable and serve as sources of short-lived radionuclides in institutions without cyclotron or reactor facilities.
- A radionuclide generator consists of a glass or plastic column fitted at the bottom with a fretted disk.
- The column is filled with adsorbent material such as ion exchange resin, alumina, and so forth, on which the parent nuclide is adsorbed.
- The parent decays to the daughter until transient or secular equilibrium is established in several half- lives of the daughter.

- After equilibrium, the daughter appears to decay with the same half-life as the parent. Because of the differences in chemical properties, the daughter activity is eluted with an appropriate solvent, leaving the parent on the column.
- After elution, the daughter activity builds up again and can be eluted repeatedly.

CONSTRUCTION

A schematic diagram of a radionuclide generator is shown below.

- The vial containing the eluant is first inverted onto needle A, and an evacuated vial is inverted on the other needle B.
- The vacuum in the vial on needle B draws the eluant from the vial A through the column and elutes the daughter nuclide, leaving the parent nuclide on the column.
- In some commercial generators, a bottle of eluant is placed inside the housing, and aliquots of eluant are used up in each elution by the evacuated vial.
- An ideal radionuclide generator should be simple and sturdy for transportation.
- The generator eluate should be free of the parent nuclide and the adsorbent material.



^{99}Mo–^{99m}Tc *Generator*

A **technetium-99m generator**, or colloquially a **technetium cow** or **moly cow**, is a device used to extract the metastable isotope ^{99m}Tc of technetium from a source of decaying molybdenum-99.

^{99}Mo has a half-life of 66 hours and can be easily transported over long distances to hospitals where its decay product technetium-99m (with a half-life of only 6 hours, inconvenient for transport) is extracted and used for a variety of nuclear medicine diagnostic procedures, where its short half-life is very useful.

- The ^{99}Mo–^{99}mTc generator is constructed with alumina (Al_2O_3) loaded in a plastic or glass column.
- The ^{99}Mo activity is adsorbed on alumina in the chemical form MoO_4 2^- (molybdate) and in various amounts.
- The amount of alumina used is about 5–10 g depending on the ^{99}Mo activity. Currently, all generators use fission-produced ^{99}Mo.
- The ^{99m}Tc activity is eluted with 0.9% NaCl solution (isotonic saline) and obtained in the chemical form of $Na^{99m}TcO_4$.

Considering that only 87% of ^{99}Mo decays to ^{99m}Tc, the ^{99m}Tc activity *A*Tc can be calculated as

$$A_{\mathrm{Tc}} = 0.957(A_{\mathrm{Mo}})_0(e^{-0.0105t} - e^{-0.1155t})$$

- where $(A_{\mathrm{Mo}})_0$ is the ^{99}Mo activity at $t = 0$, λ_{Mo} = 0.0105 hr^{-1}, and

λ_{Tc} = 0.1155 hr^{-1}. The time *t* has the unit of hour. At transient equilibrium

$$\begin{aligned} A_{\mathrm{Tc}} &= 0.957(A_{\mathrm{Mo}})_0 e^{-0.0105t} \\ &= 0.957(A_{\mathrm{Mo}})_t \end{aligned}$$

Upon elution with saline, approximately 75% to 85% of the total activity is eluted from the column. After about 4 half-lives, the ^{99m}Tc activity reaches maximum.

UNIT IV

INTERACTION OF RADIATION WITH MATTER

INTERACTION OF CHARGED PARTICLES WITH MATTER

- The energetic charged particles such as a-particles, protons, deuterons, and b-particles (electrons) interact with the absorber atoms, while passing through it.
- The interaction occurs primarily with the orbital electrons of the atoms and rarely with the nucleus. During the interaction, both *ionization* and *excitation* as well as the breakdown of the molecule may occur.
- In excitation, the charged particle transfers all or part of its energy to the orbital electrons, raising them to higher energy shells. In ionization, the energy transfer may be sufficient to overcome the binding energy of the orbital electrons, ultimately ejecting them from the atom.
- Electrons ejected from the atoms by the incident charged particles are called *primary electrons*, which may have sufficient kinetic energy to produce further excitation or ionization in the absorber.
- The high-energy secondary electrons from secondary ionizations are referred to as *delta* (d-) rays. The process of excitation and ionization will continue until the incident particle and all electrons come to rest.
- Both these processes may rupture chemical bonds in the molecules of the absorber, forming various chemical entities.

In ionization, an average energy of *W* is required to produce an ion pair in the absorber and varies somewhat with the type of absorber. The value of *W* is about 35 eV in air and less in oxygen and xenon gases but falls in the range of 25–45 eV for most gases.

- Three important quantities associated with the passage of charged particles

through matter are specific ionization, linear energy transfer, and range
of the particle in the absorber .

SPECIFIC IONIZATION

- Specific ionization (SI) is the total number of ion pairs produced per unit length of the path of the incident radiation.The SI values of a-particles are slightly greater than those of protons and deuterons, which in turn are larger than those of electrons.
- Specific ionization increases with decreasing energy of the charged particle because of the increased probability of interaction at low energies. Therefore, toward the end of the travel, the charged particle shows a sharp increase in ionization. This peak ionization is called *Bragg ionization*. This phenomenon is predominant for heavy charged particles and is negligible for electrons.

LINEAR ENERGY TRANSFER

The linear energy transfer (LET) is the amount of energy deposited per unit length of the path by the radiation. From the preceding, it is clear that

$$\mathrm{LET} = \mathrm{SI} \times W$$

- The LET is expressed in units of keV/mm and is very useful in concepts of radiation protection. Electromagnetic radiations and b-particles interact with matter, losing only little energy per interaction and therefore have low LETs.

- In contrast, heavy particles (a-particles, neutrons, and protons) lose energy very rapidly, producing many ionizations in a short distance, and thus have high LETs. Some comparative approximate LET values in keV/mm in tissue are given in Table

TABLE 6.1. LET values of some radiations in tissue.

Radiation	LET (keV/μm)
3 MV x-rays	0.5
250 KV x-rays	3.0
5-MeV α-particles	100.0
1-MeV electrons	0.25
14-MeV neutrons	20.0

RANGE

- The *range* (*R*) of a charged particle in an absorber is the straight-line distance traversed by the particle in the direction of the particle.
- The range of a particle depends on the mass, charge, and kinetic energy of the particle and also on the density of the absorber.
- The heavier and more highly charged particles have shorter ranges than lighter and lower charged particles.
- The range of charged particles increases with the energy of the particle.Thus, a 10-MeV particle will have a longer range than a 1-MeVparticle.
- The range of the particle depends on the density of the absorber, in that the denser the absorber, the shorter the range. The unit of range is given in mg/cm^2 of the absorber.

- Depending on the type of the charged particle, the entire path of travel may be unidirectional along the initial direction of motion, or tortuous.

- Because the α-particle loses only a small fraction of energy in a single collision with an electron because of its heavier mass and is not appreciably deflected in the collision, the α-particle path is nearly a straight line along its initial direction .

- Many collisions in a short distance create many ion pairs in a small volume. In contrast, β-particles or electrons interact with extranuclear orbital electrons of the same mass and are deflected considerably. This leads to tortuous paths of these particles.

In this situation, the true range is less than the total path traveled by the particle.

- It is seen that the ranges of all identical particles in a given absorber are not exactly the same but show a spread of 3% to 4% near the end of their path.

- This phenomenon, referred to as the *straggling of the ranges*, results from the statistical fluctuations in the number of collisions and in the energy loss per collision.
- The range straggling is less prominent with α-particles but is severe with electrons because it is mostly related to the mass of the particle. The light mass electrons are considerably deflected during collisions and hence exhibit more straggling. If the transmission of a beam of charged particles through absorbers of different thicknesses is measured, the beam intensity will remain constant until the region of range straggling is encountered, where the beam intensity falls sharply from its initial value to zero.
- The absorber thickness that reduces the beam intensity by one half is called the *mean range*. The mean range of heavier particles such as a-particles is more well defined than that of electrons. Because β^-particles are emitted with a continuous energy spectrum, their absorption, and hence their ranges, become quite complicated.

BREMSSTRAHLUNG

- When energetic charged particles, particularly electrons, pass through matter and come close to the nucleus of the atom, they lose energy as a result of deceleration in the Coulomb field of atomic nuclei. The loss in energy appears as an x-ray that is called *bremsstrahlung* (German for "braking" or "slowing down" radiation).
- These bremsstrahlung radiations are commonly used in radiographic procedures and are generated by striking a tungsten target with a highly accelerated electron beam.

Bremsstrahlung production increases with the kinetic energy of the particle and the atomic number (Z) of the absorber.

- For example, a 10-MeV electron loses about 50% of its energy by bremsstrahlung, whereas a 90-MeV electron loses almost 90% of its energy by this process.
- The bremsstrahlung production is proportional to Z^2 of the absorber atom. Therefore, bremsstrahlung is unimportant in lighter metals such as air, aluminum, and so forth, whereas it is very significant in heavy metals such as lead and tungsten. High-energy b^--particles from radionuclides such as ^{32}P can produce bremsstrahlung in heavy metals such as lead and tungsten.
- For this reason, these radionuclides are stored in low-Z materials such as plastic containers rather than in lead containers.

- Bremsstrahlung is inversely proportional to the mass of the charged particles and therefore is insignificant for heavy particles, namely a-particles and protons, because the probability of penetrating close to the nuclei is relatively low due to their heavier masses.

ANNIHILATION

- When energetic b□-particles pass through an absorber, they lose energy via interaction with orbital electrons of the atoms of the absorber.
- When the b□-particle comes to almost rest after losing all energy, it combines with an orbital electron of the absorber atom and produces two 511-keV annihilation radiations that are emitted in opposite directions (180°). These annihilation radiations are the basis

of positron emission tomography (PET) in which two photons are detected in coincidence.

INTERACTION OF γ -RADIATIONS WITH MATTER

MECHANISM OF INTERACTION OF γ -RADIATIONS

- When penetrating γ-rays pass through matter, they lose energy by interaction with the orbital electrons or the nucleus of the absorber atom.
- The γ ray photons may lose all of their energy, or a fraction of it, in a single encounter. The specific ionization of γ-rays is one-tenth to one-hundredth of that caused by a non-penetrating electron of the same energy.
- There is no quantity equivalent to a range of particles for γ-rays, but they travel a long path in the absorber before losing all energy. The average energy loss per ion pair produced by the photons is the same as for electrons, that is, 35keV in air.

There are three mechanisms by which γ-rays interact with absorber atoms during their passage through matter, and they are described below.

PHOTOELECTRIC EFFECT

- In the photoelectric effect, the incident γ -ray transfers all its energy to an orbital electron of the absorber atom whereby the electron, called the *photoelectron*, is ejected with kinetic energy equal to $E_\gamma - E_B$, where E_γ and E_B are the energy of the γ -ray and the binding energy of the electron, respectively.
- The photoelectron loses its energy by ionization and excitation in the absorber, as discussed previously. The photoelectric effect occurs primarily in the low-energy range and decreases sharply with increasing photon energy.
- It also increases very rapidly with increasing atomic number Z of the absorber atom. Roughly, the photoelectric effect is proportional to $Z^5/E^3{}_g$.

The photoelectric contribution from the 0.15-MeV g -rays in aluminum (Z =13) is about the same (~5%) as that from the 4.7-MeV g -rays in lead (Z=□82).

- The photoelectric effect occurs primarily with the K-shell electrons, with about 20% contribution from the L-shell electrons and even less from higher shells.
- There are sharp increases (discontinuities) in photoelectric effects at energies exactly equal to binding energies of K-, L- (etc.) shell electrons.
- These are called K-, L- (etc.) absorption edges. The vacancy created by the ejection of an orbital electron is filled in by the transition of an electron from the upper energy shell.
- It is then followed by emission of a characteristic x-ray or Auger electron, analogous to the situations in internal conversion or electron capture decay.

COMPTON SCATTERING

- In Compton scattering, the g-ray photon transfers only a part of its energy to an electron in the outer shell of the absorber atom, and the electron is ejected.

