MLS 314 LECTURE NOTE

MEDICAL PHYSICS

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Course Outline

1. The Mechanics of the Body
    - 1.1-Physics of Skeleton
    - 1.2-Physics of Muscle
    - 1.3-Applications

2. The Energy Household of the Body
    - 2.1-Concept of Heat and Temperature
    - 2.2-Thermodynamic Processes
    - 2.3-Applications

3. The Pressure System of the Body
    - 3.1-Physics of Breathing
    - 3.2-Physics of Cardiovascular System
    - 3.3-Applications

4. The Electrical System of the Body

5. Radiation and Radiation Protection
    - 5.1-Radiation-Concept & Explanation
    - 5.2-Radiation Measurement-Dosimetry
    - 5.3-Biological Effects of Radiation
    - 5.4-Radiation Protection

1.0 RADIATION

Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium.

1.1 TYPES OF RADIATION

There are two distinct types of radiation based on its interaction with matter.

(i) Ionizing radiation, and

(ii) Non-ionizing radiation.

Ionizing radiations have sufficient energy to ionize an atom. It can be classified into:

(a) **particulate** (e.g. alpha particles, electrons or beta particles, protons, neutrons, etc) and

(b) **electromagnetic** (x-rays and gamma rays).

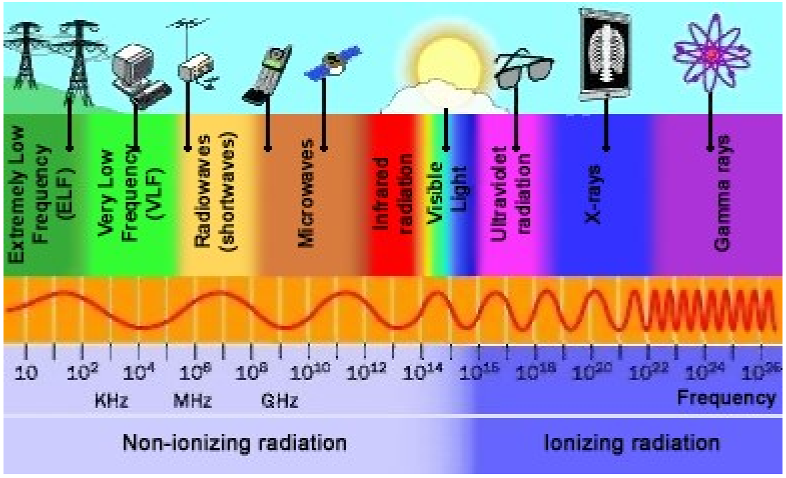
The ability of an electromagnetic wave (photons) to ionize an atom or molecule depends on its frequency. Recall,

$$E = hf$$

Where E is the energy of the photon, h is the Plank's constant and f is the frequency of the photon.

Non-ionizing radiations have insufficient energy to cause ionization in an atom. Examples are visible light, microwaves and radio wave.

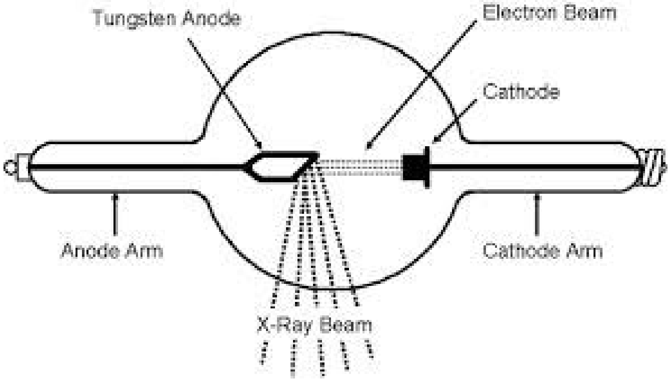
The electromagnetic spectrum in the figure below shows the various forms of electromagnetic radiation.



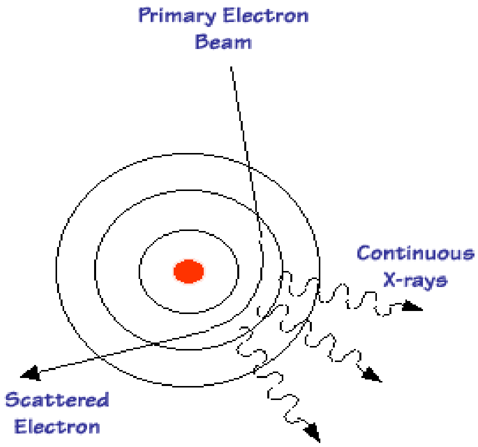
Electromagnetic Spectrum

In this study, we shall attempt to understand the applications of radiation physics in medicine.

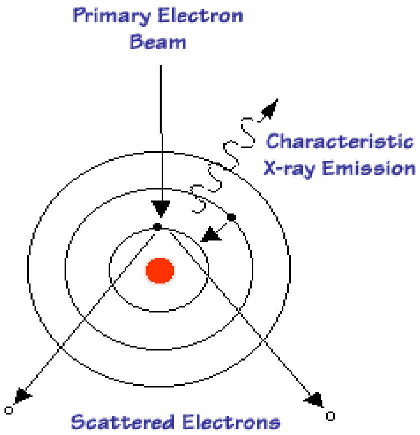
1.2 X-RAY PRODUCTION AND APPLICATION



X-ray production occurs whenever electrons of high energy strike a heavy metal target (i.e. metals with high atomic number, like tungsten or copper). When electrons hit this material, **some (a fraction)** of the electrons will approach the nucleus of the metal atoms where they are deflected because of their opposite charges (electrons are negative and the nucleus is positive, so the electrons are attracted to the nucleus). This deflection causes the energy of the electrons to decrease, and this decrease in energy then results in forming an x-ray. These x-rays are commonly called brehmsstrahlung or "braking radiation".

