Principle of the first law of thermodynamic 1:

For closed system or fixed mass the 1st law can be expressed as :

Net energy transfer to (or from) the system as heat or work =net increase (or decrease) in the total energy of the system

$$Q - W = \Delta E \quad ....(1)$$

Where : Q=Net heat transfer across system boundary $\left(\sum Q_{in} - \sum Q_{out}\right)$

W=Net work done in all forms $\left(\sum W_{Out} - \sum W_{in}\right)$

ΔE=net change in total energy of system $\left(E_2 - E_1\right)$

The total energy (E) of system is consist of three parts :

$$\Delta E = \Delta U + \Delta K.E + \Delta P.E \quad ....(2)$$

Where : ΔU :Internal energy

K.E: Kinetic energy

P.E: Potential energy

Substitute this relation in eq.(1) we obtain :

$$Q - W = \Delta U + \Delta K.E + \Delta P.E \quad ....(3)$$

Where

$$\Delta U = M\left(U_2 - U_1\right)$$

$$\Delta K.E = \frac{1}{2} M\left(V_2^2 - V_1^2\right)$$

$$\Delta P.E = mg\left(Z_2 - Z_1\right)$$

For stationary closed system, the change kinetic energy and potential energy are neglected .

That is : $\Delta K.E = \Delta P.E = 0$

The first law of the thermodynamic reduce to :

$$Q - W = \Delta U \quad ....(4)$$

Sometimes it`s convenient to consider the work term in 2 parts $(W_{other} - W_{boundary}), W_{other}$ all forms of work except boundary work .

Then the first law will take the following form :

$$Q - W_{other} - W_{boudary} = \Delta E \qquad ....(5)$$

For a cyclic process, the initial and final states are identical, therefore :

$$\Delta E = E_2 - E_1 = 0$$

Then the first law will be :

$$Q - W = 0$$
$$W_{net} = Q_{net}$$

<u>Adiabatic processes</u> : in this process no change in energy . the quantity thermal energy is constant .

$$Q_1 = Q_2$$

when Q is constant .

dQ=zero .

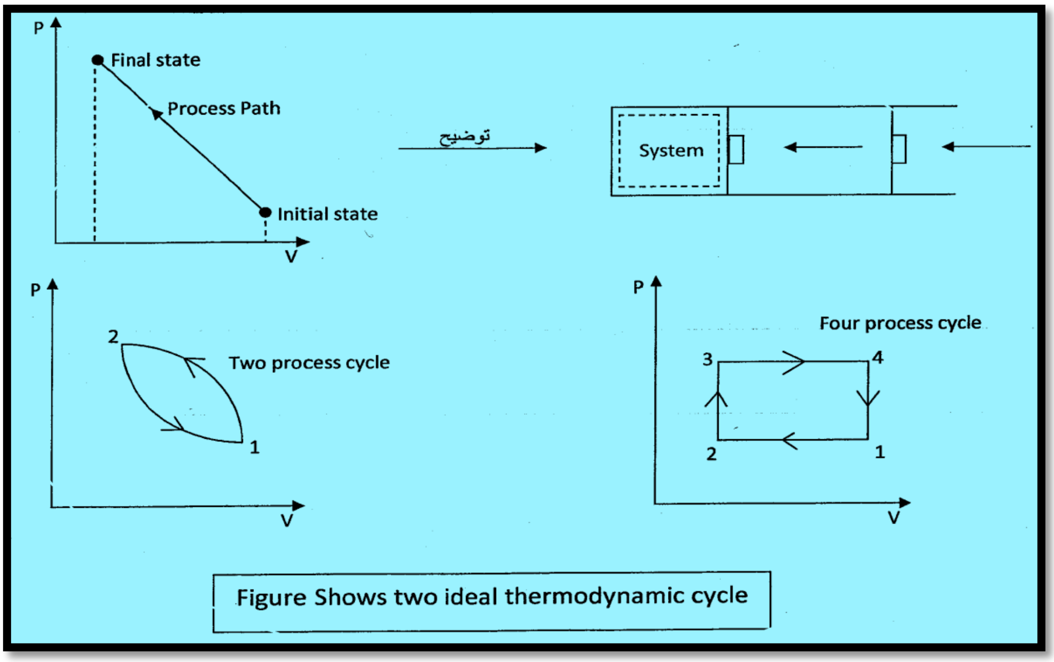

Figure Shows two ideal thermodynamic cycle

Metabolism: Energy, Heat, Work, and Power of the Body

We cannot function without energy. The processes involved in the energy intake, storage, and use by the body are collectively called the **metabolism;** the discipline describing this area is sometimes called *bioenergetics*. More generally, metabolism is any energy usage by the body, and is the sum of all chemical processes performed by the cells in order to keep the body alive. ***For a complete picture we need to include input of food and oxygen to the body, energy storage, and loss of energy by the body through the loss of heat and work done by the body, as is shown in Fig.1.***