- The photon, itself with reduced energy, is deflected from its original direction This process is called the *Compton scattering*.
- The scattered photon of lower energy may then undergo further photoelectric or Compton interaction, and the Compton electron may cause ionization or excitation, as discussed previously.
- At low energies, only a small fraction of the photon energy is transferre to the Compton electron, and the photon and the Compton electron are scattered at an angle θ. Using the law of conservation of momentum and energy, the scattered photon energy is given by

$$E_{sc} = E_\gamma/[1 + (E_\gamma/0.511)(1 - \cos\theta)]$$

- Where E_γ and E_{sc} are the energies in MeV of the initial and scattered photons.The scattered photon energy varies from a maximum in a collision at 0° (forward) to a minimum at q = 180° in a backscattering collision.
- Conversely, the Compton electron carries a minimum energy in the forward collision to a maximum energy in the backscattering collision.
- At higher energies, both the scattered photon and the Compton electron are predominantly scattered in the forward direction.
- If the photon is backscattered, that is, scattered at 180°, then the backscattered photon has the energy *Esc* given by the expression (cos 180° = −1):

$$E_{sc} = E_\gamma/(1 + E_\gamma/0.256)$$

- In backscattering of a 140-keV photon, the scattered photon and the Compton electron would have 91 keV and 49keV, respectively, whereas for a 1330-keV photon these values are 215keV and 1115keV, respectively.
- It can be seen that as the photon energy increases, the scattered photon energy approaches the minimum limit of 256keV, and the Compton electron receives the maximum energy.
- Compton scattering is almost independent of the atomic number *Z* of the absorber. Compton scattering contributes primarily in the energy range of 0.1 to 10MeV, depending on the type of absorber.

PAIR PRODUCTION

- When the g-ray photon energy is greater than 1.02MeV, the photon can interact with the nucleus of the absorber atom during its passage through it, and a positive electron and a negative electron are produced at the expense of the photon .

- The energy in excess of 1.02MeV appears as the kinetic energy of the two particles. This process is called *pair production*.

- It varies almost linearly with Z^2 of the absorber and increases slowly with the energy of the photon. In soft tissue, pair production is insignificant at energies up to 10MeV above 1.02MeV.

- Positive electrons created by pair production are annihilated to produce two 0.511-MeV photons identical to those produced by positrons from radioactive decay.

- The relative importance of photoelectric, Compton, and pair production interactions with absorbers of different atomic numbers is shown in Figure , as a function of the energy of the incident photons.

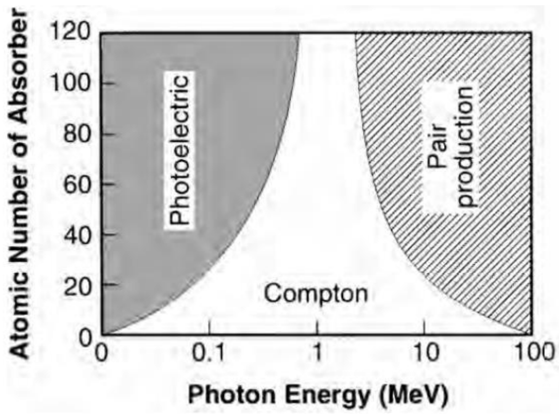


Fig. Relative contributions of the photoelectric effect, Compton scattering, and pair production as a function of photon energy in absorbers of different atomic numbers.

- It is seen that the photoelectric effect is predominant in high *Z* absorbers at lower energies (<0.1MeV), whereas the Compton scattering is predominant in inter- mediate *Z* absorbers at medium energies (~1MeV). At higher energies (>10MeV), pair production predominates in all *Z* absorbers.

ATTENUATION OF GAMMA RADIATION

LINEAR AND MASS ATTENUATION COEFFICIENTS**:**

- g-ray and x-ray photons are either attenuated or transmitted as they travel through an absorber. Attenuation results from absorption by the photoelectric effect, Compton scattering, and pair production at higher energies.
- Depending on the photon energy and the density and thickness of the absorber, some of the photons may pass through the absorber without any interaction leading to the transmission of the photons (Fig. 6.7). Attenuation of g-radiations is an important factor in radiation protection.
- if a photon beam of initial intensity I_0 passes through an absorber of thickness *x*, then the transmitted beam I_t is given by the exponential equation

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

where μ is the *linear attenuation coefficient* of the absorber for the photons of interest and has the unit of cm^{-1}. The factor $e^{-\mu x}$ represents the fraction of the photons transmitted. Because attenuation is primarily due to photoelectric, Compton, and pair production interactions, the linear attenuation coefficient μ is the sum of photoelectric coefficient (τ), Compton coefficient (σ), and pair production coefficient (κ). Thus,

$$\mu = \tau + \sigma + \kappa$$

Linear attenuation coefficients normally decrease with the energy of the γ-ray or x-ray photons and increase with the atomic number and density of the absorber. The relative contributions of photoelectric effect, Compton scattering, and pair production in water (equivalent to body tissue) at different energies are illustrated in Figure 6.8.

An important quantity, μ_m, called the *mass attenuation coefficient*, is given by the linear attenuation coefficient divided by the density ρ of the absorber

$$\mu_m = \frac{\mu}{\rho}$$

The mass attenuation coefficient μ_m has the unit of cm^2/g or cm^2/mg. The mass attenuation coefficients for fat, bone, muscle, iodine, and lead are given in Figure 6.9.

HALF-VALUE LAYER

The concept of *half-value layer* (HVL) of an absorbing material for γ- or x-radiations is important in the design of shielding for radiation protection.

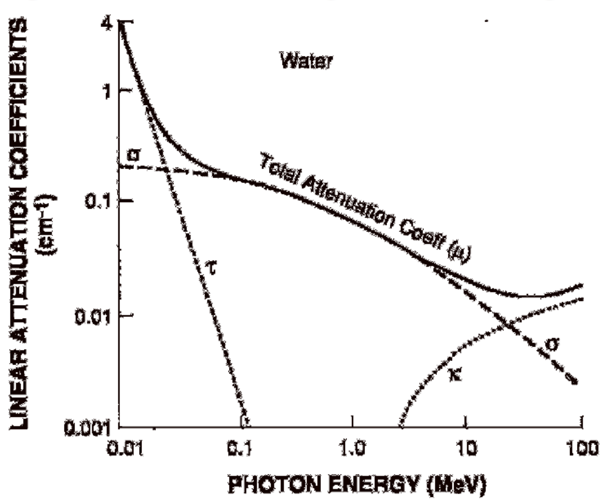


Fig. 6.8. Plot of linear attenuation coefficient of g-ray interaction in water (equivalent to body tissue) as a function of photon energy. The relative contributions of photoelectric, Compton, and pair production processes are illustrated.

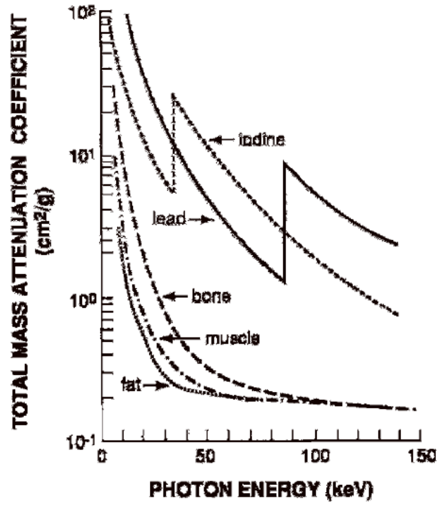


FIG. 6.9. Attenuation coefficients for fat, muscle, bone, iodine, and lead as a function of photon energy. (Adapted with permission from Hendee WR. *Medical Radiation Physics*. 1st ed. Chicago: Year Book Medical Publishers, Inc; 1970:221.)

TABLE 6.2. Half-value layer values (HVLs) of lead for commonly used radionuclides.

Radionuclides	HVL, Lead (cm)*	HVL, Water (cm)†
^{137}Cs	0.65	—
^{99m}Tc	0.03	4.6
^{201}Tl	0.02	—
^{99}Mo	0.70	—
^{67}Ga	0.10	—
^{123}I	0.04	—
^{111}In	0.10	—
^{125}I	0.003	1.7
^{57}Co	0.02	—
^{131}I	0.30	6.3
^{18}F	0.39	11.2

It is defined as the thickness of the absorber that reduces the intensity of a photon beam by one-half. Thus, an HVL of an absorber around a source of γ-radiations with an exposure rate of 150 mR/hr will reduce the exposure rate to 75 mR/hr. The HVL depends on the energy of the radiation and the atomic number of the absorber. It is greater for high-energy photons and smaller for high-Z materials.

For monoenergetic photons, the HVL of an absorber is related to its linear attenuation coefficient as follows:

$$\mathrm{HVL} = \frac{0.693}{\mu}$$

Because μ has the unit of cm^{-1}, the HVL has the unit of cm. The HVLs of lead for different radionuclides are given in Table 6.2.

Another important quantity, tenth-value layer (TVL), is the thickness of an absorber that reduces the initial beam by a factor of 10. It is given by

$$\begin{aligned} \mathrm{TVL} &= -\frac{\ln(0.1)}{\mu} \\ &= \frac{2.30}{\mu} \\ &= 3.32\ \mathrm{HVL} \end{aligned}$$

INTERACTION OF NEUTRON WITH MATTER

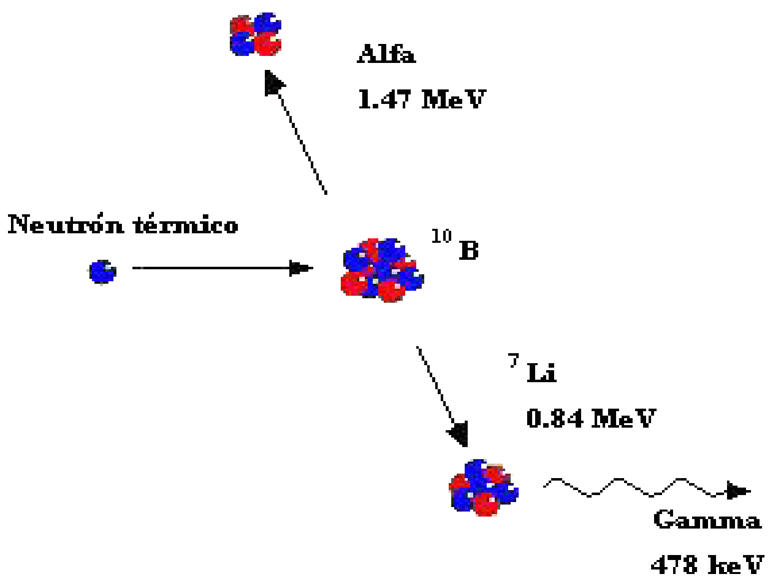
- Because neutrons are neutral particles, their interactions in the absorber differ from those of the charged particles.
- They interact primarily with the nucleus of the absorber atom and very little with the orbital electrons.
- The neutrons can interact with the atomic nuclei in three ways: elastic scattering, inelastic scattering, and neutron capture.
- If the sum of the kinetic energies of the neutron and the nucleus before collision is equal to the sum of these quantities after collision, then the interaction is called *elastic*.
- If a part of the initial energy is used for the excitation of the struck nucleus, the collision is termed *inelastic*.
- In neutron capture, a neutron is captured by the absorber nucleus, and a new excited nuclide is formed.
- Depending on the energy deposited, an a-particle, a proton, a neutron, or g-rays can be emittedfrom the excited nucleus, and a new product nuclide (usually radioactive) is produced.

APPLICATION: Boron-Neutron Capture Therapy (BNCT)

Boron Neutron Capture Therapy (BNCT) is a binary technique that involves the concurrent presence of a flux of neutrons of adequate energy and a ^{10}B capture compound that accumulates mainly in tumor cells. Their interaction generates heavy particles that damage tumor cells. The neutron and boron components do not produce significant damage to tissues when they are present separately.

After neutron capture, the following reaction occurs:

$$^{10}B + n \square \, ^{7}Li + {}^{4}He + 2.79 \text{ MeV}$$



94% of the time, a 478 keV photon is emitted in the nuclear decay of ^{7}Li. The range in tissue of ^{7}Li and ^{4}He (alpha particle) is approximately 5 µm and 8 µm respectively, i.e. about the diameter of a tumor cell (~ 10 µm).

