FORCES ON AND IN THE BODY

Contents

1-*Classification of forces in physics and in mechanics.*

This lecture is allocated to a summary of some concepts of mechanics (statics and dynamics) and to some mechanical effects and applications to the human body. Mechanics is the science of forces and motion. In physics forces include: **(1)** gravitational (and other mechanical forces). **(2)** electrical (and magnetic) forces. **(3)** strong (and weak) nuclear forces. Mechanical forces include: gravitational, constraining, frictional, impact (collision), buoyant and viscosity (retarding) forces…etc.

(1) ***Gravitational force:*** Newton formulated the law of universal gravitation which states that "there is a force of attraction between any two objects which is proportional to the product of their masses and inversely proportional to the square of the distance between them". For example; our weight is due to the attraction between the earth and our bodies. The gravitational force is smaller on the moon than on the earth in proportion to their respective masses.

Effects of the gravitational force on the body:

i) The formation of varicose veins in the legs: This happens because of the attraction of the earth to the blood. This attraction resists the upflow of the venous blood which travels against the force of gravity on its way to the heart. As a result, pooling of blood occurs especially in the legs.

ii) The loss of bone mineral: Stresses (gravitational force per unit area) on the contact surfaces of the bone joints, in some way contribute to "healthy bones" where these stresses are in their normal magnitudes. Serious loss of bone mineral occurs where these stresses are eliminated for long periods as in space flight weightlessness, or greatly reduced as in long term bed rest of elderly persons, or long term bed confinement of patients seriously sick or injured in accidents.

(2) *Electrical force:* Like electrical charges repel and unlike charges attract with a force proportional to the product of the charges and inversely proportional to the square of the distance between them (Coulomb's law). This is an inverse square law similar to Newton's law of universal gravitation. Magnetic forces are produced by moving electrical charges, (currents) that generate North and South poles.

Electrical forces are immense as compared to the weak gravitational forces. For example; the electrical force between an electron and a proton in H atom is about (10^{39} times) greater than the gravitational force between them.

Electrical current: this consists of moving electrical charges, (moving electrons). Most of the forces dealt with in mechanics are of electromagnetic origin, but they produce the mechanical effects of acceleration, torque, and deformation. Our bodies are basically electrical machines in which the muscular forces are produced by electrical charges attracting or repelling other electrical charges.

(3) ***Nuclear forces***: these forces counteract the enormous Coulomb's repulsion of the positively charged "protons" and hold them together inside the nucleus. There are two types of nuclear forces:

i) **Strong nuclear forces:** (as defined above)

ii) **Weak nuclear forces:** associated with electron decay from the nucleus (It may be related to the electrical forces).

The other mechanical forces will be considered as they arise in the context.

2- Statics: The three classes of levers and the bone joints of the body

Statics deals with forces in equilibrium *i.e.* where the sum of the component forces in any direction is equal to zero, and the sum of the component torques about any axis is also equal to zero. Many of the body's muscles and bone systems act as levers which are usually classified into three classes according to which of the three points of application (W, M and F) is the middle point:

a) ***First class levers:*** these are least common in the body. The **fulcrum point (F)** is between the **muscle force (M)** and the **weight (W),** for example: the **head-neck joint.**

b) ***Second class levers:*** these are found more than the first. Here (W) is between (F) and (M); for example: **standing on the toes**.

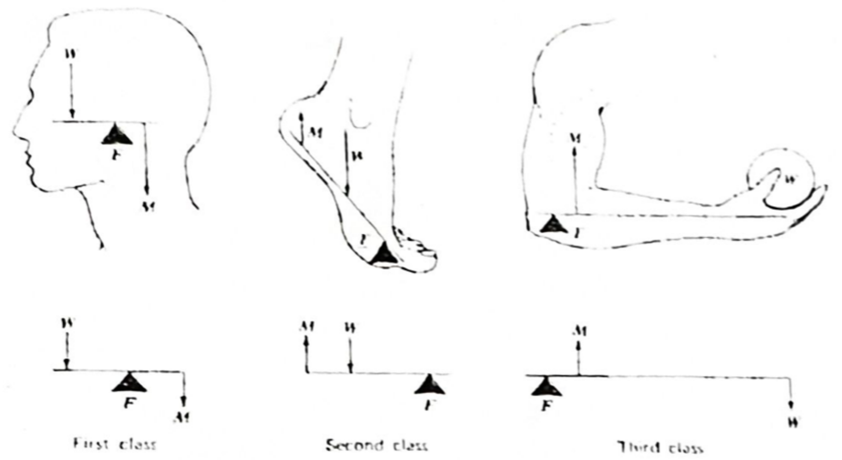


Figure 2.1. The three lever classes and schematic examples of each in the body. *W* is a force that could be the weight, *F* is the force at the fulcrum point, and *M* is the muscle force.

c) ***Third class levers:*** these are most common in the body. Here (M) is between (F) and (W), for example; the **elbow joint.**

In general; each muscle has a minimum length to which it can be contracted and a maximum length to which it can be stretched and still functions. We can find the force supplied by any muscle by the equation. $M = 7.5\,W$. This equation is used when we neglect (the weight of the forearm and hand = H). When we do not neglect this weight, the equation will be: $M = 3.5\,H + 7.5\,W$. By taking the sum of torques about the shoulder joint, the **tension** T can be calculated from: $T = (2W_1 + 4W_2) / \sin\alpha$, where W_1 is the weight of the arm, W_2 is the weight of the hand and α is the angle between the forearm and the x-axis.

It should be noted that: **(1)** The muscle's resting length (L), is close to the optimum length for producing force. **(2)** At about half its length (L /2), the muscle cannot shorten further and the force produced drops. **(3)** At stretch of about double length (2L), irreversible tearing of muscle takes place.

3- *Frictional forces: effects and applications to the human body.*

Friction and the energy loss due to friction appear everywhere in our everyday life. Friction limits the efficiency of most machines such as the electrical generators and automobiles. On the other hand we make use of friction in devices such as rubber tires and automobile brakes.

In the body, friction effects are often important. The maximum force of friction f is usually described by: $f = \mu N$ where **N** is the normal component force and **μ** is the coefficient of friction between the two rubbing surfaces. The value of **μ** depends upon the two materials in contact and it is essentially independent of the surface area.

Below are examples of **the effects and applications of frictional forces to the body:**

1) Normal walking: in normal walking the heel strikes the ground with a muscular force having downward and forward components, and the toes hit the ground with a muscular force having downward and backward components. The constraining force exerted by the ground counteracts the vertical components and prevents free fall of the body under gravity. The frictional forces counteract the horizontal components of the muscular forces and prevent the heel from sliding forwards and the toes from sliding backwards. Without friction normal walking is not possible. Likewise cars cannot move normally where the road is covered with ice or spilt oil, due to the resulting lack of friction.

2) Lubrication of bone joints by their synovial fluid (to be discussed in Lecture Three).

3) Adding saliva while chewing food to lessen friction, otherwise swallowing would be painful and could cause injury of the upper digestive tract.

4) Most of the large body's organs function by movement: the heart beats to circulate the blood, the lungs move inside the chest with each breath to inhale and exhale air, and the intestines have a slow rhythmic motion (peristalsis) to push food forward. All of these organs are lubricated by a **slippery mucus covering** to minimize friction.

5) A woman's vagina secretes a "lubricant" prior to coitus to lessen friction.

4- *Dynamics: impact forces, effects and applications to the human body*

Impact (or collision) forces are distinct from "action-at-a-distance" gravitational forces in that they are "contact" forces that arise during impact (collision) of bodies. These forces have a number of distinguishing features:

1) Impact forces last for a short time interval Δt and for a short distance Δx.

2) Under such conditions of Δt and Δx being short intervals, acceleration a and force F are approximately constant quantities ($\frac{dv}{dt} \cong \frac{\Delta v}{\Delta t}$), and the relevant problems can be solved by simple algebra and not necessarily by calculus.

3) These forces are momentum-change forces given by $F = \frac{\Delta(mv)}{\Delta t}$. This is the original form in which Newton put his second law $F = ma$, where $a = \frac{\Delta v}{\Delta t}$.

4) Impact forces can be elevated by their short Δt and Δx to dangerous amounts exceeding the body tolerance.

5) The dangers of these forces can be reduced by lengthening the Δt and Δx intervals by some safety measures and devices, (to be shown later).

For determining the dynamic force F as a momentum-change dependent force, only Δt (and not Δx) need be measured. However, where it is easier to measure Δx (e.g., the difference between the lengths of a car before and after collision), then the relation $W = \Delta(E_k)$, [work is equal to the change in kinetic energy] can be used, where $W = Fx$ and $E_k = \frac{1}{2}mv^2$, or $F\Delta x = \frac{m}{2}({v_2}^2 - {v_1}^2)$

.

Example: a 60 kg person walking at 1 m/s bumps into a wall and stops in a distance of 2.5 cm in about 0.05 sec. What is the force developed on impact?

Solution

(a) **By using the relation:** $F = \frac{\Delta(mv)}{\Delta t}$

$\Delta(mv)$ = (60 kg)(1 m/sec) – (60 kg)(0 m/sec)= 60 kg m/sec

$F = \frac{\Delta(mv)}{\Delta t} = \frac{60\ kg\ m/sec}{0.05\ sec} = 1200\ kg\ m/sec^2$ or 1200 N (or ≅ twice the person's weight: $w = mg = 60kg \times \frac{10m}{sec^2} = 600N$).

(b) **By using the relation:** $F\Delta x = \frac{m}{2}({v_2}^2 - {v_1}^2)$ where $v_1 = 0$.

$$F\frac{2.5}{100}\text{m} = \frac{60\ kg}{2}((1\text{m/sec})^2 - 0^2) = \frac{1000}{25\text{m}} \times 30\frac{kg\ \text{m}^2}{sec^2} = 1200\ \text{N},$$

which is the same as in (a) above.

The following **effects and applications of impact forces** should be noted:

1) **Increase and decrease of weight during changes in the direction and magnitude of velocity under engine thrust and drag forces:** In air combat, a pilot often has to make some acrobatic movements with his fighter plane such as sudden climbing, diving and overturning. He does that by changing the orientation of his plane so as to change the area of exposure to air resistance and thereby change the magnitude of this frictional force (drag). During such sudden changes the pilot experiences an increase and decrease of his weight. He also notices similar changes in the weights of the aircraft control levers which now

require from the pilot greater or lesser muscular effort than usual to operate them. Similar weight effects are experienced by kids in carriages while suddenly ascending, descending, and turning on their rails in amusement parks. Also in driving on uneven roads the resulting jiggles produce such charges in weight.

2) Changes in internal hydrostatic pressure: These changes are associated with the changes in the weight of the body and of all of its constituents as a result of the action of impact forces.

3) The slight contribution of heart beats to increase in the body's weight: It may be interesting to know that when the heart beats (systole) a certain upward force is exerted on the mass of blood to overcome gravity. By Newton's third law an equal downward reaction force acts on the rest of the body. The reaction force is slight as compared with the body's weight yet enough to produce a noticeable jiggles on a sensitive spring balance while weighing the body.

4) The great increase in body's weight due to impact forces: If a person jumps from a height of 1m and lands stiff-legged, he is in for a shock. By free fall acceleration due to gravity the body will be travailing at 4.5 m/sec just prior to hitting. If the padding of the feet collapses by 1 cm the body stops in about 0.005 sec. The impact force in the legs will then be as great as 100 times the person's weight! In sports, a player falling from a height lands on a gym net or mat to prolong the deceleration time and thereby minimize the collision force. A trained parachutist will land on toes first, with his knees bent, and roll his body on the ground for the same purpose.

5) Impact forces in car accidents and their possible fatal effects: In auto collisions a fast car often stops in a short time of only few milliseconds producing very large forces that can be far beyond the human tolerance. The results of these forces on the passengers can be broken bones, internal injuries, and sometimes death. To minimize these hazardous effects safety devices are now used, such as seat belts shoulder belts, headrests, air bags, dash padding, energy-absorbing steering columns, penetration-resistant windshields, and strengthened side-door beams. Installation of some of these devices in the car and using them by the driver and passengers are now enforced by traffic laws.

6) Increasing body tolerance by proper body orientation: When the body is in the **standing position** the feet withstand all of the body weight which is distributed on the small support area of the feet. Stresses (force per unit area) through the legs and their bone joints are maximum in this position. After a long walk one needs to rest on a chair to provide a wider supporting area for most of the body's weight and lessen the stresses. The legs will now rest by being exempted from these stresses in the **sitting position**. In bed rest the body is in the **lying position** and enjoys maximum comfort due to the minimized weight stresses. In launching manned space vehicles where the astronauts are **seated on their backs** to minimize the body's limitations and maximize its tolerance during launching when weight becomes several times greater than its normal value.