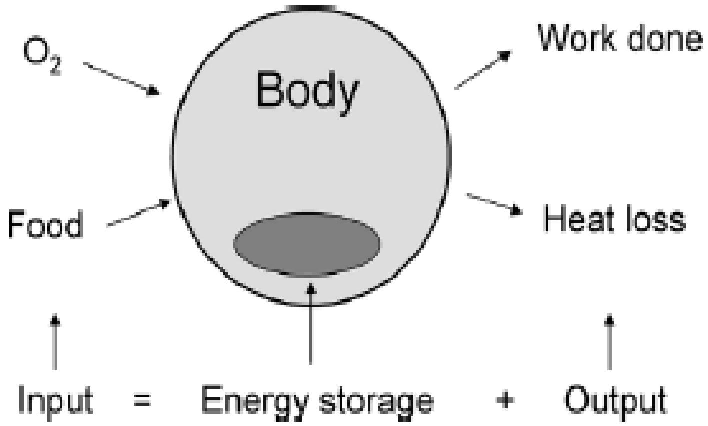

Fig. 6.1. Energy flow into and from the body

Metabolic processes can be divided into catabolic and anabolic reactions. In *catabolic* reactions complex molecules are broken into simple ones, for purposes such as energy usage. In *anabolic* reactions simple molecules are combined to form complex ones, for purposes such as energy storage.

The body uses food to

(1) operate organs .

(2) maintain a constant temperature by using some of the heat that is generated by operating the organs (while the rest is rejected) .

(3) do external work .

(4) build a stored energy supply (fat) for later needs. About 5–10% of the food energy intake is excreted in the feces and urine.

Conservation of Energy and Heat Flow

Let us briefly review some of the basics of the thermodynamics and heat flow physics that we will use in this discussion.

The First Law of Thermodynamics is essentially the conservation of energy in any process. In reference to the body, it can be stated as

$$\Delta U = Q - W, \qquad (1)$$

where ΔU is the change in stored energy, Q is the heat flow to the body, and W is the mechanical work done by the body. The stored energy decreases, $\Delta U < 0$, when there is heat flow from the body, $Q < 0$, and work done by the body, $W > 0$. This type of work is purely mechanical in nature, such as in moving and lifting items. Heat flow includes heat production from the metabolism (Q_{met}) and heat loss (Q_{loss}) from radiation, convection, conduction, and evaporation. We can express :

$$Q = Q_{met} + Q_{loss} ,$$

where metabolic heat production is positive and a negative Q_{loss} indicates heat flow away from the body, so

$$\Delta U = Q_{met} + Q_{loss} - W \qquad (2)$$

Q_{met} is called the metabolic rate (***MR***).

Relationships in thermodynamics involve amounts of energies changing in a process at equilibrium and not those changing per unit time, i.e., the kinetics of that process, which involves the rates of energy changes or flows. The study of the metabolism usually involves rates and therefore is more appropriate.

$$\frac{dU}{dt} = \frac{dQ_{met}}{dt} + \frac{dQ_{loss}}{dt} - \frac{dW}{dt}$$

{We need to be careful about signs. The body increases its energy with terms such as $\mathbf{d}\boldsymbol{Q}_{\text{met}}\,/\mathbf{dt}$ that are ***positive*** and loses it with terms such as $\mathbf{d}\boldsymbol{Q}_{\text{loss}}/\mathbf{dt}$ that are ***negative***. The amount of heat flowing from the body is $-\mathbf{d}\boldsymbol{Q}_{\text{loss}}\,/\mathbf{dt}$, which is a positive quantity.}

All types of energy have the same units, including heat (often expressed in terms of ***calories***) and work (often expressed in terms of ***joules***). One important conversion between units is

1 calorie (cal) = 4.184 joule (J). (4)

1 kilocalorie (1 kcal = 1,000 cal) is sometimes called 1 Cal, which is also known as a food calorie. The energy content of food is always expressed in terms of these Cal (kcal) units.

Units of power

1watt (W) = 1 J/s
100W = 1.43 kcal/min
1 horse power (hp) = 746W = 642 kcal/h
1 kcal/min = 69.7W = 0.094 hp
1 kcal/h = 1.162W

The convenient of unit for expressed the rate of energy consumption of the body is the (met) .

1met=50 Kcal/m^2.hr=58 w/m^2

Q/ Prove 1met=58 w.m^{-2} ?