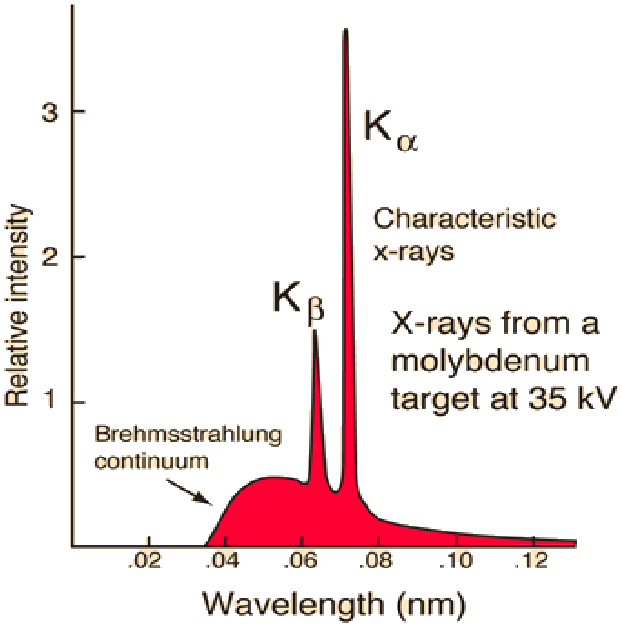


Breaking Radiation



Fluorescence

If the bombarding electrons have sufficient energy, they can knock an electron out of an inner shell of the target metal atoms. Then electrons from higher states drop down to fill the vacancy, thereby emitting x-ray photons with precise energies determined by the electron energy levels. These x-rays are called **characteristic x-rays**. Characteristic x-rays are emitted from heavy elements when their electrons make transitions between the lower atomic energy levels.



The characteristic x-ray emission which is shown as two sharp peaks in the illustration above occur when vacancies are produced in the $n = 1$ or K-shell of the atom and electrons drop down from above to fill the gap. The x-rays produced by transitions from the $n = 2$ to $n = 1$ levels are called **K-alpha x-rays**, and those for the $n = 3 \rightarrow 1$ transition are called **K-beta x-rays**. Transitions to the $n = 2$ or L-shell are designated as L x-rays ($n = 3 \rightarrow 2$ is L-alpha, $n = 4 \rightarrow 2$ is L-beta, etc.). The continuous distribution of x-rays which forms the base for the two sharp peaks at left is called "bremsstrahlung" radiation.

This is the operating principle of traditional diagnostic X-ray tube. The fraction of energy in the electron beam converted into x-rays is given by

$$\boldsymbol{f_e = 1 \times 10^{-3} \times ZE}$$

Where

$f_e = fraction\ of\ the\ energy\ in\ the\ electron\ beam\ converted\ into\ x - rays$

$Z = Atomic\ number\ of\ the\ target\ in\ the\ x - ray\ tube$

$E = Voltage\ across\ the\ x - ray\ tube$

In diagnostic radiology, X-rays are produced inside an x-ray tube. The essential features of a simple x-ray tube include:

(i) **A heated filament:** to produce a copious supply of electrons by thermionic emission and to act as cathode.

(ii) **An evacuated chamber:** across which a potential difference can be applied with an anode to compliment the cathode.

(iii) **A metal anode (the target):** at a high efficiency for conversion of electron energy into x-ray photons.

(iv) **A thinner window** in the chamber that will be transparent to most of the x-rays for passage of the x-rays.

1.3 APPLICATIONS OF X-RAY

(i) Radiographs

A radiograph is an X-ray image obtained by placing a part of the patient in front of an X-ray detector and then illuminating it with a short X-ray pulse. Bones contain much calcium, which due to its relatively high atomic number absorbs x-rays efficiently. This reduces the amount of X-rays reaching the detector in the shadow of the bones, making them clearly visible on the radiograph. Take a chest X-ray image, for example. The calcium density of the spine and ribs blocks the most X-rays, leaving white areas on a film. No X-rays penetrate to expose the film and darken those spots. The water densities of the stomach and liver are grayish. They block less of the X-ray beam than bones. It is therefore easy to see the contrast between them. The fat density of muscles is less than that of the water. They look only slightly darker, but the distinction is there for a trained eye. Finally, the air spaces in the lungs allow penetration of most of the X-ray beam, and look almost black on the films.

(ii) Computed tomography

Computed tomography (CT scanning) is a medical imaging modality where tomographic images or slices of specific areas of the body are obtained from a large series of two-dimensional X-ray images taken in different directions. These cross-sectional images can be combined into a three-dimensional image of the inside of the body and used for diagnostic and therapeutic purposes in various medical disciplines.

(iii) Radiotherapy

The use of X-rays as a treatment is known as radiation therapy and is largely used for the management (including palliation) of cancer; it requires higher radiation energies than for imaging alone.