A few alpha particles suffice to destroy a tumor cell. The killing effect of the capture reaction would occur mainly in those cancer cells that have selectively accumulated boron. The normal cells that have not incorporated important amounts of boron will not suffer significant damage.

UNIT V

BASIC RADIATION QUANTITIES

INTRODUCTION

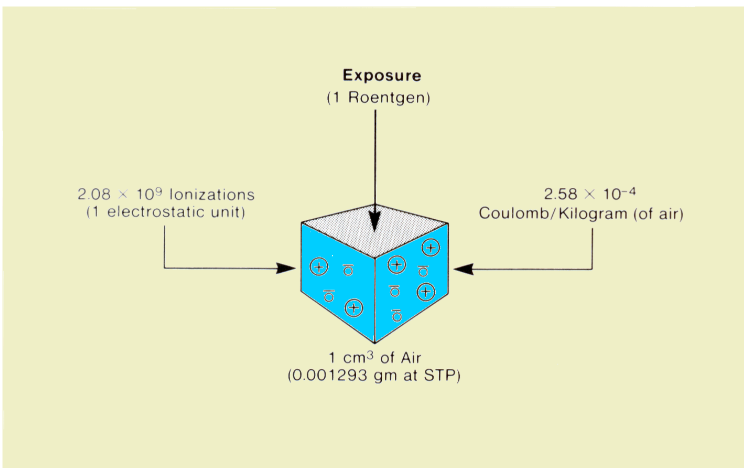
- There are many different quantities and units used to quantify radiation, because there are a number of different aspects of an x-ray beam or gamma radiation that can be used to express the amount of radiation.
- The selection of the most appropriate quantity depends on the specific application.
- The primary objective of this chapter is to help the reader develop a conceptual understanding of the various radiation quantities and units and gain sufficient factual knowledge to support their usage.

EXPOSURE

- Exposure is the quantity most commonly used to express the amount of radiation delivered to a point. The conventional unit for exposure is the roentgen (R), and the Sl unit is the coulomb per kilogram of air (C/kg):

$$\mathbf{1\ R = 2.58 \times 10^{-4}\ C/kg}$$
$$\mathbf{1\ C/kg = 3876\ R}$$

- The reason exposure is such a widely used radiation quantity is that it can be readily measured.
- All forms of radiation measurement are based on an effect produced when the radiation interacts with a material.
- The specific effect used to measure exposure is the ionization in air produced by the radiation.

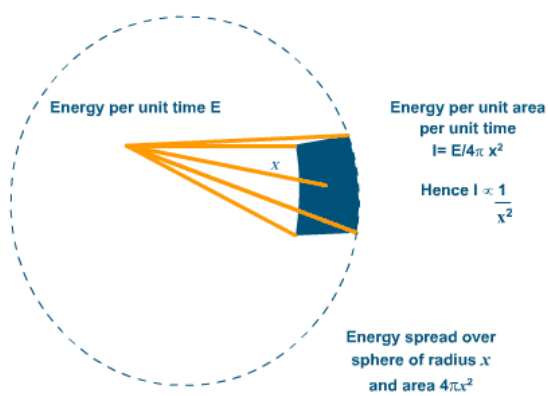


- Exposure is generally measured by placing a small volume of air at the point of measurement and then measuring the amount of ionization produced within the air.
- The enclosure for the air volume is known as an ionization chamber.

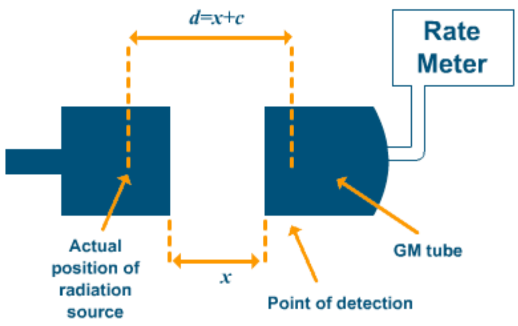
- The concept of exposure and its units can be developed from the figure above.
- When a small volume of air is exposed to ionizing radiation (x-ray, gamma, etc.), some of the photons will interact with the atomic shell electrons.
- The interaction separates the electrons from the atom, producing an ion pair.
- When the negatively charged electron is removed, the atom becomes a positive ion.
- Within a specific mass of air the quantity of ionizations produced is determined by two factors: the concentration of radiation photons and the energy of the individual photons.
- An exposure of 1 roentgen produces 2.08×10^9 ion pairs per cm^3 of air at standard temperature and pressure (STP); 1 cm^3 of air at STP has a mass of 0.001293 g.
- The official definition of the roentgen is the amount of exposure that will produce 2.58×10^{-4} C (of ionization) per kg of air.
- A coulomb is a unit of electrical charge.
- Since ionization produces charged particles (ions), the amount of ionization produced can be expressed in coulombs. One coulomb of charge is produced by 6.24×10^{18} ionizations.

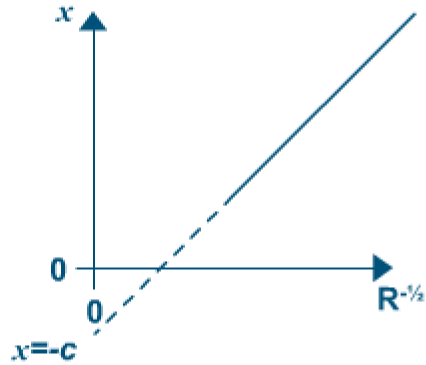
INVERSE SQUARE LAW

- The radiation spreads in all directions about the source, and therefore when it is a distance x from the source it is spread over the surface of a sphere of radius x and area $4\pi x^2$.
- If E is the energy radiated per unit time by the source, the intensity (energy per unit time per unit area) is given by $I = E/4\pi x^2$ or simply as $I \propto 1/x^2$. Thus the energy varies as the inverse square from the source.
- The procedure is slightly complicated by the fact that the distance between point of emission and detection (d = x +c in the diagram) is impossible to measure directly. As we shall see as x is measurable and c is a constant this is not a problem.



Experimental arrangment for inverse square law





Inverse Square Law Graph

The aim is verify that

$$I \propto 1/d^2$$

i.e., $I \propto 1/(x+c)^2$

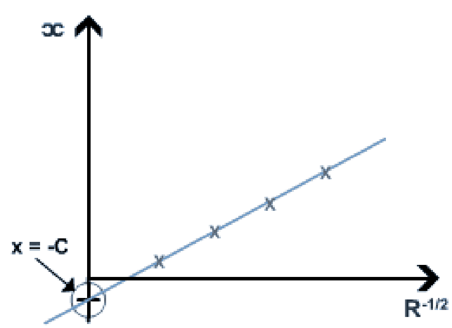
Since I is proportional to the **corrected count rate** R (i.e. the actual count rate minus the background count rate) this can be written as

$$R \propto 1/(x+c)^2$$

Introducing a constant k and rearranging gives

$$x = k\,R^{-1/2} - c.$$

Hence a plot of x against $R^{-1/2}$ turns out to be a straight line if the inverse square law has been verified. **As shown below the intercept when $R^{-1/2}$ is zero gives c.**



The inverse square law is important as it gives a measure of how the intensity of radiation falls off with distance from a source. This has implications for the storage and use of radioactive sources.

KERMA

Kerma is an acronym for Kinetic Energy Released per unit Mass. It is a non-stochastic quantity applicable to indirectly ionizing radiations, such as photons and neutrons. It quantifies the average amount of energy transferred from the indirectly ionizing radiation to directly ionizing radiation without concerns to what happens after this transfer. In the discussion that follows we will limit ourselves to photons.

Energy of photons is imparted to matter in a two-stage process

- In the first stage, the photon radiation transfers energy to the secondary charged particles (electrons) through various photon interactions (photo-effect, Compton effect, pair production, etc).
- In the second stage, the charged particle transfers energy to the medium through atomic excitations and ionisations.

In this context, the kerma is defined as the mean energy transferred from the indirectly ionizing radiation to charged particles (electrons) in the medium $d\bar{E}_{\mathrm{tr}}$ per unit mass dm:

$$K = \frac{d\bar{E}_{\mathrm{tr}}}{dm} .$$

The unit of kerma is joule per kilogram ($J \cdot kg^{-1}$). The special name for the unit of kerma is the gray (Gy), where 1 Gy = 1 $J \cdot kg^{-1}$.

ABSORBED DOSE

Absorbed dose is a non-stochastic quantity applicable to both indirectly and directly ionizing radiations. For indirectly ionizing radiations, energy is imparted to matter in a two step process. In the first step (resulting in kerma) the indirectly ionizing radiation transfers energy as kinetic energy to secondary charged particles. In the second step these charged particles transfer some of their kinetic energy to the medium (resulting in absorbed dose) and lose some of their energy in the form of bremsstrahlung losses.

The absorbed dose is related to the stochastic quantity energy imparted. The absorbed dose is defined as the mean energy $\bar{\varepsilon}$ imparted by ionizing radiation to matter of mass m in a finite volume V by:

$$D = \frac{d\bar{\varepsilon}}{dm} .$$

- The energy imparted $\overline{\varepsilon}$ is the sum of all energy entering the volume of interest minus all energy leaving the volume, taking into account any mass-energy conversion within the volume. Pair production, for example, decreases the energy by 1.022 MeV, while electron-positron annihilation increases the energy by the same amount.

- Note that because the electrons travel in the medium and deposit energy along their tracks, this absorption of energy does not take place at the same location as the transfer of energy described by kerma. The unit of absorbed dose is joule per kilogram ($J \cdot kg^{-1}$). The special name for the unit of absorbed dose is the gray (Gy).

STOPPING POWER

- **Stopping power** in nuclear physics is defined as the retarding force acting on charged particles due to interaction with matter, resulting in loss of particle energy.
- Its application is important in areas such as radiation protection and nuclear medicine. Typical particles include alpha particles, and beta particles.

Definition

- Both charged and uncharged particles lose energy while passing through matter, but stopping power describes only the energy loss of charged particles.
- Positive ions are considered in most cases below. The stopping power depends on the type and energy of the radiation and on the properties of the material it passes.
- Since the production of anion pair (usually a positive ion and a (negative) electron) requires a fixed amount of energy (for example, 33.97 eV in dry air), the density of ionization is proportional to the stopping power.
- The *stopping power* of the material is numerically equal to the loss of energy *E* per unit path length, *x*:

$$S(E) = -dE/dx$$

The minus sign makes S positive.

- The force usually increases toward the end of range and reaches a maximum, the Bragg peak, shortly before the energy drops to zero.
- The curve that describes the force as function of the material depth is called the *Bragg curve*. This is of great practical importance forradiation therapy.
- The equation above defines the **linear stopping power** which in the international system is expressed in N but is usually indicated in other units like MeV/mm or similar.
- If a substance is compared in gaseous and solid form, then the linear stopping powers of the two states are very different just because of the different density.
- One therefore often divides the force by the density of the material to obtain the **mass stopping power** which in the international system is expressed in m^4/s^2 but is usually

found in units like MeV/(mg/cm^2) or similar.

- The mass stopping power then depends only very little on the density of the material.

This particular energy corresponds to that of the alpha particle radiation from naturally radioactive gas radon (^{222}Rn) which is present in the air in minute amounts wherever the ground contains granite.

- The mean range can be calculated by integrating the reciprocal stopping power over energy:

$$\Delta x = \int_0^{E_0} \frac{1}{S(E)}\, dE$$

where:

- E_0 is the initial kinetic energy of the particle
- Δx is the "continuous slowing down approximation (CSDA)" range and
- $S(E)$ is the linear stopping power.

The deposited energy can be obtained by integrating the stopping power over the entire path length of the ion while it moves in the material.

RELATIONSHIP BETWEEN THE DOSIMETRIC QUANTITIES

ENERGY FLUENCE AND KERMA (PHOTONS)

The energy transferred to electrons by photons can be expended in two distinct ways:

(1) through collision interactions (soft collisions, hard collisions),
(2) through radiative interactions (bremsstrahlung, electron-positron annihilation).
Therefore, the total kerma is usually divided into two components: the collision kerma K_{col} and the radiative kerma K_{rad}.