Ans.

$$1met = 50\,k\,cal.m^{-2}.hr = \frac{50 \times 69.7\,w.m^{-2}}{60\min} = 58\,w.m^{-2}$$

Q/ Prove 1kcal/min =69.7 W ? (H.W)

Heat and Cold in Medicine

Physical Basis of Heat and Temperature

❍ Matter is composed of molecules in motion

- Kinetic energy (K.E.) is related with temperature (T)
- K.E. ↑⇔ T ↑

❍ Heat

- Energy transferred to molecules to increase T
- Solid + heat ⇒ liquid
- Liquid + heat ⇒ gas
- Gas + heat ⇒ ions

4.2 Thermometry and Temperature Scales

❍ Thermometry: indirect measurement of T

❍ Temperature scales

- Fahrenheit (°F) scale $T_F = 9/5\ T_C + 32$

Or $T_C = 5/9\,(T_F - 32)$

Water freezes at 32°F and boils at 212°F

□ Normal body T (rectal) is about 98.6°F

- Celsius (°C) scale

□ Water freezes at 0°C and boils at 100°C

□ Normal body T (rectal) is about 37°C

- Absolute (°K) scale

□ Water freezes at 273.15°K and boils at 373.15°K

□ Normal body T (rectal) is about 310°K

□ Absolute zero (0°K) is –273.15°C

❍ Glass thermometer

- Increase in T of different materials ⇒ expansion by different amounts
- Mercury or alcohol in a glass capillary

□ Mercury or alcohol expands more than glass as T ↑

- Mercury fever thermometer

□ T change from 0 to 100°C in 1cm^3 mercury ⇒ 1.8% change in volume

□ Capillary with smaller diameter (0.1 mm) ⇒ high sensitivity

Magnifying glass and opaque white backing ⇒ □ improved visibility (Fig.4.2)

□ T measurement underneath the tong or in the rectum requires several minutes for stabilization

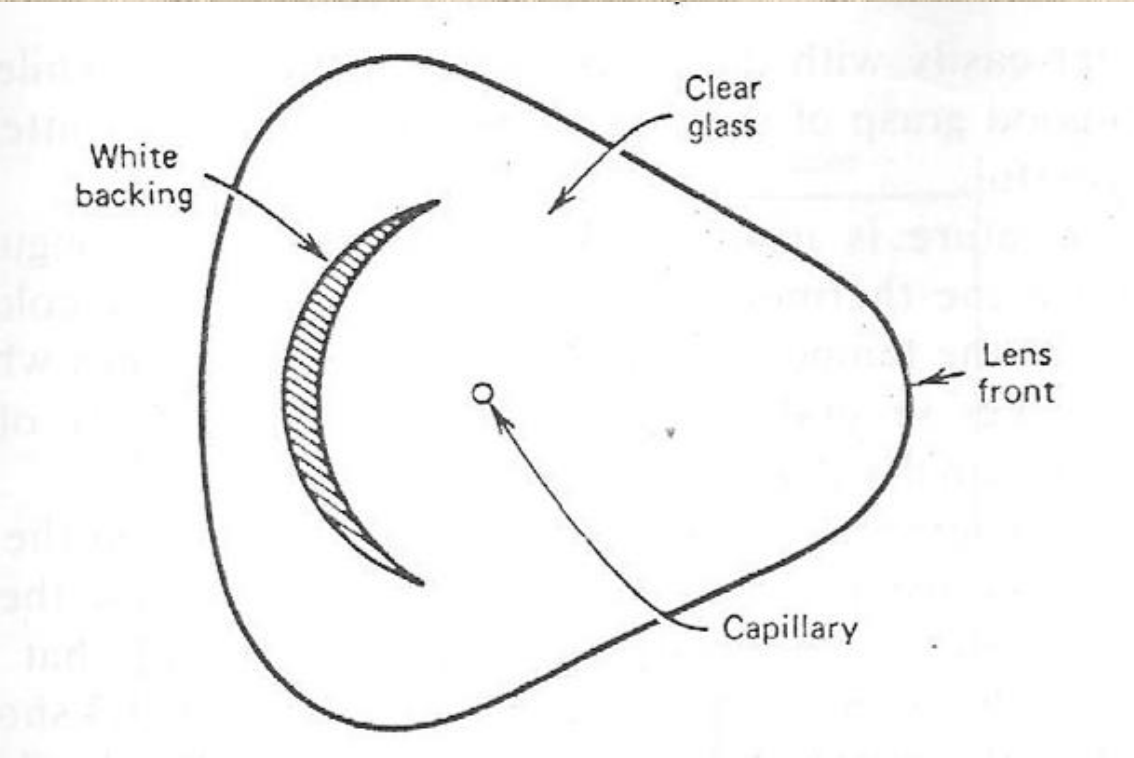

Figure (4-2)