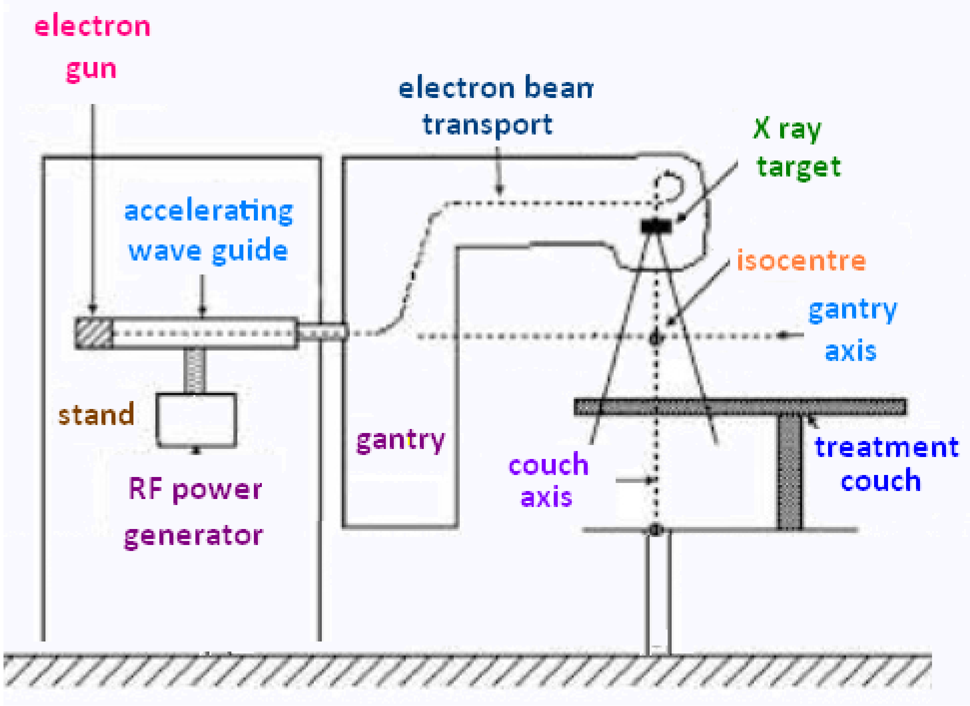
(iv) Mammography

Mammography is the process of using low-energy X-rays (usually around 30 kVp) to examine the human breast, which is used as a diagnostic and screening tool. The goal of mammography is the early detection of breast cancer, typically through detection of characteristic masses. Like all X-rays, mammograms use doses of ionizing radiation to create images. Radiologists then analyze the images for any abnormal findings.

1.4 LINEAR ACCELERATOR

A linear accelerator (LINAC) is the device most commonly used for external beam radiation treatments for patients with cancer. The linear accelerator is used to treat all parts/organs of the body. It delivers high-energy x-rays to the region of the patient's tumor. These x-ray treatments can be designed in such a way that they destroy the cancer cells while sparing the surrounding normal tissue. The LINAC is used to treat all body sites, using conventional techniques, Intensity-Modulated Radiation Therapy (IMRT), Image Guided Radiation Therapy (IGRT), Stereotactic Radiosurgery (SRS) and Stereotactic Body Radio Therapy (SBRT).

The linear accelerator uses microwave technology (similar to that used for radar) to accelerate electrons in a part of the accelerator called the "wave guide," then allows these electrons to collide with a heavy metal target to produce high-energy x-rays. These high energy x-rays are shaped as they exit the machine to conform to the shape of the patient's tumor and the customized beam is directed to the patient's tumor. The beam may be shaped either by blocks that are placed in the head of the machine or by a multileaf collimator that is incorporated into the head of the machine. The patient lies on a moveable treatment couch and lasers are used to make sure the patient is in the proper position. The treatment couch can move in many directions including up, down, right, left, in and out. The beam comes out of a part of the accelerator called a gantry, which can be rotated around the patient. A schematic diagram of a typical linac is shown below.



Radiation can be delivered to the tumor from any angle by rotating the gantry and moving the treatment couch.

Who operates this equipment?

The patient's radiation oncologist prescribes the appropriate treatment volume and dosage. The medical radiation physicist and the dosimetrist determine how to deliver the prescribed dose and calculate the amount of time it will take the accelerator to deliver that dose. Radiation therapists operate the linear accelerator and give patients their daily radiation treatments.

How is safety ensured?

Patient safety is very important and is assured in several ways. Before treatment is delivered to the patient, a treatment plan is developed and approved by the radiation oncologist in collaboration with the radiation dosimetrist and physicist. The plan is double-checked before treatment is given and quality-control procedures ensure that the treatment is delivered as planned.

Quality control of the linear accelerator is also very important. There are several systems built into the accelerator so that it will not deliver a higher dose than the radiation oncologist has prescribed. Each morning before any patients are treated, the radiation therapist performs checks on the machine using a piece of equipment called a "tracker" to make sure that the radiation intensity is uniform across the beam and that it is working properly. In addition, the radiation physicist conducts more detailed weekly and monthly checks of the linear accelerator.

Modern linear accelerators also have internal checking systems that do not allow the machine to be turned on unless all the prescribed treatment requirements are met.

During treatment, the radiation therapist continuously observes the patient using a closed-circuit television monitor. There is also a microphone in the treatment room so that the patient can speak to the therapist if needed. Port films (x-rays taken with the treatment beam) or other imaging tools such as cone beam CT are checked regularly to make sure that the beam position does not vary from the original plan.