7) Emergency escape from military fighter and bomber aircrafts: Military fighter and bomber aircrafts are equipped with ejection-seats for the crews to abandon their planes in case of emergency. These seats are ejected along rails fixed to the plane. The lower part of the seat is curved to receive the parachute which is fastened to the pilot and on which the pilot sits as a cushion. In case of emergency the seat is ejected by a shot through a removable cockpit cover and leaves the plane. The pilot is the last of the crew to leave. In the short time of acceleration in the seat-to-head direction the lack of blood flow to the brain can cause blackout and unconsciousness. By knowing the limitations of the body, the amount of the accelerative force and its duration can be adjusted to minimize the probability of injury during emergency escape.

8) Exposure to "reduced stresses in bed rest" and to "eliminated stresses in space flight weightlessness": These conditions affect the circulation of blood by affecting the performance of the heart and of the other muscles generally. Consequently the functioning of many of the body's organs will be affected. Fortunately, none of these physiological changes has proved to be incapacitating or permanent, but long-term exposure to these changes may cause serious loss of bone mineral.

9) The body's elastic tissues under impact forces suffer distortion, and can suffer irreversible tearing (rupture) under elevated magnitudes of impact forces.

10) Sound pressure waves cause fatigue and discomfort: Excessive vibration in motor trucks, jet planes and some workshops results in fatigue and discomfort and may cause audio and visual disturbances. Even infrasound (below 20 Hz) can cause such effects. Each of the body's major organs has its own **resonant frequency**. Pain or discomfort, occurs in a particular organ when vibrated at its resonant frequency.

11) Sedimentation of solid particles suspended in a liquid by a centrifuge (as discussed below).

5- *Centrifugation: Laboratory tests of RBC's sedimentation rate and of hematocrit for diagnosing the related blood diseases*

(1) Tests without using a centerfuge

Consider a spherical particle of radius a and density ρ moving with terminal velocity υ in a liquid of viscosity η and density ρ_o. The particle is acted upon by three forces: the downward **gravitational force** $F_g = \frac{4}{3}\pi a^3 \rho g$, the upward **buoyant force** $F_B = \frac{4}{3}\pi a^3 \rho_o g$ and the **retarding force** $F_d = 6\pi a \eta v$. (as found by Stokes). The velocity v is constant when the three forces are in equilibrium, $F_g - F_B = F_d$, from which the expression for the terminal (sedimentation) velocity is obtained $v = \frac{2a^2}{9\eta} g(\rho - \rho_o)$, (*Note*: g = 9.8 ~ 10 m/sec^2).

In some diseases (**rheumatic fever, rheumatic heart disease and gout**) the red blood cells (RBC's) clump together and the effective radius a increases; thus, the sedimentation velocity (rate) is **faster than normal**. In other diseases: (**hemolytic jaundice and sickle cell anemia**), the RBCs change shape or break. The radius decreases; thus, the rate of sedimentation is **slower than normal.** Determining the RBCs sedimentation rate is a simple and routine clinical laboratory test that enables the hematologist to diagnose the above mentioned blood diseases.

(2) Tests of hematocrit by using a centerifuge

Another medical test, also dependent on the last equation for determining v, is the determination of the **hematocrit** (the percent of RBC's in the blood). In the said equation v can be increased by increasing g by means of a centrifuge, which provides an effective acceleration $g_{eff} = 4\pi f^2 r^2$, where f

is the rotation rate in revolution per second and r is the position on the radius of the centrifuge where the solution is located. The hematocrit depends on: **(1)** Radius of centrifuge **(2)** Speed **(3)** Duration. The increase of any of these leads to more dense packing of the RBC's, or a smaller hematocrit. One standard method for hematocrit utilizes centrifugation for (30 min) duration at rotation rate (3000 rpm) with (r=22 cm). A normal hematocrit is from 40 to 60. Hematocrit < 40 indicates anemia, and hematocrit > 60 indicates polycythemia vera. There also exists what is called "**ultracentrifuge**" used in the determination of the molecular weight of large macromolecules. Ultracentrifuges run at 40.000 to 100.000 rpm and have a g_{eff} of about 300.000 g. They have been very useful in protein research; however, they are not used in clinical medicine.

6- *Glossary of medical and physical terms for lecture One*

Body's systems	**أجهزة الجسم**	**Senses**	**الحواس**	**Branches of physics**	**فروع الفيزياء**
nervous	العصبي	vision	البصر	mechanics	الميكانيك
skeletal	العظمي	hearing	السمع	heat	الحرارة
muscular	العضلي	smelling	الشم	sound	الصوت
circulatory	الدوران	tasting	الذوق	electricity	الكهربائية
respiratory	التنفسي	touch	اللمس	magnetism	المغناطيسية
digestive	الهضمي	**teeth**	**الاسنان**	light	الضوء
urinary	البولي	incisors	القواطع	atomic	الذرية
genetal	التناسلي	canines	الانياب	nuclear	النووية
immune	المناعي	molars	الطواحن	radiation	الاشعاعية

Forces	**القوى**			twisting	اللي
gravitational	الجذبية	viscosity	اللزوجة	adhesion	الالتصاق
electrical	الكهربائة	centripetal	المركزية	osmotic	التناضح
nuclear	النووية	tensile	الشد	muscular	العضلية
frictional	الاحتكاك	compressive	الكبس	buoyant	الرافعة
constraining	المانعة	shearing	القص	impact	الاصطدام

unconsciousness	اغماء	secrete	افراز، اخفى	allocate	يخصص
blackout	عمى وقتي	coitus, coital	الاتصال الجنسي	stiff-legged	منتصب الساقين
saliva	اللعاب	clinic, -al	عيادة	shock	رجة، صدمة
chewing	المضغ	vagina, -nal	مهبل	strengthened	مقوى
swallowing	البلع	optimum	اقصى	collapse	يتقوض ينهار
breath, v,n	النفس	limitations	تحديدات	exempted	مستثنى
intestine, -nal	الامعاء	brain	الدماغ	enforced	مفروض قسرا
vein, venous	وريد	rheumatism	روماتزم	launching	اطلاق
liver	كبد	rheumatic	روماتيزمي	eliminate	يزيل
lever	عتلة	fever	حمى	reduce	يقلل
spine, -nal	العمود الفقري	cell, cellular	خلية، خلوي	effect, affect	اثر، يؤثر
spleen	الطحال	escape	يهرب	systole	انقباض القلب
inhalation	الشهيق	gout	داء المفاصل ،النقرص	abandon	يترك ،يتخلى عن
exhalation	الزفير	sickle	منجل	astronauts	رواد فضاء
mucus، mucous	مخاط،مخاطي	clump	يتكتل، يتجمع	elevated	عالي المقدار
tolerance	تحمل	anemia	فقر الدم	military	عسكري
exceed	يتجاوز	hemoglobin	هيموغلوبين	pilots	طيارون
maximize	يزيد الى الاقصى	jaundice	يرقان، صفرة	jiggles	صدمات
minimize	يقلل الى الادنى	necessarily	بالضرورة	padding	بطانة لينة
particles	دقائق	duration	فترة زمنية	discomfort	عدم الراحة
expose	يعرض	interval	فترة تغير	comfort	راحة
exposure	تعرض	consequently	وبالنتيجة	seated	جالس في مقع
muscle, muscular	عضلة	performance	اداء،انجاز	incapacitating	معوق
fighter	طائرة مقاتلة	functioning	اداء لوظيفة	rupture	تمزق او تشقق
bomber	طائرة قاصفة	ultracentrifuge	جهاز التدوير الفائق	distortion	تشوه
effective	فعال	lecture	محاضرة	fatigue	تعب، اعياء
glossary	معجم	terms	مصطلحات	suspended	معلق
principles	مبادئ	summary	خلاصة	concepts	مفاهيم
human	بشري	motion	حركة	classification	تصنيف
repulsion	التنافر	formulate	يصوغ	context	سياق

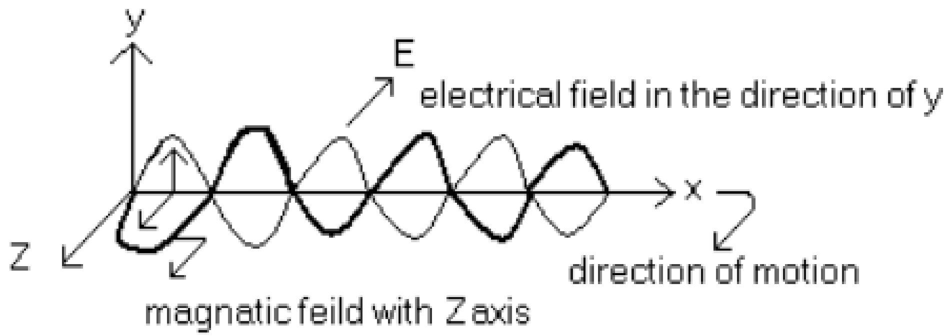
varicose veins	اوردة دوالي الساق
hemolytic	تكسر خلايا الدم الحمراء وتحرر الهيموغلوبين
dash padding	بطانة لينة ماصة للصدم
venous blood	الدم الوريدي (قليل الاوكسجين)
bone mineral	المحتوى المعدني للعظم
long-term bed rest	الراحة السريرية لفترة طويلة
long-term bed confinement	الاحتجاز السريري (بسبب حادث) لوقت طويل
long-term space flight weightlessness	انعدام الوزن في الطيران الفضائي لفترة طويلة
body orientation	توجيه الجسم
lever fulcrum, supported weight, and muscular force	نقاط ارتكاز العتلة،الوزن المسنود والقوة العضلية
(bone joints: shoulder elbow, wrist, fingers, hip, knee, ankle, toes, neck and spine)	(المفاصل العظمية: الكتف،المرفق،الرسغ،اصابع اليد، الورك ،الركبة،الكعب،اصابع القدم،العنق والعمود الفقري)
muscle's minimum and maximum lengths	الطول الادنى والطول الاقصى للعضله
rubber tyres and automobile brakes	العجلات المطاطية وموقفات المركبات

normal and horizontal components of a force	المركبات العموديه والافقية للقوة
centripetal and tangential components of velocity	المركبات المركزيه والمماسيه للسرعة
coefficient of friction	معامل الاحتكاك
centrifuge	جهاز التدوير الانتباذي
rotational velocity: rpm=revolution per minute	السرعة الدورانية:دورة بالدقيقة
red blood cells (RBC's)	كريات الدم الحمراء
white blood cells (WBC's)	كريات الدم البضاء
diagnosis of blood diseases	تشخيص امراض الدم
clinical (laboratory) tests	الفحوصات السريرية (المختبرية)
hematocrit	النسبة المئوية للكريات الحمراء في الدم
statics and dynamics	مبحثا البسكون والحركة في الميكانيك
{ acceleration, deceleration, torque (moment), momentum, deformation }	{ التسارع، التباطئ،العزم الدوراني، الزخم ،تغير الشكل(الانبعاج) }
electric current, potential difference	التيار الكهربائي،فرق الجهد
{ muscle contraction and stretching, upper arm, fore-arm, hand, thigh, leg, foot }	{ تقلص وانبساط العضلة، العضد والساعد والكتف والفخذ والساق والقدم }
inhale and exhale air	يستنشق ويزفر الهواء
slippery mucus covering	غطاء مخاطي زلق
genital organs	الاعضاء التناسلية
mucous membranes	الاغشية المخاطية
emergency cases	حالات الطوارى
removable cockpit cover	غطاء مقصورة الطيار يمكن ازالته اضطراريا
ejection seat	مقعد قذف
lack of blood flow	انعدام جريان الدم
probability of injury during emergency escape	احتمال الاصابة اثناء الهروب الاضطراري
RBC's sedimentation rate and hematocrit	معدل ترسيب كريات الدم الحمراء ونسبتها المئوية في الدم
diagnosis of blood diseases	تشخيص امراض الدم
upward (s), downward (s), forward (s), backward(s)	نحو الاعلى، الاسفل، الامام، الخلف
distinguishing features	ملامح مميزة
heart beats	ضربات القلب
circulation of blood	دوران الدم
launching manned space vehicles	اطلاق مركبات فضائية ماهولة
resonant frequency	تردد الرنين
audio and visual disturbances	اضطرابات سمعية وبصرية
terminal velocity	سرعة المنتهى
radius, radii, radial	نصف قطر،انصاف اقطار،نصف قطري
medicine, medical, medication	طب،طبي، تطبيب
dentistry, dental, dentist	طب الاسنان
proportional, inversely proportional	متناسب طرديا ،عكسيا
synovial fluid	مانع زلالي(لتقليل الاحتكاك في المفاصل)
heel of the foot	كعب القدم
spilt oil	زيت مسكوب
contact, and action-at-a-distance forces	القوى التماسية وقوى التاثير عن بعد
ascend, descend, and turn	يصعب، يهبط، يستدير

X – Rays

- X-Ray is an electromagnetic waves the same as light, radio waves, microwaves, ultraviolet and ɣ-ray.
- These electromagnetic waves are different by their energy for example ultraviolet has higher energy than visible light and infrared, ɣ-ray has higher energy than UV.
- X-ray is a high electromagnetic wave has higher energy than all electromagnetic waves except for ɣ-ray which has energy in the region of X-ray, the higher energy electromagnetic waves obviously has higher frequency and short wave length.
- In quantum physics these electromagnetic waves called photons (bundles or packs of energy) each pack of energy in one photon.