Thermistor

- Resistor with negative T coefficient (-5%/°C)
- Bridge circuit in Fig. 4.3
- Highly sensitive to detect T change of 0.01°C
- Small mass and fast response
- Application to pneumograph (respiration monitoring)

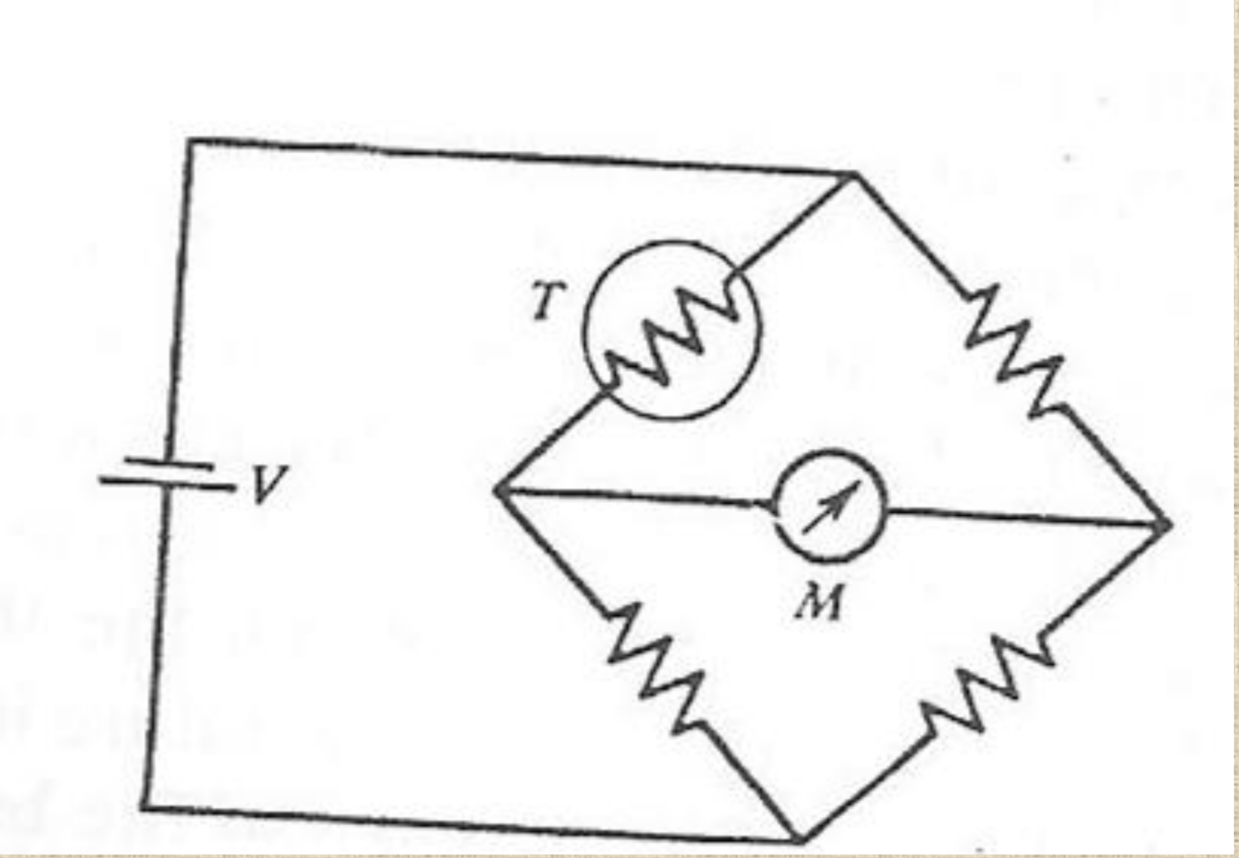

Figure (4-3)

❍ Thermocouple

- Two junctions of two different metals (copper-constantan) which is shown in Fig. 4.4
- T difference between two junctions ⇒ voltage of 4 mV/100°C ⇒ needs amplification
- Cold junction at 0°C using ice bath or semiconductor circuit
- Wide T range: -190 to 300°C
- Very small