Safety of the staff operating the linear accelerator is also important. The linear accelerator sits in a room with lead and concrete walls so that the high-energy x-rays are shielded and no one outside of the room is exposed to the x-rays. The radiation therapist must turn on the accelerator from outside the treatment room. Because the accelerator only emits radiation when it is actually turned on, the risk of accidental exposure is extremely low.

Example

Calculate (i) the maximum x-ray photon energy, (ii) the electron velocity, and (iii) minimum x-ray photon wavelength for a diagnostic x-ray tube operating at 30kV.

Solution

$(i) \quad Kinetic\ Energy\ of\ Photon\ E = charge\ of\ electron \times potential\ difference$

$$E = 1.6 \times 10^{-19}C \times 30kV$$

$$E = 1.6 \times 10^{-19} \times 30 \times 10^{3}V$$

$$E = 4.8 \times 10^{-15}J$$

$$\therefore Max\ Photon\ energy\ E = 4.8 \times 10^{-15}J$$

$(ii) \quad Now, E = \frac{1}{2}m_e v^2$

$$v = \sqrt{\frac{2E}{m_e}} = \sqrt{\frac{2 \times 4.8 \times 10^{-15}}{9.11 \times 10^{-31}}} = 1.03 \times 10^{8}m/s$$

$(iii) \quad The\ maximum\ energy\ of\ the\ photon\ that\ is\ emitted\ when\ the\ electron\ emits$ $all\ its\ energy = 4.8 \times 10^{-15}J$

$\boldsymbol{Note}$: $when\ E\ is\ maximum, \lambda\ is\ minimum$

$$E = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{4.8 \times 10^{-15}} = 4.14 \times 10^{-11}m$$

1.5 RADIOACTIVITY

Radioactivity may be defined as spontaneous nuclear transformations in unstable atoms that result in the formation of new elements. These transformations are characterized by one of several different mechanisms, including

- Alpha particle emission,
- Beta particle and positron emission, and

- Orbital electron capture.

Each of these transformations may or may not be accompanied by *gamma radiation.

1.5.1 Alpha Emission

An alpha particle is a highly energetic helium nucleus that is emitted from the nucleus of an unstable atom when the neutron-to-proton ratio is too low. It is a positively charged, massive particle consisting of an assembly of two protons and two neutrons. Since atomic numbers and mass numbers are conserved in alpha transitions, it follows that the result of alpha emission is a daughter whose atomic number is two less than that of the parent and whose atomic mass is four less than that of the parent. In the case of Polonium (^{210}Po), for example, the reaction is

$$^{210}_{84}\boldsymbol{Po} \rightarrow {}^{4}_{2}\boldsymbol{He} + {}^{206}_{82}\boldsymbol{Pb}$$

The alpha particle is relatively large and heavy. As a result, alpha rays are not very penetrating and are easily absorbed. A sheet of paper or a 3cm layer of air is sufficient to stop them. Its energy is transferred within a short distance to the surrounding media.

The alpha particle cannot penetrate the outer layer of the skin, but is dangerous if inhaled or swallowed. The delicate internal workings of the living cells forming the lining of the lungs or internal organs, most certainly will be changed (mutated) or killed outright by the energetic alpha particle.

The number of lung cancer cases among uranium miners from inhaled and ingested alpha sources is much higher than those of the public at large. Radon, the gas produced by the decay of radium-226, also emits alpha particles which poses a hazard to the lungs and airways when inhaled.

1.5.2 **Beta Emission**

A beta particle is a charged particle that is indistinguishable from an ordinary electron. It is ejected from the nucleus of an unstable radioactive atom whose neutron-to-proton ratio is too high. The particle has a very small mass and a single negative electric charge (-1.6x10^{-19}C), and therefore is called a negatron.

The beta particle is formed when there is a transformation of a neutron into a proton and an electron according to the equation:

$$\boldsymbol{{}_{0}^{1}n \rightarrow {}_{1}^{1}H + {}_{-1}^{0}e}$$

Beta particles can be stopped by an aluminium sheet a few millimeters thick or by 3 meters of air. Although the beta particle is about 8000 times smaller than the alpha particle, it is capable of penetrating much deeper into living matter.

1.5.3 **Positron Emission**

In some instances where the neutron-to-proton ratio is too low and alpha emission is not energetically possible, the nucleus may, under certain conditions attain stability by emitting a positron. A positron is a beta particle whose charge is positive. In all other respects aside from its charge $+1.6 \times 10^{-19}C$, it is the same as the negative beta particle or an ordinary electron.

The positron does not exist independently in an atom, rather, it is believed that the positron results from a transformation within the nucleus, of a proton to a neutron according to the equation:

$$\boldsymbol{{}_{1}^{1}H \rightarrow {}_{0}^{1}n + {}_{+1}^{0}e}$$

1.5.4 **Gamma Rays**

Gamma rays are electromagnetic radiations that are emitted from the nucleus of excited atoms following radioactive transformations. They are electromagnetic radiation of extremely high frequency and therefore high energy per photon. Gamma rays typically have frequencies above $10^{19} Hz$ and therefore have energies above 100KeV. Gamma rays are usually distinguished from the x-ray by their origin: x-rays are emitted by electrons outside the nucleus while gamma rays are emitted by the nucleus.