X – rays:- electromagnetic radiation (EMR) of very short wave length ($\lambda \angle 1 \rightarrow 0.1\ A^o$) & very high penetrating power. It is very useful in diagnosis & radio therapy.



The amount of energy carried by each photon depends on the frequency of radiation:

$$\mathbf{E = h\,\upsilon = h\,c / \lambda}$$

Where

h = Plan's constant = 6.6×10^{-34} (joule. sec)
c = velocity of light = 3×10^{8} m/sec
υ = frequency of radiation

X – rays production :

To produce photons of X – rays we need :

1. A filament (is a concave part of cathode) which is a source of electrons.
2. Target (anode) which is strike by the electrons which have a negative charged and these electrons are repelled by the cathode at attracted to the anode reaching it with very high kinetic energy.
3. High positive voltage applied between the cathode and anode to accelerate the negative electrons. In diagnostic radiography, this usually within the range 40 to 120 Kev.
4. An evacuated space (with low pressure 10^{-6} tor) : which is accelerate the electrons from the cathode to the anode.
5. The space between the tubes insert(the enveloped and electrode)and the shield is filled with oil, the oil converts heat from the insert to the tube shield(oil used to cool the target)

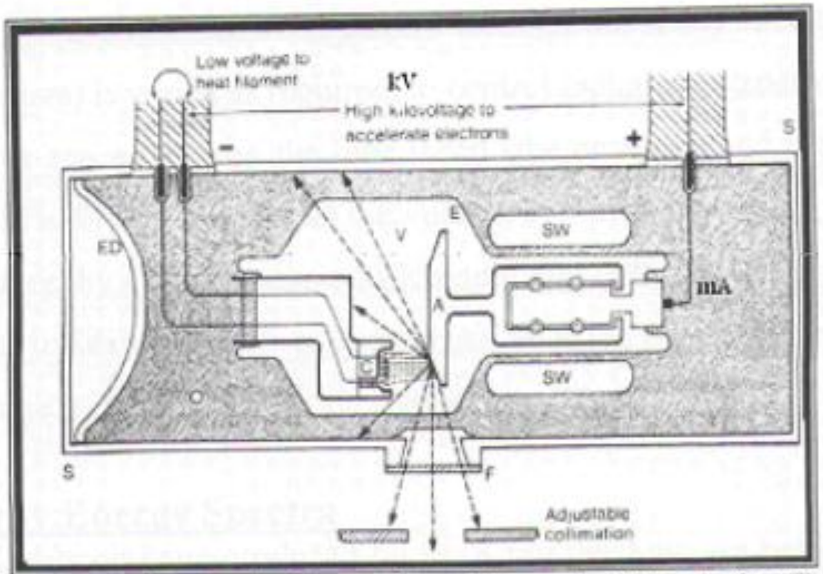


Figure. A rotating anode X-ray tube.: (A) anode; (C) cathode; (E) envelope; (V) vacuum; (SW) stator windings; (O) oil; (ED) expansion diaphragm; (F) aluminum filter; (S) shield[8].

NOTE: The energy of most electrons striking the target (99.8%) is dissipated in the form of heat. The remaining few energy (0.2%) produce useful X- rays.

X-ray Energy Spectra:

X-rays photons produced by an X-ray machine are heterogeneous in energy
The spectrum of x-rays produce by a modern x-ray generator is shown in figure, the broad smooth curve is due to the bremsstrahlung and the spikes represent the characteristic X-ray. Many of the low energy (soft) x-ray photons produced are absorbed in the glass walls of the x-ray tube.

* If no filtration inherent or added, of the beam is assumed, the calculated energy will be a straight line (shown as doted line in fig).

* The purpose of added filtration is to enrich the beam with higher energy photon by absorbing the lower energy components of the spectrum, and hence improving the penetration power of the beam.

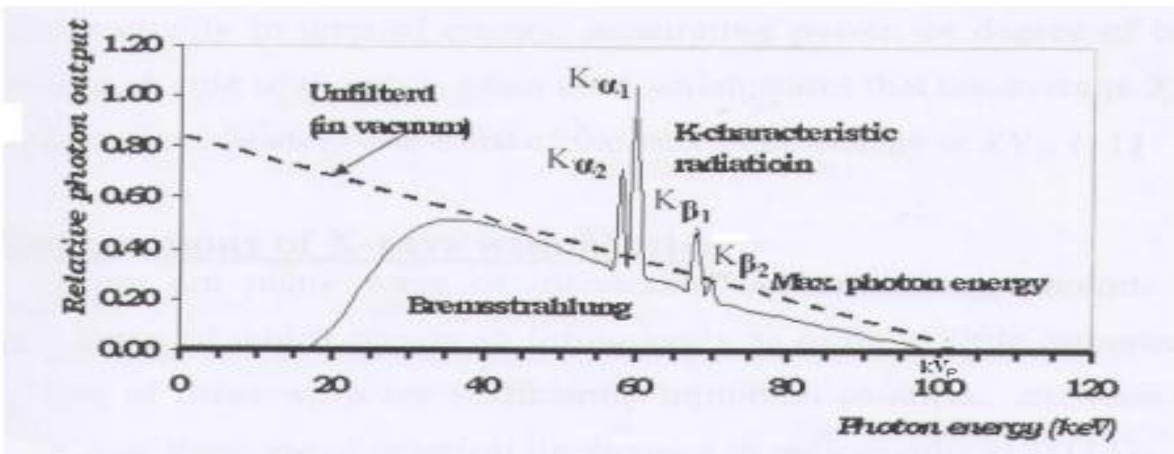
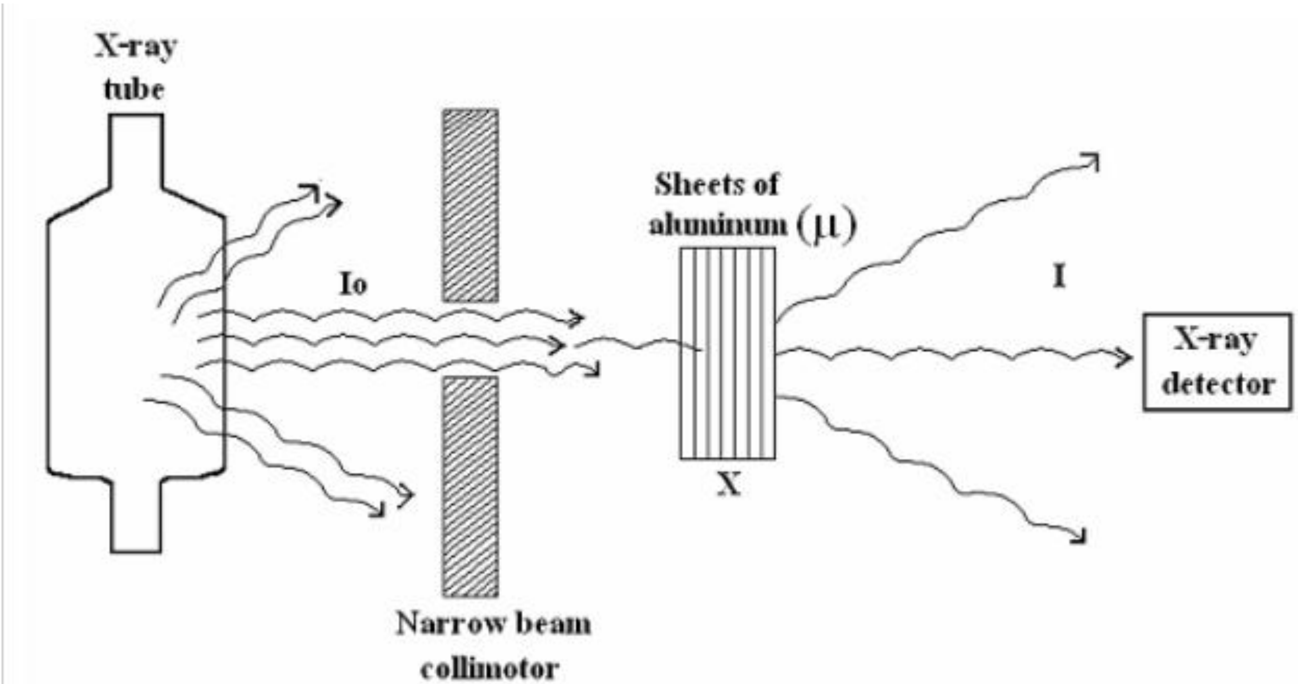


Figure: diagrams the energy of K-characteristic X-rays of tungsten, superimposed on the continuous spectrum (Bremsstrahlung)

Attenuation of X-rays:

Is the reduction of x-ray beam due to the absorption & scattering of some of photons of the beam.

* To measure the un attenuated (transmitted) beam intensity I, we use.



$$I = Io\ e^{-\mu x}$$

Where

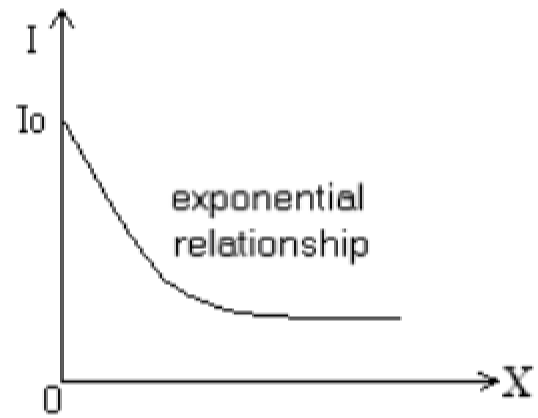
Io = initial beam intensity.

I = un attenuated (transmitted) beam intensity.

μ = linear attenuation Coefficient.

e = 2.718

x = Thickness of the attenuator such as (brain tumor, bone, aluminum)



Linear attenuation Coefficient (μ):

measure the probability that photon interact (absorbed or scattered) per unit length it travel in specified material.

It depends on:

1. energy of x-rays
2. atomic number (Z)
3. density (ρ) of material

Half value thickness HVT ($X_{1/2}$) : is the thickness of material which reduce the intensity of the beam of radiation one – half of its value (50%).

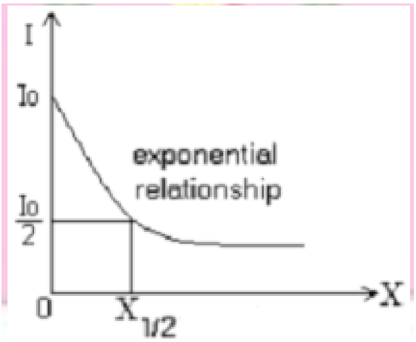


Figure. Transmitted intensity of x-ray versus the thickness of aluminum attenuator

At time $x = x_{1/2}$ then $I = (1/2)\, Io$

Substitute this condition in the equation

$$I = Io\, e^{-\mu x}$$
$$(1/2)\, Io = Io\, e^{-\mu X_{½}}$$
$$(1/2) = e^{-\mu X_{½}}$$
$$2^{-1} = e^{-\mu X_{½}}$$

By taking Ln of both sides we get:

$$-\operatorname{Ln}(2) = -\mu X_{1/2} \times \operatorname{Ln} e$$
$$0.693 = \mu X_{1/2} \times 1$$
$$X_{1/2} = 0.693 / \mu$$

Biological Effects :

Mass attenuation – coefficient :a portion of X-ray energy that will be absorbed by the biological material & can produce changes at the cellular level.
The mass attenuation coefficient **(μ/ρ)** is obtained by dividing the linear coefficient by the density of the material. Therefore independent of density and depends only on the atomic number and photon energy.

$$\mu_m = \mu / \rho$$

There for the equation

$$I = Io\ e^{(-\mu/\rho).\rho x}$$

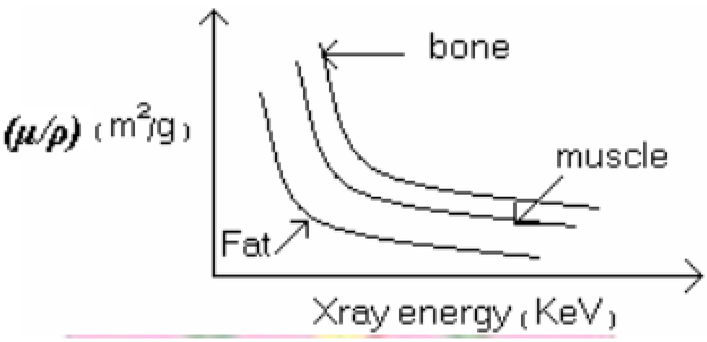


Figure. Mass attenuation coefficient (μ/ρ) for various tissues

Interaction of X-rays with matter:

There are three types of interaction between X-ray with matter contribute to attenuation.