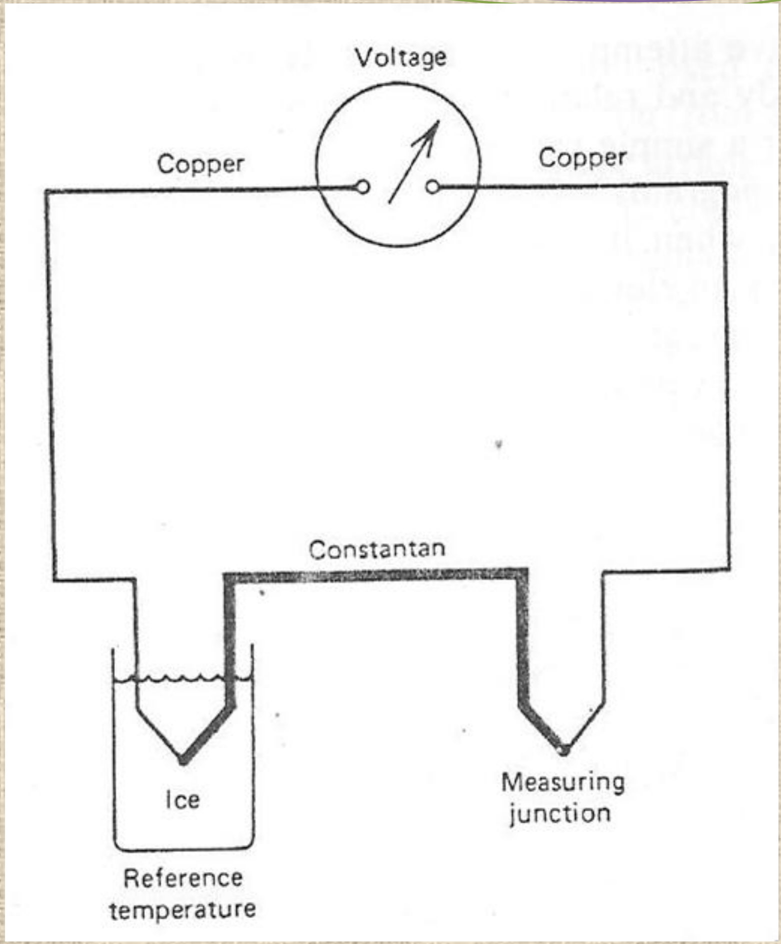
Voltage
Copper
Copper
Constantan
Ice
Reference
temperature
Measuring
junction

Figure (4-4)

4.3 Thermography – Mapping the Body's Temperature

- Body surface T
  - External physical factors
  - Internal metabolic and circulatory processes near the skin (blood flow near the skin dominates)
- Thermogram: surface T map
  - Surface T above tumor is about 1°C higher ⇒ breast cancer detection ⇒ not Successful
  - Radiation emitted by body

□ $w = e\sigma T^4$: **4.3 Thermography – Mapping the Body's Temperature**

- Body surface T

λ_{max} *=2898/T* Wien's displacement law□

□ *T = 300°K ⇒ λ max = 9.66μm (infrared region, not visible)*

- Basic thermographic unit (Fig. 4.5) and commercial instrument (Fig. 4.6)