2.0 MECHANISMS OF RADIATION DAMAGE

Ionizing radiation affects living things on an atomic level, by ionizing molecules inside the microscopic cells. When ionizing radiation comes in contact with a cell, any of the following may happen:

(i) It may pass directly through the cell without causing any damage.
(ii) It may damage the cell but the cell will repair itself.
(iii) It may affect the cell's ability to reproduce itself correctly, possibly causing a mutation.
(iv) It may kill the cell. The death of one cell is of no concern but if too many cells in one organ such as the liver die at once, the organism will die.

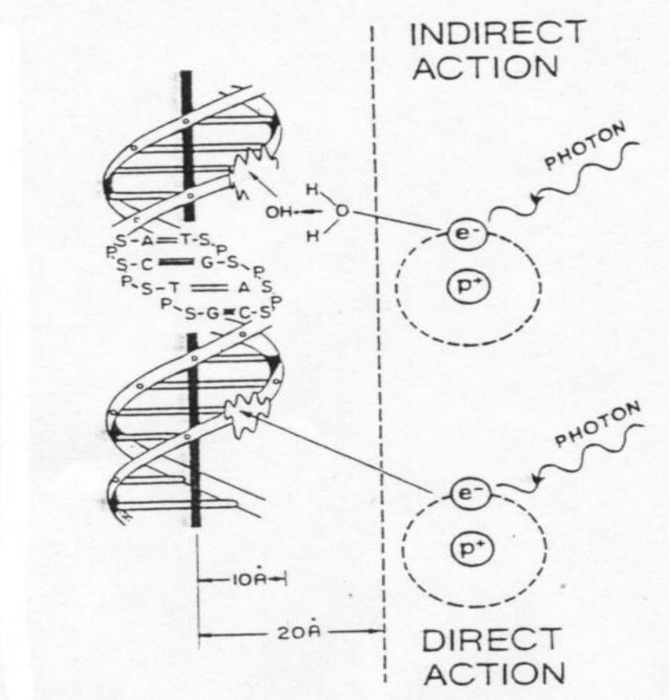
Radiation which is absorbed in a cell has the potential to impact a variety of critical targets in the cell, the most important of which is the DNA. Evidence indicates that damage to the DNA is what causes cell death, mutation and carcinogenesis. The mechanism by which the damage occurs can happen via one of two scenarios.

(i) Direct Action

In the first scenario, radiation may impact the DNA directly, causing ionization of the atoms in the DNA molecule. This can be visualized as a "direct hit" by the radiation on the DNA, and this is a fairly uncommon occurrence due to small size of the target; the diameter of the DNA helix is only about 2nm. It is estimated that the radiation must produce ionization within a few nanometers of the DNA molecule in order for this action to occur.

(ii) Indirect Action

In the second scenario, the radiation interacts with non-critical target atoms or molecules, usually water. This results in the production of free radicals, which are atoms or molecules that have an unpaired electron and thus are very reactive. These free radicals can then attack critical targets such as the DNA (see figure below). Because they are able to diffuse some distance in the cell, the initial ionization event does not have to occur so close to the DNA in order to cause the damage. Thus, damage from indirect action is much more common that damage from direct action, especially for radiation that has a low specific ionization.



Mechanism of Radiation Damage

When the DNA is attacked, either via direct or indirect action, damage is caused to the strands of molecules that make up the double-helix structure. Most of this damage consists of breaks in only one of the two strands and is easily repaired by the cell, using the opposing strand as a template. If however, a double-strand break occurs, the cell has much more difficulty repairing the damage and may make mistakes. This can result in mutations, or change to the DNA code, which can result in consequences such as cancer or cell death. Double-strand breaks occur at a rate of about one double-strand break to 25 single-strand breaks. Thus, most radiation damage to DNA is reparable.

2.1 DETERMINANTS OF BIOLOGICAL EFFECTS

2.1.1 Rate of Absorption

The rate at which the radiation is administered or absorbed is most important in the determination of what effects will occur. Since a considerable degree of recovery occurs from the radiation damage, a given dose will produce less effect if divided (thus allowing time for recovery between dose increment) than if it were given in a single exposure.

2.1.2 Area Exposed

The portion of the body irradiated is an important exposure parameter because the larger the area exposed, other factors being equal, the greater the overall damage to the organism. This is because more cells have been impacted and there is a greater probability of affecting large portions of tissues or organs. An example of this phenomenon is in radiation therapy, in which doses which would be lethal if delivered to the whole body are commonly delivered to very limited areas, e.g. to tumor sites.

2.1.3 Variation in Species and Individual Sensitivity

There is a wide variation in the sensitivity of various species. Lethal doses for plants and microorganisms, for example, are usually hundreds of times larger than those for mammals. Even among different species of rodents, it is not unusual for one to demonstrate three or four times the sensitivity of another.

Within the same species, individuals vary in sensitivity. For this reason the lethal dose for each species is expressed in statistical terms, usually for animals as the $LD_{50/30}$ for that species, i.e. (the dose required to kill 50 percent of the individuals in a large population in a thirty day period). For humans, the $LD_{50/60}$ (the dose required to kill 50 percent of the population in 60 days) is used because of the longer latent period in humans. The $LD_{50/60}$ for humans is estimated to be approximately 300 – 400 rad for whole body irradiation, assuming no treatment is given. It can be as high as 800 rad with adequate medical care.