1. Photoelectric effect (P.E)

The photoelectric effect is one way x-ray lose energy in the body. It occur when the incoming x-ray photon transfers all of its energy to an electron which escapes from the atom (Fig).
P.E is more apt to occur in the intense electric field near the nucleus than in the outer levels of atom and it is more common elements with high (Z) than in those with low Z.
When the energy of the x-ray is just slightly greater the binding energy of electron, the probability that P.E effect will occur increase.

In the other word :

The energy of the photon is completely absorbed by the electron(e^-). The (e^-) eject out of the atom & the atom will be positive ion.
Probability of photon electric occur at low X-rays energies.
It usually occur at a high atomic number (Z) of material. e.g. :-

Muscles ≤ 30 KeV
Bone ≤ 50 KeV

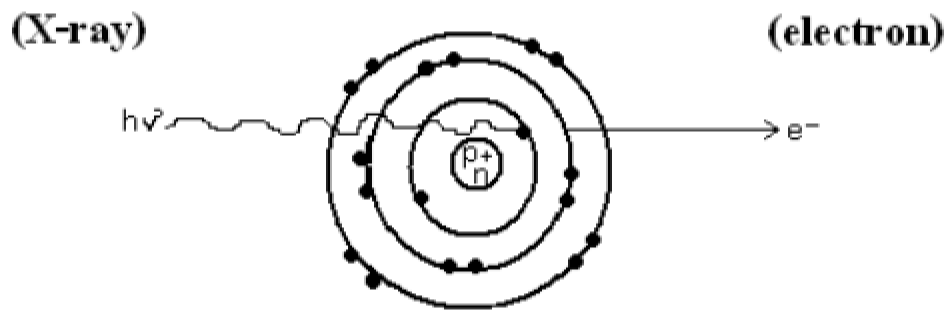


Figure. X-ray lose energy in the photoelectric effect

2-Compton effect (C.E):

Another important X-ray lose energy in the body is done by C.E. Compton suggested that an X-ray photon can collide with loosely bound outer electron much like a billiard ball collides with another billiard ball.

At the collision, the electron receives part of energy and the remainder is given to a Compton scattered photon ,which then travels in a direction different from that of the original x-ray(figure)

In the other word :

The energy of the photon is partially absorbed by the electron (e^-) which is ejected out of the atom, the atom will be positive ion

The energy of a photon is reduce from hυ to hύ ,and they scattered in different direction.

C.E. occur greatest at low Z material. e.g. :-

* In water or soft tissue C.E. is more probable occur than P.E effect at energy ≥ 30 KeV.

* In bone C.E. is more probable occur than the P.E. effect at energy ≥ 100 KeV.
* At 30 kev bone absorbed x-ray about 8 times better than tissue due to P.E effect.

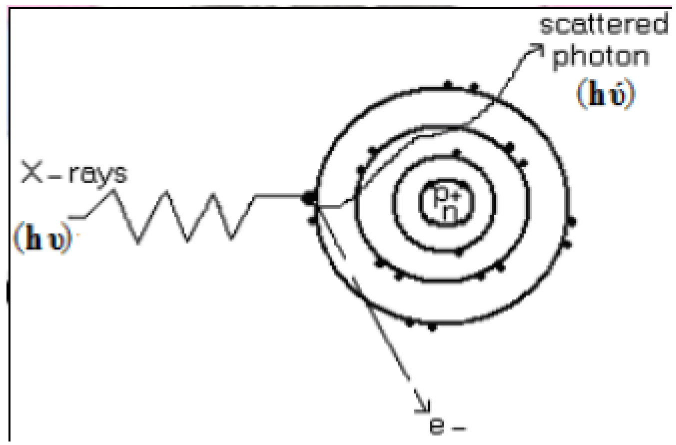


Figure. X-ray lose energy in the Compton effect

3. Pair Production (P.P):

P.P is the third major way x-ray give up energy. When a very energetic photon enters the intense electric field of the nucleus ,it may converted into two particles an electron and positron **(β)**(positive electron).
Providing the mass of the two particles requires a photon with an energy of at least 1.02 Mev and the remainder of the energy over 1.02 Mev is given to the particles as kinetic energy.

After it has spent its kinetic energy in ionization it does a death dance with an electron Both then vanish ,and their mass energy usually appear as two photon of 511 kev each called annihilation radiation.
Since a minimum of 1.02 Mev is necessary for P.P,this type of interaction is only impotent at very high energies.

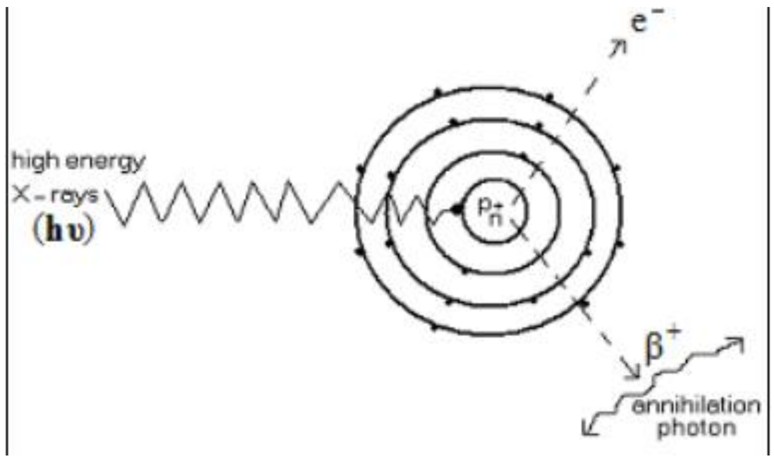


Figure. X-ray lose energy in the pair production

* **P.P.** is more apt occurs in high Z element than low Z element.
* **P.P.** is no use diagnostic radiology because of high energy needed .
* **P.E.** is more useful used in diagnostic than Compton effect because it need low energy and primate us to see bone & other heavy material such as bullets in the body.

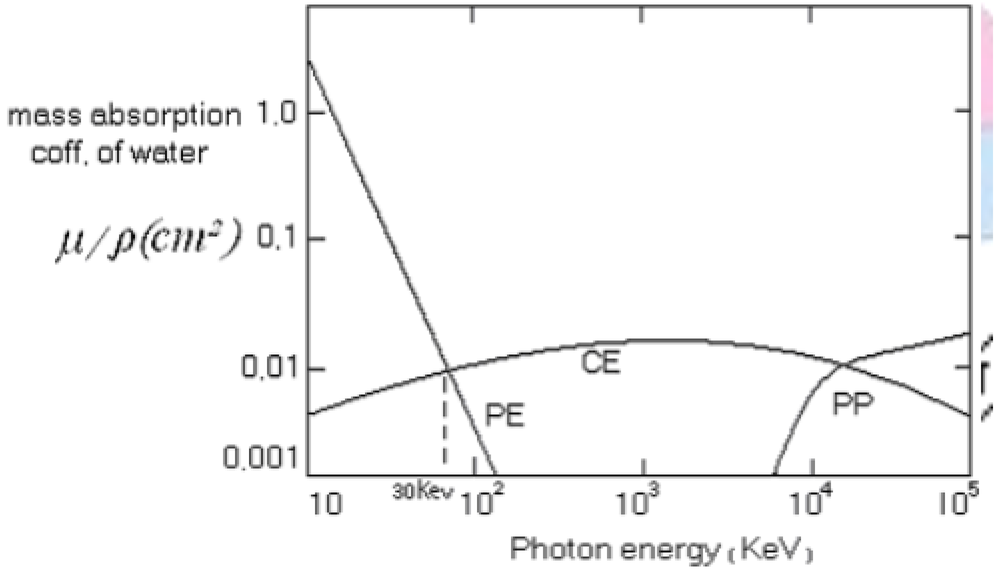


Figure. Mass absorption coefficient for water.

(P.E. and C.E. are about equally probable at about 30 kev, P.P. occurs only at high energies and is of no important in diagnostic radiology.)

Photographic process:

as follows :

1. **Development** :Immerse the exposed film in the developer solution to free the silver atoms in those grains which have received sufficient exposure & contain latent image center.
2. **Fixing** : Fixing to neutralize the developer on the film & stop the developing action.

3. **Washing** : the film washed in running water to remove the fixing chemicals &dissolve silver halides.
4. **Drying** :The final step in processing is to dry the radiograph, and this is done by blowing warm dry air over both surfaces of the film as it is transported through the drying chamber.

* The total sequence the events involved in manual processing requires over 1hr.
* Most modern automatic processors are identified as 90 sec.

Operational Model

First-Generation Scanners

The previous description of a finally collimated X-ray beam-single detector assembly translating across the patient and between successive translations is characteristic of early CT designs. These are now called First-generation CT scanners
The original EMI scanner required 180 translations, each separated by a 1 degree rotation
*Scan time for first generation units was almost 5 minutes.

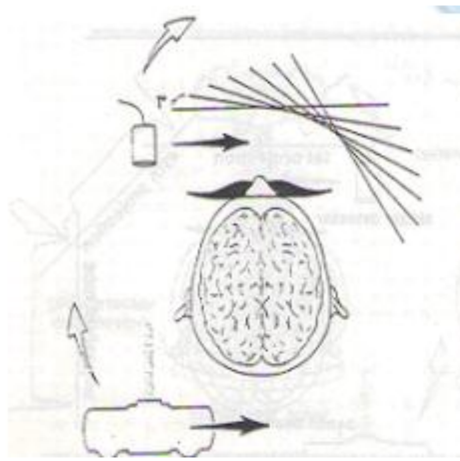


Fig. 4-4. First-generation CT scanners used a pencil x-ray beam and a single detector moving in the translate-rotate mode. A single slice image is generated following many such motions.

Second-Generation scanner

Were also of the translate-rotate type, but these units are no longer produced. These units incorporated the natural extension of the single detector to a multiple detector assembly intercepting a fan-shaped rather than a pencil beam.

* The principal limitation of second-generation CT scanner was examination time, most units were designed for scans times of 20 s or more

.

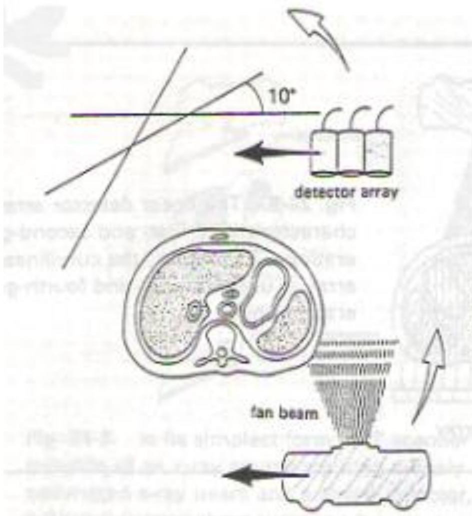


Fig. 4-6. Second-generation scanners operated in the translate-rotate mode with a multiple detector array intercepting a fan-shaped x-ray beam.

Third-generation scanners

Third-generation scanners evolved in which the X-ray tube and detector array were rotated concentrically about the patient. As rotate-only units, third generation scanners accommodate scan times as low as 1 s.