□ Detect T difference of 0.2 or 0.1°C

□ Frame time of 2 s

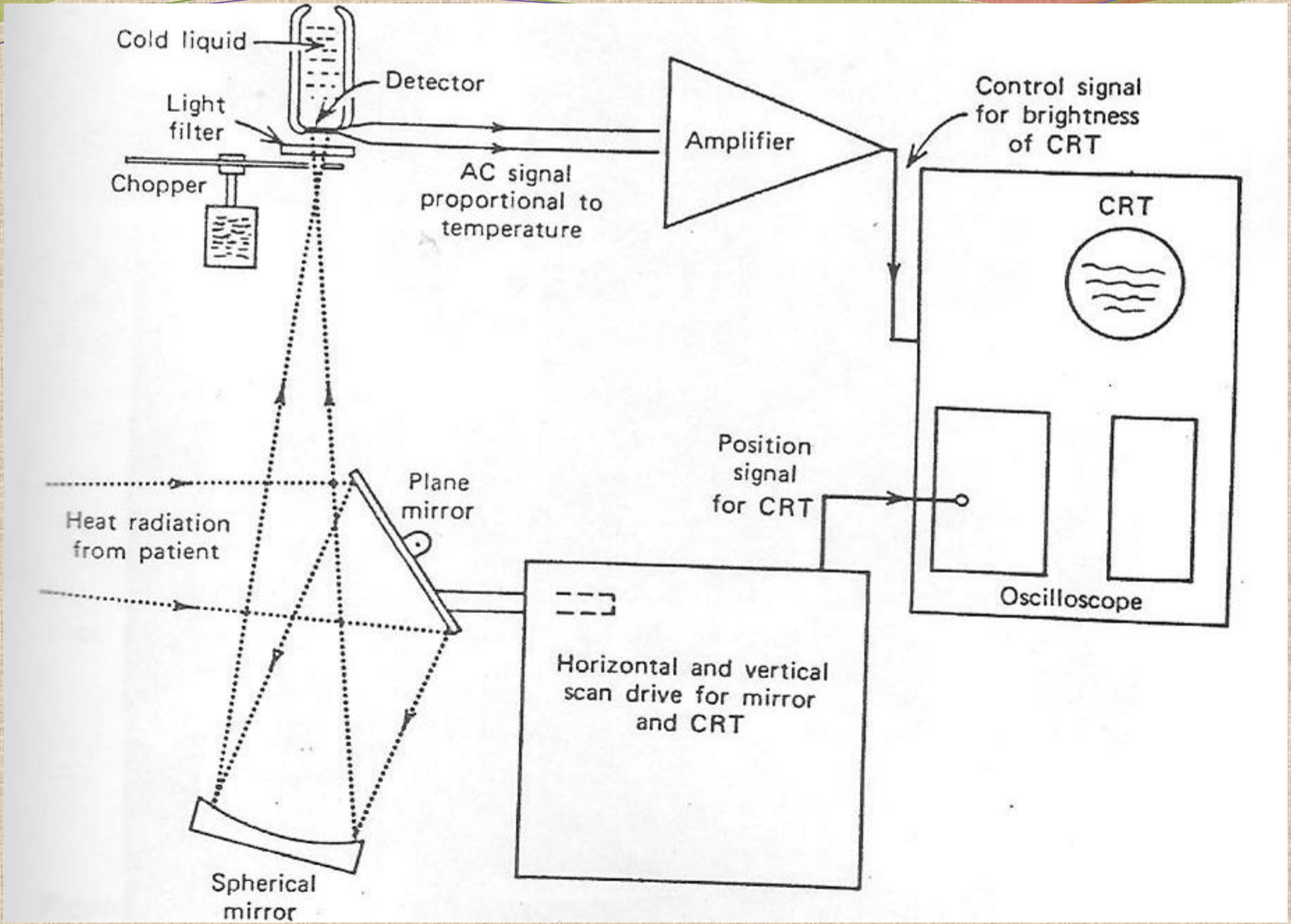
Cold liquid
Detector
Light filter
Chopper
AC signal proportional to temperature
Amplifier
Control signal for brightness of CRT
CRT
Position signal for CRT
Plane mirror
Heat radiation from patient
Horizontal and vertical scan drive for mirror and CRT
Oscilloscope
Spherical mirror

Figure (4-5)