2.1.4 Variation in Cell Sensitivity

Within the same individual, a wide variation in susceptibility to radiation damage exists among different types of cells and tissues. In general, those cells which are rapidly dividing or have a potential for rapid division are more sensitive than those which do not divide. It is possible to rank various kinds of cells in descending order or radiosensitivity. Most sensitive are the white blood cells called lymphocytes, followed by immature red blood cells. Epithelial cells, which line and cover body organs, are of moderate high sensitivity; in terms of injury from large doses of whole-body external radiation, the epithelial cells which line the gastrointestinal tract are often of particular importance. Cells of low sensitivity include muscle and nerve, which are highly *differentiated* and do not divide.

3.0 RADIATION MEASUREMENT

Radiation is measured in the following units.

3.1 Gray (Gy)

The gray is a unit used to measure a quantity called absorbed dose.

$$1\ Gray\ (Gy) = 1\ Joule/kg$$

This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material, but it does not describe the biological effects of the different radiations.

3.2 Sievert (Sv)

The sievert is a unit used to derive a quantity called equivalent dose.

$$1Sv = 1Gray \times QF$$

QF is a "quality factor" based on the type of particle. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiations have the same biological effect, even for the same amount of absorbed dose.

3.3 Becquerel (Bq)

The Becquerel is a unit used to measure radioactivity. One Becquerel is that quantity of a radioactive material that will have 1 transformation in one second.

$$1Bq = 1\ count\ per\ second = 1\ event\ per\ second.$$

4.0 **ACUTE RADIATION SYNDROME** (ARS)

Data on the various forms of ARS have been drawn from many sources. Animal experiments provide the bulk of the data. At the human level, data have been drawn from experiences in radiation therapy, studies of Japanese survivors of Hiroshima and Nagasaki, the victims of nuclear installations including Chenobyl etc.

If a person receives a single, large, short-term and whole body dose of radiation on a number of vital tissues and organs simultaneously, the effect and severity will depend on the dose and the particular conditions of the exposure. The ARS can be characterized by four (4) sequential stages.

(i) **Prodromal radiation syndrome**: this varies in the time of on-set, severity and duration. The principal symptoms of a prodromal syndrome are anorexia (loss of appetite), nausea, vomiting and easy fatigability.

(ii) **Hematopoietic syndrome**: results from total body exposure from 2.5-5Gy. The radiation sterilizes some or all of the mitotically active precursor cells. Symptoms result from lack of circulating blood elements three or more weeks later (i.e low blood count).

(iii) **Gastrointestinal syndrome**: this results from a total body exposure to radiation of about 10Gy. Death occurs about 5-10 days in human because of depopulation of the epithelial lining of the gastrointestinal tract.

(iv) **Cerebrovascular syndrome**: this results from a total body exposure to radiation of about 100Gy of Gamma rays. In human, it results in death in about 24 to 48 hours.

5.0 THE MECHANICS OF THE BODY

The main force acting on the body is the **gravitational force**.

$$Gravitational\ Force\ F_g = weight, W = mg$$

Gravitational force W applies at the center of gravity centre of gravity (**CG)** of the body.

The CG of the human body is determined by the location of the limbs at any given time.

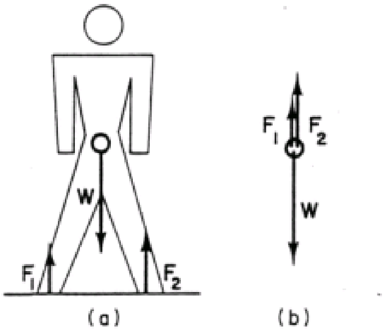
When standing in anatomical position, the height of your centre of gravity is:

(i) 55% of your standing height for women.

(ii) 57% of your standing height for men.

To maintain stability the vector sum of all forces applying at the **CG** must be zero.

$$\sum \vec{F_i} = 0$$



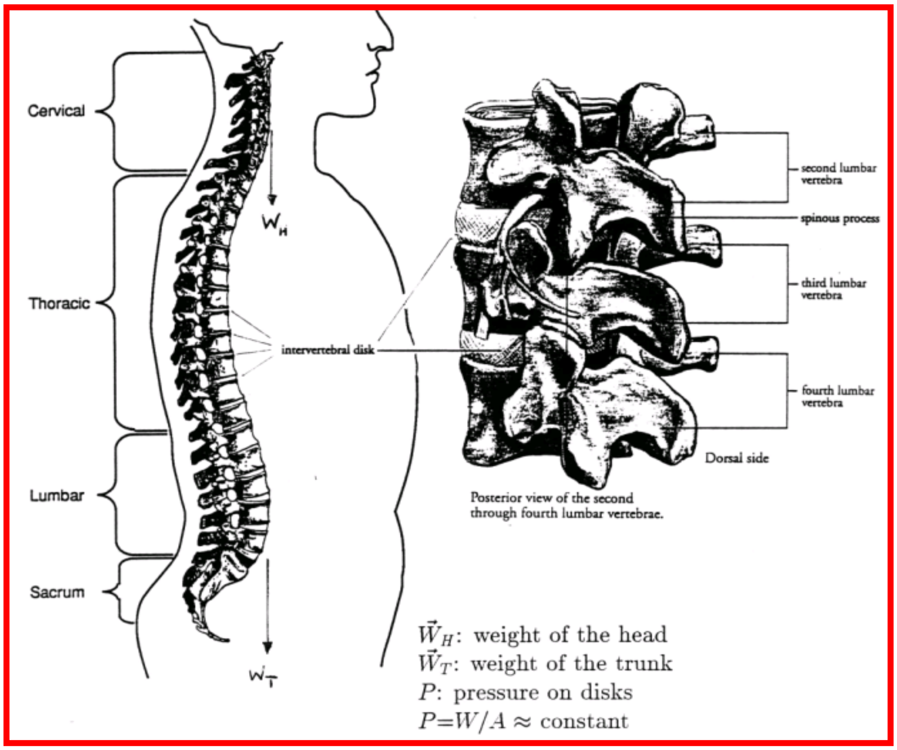
(a) (b)

$$\vec{F_1} + \vec{F_2} = \text{W}$$

$\vec{F_1}$, $\vec{F_2}$ are the forces the ground applies to the feet

5.1 Forces on the Spinal Column

Spinal column supplies the main support for the head and trunk of the body. The spinal column is S-shaped to increase stability. Its bones, the vertebrae carry the load, while the vibrous disks between the vertebrae cushion the applied forces.