* The third-generation scanner employs a curvilinear detector array containing at least thirty elements and a fan beam. The number of detectors and the width of the fan beam, between 30 and 60 degree

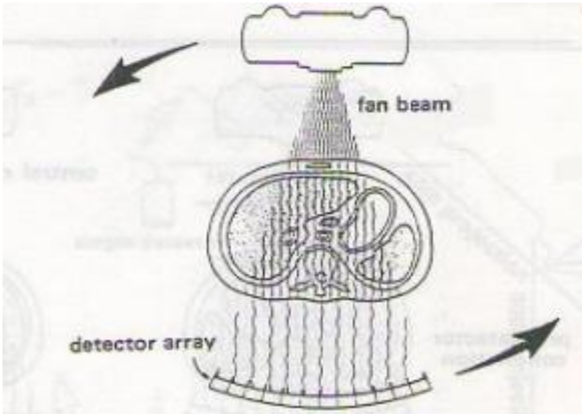


Fig. 4-7. Third-generation CT scanners operate in the rotate-only mode with a fan x-ray beam–multiple detector array revolving concentrically around the patient.

Fourth-Generation Scanners

The fourth-generation design for CT scanner is, as for those of the third generation, a rotate-only motion

* With fourth-generation machines, however, the X-ray source rotates but the detector assembly does not. Radiation detection is accomplished through a fixed circular array of detectors, which contains as many as 1000 individual elements.

* These units are capable of 1 s scanning times.

* The principal disadvantage of fourth-generation machines appears to be patient dose, which is somewhat higher than that with other types of scanners.

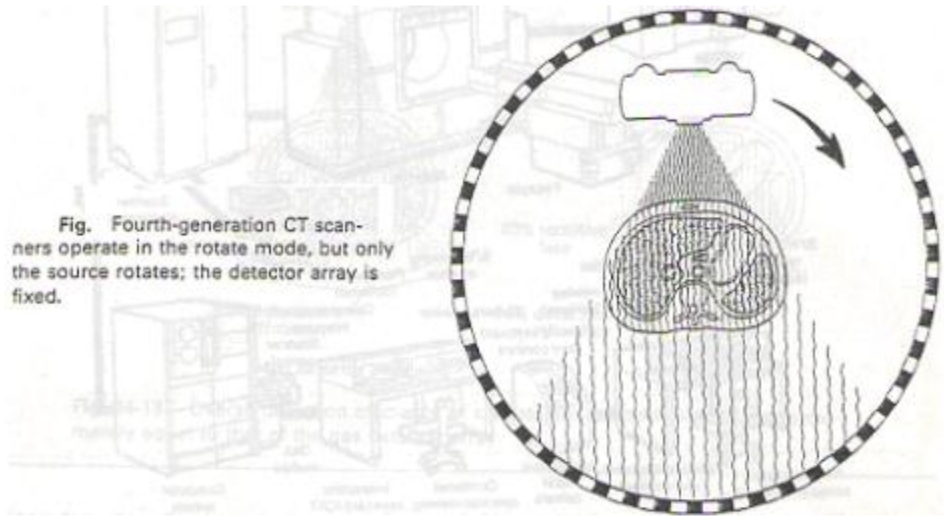


Fig. Fourth-generation CT scanners operate in the rotate mode, but only the source rotates; the detector array is fixed.

Pressure

Introduction:

Pressure is defined as the force per unit area in a gas or liquid. For a solid the quantity force per unit area is referred to as stress. In the metric system pressure is measured in dynes per square centimeter (Dy/cm^2) or Newton per square meter (N/m^2) or Pascal (Pa).

If the unit is Dy/cm^2

$P = \rho g h$ ρ = **density of liquid (g/cm^3)**
$g=980(cm/sec^2)$ acceleration of gravity
h= in (cm) the height of liquid

Or the unit is N/m^2

$P = \rho g h$ $\rho = (kg/m^3)$
$g= 9.8\ m/sec^2$
h= In (m)

Example -1-

Find the pressure of 10 m of water in Dy/cm^2 and N/m^2?

$10 \times 100 = 1000$ cm 1m=100cm

$\therefore\ P = \rho g h = 1\times980\times1000 = 980000 = 9.8\times10^5\ Dy/cm^2$

$P = \rho g h = 1000 \times 9.8 \times 10 = 9.8\times10^4\ N/m^2$

The most comm0n method of indicating pressure in medicine is by the height of a column of mercury (Hg). For example, a peak (systolic) blood pressure reading of 120 mmHg indicates that a column of mercury of this height has a pressure at its base equal to the patient's systolic blood pressure.

Example -2-

Calculate the systolic pressure in Dy/cm^2 and N/m^2?

In systolic pressure =120 mmHg=12 cmHg

= 0.12 m Hg

$\therefore\ P = \rho_{Hg}\, g\, h_{Hg} = 13.6\times980\times12 = 159936 = 1.6\times10^5\ Dy/cm^2$

$P = \rho_{Hg}\, g\, h_{Hg} = 13600\times9.8\times0.12 = 1.6\times10^4\ N/m^2$

Manometer: This is a U-shaped tube containing a fluid that is connected to the pressure to be measured, The levels in the arms change until the different in the levels (h) is equal to the pressure.

*** this type of manometer can measure both (positive) and (negative) pressure.**

*** The fluid used can be:**

1. Mercury for high pressure measurements.
2. Water or other low density fluid for low pressures.

P_0= atmospheric pressure
h= height of liquid
P=the pressure of container.

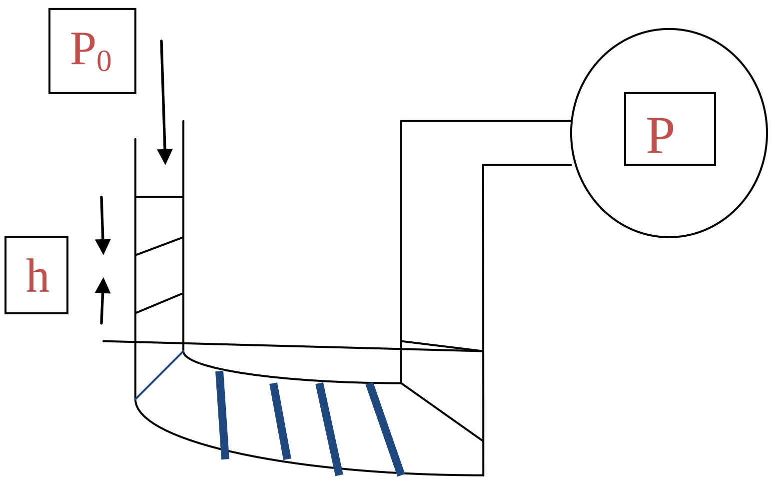


Fig (1)

Figure. A U tube manometer for measuring pressure P.P can be expressed as the height of the fluid**.**

Sphygmomanometer: is the clinical instrument used for measuring the blood pressure. It can be provided by one of two types of gauges.

1- Mercury gauge: the pressure is indicated by the height of mercury inside a glass tube.
2-Aneroid type: the pressure changes the shape of a sealed flexible container, which cause a needle to move on a dial.

Gauge pressure :is defined as the excess pressure over atmospheric pressure.

Gauge pressure $=\rho\, g\, h$

$=1000 \times 9.8 \times 10$

$=10^5\ N/m^2 = 1\ atm$

Absolute pressure=atmospheric pressure+gauge pressure

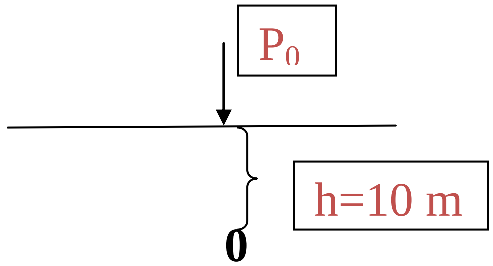
$=1+1=2\ atm$

Or In N/m^2

$=10^5+10^5=2\times 10^5\ N/m^2$

Atmospheric pressure $=\rho_{Hg}\, g\, h_{Hg} = 13600 \times 9.8 \times 0.76$

$=10^5\ N/m^2$



Negative pressure:

• Any pressure lower than atmospheric pressure. For example: The lung pressure during inspiration is a few centimeter of water negative ,a person drink through a straw the pressure in his mouth must be negative.

• There are numbers of places in the body where the pressure is lower than atmospheric pressure or negative .For example when we breath inspire the pressure in the lungs must be lower than the atmospheric pressure .

The most common clinical instrument used in the measuring pressure is the sphygmomanometer, which measure s blood pressure.

Typical pressure in the normal body:

Different parts of the body	**Typical pressure(mmHg)**
Arterial blood pressure Max.(systole)	100 - 140
Min.(diastole)	60 - 90
Venous blood pressure	3 - 7
Middle ear pressure	less than 1
Eye pressure	20
CSF inside the brain	5 - 12

Measurement of pressure in the body An instrument that measures pressure is called a manometer.
The common clinical instrument used in measuring pressure is thesphygmomanometer .Two types of pressure gauges are used in sphygmomanometer, they are

Pressure inside the skull :

The brain contains approximately(150 cm3) of cerebrospinal fluid (CSF) in a series of interconnected opening called ventricles.

CSF is generated inside the brain and flows through the ventricles into the spinal column and eventually into the circulatory system.

* If at birth the narrow opening of the ventricle (aqueduct) is blocked then the CSF is trapped inside the skull and hence increases the internal pressure and causes the skull to enlarge (A case named hydrocephalus).

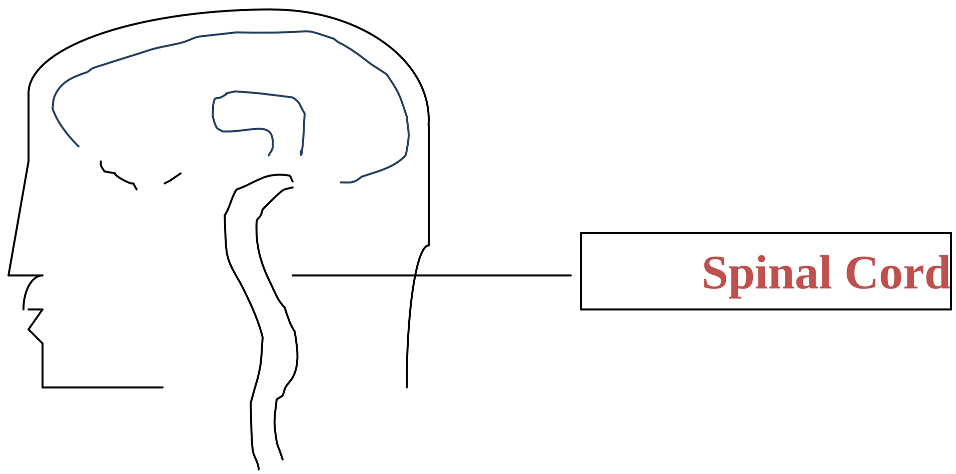
*** There are two methods to detect hydrocephalus :**

1. By measuring the circumference of the skull just above the ears.
2. Transillmination making use of light-scattering properties of the clear CSF inside the skull.

Measurement of hydrocephalus

1- Crude method: - In this method the circumference of the skull just above the ears .Normal values of newborn infants are from (32-37 cm) , and larger than this may indicate hydrocephalus.

2- qualitative method (transillumination):-
In this method light – scattering properties is used.


Spinal Cord

Eye pressure

The clear fluids in the eyeball (the aqueous and vitreous humors) that transmit light to the retina are under pressure

* This pressure maintain the eyeball in a fixed size & shape. →A change of only 0.1 mm in the eye diameter has a significant effect on the clarity of vision.

* The pressure in normal eyes range from 12 to 23mm Hg.

* The eye continuously produces aqueous humors and a drain system allows escaping. If the pressure increased due to a partial blockage then the blood supply to the retina will be restricted and thus affecting vision (glaucoma) which produce tunnel vision in moderate cases and blindness in sever cases.

Ton meters:

These are instruments used for measuring the amount of indentation produced by a certain force

.

Pressure in the digestive system:

The digestive system is an opening through the body with about 6 meter length from the mouth to anus

* It has several values and sphincters (circular muscles) which open for the passage of food, drink, and their by-products, in a unidirectional flow.

<u>Esophagus:</u>

The pressure is less than the atmospheric because it is coupled to the pressure between the lungs and chest wall (intra-thoracic pressure).

<u>Stomach:</u>

The pressure is higher than the atmospheric pressure because of the stretching of the stomach walls and due to air swallowed during eating.

<u>Gut:</u>

gas flatus generated by the bacterial action increases the pressure, and hence it is higher the atmospheric.

* Occasionally a blockage forms in the small or large intestine and a pressure build up between the blockage and the pylorus.