- Collision kerma K_{col} is that part of kerma that leads to the production of electrons that dissipate their energy as ionisation in or near the electron tracks in the medium, and is the result of Coulomb-force interactions with atomic electrons. Thus, the collision kerma is the expectation value of the net energy transferred to charged particles per unit mass at the point of interest, excluding both the radiative energy loss and energy passed from one charged particle to another.
- Radiative kerma K_{rad} is that part of kerma that leads to the production of bremsstrahlung as the secondary charged particles are decelerated in the medium. It is the result of Coulomb field interactions between the charged particle and the atomic nuclei.
- The total kerma K is thus given by the following equation:

$$K = K_{\text{col}} + K_{\text{rad}} \ .$$

- The average fraction of the energy transferred to electrons that is lost through radiative processes is represented by a factor referred to as the bremstrahlung fraction g. Hence, the fraction lost through collisions is $(1-\overline{g})$.

  - A frequently used relation between collision kerma and total kerma K may be written as follows:

$$K_{\text{col}} = K(1-\overline{g}) \quad .$$

  - For monoenergetic photons the collision kerma K_{col} at a point in a medium is related to the energy fluence Ψ at that point in the medium by the following equation:

$$K_{\text{col}} = \Psi \left(\frac{\mu_{\text{en}}}{\rho} \right) ,$$

  - where (μ_{en} / ρ) is the mass-energy absorption coefficient for the monoenergetic photons in the medium.

  - For polyenergetic beams, a formally similar relation exists, but use is made of spectrum-averaged quantities. If a photon energy fluence spectrum $\Psi_{\text{E}}(E)$ is present at the point of interest, the collision kerma at that point is obtained as follows:

$$K_{\text{col}} = \int_{o}^{E_{\max}} \Psi_{\text{E}}(E) \left(\frac{\mu_{\text{en}}}{\rho} \right) \text{d}E = \Psi \left(\frac{\overline{\mu}_{\text{en}}}{\rho} \right) \quad .$$

  - $$\Psi = \int_{0}^{E_{\max}} \Psi_{\text{E}}(E) dE$$ stands for the total (integrated) energy fluence, and

$$\left(\frac{\overline{\mu}_{\text{en}}}{\rho} \right) = \frac{1}{\Psi} \int_{0}^{E_{\max}} \Psi_{\text{E}}(E) \frac{\mu_{\text{en}}}{\rho}(E) dE$$ is a shorthand notation for the mass energy absorption coefficient for the medium averaged over the energy fluence spectrum.

- For mono-energetic photons the total kerma K at a point in a medium is related to the energy fluence Ψ in the medium by the following equation:

$$K = \Psi \left(\frac{\mu_{tr}}{\rho} \right),$$

- **Where** (μ_{tr} / ρ) is the mass-energy transfer coefficient of the medium for the given monoenergetic photon beam. For poly-energetic beams, similarly as above, spectrum-averaged mass-energy transfer coefficients can be used in conjunction with total energy fluence to obtain the total kerma.

- one can obtain the frequently used relation between collision kerma in two different materials, material 1 and material 2, as follows:

$$\frac{K_{col,2}}{K_{col,1}} = \frac{\Psi_2 \left(\frac{\overline{\mu}_{en}}{\rho} \right)_2}{\Psi_1 \left(\frac{\overline{\mu}_{en}}{\rho} \right)_1} \equiv (\Psi)_1^2 \left(\frac{\overline{\mu}_{en}}{\rho} \right)_1^2 .$$

- This equation is often used in circumstances where the fluence ratio $(\Psi)_1^2$ can be assumed unity through a proper scaling of dimensions (the scaling theorem), or for very similar materials.

COLLISION KERMA AND EXPOSURE

- Exposure X is the quotient of dQ by dm, where dQ is the absolute value of the total charge of the ions of one sign produced in air when all the electrons and positrons liberated or created by photons in mass dm of air are completely stopped in air:

$$X = \frac{dQ}{dm} .$$

- The unit of exposure is coulomb per kilogram (C/kg). The special unit used for exposure is the roentgen R, where 1 R = 2.58 x 10^{-4} C/kg. In the SI system of units, roentgen is no longer used and the unit of exposure is simply 2.58×10^{-4} C/kg of air.

- The average energy expended in air per ion pair formed W_{air} is the quotient of E by N, where N is the mean number of ion pairs formed when the initial kinetic energy E of a charged particle is completely dissipated in air:

$$W_{air} = \frac{E}{N} \quad .$$

- The current best estimate for the average value of W_{air} is 33.97 eV/ion pair or 33.97 × 1.602 × 10^{19} J/ion pair:

$$\frac{W_{air}}{e} = \frac{33.97 \ (\mathrm{eV}/ion\ pair) \times 1.602 \times 10^{-19} \ (\mathrm{J}/\mathrm{eV})}{1.602 \times 10^{-19} \ (\mathrm{C}/ion\ pair)} = 33.97 \ \mathrm{J/C} \ .$$

- Multiplying the collision kerma by (e/W_{air}), the number of coulombs of charge created per joule of energy deposited, gives the charge created per unit mass of air or exposure:

$$X = (K_{col})_{air} \left(\frac{e}{W_{air}} \right) .$$

- The relationship between total kerma and exposure is obtained by combining above two equations

$$K_{air} = X \left(\frac{W_{air}}{e} \right) \frac{1}{1 - \bar{g}} .$$

BREMSSTRAHLUNG RADIATION

- Bremsstrahlung radiation is the radiation given off by a charged particle (most often an electron) due to its acceleration caused by an electric field of another charged particle (most often a proton or an atomic nucleus).

- The word “Bremsstrahlung” is a German word meaning “braking radiation,” which refers to the way in which electrons are “braked” when they hit a metal target.

- The incident electrons are free, meaning they're not bound to an atom or ion, both before and after the braking.

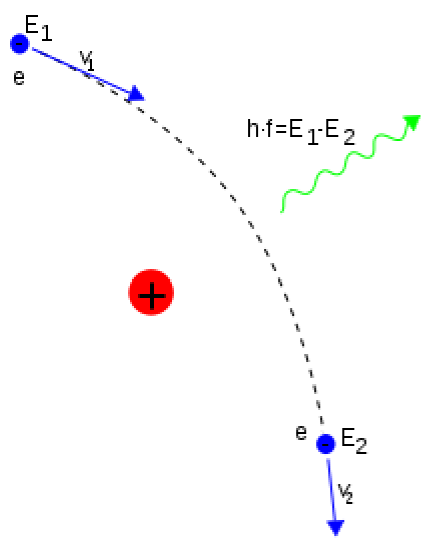
- Consequently, this kind of radiation's spectrum is continuous (unlike atomic spectra, which contain sharp spectral lines) and sometimes referred to as "free-free" radiation.

- If the energy of the incident electrons is high enough, they emit X-rays after they have been braked.

- One of the most interesting examples of Bremsstrahlung radiation in the universe is that coming from the hot intracluster gas of galaxy clusters.

- In this case, the electrons don't bounce off a metal target but are deflected by the electric field of protons.

- The gas has X-ray luminosities of 10^{36} to 10^{38} W (roughly 10 billion to 1 trillion times the luminosity of the sun!) and temperatures on the order of 10 million K. X-ray telescopes can detect this radiation as diffuse light,



Bremsstrahlung produced by a high-energy electron deflected in the electric field of an atomic nucleus

Sources of Bremsstrahlung

X-ray tube

- In an X-ray tube, electrons are accelerated in a vacuum by an electric field and shot into a piece of metal called the "target".
- X-rays are emitted as the electrons slow down (decelerate) in the metal. The output spectrum consists of a continuous spectrum of X-rays, with additional sharp peaks at certain energies (see graph on right).

- The continuous spectrum is due to bremsstrahlung, while the sharp peaks are characteristic X-rays associated with the atoms in the target. For this reason, bremsstrahlung in this context is also called **continuous X-rays**.

The shape of this continuum spectrum is approximately described by Kramers' law.

- The spectrum has a sharp cutoff at low wavelength, which is due to the limited energy of the incoming electrons.
- For example, if an electron in the tube is accelerated through 60 kV, then it will acquire a kinetic energy of 60 keV, and when it strikes the target it can create X-rays with energy of at most 60 keV, by conservation of energy.
- A photon with energy of at most 60 keV has wavelength of at least 21 pm, so the continuous X-ray spectrum has exactly that cutoff, as seen in the graph. More generally the formula for the low-wavelength cutoff is

$$\lambda_{\min} = \frac{hc}{eV} \approx \frac{1239.8 \text{ pm}}{V \text{ in kV}}$$

where *h* is Planck's constant, *c* is the speed of light, *V* is the voltage that the electrons are accelerated through, *e* is the elementary charge, and *pm* is picometres. This is called the Duane–Hunt law.

Beta decay

- Beta particle-emitting substances sometimes exhibit a weak radiation with continuous spectrum that is due to bremsstrahlung (see the "outer bremsstrahlung" below).
- In this context, bremsstrahlung is a type of "secondary radiation", in that it is produced as a result of stopping (or slowing) the primary radiation (beta particles).
- It is very similar to X-rays produced by bombarding metal targets with electrons in X-ray generators (as above) except that it is produced by high-speed electrons from beta radiation.

Radiation safety

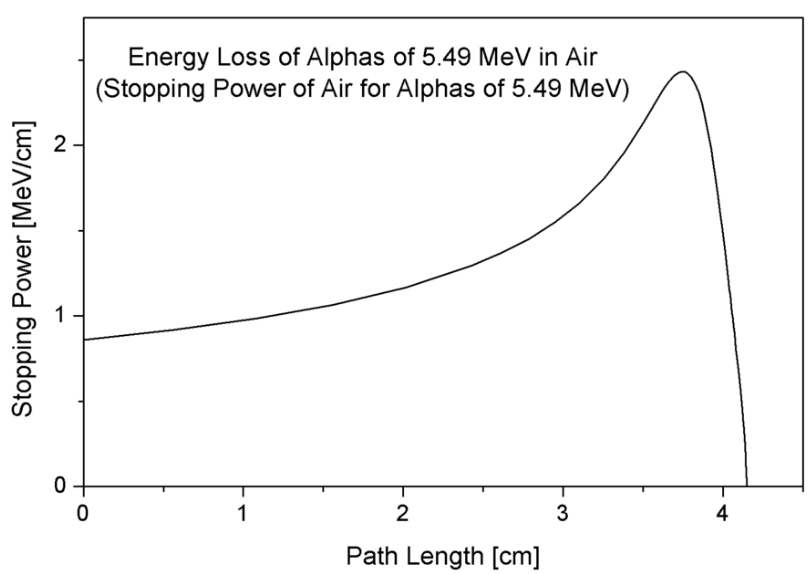
- In some cases, *e.g.* ^{32}P, the bremsstrahlung produced by shielding the beta radiation with the normally used dense materials (*e.g.* lead) is itself dangerous; in such cases, shielding must be accomplished with low density materials, *e.g.* Plexiglas (Lucite), plastic, wood, or water; as the atomic number is lower for these materials, the intensity of bremsstrahlung is significantly reduced but a larger thickness of shielding is required to stop the electrons (beta radiation).