<u>Question</u>:

Given that the mass of the head is 3 kg and the area of the upper cervical vertebrae is 5 cm^2. Calculate the pressure on the upper cervical vertebrae in Nm^{-2}.

<u>Solution</u>:

$$Pressure, P = \frac{Force}{Area} = \frac{Weight\ of\ the\ head}{Upper\ Area\ of\ cervical\ vertebrae}$$

$$P = \frac{mg}{A} = \frac{3kg \times 9.8\, m/s^2}{5 \times 10^{-4} m^2}$$

$$P = 5.88 \times 10^5 Nm^{-2}$$

6.0 THE ELECTRICAL SYSTEM OF THE BODY

All body functions are controlled by its electrical system. The electrical system controls:

- information transfer in the central and autonomous nervous system;
- operation of the brain and spinal cord;
- operation of muscle functions;
- operation of body organs.

To control and maintain this system, billions of electrical signals have to be generated in the human nervous system. The source of the electrical signals is electrochemical potentials in the nerve cells.

Measurement of electrical signals and electrical potential in nerve transmission (as well as body response) allows for obtainment of useful clinical information.

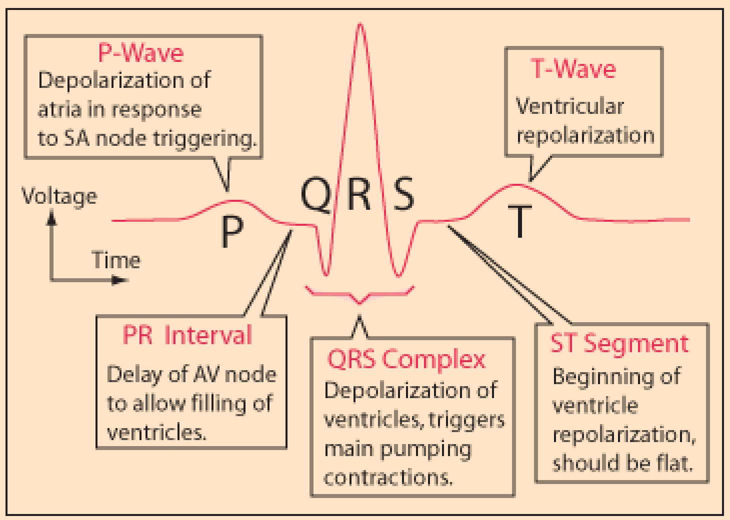
The following are diagnostics tools for assessment of different electrical functions of the body:

Diagnostic Tool	**Acronym**	**Function**
Electromyogram	EMG	Muscle function
Electrocardiogram	ECG	Heart function
Electroencephalogram	EEG	Brain function
Electroretinogram	ERG	Eye functions
Electrooculogram	EOG	Eye functions

6.1 Electrocardiograms

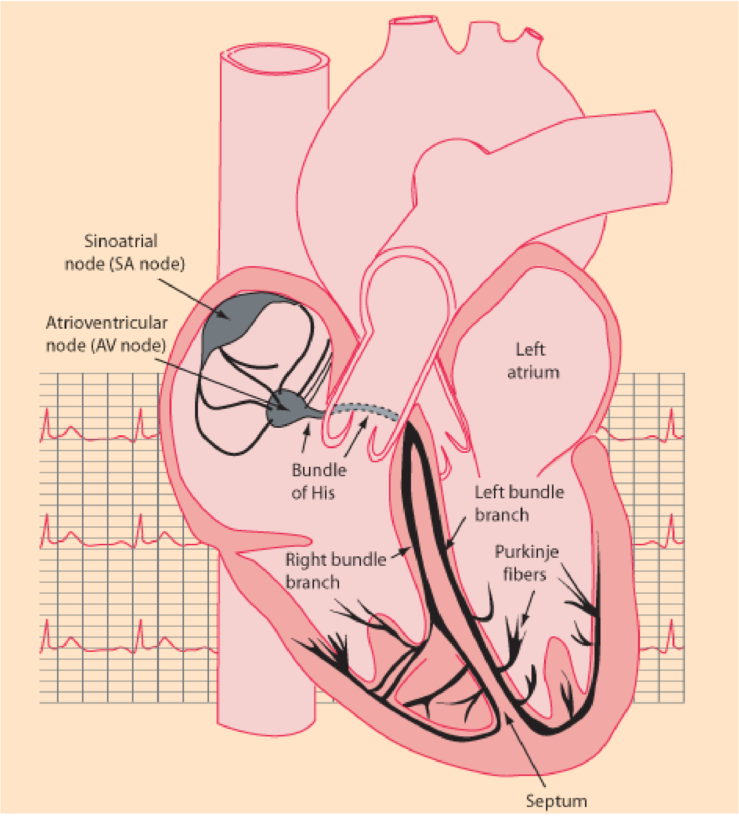
The ***electrocardiogram*** or ECG is a measurement taken at the surface of the skin which reflects the electrical phenomena in the heart when the sinoatrial (SA node) triggers the electrical sequence that controls heart action. The medical equipment that records these electrical phenomena is called ***electrocardiograph***.