If this pressure becomes great enough to restrict blood flow to critical organs, it can cause death. And can be solved by:

1. **Intubation: -** passing of a hollow tube through nose, stomach, and pylorus.
2. **Surgry: -** chosen when the intubations don't work**.**

Pressure in skeleton:

This is the highest pressure that can be found in the body-for example when all the weight of the body is on one leg, such as when walking, the pressure in the knee joint may be more than 10 atmospheres!!

***** The surface area of a bone at the joint is greater than its area either above or below the joint. The larger area at the joint distributes the force, thus reducing the pressure

Example: The surface area of a bone at the joint is greater than its area either above or below the joint.

* Healthy bone joints are better lubricated than the best man-made bearings. The human joints system is such that; the higher pressure → the better lubrication.

Pressure in the urinary bladder :

The internal pressure in the bladder is due to the accumulation of the urine. The figure below shows the typical pressure - volume curve for the bladder, which stretches as the volume increase.

Pressure H_2O cm

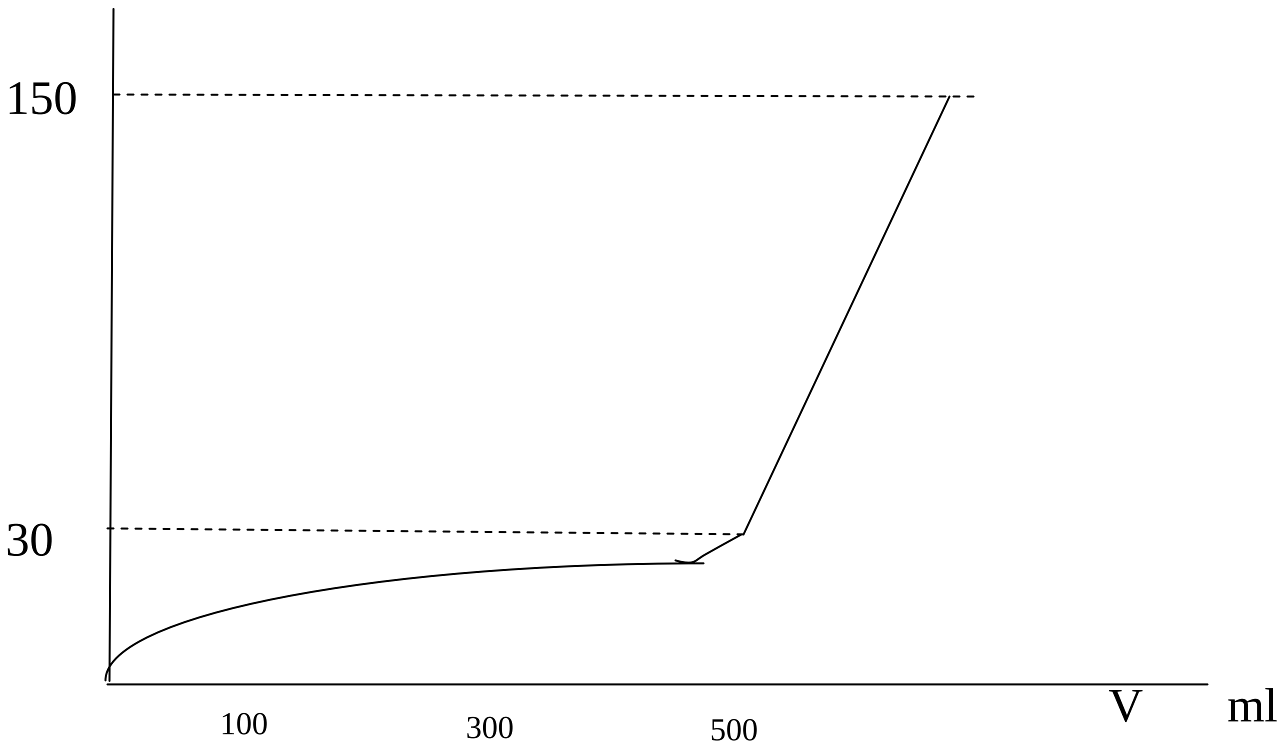


Fig 2 :Pressure in the Urinary bladder

The above relationship accounts for the relatively low slope in the major portion of the figure.

→ For adults, the typical maximum volume of the bladder before voiding is 500 ml and at some pressure (~ 30 cm H_2O) the micturation reflex occurs

→ The resulting sizable muscular contraction in the bladder wall produce a momentary pressure up to (150cm H_2O.)

→ Normal voiding pressure is fairly low (20 to 40 cm H_2O) but for men who suffer from prostatic obstruction of the urinary passage it may be over 100 cm H_2O.

Measurement:

1. The pressure in the bladder is measured by passing a catheter with a pressure sensor to the bladder through the urinary passage (Urethra).

2. Direct cystometry: A needle is inserted through the walls of the abdomen directly to the bladder

Hyperbaric Oxygen Therapy (HOT):-

The body normally lives in an atmosphere that is about one fifth O_2 and four – fifth N_2. In some medical situations it is beneficial to increase the proportion of O_2 in order to provide more O_2 to the tissue.

1- Gas gangrene :-

The bacillus causes gas gangrene then its treated with (HOT) . That is due to bacillus cannot survive in the presence of oxygen (O_2).

2- Carbon Monoxide poisoning :-

- The red blood cells cannot carry O_2 to the tissues because the carbon monoxide fasters to the hemoglobin at the places normally used by O_2.
- Normally the amount of O_2 dissolved in the blood is about 2% of that carried on the red blood cells.
- By using the (HOT) technique , the partial pressure of O_2can be increased by a factor of 15, permitting enough O_2 to be dissolved to fill the body's need .

3- Treatment of cancer :-

(HOT) with radiation is given to the patient in transparent plastic tank. The theory was that more oxygen would make the poorly oxygenated radiation-resistant cell in the center of the tumor more susceptible to radiation damage .

Q: If the pressure of a man is 8 cm Hg, Does the man have prostate or not?

A/: $P_{Hg} = P_{Water}$

$Pgh_{Hg} = \rho gh_{water}$

The (g) is canceled from both sides

$13.6 x 8 = 1 x h_{water}$

$H_{Water} = 108.8$ cm.so the man has prostate

Note:

- ▲ If $h_{water} = 100$…..the man has prostate
- ▲ If $h_{water} > 100$…..the man has prostate
- ▲ If $h_{water} < 100$…..the man is normal

Kut University College
Department of Dentistry

Lec. Rusul Saeed
First Year
Lecture: 3

Sound in medicine

Sound :

It is the audible waves of frequency between 20 Hz and 20 kHz.

Infrasound : refers to the sound of frequency below the normal hearing range (<20 HZ) and subsonic (0) to (20 HZ) which cannot be heard.

Ultrasound : It ranges above 20 kHz ,which is also cannot be heard.

General Properties of Sound:

A sound wave is a mechanical disturbance in a gas, liquid, or solid that travels outward from the source with some definite velocity. We can use a loudspeaker vibrating back and forth in air at a frequency f to demonstrate the behavior of sound. The vibrations cause local increases and decreases in pressure relative to atmospheric pressure. These pressure increases, called compressions, and decreases, called rarefactions, spread outward as a longitudinal wave, that is, a wave in which the pressure changes occur in the same direction the wave travels.

The relationship between the frequency of vibration f of the sound wave, the wavelength , and the velocity v of the sound wave is (v= f).

Energy is carried by the wave as potential and kinetic energy. The intensity I of a sound wave is the energy passing through 1m2 /sec, or watts per square meter. For a plane wave I is given by: -

$$I = \frac{1}{2}\rho v A^2 (2\pi f)^2 = \frac{1}{2} Z(A\omega)^2$$

Where is the density of the medium; v is the velocity of sound; f is the frequency; is the angular frequency, which equals 2πf.
A is the maximum displacement amplitude of the atoms or molecules from the equilibrium position; and Z, which equals (ρ × v) is the acoustic impedance. The intensity can also be expresses as: -

$$I = \frac{P_o^2}{2Z}$$

Where Po is the maximum change in pressure

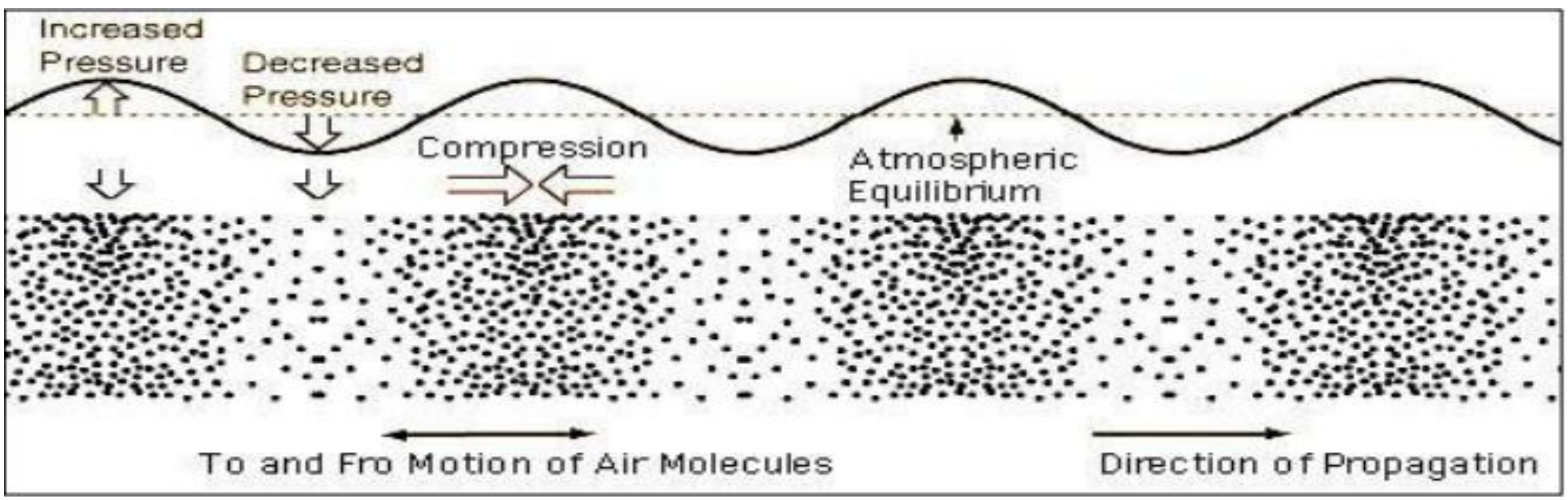


Figure: sound wave compression and rarefaction

Example1:-

a. The maximum sound intensity that the ear can tolerate at 1000Hz is approximately 1W/m2 . What is the maximum displacement in air corresponding to this intensity?
(ρ air=1.29kg/m3), (v =3.31x102m/sec).

$$A = \frac{1}{2\pi f} \times \sqrt{\left(\frac{2I}{Z}\right)}$$

$$A = \frac{1}{2\times3.14\times1000} \times \sqrt{\frac{2\times1}{1.29\times3.31}}$$

$$A = 1.1 \times 10^{-5} m$$

b. The faintest sound intensity the ear can hear at 1000Hz is approximately10-12W/m^2 . What is A under these conditions?

$$\frac{A_b}{A_a} = \left(\frac{I_b}{I_a}\right)^{1/2}$$

$$A_b = A_a\left(\frac{I_b}{I_a}\right)^{1/2} = 1.1 x10^{-5}\left(\frac{10^{-12}}{10^{0}}\right)^{1/2} = 1.1 x10^{-11} m$$

c. Calculate the sound pressures for cases a and b.

$$P_o = \sqrt{2ZI}$$

$$P_{oa} = \left[(2)x430x(1)\right]^{1/2} = 29\,N/m^2$$

$$P_{ob} = [(2)x430x(10^{-12})]^{1/2} = 2.9x10^{-5}\,N/m^2$$

A special unit, the bel , has been developed for comparing the intensities of two sound waves (I_2/I_1). This unit was named after Alexander Graham Bell, who invented the telephone . The intensity ratio in bels is equal to log10 (I_2/I_1). Thus of one sound is ten times more intense than another, (I_2/I_1)=10, since log10 10 = 1, the two sound intensities differ by 1 bel. Because the bel is a rather large unit, it is common to use the decibel (dB) in comparing two sound intensities (1bel = 10dB).