BRAGG’S CURVE

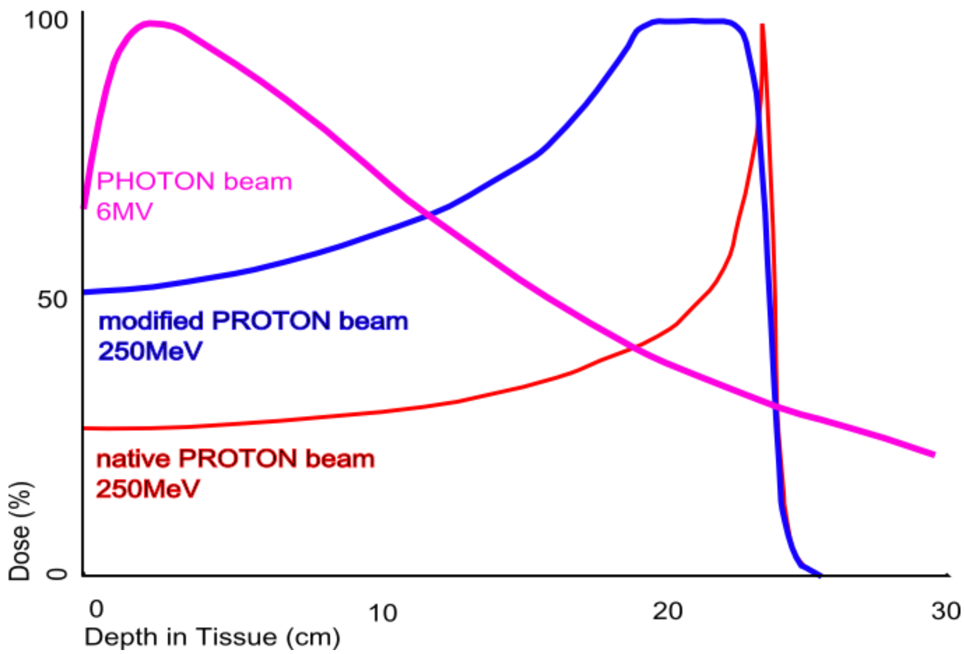
- The **Bragg peak** is a pronounced peak on the *Bragg curve* which plots the energy loss of ionizing radiation during its travel through matter.
- For protons, α-rays, and other ion rays, the peak occurs immediately before the particles come to rest. This is called Bragg peak, for William Henry Bragg who discovered it in 1903.
- When a fast charged particle moves through matter, it ionizes atoms of the material and

deposits a dose along its path.

- A peak occurs because the interaction cross section increases as the charged particle's energy decreases.
- Energy lost by charged particles is inversely proportional to the square of their velocity, which explains the peak occurring just before the particle comes to a complete stop.
- In the upper figure, it is the peak for alpha particles of 5.49 MeV moving through air. In the lower figure, it is the narrow peak of the "native" proton beam curve which is produced by a particle accelerator of 250 MeV.
- The figure also shows the absorption of a beam of energetic photons (X rays) which is entirely different in nature; the curve is mainly exponential.
- The phenomenon is exploited in particle therapy of cancer, to concentrate the effect of light ion beams on the tumor being treated while minimizing the effect on the surrounding healthy tissue.
- The blue curve in the figure ("modified proton beam") shows how the originally monoenergetic proton beam with the sharp peak is widened by increasing the range of energies, so that a larger tumor volume can be treated. This can be achieved by using variable thickness attenuators like spinning wedges.



The Bragg curve of 5.49 MeV alphas in air has its peak to the right and isskewed to the left, unlike the x-ray beam below.



The dose produced by a native and by a modified proton beam in passing through tissue, compared to the absorption of a photon or x-ray beam

CONCEPT OF LD 50

- The median lethal dose, LD_{50} (abbreviation for "**lethal dose**, 50%"), LC_{50} (lethal concentration, 50%) or LCt_{50} (lethal concentration and time) of a toxin, radiation, or pathogen is the dose required to kill half the members of a tested population after a specified test duration.
- LD_{50} figures are frequently used as a general indicator of a substance's acute toxicity. A lower LD_{50} is indicative of increased toxicity.

The test was created by J.W. Trevan in 1927.The term "semilethal dose" is occasionally used with the same meaning, in particular in translations from non-English-language texts, but can also refer to a *sub*lethal dose; because of this ambiguity, it is usually avoided.

- LD_{50} is usually determined by tests on animals such as laboratory mice. In 2011 the US Food and Drug Administration approved alternative methods to LD_{50} for testing the cosmetic drug Botox without animal tests.

LD values for humans are best estimated by extrapolating results from human cell cultures.

- One form of measuring LD is to use animals like mice or rats, converting to dosage per kilogram of biomass, and extrapolating to human norms.

- The degree of error from animal-extrapolated LD values is large. The biology of test animals differs in important aspects to that of humans.
- For instance, mouse tissue is approximately fifty times less responsive than human tissue to the venom of the Sydney funnel-web spider.
- The square-cube law also complicates the scaling relationships involved. Researchers are shifting away from animal-based LD measurements in some instances. The U.S. Food and Drug Administration has begun to approve more non-animal methods in response to animal welfare concerns.

The LD_{50} is usually expressed as the mass of substance administered per unit mass of test subject, typically as milligrams of substance per kilogram of body mass, but stated as nanograms (suitable for botulinum), micrograms, milligrams, or grams (suitable for paracetamol) per kilogram.

- Stating it this way allows the relative toxicity of different substances to be compared, and normalizes for the variation in the size of the animals exposed, although toxicity does not always scale simply with body mass.

The choice of 50% lethality as a benchmark avoids the potential for ambiguity of making measurements in the extremes and reduces the amount of testing required.

- However, this also means that LD_{50} is *not* the lethal dose for all subjects; some may be killed by much less, while others survive doses far higher than the LD_{50}.
- Measures such as "LD_1" and "LD_{99}" (dosage required to kill 1% or 99%, respectively, of the test population) are occasionally used for specific purposes.
- Lethal dosage often varies depending on the method of administration; for instance, many substances are less toxic when administered orally than when intravenously administered.
- For this reason, LD_{50} figures are often qualified with the mode of administration, e.g., "LD_{50} i.v."
- The related quantities $LD_{50}/30$ or $LD_{50}/60$ are used to refer to a dose that without treatment will be lethal to 50% of the population within (respectively) 30 or 60 days.
- These measures are used more commonly with radiation, as survival beyond 60 days usually results in recovery.

STOCHASTIC AND NON-STOCHASTIC EFFECTS

STOCHASTIC EFFECTS

- Stochastic effects are those that occur by chance and consist primarily of cancer and genetic effects.
- Stochastic effects often show up years after exposure. As the dose to an individual increases, the probability that cancer or a genetic effect will occur also increases.
- However, at no time, even for high doses, is it certain that cancer or genetic damage will result. Similarly, for stochastic effects, there is no threshold dose below which it is relatively certain that an adverse effect cannot occur.

- In addition, because stochastic effects can occur in individuals that have not been exposed to radiation above background levels, it can never be determined for certain that an occurrence of cancer or genetic damage was due to a specific exposure.

While it cannot be determined conclusively, it often possible to estimate the probability that radiation exposure will cause a stochastic effect. As mentioned previously, it is estimated that the probability of having a cancer in the US rises from 20% for non radiation workers to 21% for persons who work regularly with radiation.

The probability for genetic defects is even less likely to increase for workers exposed to radiation. Studies conducted on Japanese atomic bomb survivors who were exposed to large doses of radiation found no more genetic defects than what would normally occur.

Radiation-induced hereditary effects have not been observed in human populations, yet they have been demonstrated in animals.

If the germ cells that are present in the ovaries and testes and are responsible for reproduction were modified by radiation, hereditary effects could occur in the progeny of the individual.

Exposure of the embryo or fetus to ionizing radiation could increase the risk of leukemia in infants and, during certain periods in early pregnancy, may lead to mental retardation and congenital malformations if the amount of radiation is sufficiently high.

CANCER

- Cancer is any malignant growth or tumor caused by abnormal and uncontrolled cell division.
- Cancer may spread to other parts of the body through the lymphatic system or the blood stream.
- The carcinogenic effects of doses of 100 rads (1 Gy) or more of gamma radiation delivered at high dose rates are well documented, consistent and definitive.
- Although any organ or tissue may develop a tumor after overexposure to radiation, certain organs and tissues seem to be more sensitive in this respect than others.
- Radiation-induced cancer is observed most frequently in the hemopoietic system, in the thyroid, in the bone, and in the skin.
- In all these cases, the tumor induction time in man is relatively long - on the order of 5 to 20 years after exposure.
- Carcinoma of the skin was the first type of malignancy that was associated with exposure to x-rays.
- Early x-ray workers, including physicists and physicians, had a much higher incidence of skin cancer than could be expected from random occurrences of this disease.
- Well over 100 cases of radiation induced skin cancer are documented in the literature. As early as 1900, a physician who had been using x-rays in his practice described the irritating effects of x-rays.
- He recorded that erythema and itching progressed to hyper-pigmentation, ulceration, neoplasia, and finally death from metastatic carcinoma.

- The entire disease process spanned a period of 9 years. Cancer of the fingers was an occupational disease common among dentists before the carcinogenic properties of x-rays were well understood.
- Dentists would hold the dental x-ray film in the mouths of patients while x-raying their teeth.

LEUKEMIA

- Leukemia is a cancer of the early blood-forming cells. Usually, the leukemia is a cancer of the white blood cells, but leukemia can involve other blood cell types as well. Leukemia starts in the bone marrow and then spreads to the blood.
- From there it can go to the lymph nodes, spleen, liver, central nervous system (the brain and spinal cord), testes (testicles), or other organs.
- Leukemia is among the most likely forms of malignancy resulting from overexposure to total body radiation. Chronic lymphocytic leukemia does not appear to be related to radiation exposure.
- Among American radiologists, the doses associated with the increased rate of leukemia were on the order of 100 rads (1 Gy) per year.
- With the increased practice of health physics, the difference in leukemia rate between radiologists and other physicians has been continually decreasing.

Among the survivors of the nuclear bombings of Japan, there was a significantly greater incidence of leukemia among those who had been within 1500 meters of the hypocenter than among those who had been more than 1500 meters from ground zero at the time of the bombing.

An increase in leukemia among the survivors was first seen about three years after the bombings, and the leukemia rate continued to increase until it peaked about four years later. Since this time, the rate has been steadily decreasing.

On the basis of a few limited studies, it was inferred that as little as 1-5 rads (10-50 mGy) of x-rays could lead to leukemia. Other studies imply that a threshold dose for radiogenic leukemia is significantly higher.

However, it is reasonable to infer that low level radiation at doses associated with most diagnostic x-ray procedures, with occupational exposure within the recommended limits, and with natural radiation is a very weak leukemogen, and that the attributive risk of leukemia from low level radiation is probably very small.

NONSTOCHASTIC (ACUTE) EFFECTS

- Unlike stochastic effects, nonstochastic effects are characterized by a threshold dose below which they do not occur.
- In other words, nonstochastic effects have a clear relationship between the exposure and the effect. In addition, the magnitude of the effect is directly proportional to the size of the dose.

- Nonstochastic effects typically result when very large dosages of radiation are received in a short amount of time. These effects will often be evident within hours or days.
- Examples of nonstochastic effects include erythema (skin reddening), skin and tissue burns, cataract formation, sterility, radiation sickness and death. Each of these effects differs from the others in that both its threshold dose and the time over which the dose was received cause the effect (i.e. acute vs. chronic exposure).

There are a number of cases of radiation burns occurring to the hands or fingers. These cases occurred when a radiographer touched or came in close contact with a high intensity radiation emitter. Intensity on the surface of an 85 curie Ir-192 source capsule is approximately 1,768 R/s. Contact with the source for two seconds would expose the hand of an individual to 3,536 rems, and this does not consider any additional whole body dosage received when approaching the source.

More on Specific Nonstochastic Effects

Hemopoietic Syndrome

- The hemopoietic syndrome encompasses the medical conditions that affect the blood. Hemopoietic syndrome conditions appear after a gamma dose of about 200 rads (2 Gy). This disease is characterized by depression or ablation of the bone marrow, and the physiological consequences of this damage.
- The onset of the disease is rather sudden, and is heralded by nausea and vomiting within several hours after the overexposure occurred.
- Malaise and fatigue are felt by the victim, but the degree of malaise does not seem to be correlated with the size of the dose. Loss of hair (epilation), which is almost always seen, appears between the second and third week after the exposure.
- Death may occur within one to two months after exposure. The chief effects to be noted, of course, are in the bone marrow and in the blood.
- Marrow depression is seen at 200 rads and at about 400 to 600 rads (4 to 6 Gy) complete ablation of the marrow occurs. In this case, however, spontaneous regrowth of the marrow is possible if the victim survives the physiological effects of the denuding of the marrow.
- An exposure of about 700 rads (7 Gy) or greater leads to irreversible ablation of the bone marrow.

Gastrointestinal Syndrome

- The gastrointestinal syndrome encompasses the medical conditions that affect the stomach and the intestines.
- This medical condition follows a total body gamma dose of about 1000 rads (10 Gy) or greater, and is a consequence of the desquamation of the intestinal epithelium.
- All the signs and symptoms of hemopoietic syndrome are seen, with the addition of severe nausea, vomiting, and diarrhea which begin very soon after exposure.
- Death within one to two weeks after exposure is the most likely outcome.