The figure below shows a typical electrocardiogram.



6.2 The Heart's Electrical Phenomena

The figure below illustrates the electrical phenomena of the heart.



(i) The rhythmic contractions of the heart which pump the life-giving blood occur in response to periodic electrical control pulse sequences.

(ii) The natural pacemaker is a specialized bundle of nerve fibers called the sinoatrial node (SA node).

(iii) Nerve cells are capable of producing electrical impulses called ***action potentials***.

(iv) The bundle of active cells in the SA node trigger a sequence of electrical events in the heart which controls the orderly pattern of muscle contractions that pumps the blood out of the heart.

(v) The electrical potentials (voltages) that are generated in the body have their origin in membrane potentials where differences in the concentrations of positive and negative ions give a localized separation of charges. This charge separation is called polarization.

(vi) Changes in voltage occur when some event triggers a depolarization of a membrane, and also upon the repolarization of the membrane.

(vii) The depolarization and repolarization of the SA node and the other elements of the heart's electrical system produce a strong pattern of voltage change which can be measured with electrodes on the skin.

(viii) Voltage measurements on the skin of the chest are called an electrocardiogram or ECG.

6.3 The Sinoatrial Node: The Body's Natural Pacemaker

(i) The SA node is located in the upper part of the right atrium of the heart.

(ii) It is a specialized bundle of neurons.

(iii) It acts as the heart's natural pacemaker.

(iv) The SA node “fires” at regular intervals to cause the heart to beat with a rhythm of about 60 to 70 beats per minute for a healthy, resting heart.

(v) The electrical impulse from the SA node triggers a sequence of electrical events in the heart to control the orderly sequence of muscle contractions that pump the blood out of the heart.

(vi) The depolarization and repolarization of the SA node and the other elements of the heart's electrical system produces a strong pattern of voltage change which can be measured with electrodes on the skin.

(vii) Voltage measurements on the skin of the chest are called an electrocardiogram or ECG.

(viii) While it is the norm for nerve cells that they require a stimulus to fire, the SA node can be considered to be "self-firing".

(ix) It repetitively goes through a depolarizing discharge and then repolarizes to fire again.

7.0 THE PRESSURE SYSTEM OF THE BODY

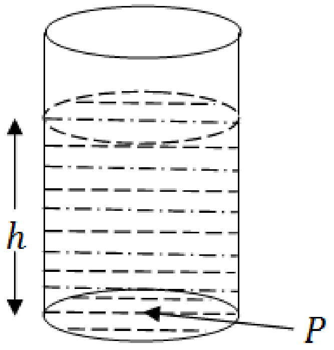
Pressure Is defined as the amount of force F on a certain area A, i.e.

$$P = \frac{F}{A}$$

The international standard unit for pressure is Pascal.

$$1\ Pa = 1\ N/m^2$$

Traditional unit for pressure in the medical community is the mmHg which corresponds to the pressure at the bottom of a column of mercury Hg of a certain height h:



$P = \rho g h$
where
$\rho = density\ of\ liquid$
$g = 9.8\ m/s^2\ (acceleration\ due\ to\ gravity)$

Example 1:

The density of mercury is $\rho = 13.6 \times 10^3\ kg/m^3$. Obtain the pressure of a column of mercury, $h = 1mm$.

Solution:

$$P = \rho g h$$

$$P = 13.6 \times 10^3 \times 9.8 \times 1 \times 10^{-3}$$

$$P = 133.3\ kgm^{-1}s^{-2}\ \ or\ 133.3\ N/m^2$$

$$P \approx 133Pa \equiv 1mmHg$$

Typical blood pressure for healthy adult ranges between

$$P_{blood} \cong 100 - 120\ mmHg\ (or\ 13.3 - 15.8\ kPa)$$

However, man exists at certain conditions of outer environment, his internal pressure system is therefore influenced by the outer pressure conditions. The total pressure is defined by the sum of the external pressure plus the internal pressure (gauge pressure).

Example 2:

The typical air pressure on the entire body is $1\ atm = 760mmHg$. Calculate the total blood pressure.

$$P_{total} = typical\ blood\ pressure + typical\ air\ pressure$$

$$P_{total} = 120 + 760 = 880mmHg$$

Example 3:

Calculate the total blood pressure of a diver at a water depth of $30m$. ($\rho_w = 1 \times 10^3 kgm^{-3}$)

Solution:

$$P_{total} = typical\ blood\ pressure + water\ pressure\ at\ 30m\ depth$$

$$typical\ blood\ pressure = 120mmHg$$

$$P_w = water\ pressure\ at\ 30m = \rho_w gh$$

$$P_w = 1 \times 10^3 \times 9.8 \times 30$$

$$P_w = 294 \times 10^3 = 294kPa$$

$$now, 133Pa = 1mmHg$$

$$P_w = \frac{294 \times 10^3}{133} = 2.21 \times 10^3 mmHg = 2210mmHg$$

$$\therefore P_{total} = 120mmHg + 2210mmHg$$

$$P_{total} = 2330mmHg$$