Sound intensity level (db) =10 log (I_2/I_1)

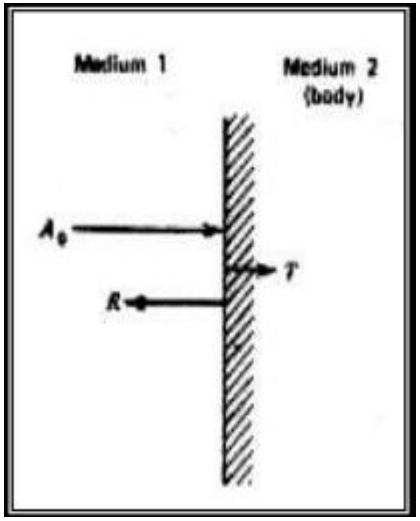
Since I is proportional to P^2, the pressure ratio between two sound levels can be expressed as 10 log10 (P_1^2/P_2^2), or 20 log10 (P_2/P_1). For hearing tests, it is convenient to use a reference sound intensity (or sound pressure) to which other sound intensities can be compared .The reference sound intensities I° or(I1) is 10-16 W/cm^2 (10-12W/m^2);P °=2 ×10-4 dyne/cm^2 .

Table : Approximate intensities of various sounds

	Intensity (W/m^2)	Sound intensity level(db)
Sound that is barely perceptible	10^{-12}	0
Whisper	10^{-10}	20
Average dwelling	10^{-9}	30
Business office	10^{-7}	50
Speech at 1 m	10^{-6}	60
Busy street	10^{-5}	70
Subway or automobile	10^{-3}	90
Sound that produces pain	10^{0}	120
Jet aircraft	10^{1}	130
On rocket launch pad	10^{5}	170

Table : gives the intensities of some typical sound in terms of this reference value. The most intense sound that the ear can tolerate without pain is about 120dB.

When a sound wave hits the body, part of the wave is reflected and part is transmitted into the body. The ratio of the reflected pressure amplitude R to the incident pressure amplitude Ao depends on the acoustic impedances of the two media, Z_1 and Z_2
. The relation is: -



$$\frac{R}{A_o} = \frac{Z_2 - Z_1}{Z_1 + Z_2}$$

For a sound wave in air hitting the body, Z_1 is the acoustic impedance of air and Z_2 is the acoustic impedance of tissue. The ratio of the transmitted pressure amplitude T to the incident wave amplitude Ao is: -

$$\frac{T}{A_o} = \frac{2Z_2}{Z_1 + Z_2}$$

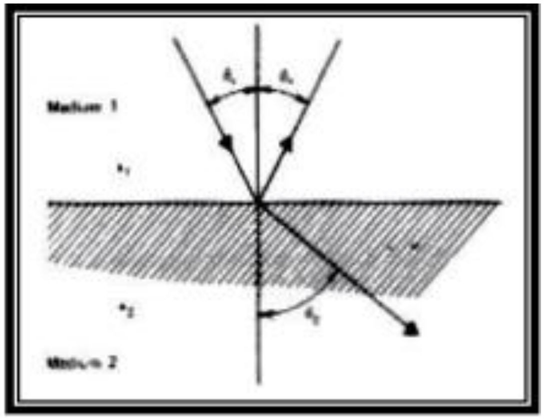
$$\frac{R}{A_o} = \frac{Z_2 - Z_1}{Z_1 + Z_2} = \frac{1.64x10^6 - 430}{1.64x10^6 + 430} = 0.9995$$

$$\frac{T}{A_o} = \frac{2Z_2}{Z_1 + Z_2} = \frac{2(1.64x10^6)}{1.64x10^6 + 430} \approx 1.9995$$

Example2:- Calculate the ratios of the pressure amplitudes of the reflected and transmitted sound waves from air to muscle (Z_1=430kg/m^2 .sec), and (Z_2=1.64x106 kg/m^2 .sec).

Choosing materials with similar acoustic impedances is called impedance matching. Getting sound energy into the body requires impedance matching. The geometric laws involving the reflection and refraction (bending) are the same as for light. This means that ɵ incident =ɵ reflected, or (ɵ i = ɵr). The angle of the refracted sound wave θ_2 is determined by the velocities of sound in the two media v_1 and v_2 from the equation: -

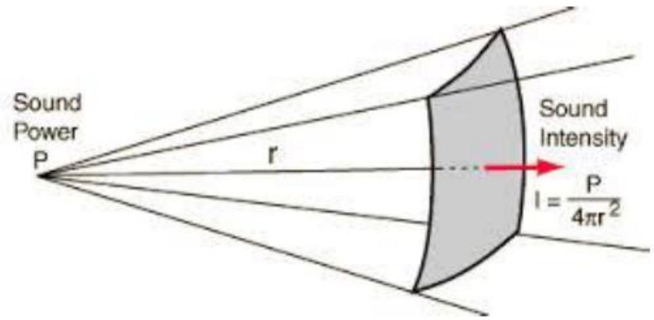
$$\frac{\sin\theta_i}{v_1} = \frac{\sin\theta_2}{v_2}$$



When a sound wave passes through tissue, there is some loss of energy due to frictional effects. The absorption of energy in the tissue causes a reduction in the amplitude of the sound wave. The amplitude A at a depth x cm in a medium is related to the initial amplitude Ao (x=0) by the exponential equation ($A=A_0\, e^{-\alpha x}$) where α, in cm^{-1} , is the absorption coefficient for the medium at a particular frequency.

Since the intensity is proportional to the square of the amplitude, its dependence with depth is ($I=I_0 e^{-\alpha x}$) where Io is the incident intensity at x=0 and I is the intensity at a depth x in the absorber.

Sound intensity



The two types of ultrasound employed in diagnostic are:

1. continuous wave
2. pulsed wave.

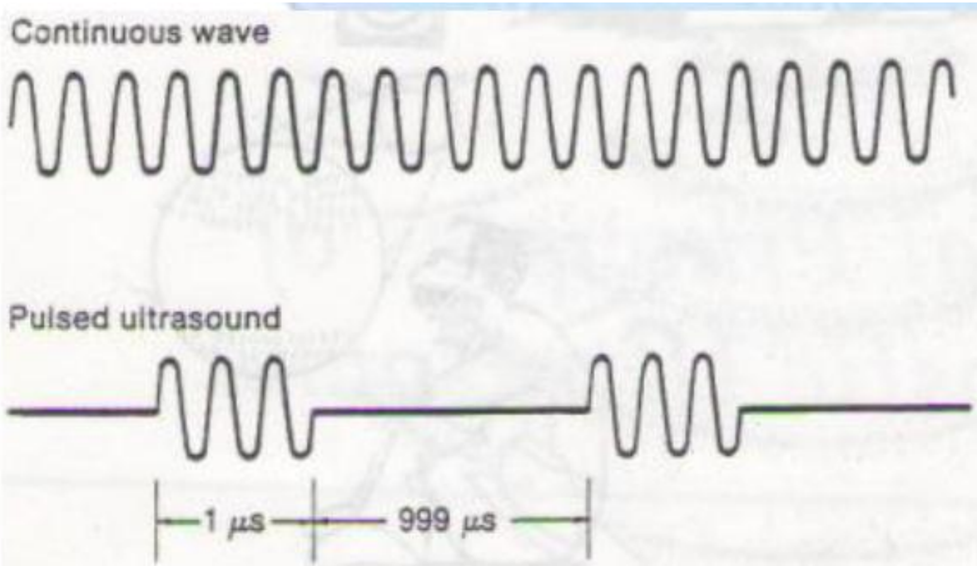


Fig. 6-2. Both continuous-wave and pulsed ultrasound are employed in medical diagnostic ultrasound.

Figure : shows the difference between these types of emission.

Ultrasound pictures of the body :

Human ears respond to sound in the frequency range of about 20-20000 Hz, although many animals can produce and hear sounds of considerably higher frequencies. For example, bats emit blips of ultrasonic frequencies (30 to 100 kHz) and navigate by listening to the echoes. It was discovered during World War II that man can use ultrasound in much the same way bats can, The navy developed sonar (SOund , NAvigation and Ranging), a method of locating under water objects, such as submarines, with ultrasound echoes.

After World War II medical engineers developed techniques for using ultrasound in diagnosis. Basically, an ultrasound source sends a beam of pulses of 1 to 5 MHz sound into the body. The time required for the sound pulses to be reflected gives information on the distance to the various structures or organs in the path of the ultrasound beam. While there are several methods of generating ultrasound, the most important for medical applications involves the piezoelectric effect. This effect was discovered by Jacques and Pierre Curie in about 1880.

A device that converts electrical energy to mechanical energy or vice versa is called a transducer. Ultrasound generators are often simply referred to as transducers. Each transducer has a natural resonant frequency of vibration. The thinner crystal, the higher the frequency at which it will oscillate. Pulses of ultrasound are transmitted into the body by placing the vibrating crystal in close contact with the skin, using water or a jelly paste to eliminate the air. This gives a good coupling at the skin and greatly increases the transmission of the ultrasound into the body and of the echoes back to the detector.

The same transducer that produced the pulse serves as the detector. The weak signals are then amplified and displayed on an oscilloscope. Many of the applications of ultrasound in medicine are based on the principles of sonar. In sonar a sound wave pulse is sent out and is reflected from an object; from the time required to receive the echo and the known velocity of sound in water, the distance to the object can be determined.

To obtain diagnostic information about the depth of structures in the body, we send pulses of ultrasound into the body and measure the time required to receive the reflected sound (echoes) from the various surfaces in it. This procedure is called the A Scan method of ultrasound diagnosis.

It must be remembered that the basis for the use of ultrasound in medicine is the partial reflection of sound at the surface between two media that have different acoustical properties. The amount of the reflection depends primarily upon the difference in the acoustical impedances of the two materials and the orientation of the surface with respect to the beam. In many diagnostic uses of ultrasound the echoes are very small signals due to weak reflection and the absorption of the sound by tissue.

The Medical Applications of Sound

1. The intensity of ultrasound used for medical diagnostic(التشخيص الطبي) is kept low to avoid tissue damage. Intensities of about 10^{-2} w/m^{2} are used and seem to cause no ill effects.
2. . Ultrasound of considerably higher intensity is used for therapeutic purposes. Ultrasound diathermy is deep heating using(التسخين العميق) ultrasound of intensities 1- $10 W/m^{2}$

3. Ultrasonic sound waves sent into the body are Doppler shifted by any motion in the objects that reflect them. It is possible, for example, to measure blood velocity(سرعة الدم) by observing the Doppler shift of ultrasound reflected from the blood cells. More commonly, the Doppler shift of ultrasound is used to monitor the fatal heart motion.
4. The ultrasound used for sterilization (تستخدم الموجات الفوق الصوتيه في التعقيم) because it kills the virus and bacteria.
5. It is also used as massage tool for muscles (تدليك العضلات) , cure the cancer (علاج السرطان) destruction the kidney stone (تدمير الحصى في الكلى)
6. Many devices use ultra-sonic sound, like toothbrushes (فرشات الاسنان الفائقة الصوتية) Sonic denture cleaner (نظافه الاسنان) or sonic cleaning device eliminates lime scale deposits.
7.

The production of speech (Phonation):

Normal speech sounds are produced by modulating an outward flow of air. For most sounds the lungs furnish the stream of air, which flows through the vocal folds (cords), sometimes called the glottis, and several vocal cavities and exits from the body through the mouth and to a slight degree through the nostrils. The speech sounds produced in this way are called voiced sounds. Some sounds are produced in the oral portion of the vocal tract without the use of the vocal folds-these are called unvoiced sounds

Heat and Cold in Medicine

Heat and low temperature:

As molecules of all materials are moving so they have kinetic energy. The average kinetic energy of an ideal gas can be shown to be directly proportional with temperature. The same thing is for liquids and solids .The movement of gas molecules are more free than liquid and liquid molecules are more free than solid , an increase of temp. of any material means an increase in the energy of molecules of that material.

In order to increase the temp. of a gas it is necessary to increase the average kinetic energy of its molecules by putting the gas in contact with a flame , the energy transferred from the flame to the gas causing temp. rise is called heat.

If enough heat added to a solid, it melts, forming a liquid. The liquid may be changed to a gas by adding more heat. Adding still more heat converts gas to ions.