Central Nervous System

- A total body gamma dose in excess of about 2000 rads (20 Gy) damages the central nervous system, as well as all the other organ systems in the body.
- Unconsciousness follows within minutes after exposure and death can result in a matter of hours to several days.
- The rapidity of the onset of unconsciousness is directly related to the dose received. In one instance in which a 200 msec burst of mixed neutrons and gamma rays delivered a mean total body dose of about 4400 rads (44 Gy), the victim was ataxic and disoriented within 30 seconds.
- In 10 minutes, he was unconscious and in shock. Vigorous symptomatic treatment kept the patient alive for 34 hours after the accident.

Other Acute Effects

- Several other immediate effects of acute overexposure should be noted. Because of its physical location, the skin is subject to more radiation exposure, especially in the case of low energy x-rays and beta rays, than most other tissues.
- An exposure of about 300 R (77 mC/kg) of low energy (in the diagnostic range) x-rays results in erythema.
- Higher doses may cause changes in pigmentation, loss of hair, blistering, cell death, and ulceration.
- Radiation dermatitis of the hands and face was a relatively common occupational disease among radiologists who practiced during the early years of the twentieth century.

The reproductive organs are particularly radiosensitive. A single dose of only 30 rads (300 mGy) to the testes results in temporary sterility among men.

For women, a 300 rad (3 Gy) dose to the ovaries produces temporary sterility. Higher doses increase the period of temporary sterility.

In women, temporary sterility is evidenced by a cessation of menstruation for a period of one month or more, depending on the dose.

Irregularities in the menstrual cycle, which suggest functional changes in the reproductive organs, may result from local irradiation of the ovaries with doses smaller than that required for temporary sterilization.

The eyes too, are relatively radiosensitive. A local dose of several hundred rads can result in acute conjunctivitis.

DIFFERENT RADIATION UNIT- ROENTGEN, GRAY, SIEVERT.

RADIATION RELATED QUANTITIES

The following table shows radiation quantities in SI and non-SI units.

Quantity	Name	Symbol	Unit	Year	System
Exposure (X)	röntgen	R	esu / 0.001293 g of air	1928	non-SI
Absorbed dose (D)			erg•g^{-1}	1950	non-SI
	rad	rad	100 erg•g^{-1}	1953	non-SI
	gray	Gy	J•kg^{-1}	1974	SI
Activity (A)	curie	c	3.7 × 10^{10} s^{-1}	1953	non-SI
	becquerel	Bq	s^{-1}	1974	SI
Dose equivalent (H)	röntgen equivalent man	rem	100 erg•g^{-1}	1971	non-SI
	sievert	Sv	J•kg^{-1}	1977	SI
Fluence (Φ)	(reciprocal area)		cm^{-2} or m^{-2}	1962	SI (m^{-2})

GRAY:

- The **gray** (symbol: **Gy**) is a derived unit of ionizing radiation dose in the International System of Units (SI). It is defined as the absorption of one joule of radiation energy per onekilogram of matter.

- It is used as a measure of absorbed dose, specific energy (imparted), and kerma (an acronym for "*k*inetic *e*nergy *r*eleased per unit *ma*ss").
- It is a physical quantity, and does not take into account any biological context. Unlike the pre-1971 non-SI roentgen unit of radiation exposure, the gray when used for absorbed dose is defined independently of any target material.
- However, when measuring kerma the reference target material must be defined explicitly, usually as dry air at standard temperature and pressure.

The equivalent cgs unit, the rad (equivalent to 0.01 Gy), remains common in the United States, though "strongly discouraged" in the style guide for U.S. National Institute of Standards and Technology authors.

Definition

One *gray* is the absorption of one joule of energy, in the form of ionizing radiation, per kilogram of matter.

$$1\ \mathrm{Gy} = 1\ \frac{\mathrm{J}}{\mathrm{kg}} = 1\ \frac{\mathrm{m}^2}{\mathrm{s}^2}$$

APPLICATIONS

The gray has a number of fields of application in measuring dose:

1. **Absorbed dose in matter**

The gray is used to measure absorbed dose rates in non-tissue materials for processes such as radiation hardening, food irradiation and electron irradiation. Measuring and controlling the value of absorbed dose is vital to ensuring correct operation of these processes.

2. **Kerma**

Kerma ("**k**inetic **e**nergy **r**eleased per unit **ma**ss") is a measure of the liberated energy of ionisation due to irradiation, and is expressed in grays. Importantly, kerma dose is different from absorbed dose, depending on the radiation energies involved, partially because ionization energy is not accounted for. Whilst roughly equal at low energies, kerma is much higher than absorbed dose at higher energies, because some energy escapes from the absorbing volume in the form of bremsstrahlung (X-rays) or fast-moving electrons.

3. **Absorbed dose in tissue**

- The measurement of absorbed dose in tissue is of fundamental importance in radiobiology and radiation therapy as it is the measure of the amount of energy the incident radiation is imparting to the target tissue.
- The measurement of absorbed dose is a complex problem and so many different dosimeters are available for these measurements. These dosimeters cover measurements that can be done in 1-D, 2-D and 3-D.
- In radiation therapy, the amount of radiation varies depending on the type and stage of cancer being treated.

- For curative cases, the typical dose for a solid epithelial tumor ranges from 60 to 80 Gy, while lymphomas are treated with 20 to 40 Gy. Preventive (adjuvant) doses are typically around 45–60 Gy in 1.8–2 Gy fractions (for breast, head, and neck cancers).
- The average radiation dose from an abdominal X-ray is 0.7 mGy, that from an abdominal CT scan is 8.0 mGy, that from a pelvic CT scan is 6 mGy, and that from a selective CT scan of the abdomen and the pelvis is 14 mGy.

ROENTGEN :

- The **roentgen** (**R**, also **röntgen**) is a legacy unit of measurement for the exposure of X-rays and gamma rays up to several mega electronvolts.
- It is a measure of the ionization produced in air by X-rays or gamma radiation and it is used because air ionization can be measured directly.
- It is named after the German physicist Wilhelm Röntgen, who discovered X-rays. Originating in 1908, this unit has been redefined and renamed over the years.
- It was last defined by the US National Institute of Standards and Technology(NIST) in 1998 as 2.58×10^{-4} C/kg, (i.e. 1 C/kg = 3876 R) with a recommendation that the definition be given in every document where the roentgen is used.
- One roentgen of air kerma (kinetic energy released per unit mass) deposits 0.00877 grays (0.877 rads) ofabsorbed dose in dry air, or 0.0096 Gy (0.96 rad) in soft tissue.
- One roentgen (air kerma) of X-rays may deposit anywhere from 0.01 to 0.04 Gy (1.0 to 4.0 rad) in bone depending on the beam energy.
- This tissue-dependent conversion from kerma to absorbed dose is called the F-factor in radiotherapy contexts. T
- he conversion depends on the ionizing energy of a reference medium, which is ambiguous in the latest NIST definition.
- Even where the reference medium is fully defined, the ionizing energy of the calibration and target mediums are often not precisely known.

Significance

- As roentgens describe radiation, their relation to absorbed dose (which is usually important for safety) is not straightforward and depends on different absorption of radiated particles (alpha, beta, gamma or neutron).
- Though as a rule of thumb: **1 roentgen is approximately 10 mSv** (Roentgen — Sievert Conversion).
- An exposure of 500 roentgens (~5 Sv) in five hours is usually lethal for human beings.
- The typical exposure to normal background radiation for a human being is about 200 milliroentgens per year, or about 23 microroentgens per hour (~2 µSv/h).

- When measuring dose absorbed in a human due to exposure, units of absorbed dose are used (the SI unit, the *gray*; or the related *rad*), or, with consideration of biological effects from differing radiation types, units of equivalent dose, effective dose, and committed dose (such as the SI *sievert*; or the related *rem*), are used.

SIEVERT :

- The **sievert** (symbol: **Sv**) is a derived unit of ionizing radiation dose in the International System of Units (SI). It is a measure of the health effect of low levels of ionizing radiation on the human body.
- Quantities that are measured in sieverts are intended to represent the stochastic health risk, which for radiation dose assessment is defined as the *probability* of cancer induction and genetic damage.
- The sievert is used for radiation dose quantities such as equivalent dose, effective dose, and committed dose. It is used both to represent the risk of the effect of external radiation from sources outside the body, and the effect of internal irradiation due to inhaled or ingested radioactive substances.
- Conventionally the sievert is not used for high dose rates of radiation which produce deterministic effects, which is the *severity* of acute tissue damage which is certain to happen. These effects are compared to the physical quantity absorbed dose measured by the unit gray (Gy).
- To enable consideration of stochastic health risk, calculations are performed to convert the physical quantity absorbed dose into equivalent and effective doses, the details of which depend on the radiation type and biological context.
- For applications in radiation protection and dosimetry assessment theInternational Commission on Radiological Protection (ICRP) and International Commission on Radiation Units and Measurements (ICRU) have published recommendations and data which are used to calculate these. These are under continual review, and changes are advised in the formal "Reports" of those bodies.
- The sievert is of fundamental importance in dosimetry and radiation protection, and is named after Rolf Maximilian Sievert, a Swedish medical physicist renowned for work on radiation dosage measurement and research into the biological effects of radiation. One sievert carries with it a 5.5% chance of eventually developing cancer.
- One sievert equals 100 rem. The rem is an older, non-SI unit of measurement.
- To enable a comprehensive view of the sievert this article deals with the definition of the sievert as an SI unit, summarises the recommendations of the ICRU and ICRP on how the sievert is calculated, includes a guide to the effects of ionizing radiation as measured in sieverts, and gives examples of approximate figures of dose uptake in certain situations.

EXTERNAL DOSE QUANTITIES

- The sievert is used to represent the biological effects of different forms of external ionizing radiation on various types of human tissue.
- Some quantities cannot be practically measured, but they must be related to actual instrumentation and dosimetry measurements.
- The resultant complexity has required the creation of a number of different dose quantities within a coherent system developed by the ICRU working with the ICRP.
- The external dose quantities and their relationships are shown in the accompanying diagram.

PHYSICAL QUANTITIES

- These are directly measurable physical quantities in which no allowance has been made for biological effects.
- Radiation fluence is the number of radiation particles impinging per unit area per unit time, kerma is the ionising effect of the radiation field, and absorbed dose is the amount of radiation energy deposited per unit mass.

PROTECTION QUANTITIES

- Protection quantities are calculated, and are used as "limiting quantities" to specify exposure limits to ensure, in the words of ICRP, "that the occurrence of stochastic health effects is kept below unacceptable levels and that tissue reactions are avoided".
- These quantities cannot be practically measured but are a calculated value of dose of organs of the human body, which is arrived at by using anthropomorphic phantoms.
- These are 3D computational models of the human body which take into account a number of complex effects such as body self-shielding and internal scattering of radiation. T
- he calculation starts with organ absorbed dose, and then applies radiation and tissue weighting factors.

As protection quantities cannot practically be measured, operational quantities are used to relate them to practical radiation instrument and dosimeter responses.

OPERATIONAL QUANTITIES

- The operational quantities are used in practical applications for monitoring and investigating external exposure situations.
- They are defined for practical operational measurements and assessment of doses in the body.Three external operational dose quantities were devised to relate operational dosimeter and instrument measurements to the calculated protection quantities.
- Also devised were two phantoms, The ICRU "slab" and "sphere" phantoms which relate these quantities to incident radiation quantities using the Q(L) calculation.

1. AMBIENT DOSE EQUIVALENT

- This is used for area monitoring of penetrating radiation and is usually expressed as the quantity $H^*(10)$. This means the radiation is equivalent to that found 10 mm within the

ICRU sphere phantom in the direction of origin of the field. An example of penetrating radiation is gamma rays.

2. DIRECTIONAL DOSE EQUIVALENT

- This is used for monitoring of low penetrating radiation and is usually expressed as the quantity $H'(0.07)$. This means the radiation is equivalent to that found at a depth of 0.07 mm in the ICRU sphere phantom.
- Examples of low penetrating radiation are alpha particles, beta particles and low-energy photons. This dose quantity is used for the determination of equivalent dose to such as the skin, lens of the eye.
- In radiological protection practice value of omega is usually not specified as the dose is usually at a maximum at the point of interest.