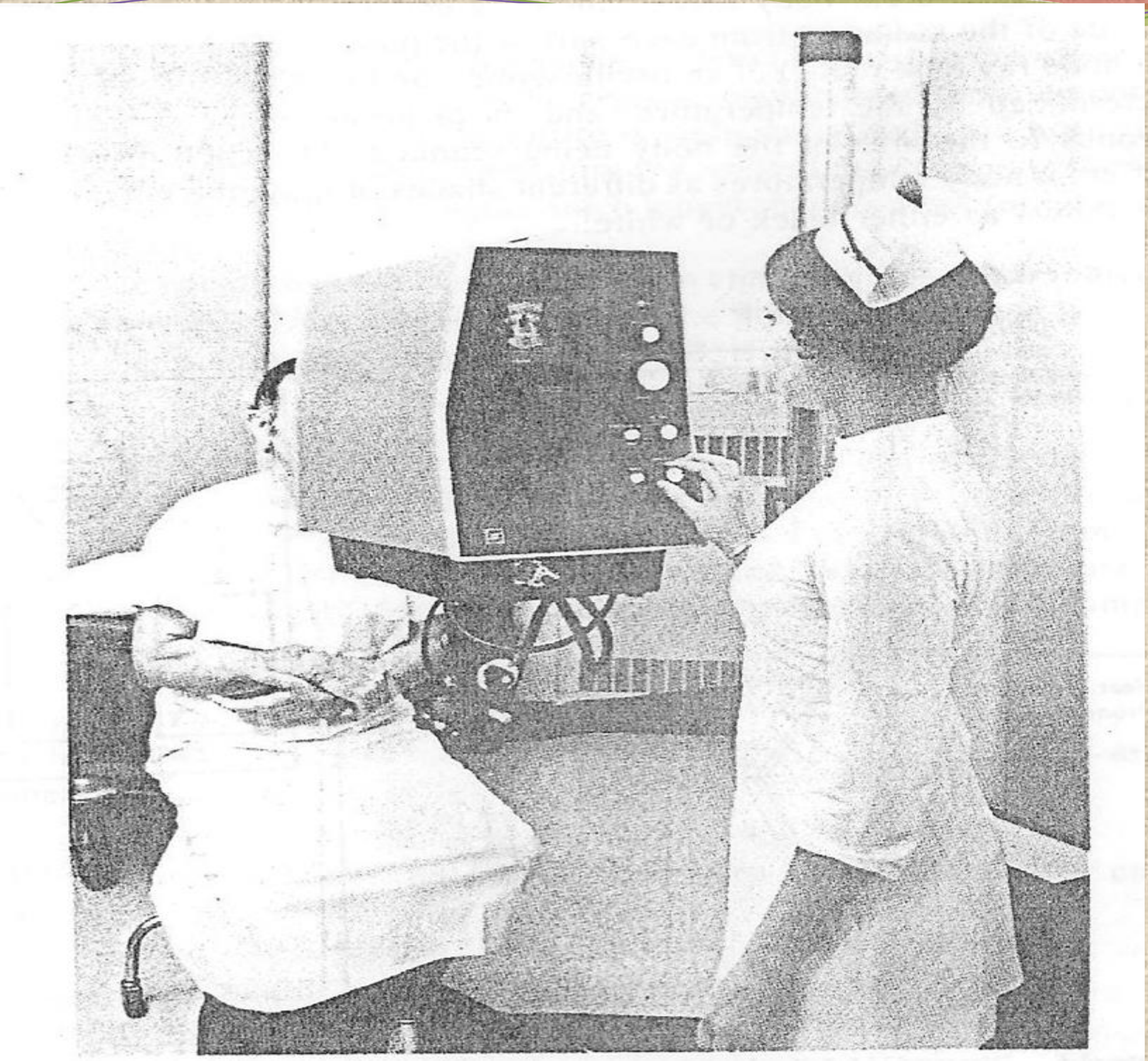

Figure (4-6)

Clothing must be removed

- Breast cancer detection
  - Thermography: high false positive and false negative
  - Palpation: difficult to detect a small tumor (less than 1 cm in diameter)
  - Mammography (low energy x-ray): successful but radiation hazard
  - Biopsy: invasive, some cancer tissue may be missed
- Circulation of blood in the head
- Detection of circulatory problem in the foot of diabetics

4.4 Heat Therapy

- Heating of tissue may be beneficial to damaged tissue
  - Increase in metabolism⇒ relaxation of the capillary system (vasodilation)
  - Increase in blood flow since blood moves to cool the heated area
- Heating methods
  - Heat conduction: hot bath, hot pack, electric heating pad, hot paraffin, etc.
    - Contact area
    - T difference
    - Duration
    - Thermal conductivity

- Radiant (IR) heat: glowing wire coil, incandescent lamp, sun, etc.

- IR wavelength: 800 to 40,000 nm
- Waves penetrate the skin by 3 mm and increase the surface T
- Excessive exposure ⇒ reddening (erythema), swelling (edema), browning and hardening of the skin

- Electrical heating: electric currents through resistive tissues produce joule heating

□Short-wave diathermy: radio frequency (500 kHz), muscle spasm, pain, degenerative joint disease, bursitis, use of electrodes (Fig. 4.9) and use of magnetic induction (Fig.4.10)

□Microwave diathermy: radar frequency (900 MHz), fractures, sprains and strains, bursitis, injuries to tendons, arthritis

□Internal heating is possible ⇒ treatment of inflammation of the skeleton, bursitis, neuralgia