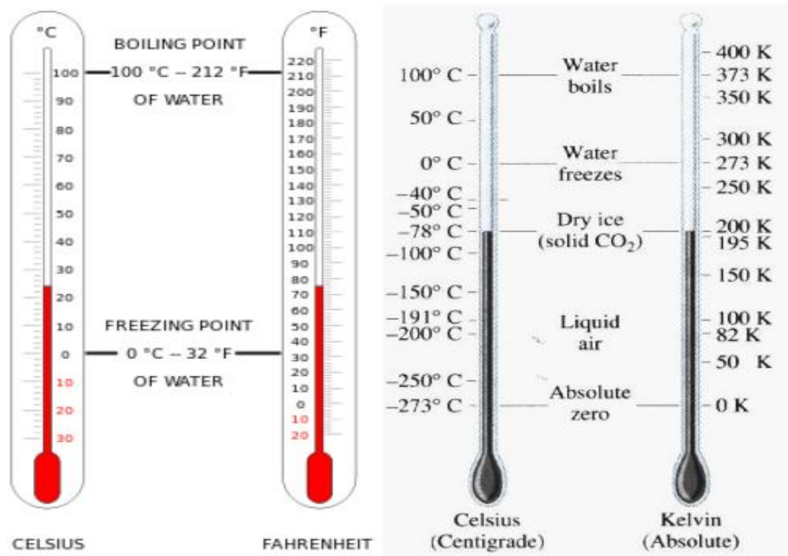
Solid (heat)~ Liquid (heat) ~Gas (heat) ~ions

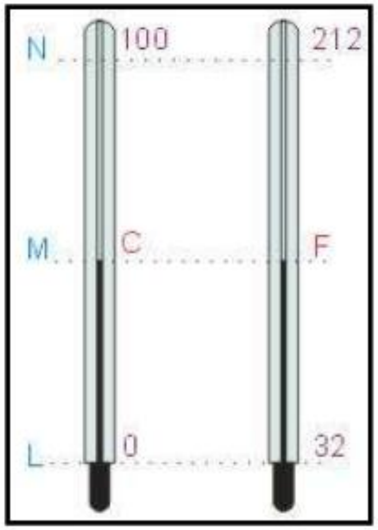
While adding heat to substance increase its molecular kinetic energy, which increase its temp., the reverse is also true, heat can be removed from a substance to lower the temp., Low temp. referred to as the cryogenic region (absolute zero,-273.15°c).

Thermometry and temperature scales:

Temperature is difficult to measure directly, so we usually measure it indirectly by measuring one of many physical properties that change with temp. .

1-Fahrenheit scale(°F):in this scale the freezing temp. is (32°F) and boiling point is (212°F) ,and normal body temp. is about (98.6°F) .
2-The Celsius(°C):the freezing point is (0°C) and the boiling point is (100°C) ,in between is divided into (100) division.
3-The Kalvin scale(°K):or the absolute scale this scale has the same divisions as the Celsius but takes the (0° K) at the absolute zero which is(=-273.15°C).





$$\frac{ML}{NL} = \frac{C-0}{100-0} = \frac{F-32}{212-32}$$

$$\therefore \frac{C}{100} = \frac{F-32}{180}$$

$$F = \frac{9}{5}C + 32$$

To change °C to °F

[°C= (°F-32) 5/9]
Or
[°F=°C (9/5)+32]

Also
°C=°K-273
Or
°K=°C+273

Thermometry (temperature scales and thermometers) :

Temperature: Temperature is a quantitative description of hotness and coldness of an object. It is the intensity of heat of the object.
Heat: Heat is the quantity of kinetic energy transferred as "heat flow" from a hotter body to a colder one due to the temperature difference existing between them

The human body temperature depends on:

1- The amount of recent physical activity.
2- The temperature of the environment.
3- The health of the individual.
4- The extent of insulation of body heat by clothes

***Temperature scales:**
Reference points on the three common scales:

Water boiling point	373 ^{0}K	100 ^{0}C	212 ^{0}
Body temperature	310 ^{0}K	37 ^{0}C	98.6 ^{0}F
Ice melting point	273 ^{0}K	0 ^{0}C	32 ^{0}F

The three equations above are for conversion from one scale to another

Example:

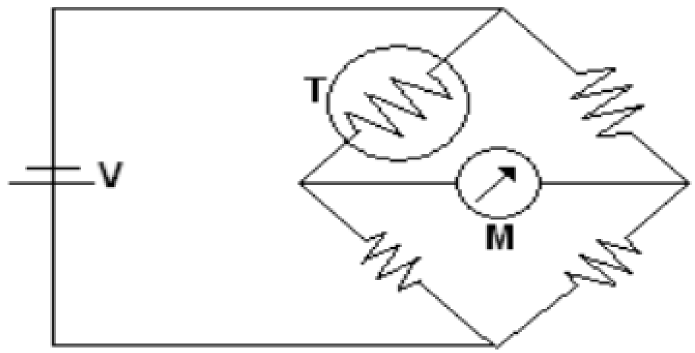
The temperature of the human body is normally about 98.6 ^{0}F,
Calculate the temperature of the body in ^{0}C and ^{0}K ?

Solution:

$$^0C = 5/9(^0F - 32)$$
$$= 5/9(98.6 - 32) = 37^0C$$
$$^0K = {}^0C + 273$$
$$= 37 + 273 = 310^0K$$

Temperature Measurement Devices :

1-Glass Fever Thermometer → It used to know the temp of the body
 * The most common way to measure a temperature is with in the glass fever thermometer containing mercury or alcohol.
 * Input fever thermometer ,a temperature increase causes the alcohol or mercury to expand more than the glass and thus produces an increase in the level of the liquid.
2-Thermistor → It's a special resistor that changes it's resistance rapidly with temp(≈%٥ ˙C).
* The principle behind this thermistor is that a temperature change causes the thermistor resistance to change



Because it is very sensitive and very fast for measuring temp change ,it has been used to monitor the breathing rate of the patient → This is called "pneumograph" .

3-Thermocouple → measuring the temp from "-190 to 300 Co ".
* A thermocouple consists of two junctions of two different metals . If the two junctions are at different temperature, a voltage is produce that depend on the temperature difference.
Because it has a sharp end then it can measure the temp of "individual cell"

Thermograph:

It is a simple method for obtaining a surface temp "mapping".

1- It has been used to detect other type of cancer not only breast cancer.
2- It used to study the circulation of the blood in the head.
3- It used to study the blood in the diabetics leg.

Thermogram :

Is done by measuring the radiation emitted from the body .At the body temp emitted radiation is in the far infrared (IR) reigon at wavelength greater than (4000-7000)A^0 .The total radiative power per surface area (w) is given by Stefan – Bultzman Low :

$$W = e\,\sigma\,T^4 \qquad \text{unit } (w/cm^2)$$

σ : S-B. constant =5.7 $*10^{-12}$ $w/cm^2 .k^4$

e : emissivity depends upon the emitter material and its temp.

(e=1 for the body).

k : Kelvin or absolute, scale=273k^0

0 k^0 = absolute zero= -273 C^0

normal body temp =(T C^0+273) k^0 (this temperature scale is not used in medicine).

Example:

A person of skin temp. of 36^0C and body surface area 1.75m^2 .

find :

1. net total power if he receives radioactive power from the surrounding walls 20^0C would be about 735w. ($\sigma = 5.7 * 10^{-12}$ w/cm^2)
2. The emissivity of surrounding walls.

Solution

1- $T = 36C^{o} + 273 = 309\ ^{o}K$

$T^{4}\ \sigma\ w = e$

$= 1*(5.7*10^{-12})*(309)^{4}$

$= 0.052\ w / cm^{2}$

Total power (w)={Total radiative power per surface area}*{surface area}

$= 0.052\ (\ w/cm^{2}\ )\ *\ 1.75*10^{4}\ (\ cm^{2}\ )$

$= 910\ w$

$\therefore$ net power $= 910 - 735 = 175w$

2- $T = 20 + 273 = 293K$

Heat from the wall $= 735 = [e*\ 5.7*10^{-12}\ *(293)^{4}\ ]\ *\ (\ 1.75*10^{4}\ )$

$\therefore\ e = 735 / (735.163)$

$= 0.998$

<u>For the Breast Cancer Detection:</u>

1- Thermography to detect the elevated temp. Area.
2- To detect the area by smooth touching (palpation or feeling).
3- Use of low voltage X-ray (mammography).
4- To be sure of the type of Breast tissue of the specific area ,biopsy examination for histopathology is done.

Physical Methods of Producing Heat in the Body :

1- Conductive heating.
2- Infrared radiant heating (IR).
3- Radio wave heating (Electro magnetic Wave).
4- Micro wave diathermy .
5- Ultrasonic wave heating.

1. Conductive Heating : → used to treatment the superficial area.
* Conductive Heating is used in treating conditions such as :-
1- Arthritis.
2- Neuritis.
3- Sprains.
4- Strains.
5- Contusions.
6- Sinusitis.
7- Back Pain.

2. IR. Heating:
The heat can be transferred to the body by radiation. It is used for surface heating of the body .This is the same heat. We feel from the sun and flame.

- The IR wave length used are between (800- 4000nm).
- These wave penetrate the skin about (3mm)& increase the surface temp.
- This type of heating is used to treat the same conditions of conductive heating.

3. Electro magnetic Wave (diathermy):

They are very useful for internal heating because E.M.R. have energy depend on their frequency $E=h\gamma$, (γ : is the frequency).

A. Short wave diathermy(Wavelength (λ) = 10nm & F=30 MHz) :

Heat from diathermy is useful for internal heating because it penetrates deeper than radiant & conductive heat.

<u>It used in treatment of :</u>

- In flammation of the skeleton , bursitis , neuralgia .
- Muscle spasm, pain from protruded intervertebral discs , degenerative joint disease.

* **The treatment is done by two method to get energy to the part of The body :**

1- Capacitance method.

$$\textbf{Heat = Constant X (current)}^2$$

2- Magnetic induction.

B. Long Wave Diathermy : The frequency = 10 kHz .

Some patients were sensitive to get electricity in this frequency than they were under electrical shock hazards.

EM Diathermy : has limitations when it used on muscle tissue surrounded by fatty layer. In infrared waves most of the energy is deposited in the surface of fatty layers. So, we use microwaves diathermy for deep area covered with fatty layers.

4. Microwave Diathermy : F= 2460 MHz It is penetrate deep into the tissue →causing temp . rise & deep heating.

*** Microwave therapy is used in the treatment of:**

1. Fractures.
2. Sprains.
3. Strains .
4. Bursitis.
5. Arthritis.
6. Injuries to tendons.

* The absorption for homogeneous tissue can be described by this equation:

$$\mathbf{I = I_o\, e^{-x/D}}$$

I : radiation intensity at the depth X in the tissue.

$\mathbf{I_o}$: radiation intensity at the surface .

X : depth in the tissue.

D : Tissue thickness at which 63% of the beam is absorbed.

Example:-

If the radiation intensity of the surface is 10^4 & tissue for treatment half of intensity absorbed at depth 3cm. Calculate the intensity under 2cm in tissue.

Solution

At the half value thickness (X1/ 2) The beam absorbed Is

$I = Io/2 \quad \rightarrow$ ie $I/Io = 1/2 \quad$ at $X = X_{1/2}$

Since $I = Io\, e^{-X/D} \quad \rightarrow$ ie $\quad I/Io = e^{-X/D}$

$\therefore\ 1/2 = e^{-X1/2/D} \quad \rightarrow \ln 1/2 = - X_{1/2}/D$

$\ln 2 = X_{1/2} / D$

$\therefore\ D = X_{1/2} / 0.693$

$= 3cm / 0.693$

$= 4.32cm$

-To calculate the intensity under 2 cm in tissue substitute the value of intensity Io and D in equation

$\therefore\ I = 10^4\, e^{-2\,cm / 4.32}$

$= 6.3 * 10^3$

Cryosurgery:

It is the application of using cryogenics methods to destroy cells.

* The advantages:

1. There is little bleeding in the destroyed area.
2. The volume of tissue destroyed can be controlled by the temp. of cryosurgical prob.
3. There is little pain sensation because low temp. tend to desensitize the nerves.

* Uses of Cryosurgery : In treatment of " Parkinson:

a. Disease or Shaking Palsy . It is a disease that associated with the basal ganglion of the brain which causes un controlled tremor in the arms and legs.

- Treatment is done by destroying the part of the thalamus in the brain that controls the transmission of nerve impulses to other parts of nervous system .

b. Treatment of tumors by cutting it.

c. In several of types of eye surgery :

1. Repair of detached retina.
2. Cataract surgery removal of a darkened lens.

Use of Cold in Medicine:

Cryogenics: is the science and technology of producing and using very low temp. in medicine to preserve blood, sperm, bone marrow and soft tissue.

Cells & Tissues which is sorted for long term should be :

1. Stored at a very low temp. (-196 C^o) since biochemical & physical processes are temp. dependents → then lowing temp. will reduce the rate of these two processes .

2. Cooled at the optium cooling rate of the tissue to be stored and the % of survival is more dependent on the cooling rate than on the warming rate.

3. Stored with adding protective agent (glycerol or dimethyle solfoxide) before cooling.