3. PERSONAL DOSE EQUIVALENT

- This is used for individual dose monitoring, such as with a personal dosimeter worn on the body. The recommended depth for assessment is 10 mm which gives the quantity$H_p(10)$.

questions	opt1	opt2	opt3
Exposure to normal levels of extremely low frequency (ELF) waves causes	Brain damage	asthma	severe burns
Which cells are considered to be the least radiosensitive?	Bone marrow cells	Neuronal cells	Lymphoid tissues
Process in which α and β rays pass close to atoms and knock electrons out is called	atomization	ionization	decay
Strongest ionizing radiation is	Alpha	beta	gamma
Non-ionizing radiations are also termed as;	Low-frequency waves	High-frequency waves	Extremely-low frequency waves
Radiation of extraterrestrial origin, which rain continuously upon the earth, is termed cosmic rays. These rays are a type of radiatons	Extremely low frequency	Non-ionizing	terrestrial
The doses due to natural sources of radiation vary depending on location and habits. Regions at higher altitudes receive cosmic rays	less	more	vely less
Cosmic rays may be termed as primary or secondary cosmic rays. Which of the following particles can be termed as primary cosmic rays?	electron	proton	pions
Our eyes detect light in	A. RGB form, Red Blue Green form	ROYGBIV, rainbow color form	The simple form of a particular color
Symbol to represent speed of light in vacuum or air is	V	c	a
Light can travel in	air only	vacuum only	both air and vacuum
Ratio of further components of color perception is	2	3	4
Less sensitive photoreceptor that allow more light in human vision are	lens	rods	cones
Dark characters used on light screen increase the	interactivity	acuity	reusability
512 calories of radiation is incident on a body. It absorbs 220 calories the coefficient of emission is	0.43	0.57	1.7
Heat energy received by the earth from the sun is due to	convection	radiation	reflection of light
Emissivity of perfectly black body is	1	2	5
When light enters from vacuum in to glass, it's velocity	decreases	remains same	increases
Speed of electromagnetic radiation is independent of	wavelength	amplitude	time period
In optics an object which has higher refractive index is called	Optically rarer	optically denser	Optical density
The optical phenomena, twinkling of stars, is due to	Atmospheric reflection	Total reflection	Atmospheric refraction
The unit of power of lens is	Metre	Centimeter	Diopter
Our eyes detect light in	RGB form, Red Blue Green form	ROYGBIV, rainbow color form	The simple form of a particular color
Symbol to represent speed of light in vacuum or air is	v	c	a
Light can travel in	air only	vacuum only	both air and vacuum

opt4	opt5	opt6	answer	
no damaging effects			severe burns	
Skin cells			Lymphoid tissues	
hydroxylation			ionization	
x-rays			Alpha	
Extremely-high frequency waves			Extremely-low frequency waves	
natural			natural	
no rays to all			more	
muons			proton	
none of these ways			ROYGBIV, rainbow color form	
I			c	
none of the mediums			both air and vacuum	
5			3	
retinas			cones	
quality			acuity	
0.34			0.57	
transmission of light			radiation	
0			1	
varies depending on mass of glass			decreases	
frequency			frequency	
Refractive index			optically denser	
Total refraction			Atmospheric refraction	
millimetre			Diopter	
Primary and secondary color			ROYGBIV, rainbow color form	
I			c	
ether			both air and vacuum	

If we observe a pebble in a pool, pebble would appear	deeper in the water than it really is	of same depth in	nearer to the surface than it really is
Straight line in which light travels is called	wave	ray	light perimeter
Image formed by a projector would be	inverted, real, diminished	virtual, upright, diminished	virtual, upright, magnified
Golden view of sea shell is due to	diffraction	dispersion	polarisation
To an astronaut in space, the sky will appear to be	violet	red	blue
On a rainy day, small oily films on water show brillia	scattering	interference	polarisation

invisible			nearer to the surface than it really is	
path			ray	
real, inverted, magnified			real, inverted, magnified	
reflection			diffraction	
black			black	
diffraction			interference	

questions	opt1
Speed of ultrasound depends upon	medium
In best piezo-electric substances, maximum value of strain is about	0.50%
A sound wave which has frequency higher than upper limit of human hearing is	infrasonic
Wavelength of 2.0 MHz ultrasound waves in tissue is	7.5 X10 -4m
A change in observed frequency of a wave when source or detector moves relative to transmitting medium is called	Doppler effect
Refractive index of water at 20°C temperature is	1.49
Bone thickness is equal to	$c\Delta t/2$
an ultrasound pulse moves through tissue in a patient’s body it will undergo a change in	Frequency
In order to estimate the total attenuation of an ultrasound pulse passing thr	The size of the pulse
Changing from a 2 MHz to a 5 MHz ultrasound transducer would generall	Faster imaging
The characteristics of tissue through which an ultrasound pulse passes will	Frequency
The rate at which an ultrasound pulse is absorbed (attenuated) as it passes through tissue is affected by	The pulse amplitude
You would generally select a high frequency transducer to get	Better tissue penetration
Factors which can have an effect on visibility of anatomical detail (blurring) in ultrasound image include	Frequency
A radioactive isotope undergoes decay with respect to time following ____	logarithmic
In ultrasound imaging, increasing the number of scan lines in the image w	Increase imaging depth
When using Doppler ultrasound to determine blood flow velocity it is nece	Transducer frequency
What property of sound waves acts like the principle of ultrasound?	Reflection and Refraction
Which of the following medical imaging modality other than ultrasound does not use any form of radiation?	PET Scan
For which of these areas can the ultrasound be taken for an infant but not f	Cranium
A piezoelectric crystal is used to produce the ultrasound waves. What kinc	Pressure wave
How is a medium characterized?	By its thickness

opt2	opt3	opt4	opt5	opt6	answer
amplitude	material	wavelength			material
0.40%	0.30%	0.10%			0.10%
ultrasonic	supersonic	megasonic			ultrasonic
8 X10 -5 m	8.5 X10 -6 m	9.2 X10 -3 m			7.5 X10 -4
A. Thermal effect	Newton's effect	Elastic effect			Doppler effect
1.46	1.36	1.33			1.33
cΔt	c/t	t/2			cΔt/2
Amplitude	Physical size	Intensity			Amplituc
Frequency	Type of tissue	Distance			The size of the pulse
deeper penetration	shorterwavelengths	shorter ultrasound pulses			shorter wavelengths
Velocity	Wavelength	Amplitude			Frequenc
The pulse intensity	The pulse frequency	the pulse ratio			The pulse frequency
Better image detail	Faster imagin	Decreased attenuation			Decreased attenuation
Amplitude	TCG	Pulse rate			Frequenc
exponential	inverse square	linear			exponent
Increase visibility of anatomical detail	decrease imaging depth	Increase pulse velocity			Increase visibility of anatomical detail
Depth of vessel	Direction of vessel	Size of vessel			Direction of vessel
Reflection only	Refraction only	Propagation			Reflection and Refraction
SPECT Scan	CT Scan	MRI			MRI
Chest	breast	Legs			Cranium
Electrical wa	Sound wave	Simple ultrasound			Pressure
By its acoustic impedance	By its water content	By its density			By its acoustic impedance

Which of the following relations are true?	γ increases, penet
What does the red dot on the probe help within the produced image?	To check if the correct probe was used
When using Doppler ultrasound to determine blood flow velocity it is nece	Transducer freque
What property of sound waves acts like the principle of ultrasound?	Reflection and Refraction
Which of the following medical imaging modality other than ultrasound does not use any form of radiation?	PET Scan

γ increases, p	γ increases, pe	γ decreases, penetration of sound increases, resolution increases			γ increase
To check the probe orientation	To check the depth of the probe that was used	To check the plane of the image			To check the probe orientation
Depth of vess	Direction of vessel	Size of vessel			Direction
Reflection on	Refraction on	Propagation			Reflection and Refraction
SPECT Scan	CT Scan	MRI			MRI

questions	opt1
Radius of nucleus ranges from	10-16 m
Number of protons in an atom determine	chemical properties
In β+ decay, an UP quark becomes	a strange quark
Most of space in an atom is	filled with positive charge
A proton is made up of	one up quark and two down quarks
Which component(s) of the Geiger-Muller detector alert(s) the operator to the presence of ionizing radiation?	The shield covering the probe's sensitivity chamber
Which of the following is not true about field survey instruments?	They are all equally sensitive in the detection of ionizing radiation.
Gamma-ray photons have:	no mass and no electric charge
Electron Capture involves:	an electron combining with a neutron
In Alpha Decay:	Z and A are unchanged
Isomeric Transition involves:	the emission of a gamma-ray
In spontaneous fission:	nuclear stability is always achieved
An alpha-particle consists of:	one proton and two neutrons
Internal Conversion involves:	the emission of a gamma-ray
Electron Emission involves the ejection of:	a beta-minus particle
In Positron Emission:	Z increases by 1 and A remains the same
Positron Emission involves the ejection of:	an alpha-particle
Fast breeder nuclear reactors using enriched uranium as fuel may contain upto a maximum of ___________ percent of U-235	15
___________ have the same mass number, but different nuclear charge	Isotones
Graphite is used in nuclear reactor as	lubricant
A fast breeder reactor employs	U-235 as a fuel
___________ has the same mass number, but different nuclear char	Isotones
Atoms with same number of neutrons, but different number of nuc	Isobars
Which of the following ores contains maximum percentage of ura	Rescolite
Percentage of U-238 in natural uranium is around	29.71
The atomic mass unit is defined as	The mass of a proton
An alpha particle is also known as	an electron
A beta particle is also known as	an electron
All of the following radioisotopes are used as systemic radionucli	Phosphorus
Which one of the following has the maximum ionization potential	an electron
Who invented nuclear fission?	Rutherford
Most of the energy released in fission process is in process of ___	Kinetic Energy

opt2	opt3	opt4	opt5
10-15 m to 10-14 m	10-10 m	10-10 m to 10-6 m	
physical properties	magnetic properties	electrical properties	
a simple quark	a down quark	an anti-quark	
empty	filled with negative charge	filled with neutrons	
an up quark and down antiquark	two up quarks and a down quark	strange quark and an anti-strange quark	
An audio amplifier and speaker	The metal that encloses the counter's gas-filled tube	The meter scale	
They detect the presence of radiation and, when properly calibrated, give a reasonable accurate measure of the exposure.	They are durable enough to withstand normal use.	They are reliable.	
no mass and an electric charge of +2	no mass and an electric charge of -1	no mass and an electric charge of +1	
a neutron being ejected from the nucleus	an electron combining with a proton	an electron being ejected from the nucleus	
Z decreases by 4 and A decreases by 2	Z decreases by 4 and A decreases by 2	Z decreases by 4 and A decreases by 4	
the conversion of a neutron to a proton	the conversion of a proton to a neutron	K-capture	
the nucleus splits into 2 or 3 fragments	the fragments are never radioactive	the nucleus is unchanged	
two protons and one neutron	two protons and two neutrons	one proton and one neutron	
the conversion of a neutron to a proton	K-capture	none of the above processes	
an alpha-particle	a beta-plus particle	a proton and two neutrons	
Z decreases by 1 and A remains the same	Z remains the same and A decreases by 1	Z remains the same and A increases by 1	
a beta-minus particle	a beta-plus particle	a proton and a neutron	
45	65	85	
Isobars	Isotopes	Isoemtropic	
fuel	fuel	retarder of neutron velocity	
water as a coolant	graphite as a moderator	none of the mentioned	
Isobars	Isotopes	Isoemtropic	
Isotones	Isotopes	Isoters	
Thorium	Pitchblende	Carnotite	
99.29	0.015	0.71	
the mass of an electron	the mass of a hydrogen-1 atom	one twelfth the mass of a carbon-12 atom	
a positron	a helium nucleus	a photon	
a positron	a helium nucleus	a photon	
Strontium	Iridium	Samarium	
a positron	a helium ion	a photon	
Hans Bethe	Otto Hahn	Marie Curie	
Thermal Energy	Light Energy	Heat Energy	

opt6	answer	
	10-15 m to 10-14 m	
	chemical properties	
	a down quark	
	empty	
	two up quarks and a down quark	
	An audio amplifier and speaker	
	They are all equally sensitive in the detection of ionizing radiation.	
	no mass and no electric charge	
	an electron combining with a proton	
	Z decreases by 4 and A decreases by 2	
	the emission of a gamma-ray	
	the nucleus splits into 2 or 3 fragments	
	two protons and two neutrons	
	the emission of a gamma-ray	
	a beta-minus particle	
	Z decreases by 1 and A remains the same	
	a beta-plus particle	
	85	
	Isobars	
	fuel	
	Isobars	
	Isotones	
	Pitchblende	
	0.015	
	one twelfth the mass of a carbon-12 atom	
	a helium nucleus	
	an electron	
	Iridium	
	a helium ion	
	Otto Hahn	

questions	opt1
Particles associated with electromagnetic radiation that have no mass or electric charge are:	ions
Coherent scattering is most likely to occur _____________ even though some of this scattering occurs throughout the diagnostic range and may result in small amounts of radiographic fog.	below 10 keV
Which of the following is not a type of interaction between x-radiation and biologic matter?	Compton scattering
The symbol Z indicates:	atomic number of an atom.
In photoelectric absorption to dislodge an inner-shell electron from its atomic orbit, the incoming x-ray photon must be able to transfer a quantity of energy:	less than the energy that binds the atom together.
Which of the following interactions between photons and matter involves a matter–antimatter annihilation reaction?	Compton scattering
The probability of occurrence of photoelectric absorption _________ as the energy of the incident photon decreases and the atomic number of the irradiated atoms _________.	increases markedly, decreases
Which of the following terms refers to the radiation that occurs when an electron drops down from an outer orbit to fill a vacancy in an inner orbit of the parent atom?	Characteristic radiation
Fluorescent radiation is also known as:	characteristic radiation.
What is the effective atomic number of compact bone?	5.9
Which of the following is not another term for coherent scattering?	Characteristic
Which of the following are by-products of photoelectric absorption?	Photoelectron and Compton scattered electron
13. Which two interactions between x-radiation and matter may result in the production of small-angle scatter?	Photoelectric absorption and Compton scattering
Which of the following particles is considered to be a form of antimatter?	Electron
Which of the following interactions results in the conversion of matter into energy?	Classical scattering

opt2	opt3	opt4	opt5	opt6	answer
negatrons	positrons	x-ray photons			x-ray photons
between 30 keV and 60 keV	between 60 keV and 90 keV	above 100 keV			below 10 keV
Bremsstrahlung	Pair production	Photoelectric absorption			Compton scattering
atomic weight of an atom.	fluorescent yield.	the number of vacancies in an atomic shell.			atomic number of an atom.
10 times as great as the energy that binds the atom together.	as large as or larger than the amount of energy that binds the electron in its orbit.	equal to or greater than 1.022 MeV, regardless of the energy that binds the electron in its orbit.			as large as or larger than the amount of energy that binds the electron in its orbit.
Coherent scattering	Pair production	Photoelectric absorption			Pair production
decreases markedly, increases	increases markedly, increases	stays the same, increases			increases markedly, increases
Bremsstrahlung	Photoelectric radiation	Primary radiation			Characteristic radiation
coherent scattering.	Compton scattering.	unmodified scattering.			characteristic radiation.
7.4	7.6	13.8			13.8
Classical	Elastic	Unmodified			Characteristic
Low-energy scattered x-ray photon and characteristic photon	Low-energy scattered x-ray photon and Compton scattered electron	Photoelectron and characteristic photon			Photoelectron and characteristic photon
Coherent scattering and Compton scattering	Photoelectric absorption and pair production	Coherent scattering and pair production			Coherent scattering and pair production
Positron	X-ray photon	Scattered x-ray photon			Positron
Photoelectric absorption	Modified scattering	Annihilation reaction			Annihilation reaction

Compton scattering is synonymous with:	coherent scattering.
During the process of coherent scattering, the incident x-ray photon interacts with:	a single inner shell electron, ejecting it from its orbit.
What is the term for the number of x-rays emitted per inner-shell vacancy during the process of photoelectric absorption?	Characteristic absorption
Which of the following results in all-directional scatter?	Classical interaction
Annihilation radiation is used in which of the following modalities?	Computed tomography (CT)
The x-ray photon energy required to initiate pair production is:	0.511 keV.
Differences in density level between radiographic images of adjacent structures as seen in a completed radiograph define:	image attenuation.
Radiographic density is:	caused by photodisintegratio n.
X-rays are carriers of:	disease.

incoherent scattering.	photoelectric absorption.	photodisintegration.			incoherent scattering.
a single outer shell electron, ejecting it from its orbit.	an atom transferring its energy by causing some or all of the electrons of the atom to vibrate momentarily and radiate energy in the form of electromagnetic waves.	a scattered photon of lesser energy, annihilating it.			an atom transferring its energy by causing some or all of the electrons of the atom to vibrate momentarily and radiate energy in the form of electromagnetic waves.
Classical gain	Fluorescent yield	Fluorescent yield			Fluorescent yield
Coherent interaction	Photoelectric interaction	Compton interaction			Compton interaction
Digital mammography	Positron emission tomography (PET)	Computed radiography (CR)			Positron emission tomography (PET)
1.022 keV.	0.511 MeV.	1.022 MeV.			1.022 MeV.
radiographic contrast.	radiographic density.	photodisintegration.			radiographic contrast.
defined as the degree of overall blackening on a completed radiograph.	not affected by milliampere-seconds (mAs).	not relevant in the production of a diagnostic radiograph.			defined as the degree of overall blackening on a completed radiograph.
electrons.	fluorescent properties that make them visible.	human-made, electromagnetic energy.			human-made, electromagnetic energy.

Which photon processes are dominant in the context of diagnostic radiology?	Compton scattering and photoelectric effect.
Frequency below which no electrons are emitted from metal surface is__________ frequency.	minimum
Energy absorbed by electron is used in	escaping the meta
In photoelectric effect, electrons should be removed from the	inner shell
Which of the following is the characteristic of a black body?	A perfect absorber but an imperfect radiator
Rayleigh-Jean's law holds good for which of the	Shorter wavelength
Which of the following does not affect the photon?	Magnetic or electric field
What is Compton shift?	Shift in frequency
Compton shift depends on which of the following?	Incident radiation
Which of the following is called as non-mechanical waves?	Magnetic waves
Which of the following is associated with an electron microscope?	Matter waves
The process of destroying cancer cells with the help of radiation is ________	. radiotherapy
Which of the following pair of scattering is important for therapeutic purposes?	Coherent and Pair Production

Photoelectric effect and pair production.	Compton scattering and pair production.	Compton and Rayleigh scattering.			Compton scattering and photoelectric effect.
angular	maximum	threshold			threshold
increasing K.E	escaping the metal a	increasing frequency			escaping t
surface	from core	nucleus			surface
A perfect radiator	A perfect radiator and a perfect absorber	A perfect conductor			A perfect radiator and a perfect absorber
. longer wavelength	High temperature	High energy			. longer wavelength
Light waves	Gravity	Current			Magnetic or electric field
Shift in charges	Shift in radiation	Shift in wavelength			Shift in w
Nature of scattering substance	Angle of scattering	Amplitude of frequency			Angle of s
Electromagnetic waves	Electrical waves	Matter waves			Electromagnetic waves
Electrical waves	Magnetic waves	Electromagnetic waves			
physiotherapy	uroplasty	rehabilitation			. radioth
Photoelectric and Disintegration	. Compton and Photoelectric	Pair Production and Disintegration			Pair Production and Disintegration

questions	opt1	opt2
Stochastic effects of radiation:	Include carcinogenesis	Have a threshold of 50 mSv/year
The metal filters contained in a film badge personnel dosimeter are generally composed of which of the following materials?	Aluminum or copper	Aluminum or lead
What is the maximum period of time that a thermoluminescent dosimeter (TLD) may be worn as a personnel dosimeter?	1 hour	1 week
What do optically stimulated luminescence dosimeters (OSLs), thermoluminescent dosimeters, film badge dosimeters, and pocket ionization chambers have in common?	These devices are all used for area monitoring.	These devices all use the same sensing material to detect ionizing radiation.
Which of the following instruments is called a cutie pie?	Geiger-Muller detector	Ionization chamber-type survey meter
Which of the following instruments generally has a check source of a weak, long-lived radioisotope located on one side of its external surface to verify its constancy daily?	Pocket dosimeter	Proportional counter
Energy passing through unit area is	intensity of x-ray	frequency of x-ray
X-rays are filtered out of human body by using	cadmium absorbers	carbon absorbers
If fast moving electrons rapidly decelerate, then rays produced are	alpha rays	beta rays
What is the difference between X-rays and gamma rays?	X-rays are produced extranuclearly whereas gamma rays are produced in nuclear decays.	X-rays have higher energies than gamma rays.
What is the main source of natural background radiation?	Electrons.	X-rays.
Direct action of radiation is the dominant process for:	x-rays	neutrons and alpha particles
In medicine thermograph is used to	identify bacteri	identify infected tissues
In a thermograph, heat is identified by	different sizes of lines on a photograph	different shapes on a photograph

opt3	opt4	opt5	opt6	answer			
Have a dose-dependent severity	Can be recognized as caused by radiation			Include carcinogenesis			
Zinc or copper	Lead or zinc			Aluminum or copper			
1 month	3 months			3 months			
These devices are all used for personnel monitoring.	Each of these devices can only be used for personnel monitoring for a maximum of 6 months.			These devices are all used for personnel monitoring.			
Optically stimulated luminescence dosimeter	Proportional counter			Ionization chamber-type survey meter			
Geiger-Muller detector	Ionization chamber-type survey meter			Geiger-Muller detector			
wavelength of x-ray	amplitude of x-ray			intensity of x-ray			
copper absorbers	aluminum absorbers			aluminum absorbers			
gamma rays	x-rays			x-rays			
gamma rays are produced by bremsstrahlung.	X-rays and gamma rays interact with matter differently.			X-rays are produced extranuclearly whereas gamma rays are produced in nuclear decays.			
Neutrons	alpha-particles			alpha-particles			
Electrons	Gamma rays			neutrons and alpha particles			
kill infected cell	identify damaged parts			identify infected tissues			
different colors on a photograph	different images on a photograph			different colors on a photograph			

Which of the following produce EM radiation in IR region?	Body with negative temperature	Body with temperature less than 1000C
Energy of emitted radiation from a body increases with ________	Increase in temperature	Decrease in temperature
The process of destroying cancer cells with the help of radiation is _________	radiotherapy	physiotherapy
The dose rate from potassium-40 in the human body is	0.1 mSv/y	0.2 mSv/y
The annual dose from radon gas is	2 mSv	10 mSv
The effective dose in a diagnostic nuclear medicine investigation is in the interval	0.5-25 mSv	0.1-100 mSv
Which of the following is called as non-mechanical waves?	Magnetic wave	Electromagnetic waves
The effective dose for a multiple-slice chest CT-scan is	1 mSv	2 mSv
In order to estimate the harm to an exposed population in terms of radiation induced cancers and hereditary effects, we use	the average absorbed dose per patient	the average effective dose per patient
Children are most sensitive than adults to radiation induced cancer, especially	lung cancer	breast and thyroid cancer
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Body with temperature less than 6000C	Body with temperature less than 10000C			Body with temperature less than 6000C			
No relation with temperature	Net energy cannot be changed			Increase in temperature			
uroplasty	rehabilitation			radiotherapy			
0.5 mSv/y	1mSv/y			0.2 mSv/y			
15 mSv	20mSv			2 mSv			
0.01-10 mSv	0.1-10 mSv			0.5-25 mSv			
Electrical	Matter waves			Electromagnetic waves			
4 mSv	8 mSv			8 mSv			
the average equivalent dose per patient	the collective effective dose to the patients and to the radiation workers			the collective effective dose to the patients and to the radiation workers			
brain cancer	ovarian cancer			breast and thyroid cancer			
the average equivalent dose per patient	the collective effective dose to the pat			the collective effective dose to the patients and t			
brain can	ovarian cancer			breast and thyroid cancer			
15 mSv	20mSv			2 mSv			
0.01-10 mSv	0.1-10 mSv			0.5-25 mSv			