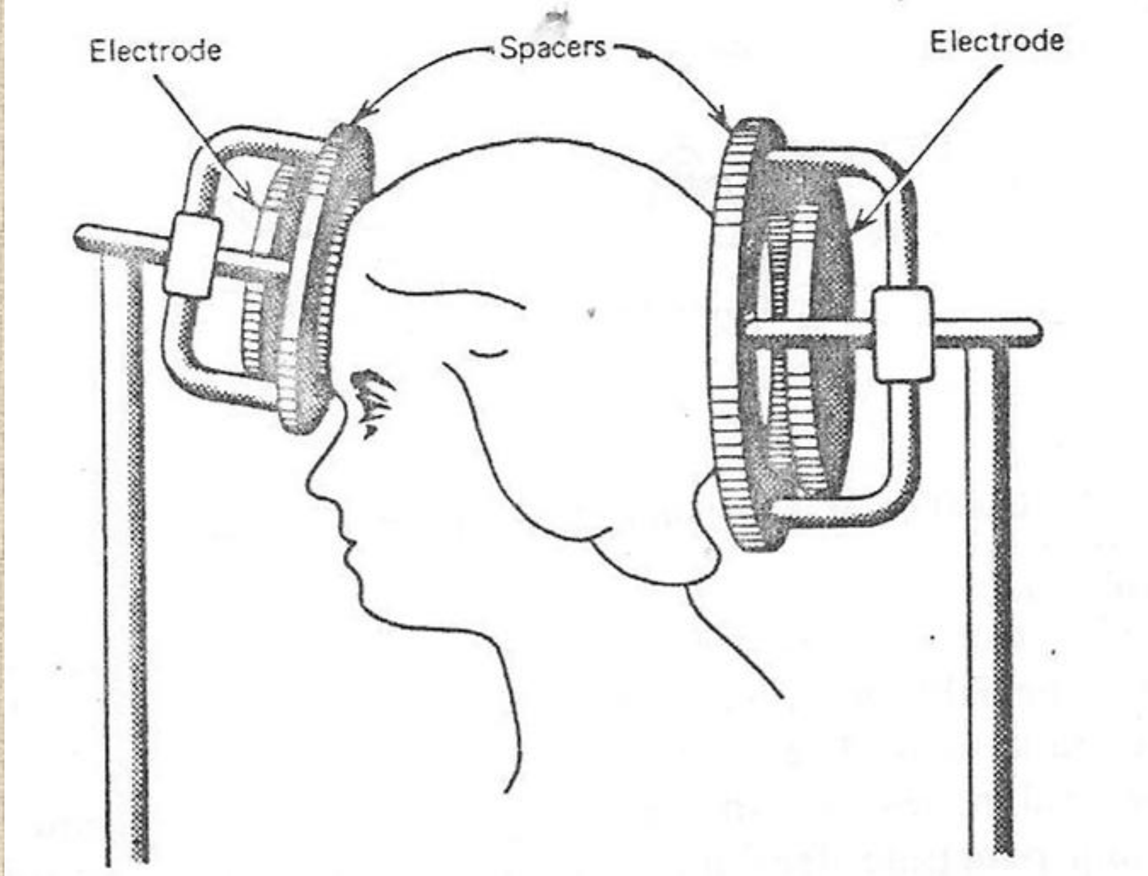

Figure (4-9)

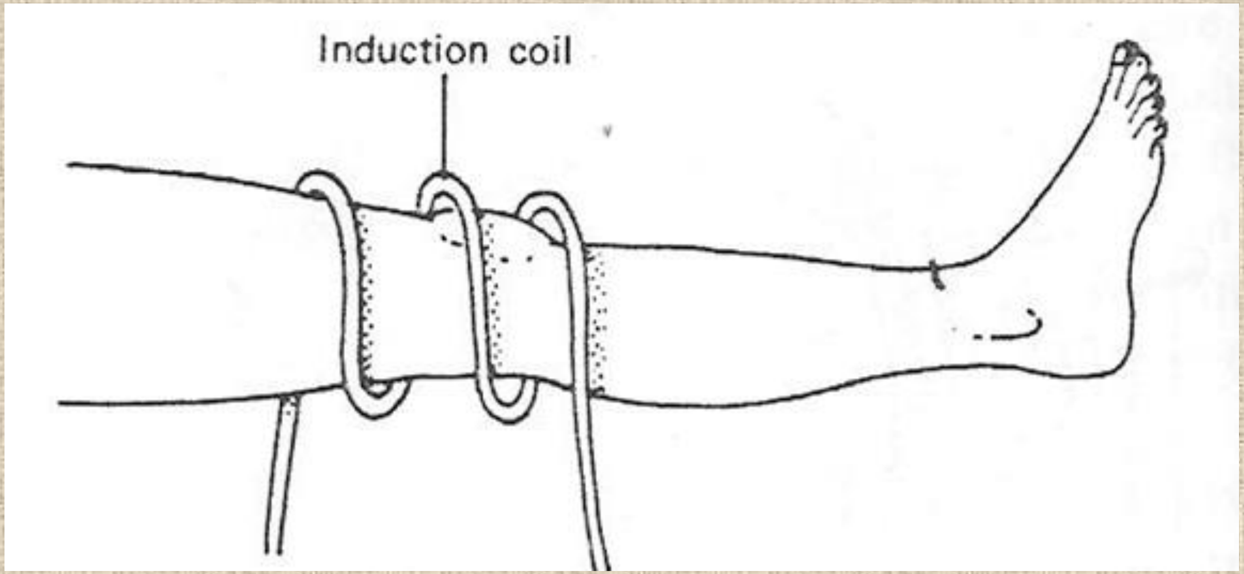

Figure (4-10)

- Ultrasonic diathermy: ultrasonic waves vibrate tissues producing heat

❍ Treatment of cancer by heat is promising (tumor heated to about 42°C for 20 to 30 min)

4.5 Use of Cold in Medicine

- Cryogenics: science and technology of producing and using very low temperature
- Cryobiology: study of low-temperature effects in biology and medicine
- Cryogenic fluids
  - Liquid helium: -269°C
  - Liquid nitrogen: -196°C
- Container: Dewar vessels (Fig. 4.11)
  - Glass or thin stainless steel: minimize conductive heat loss

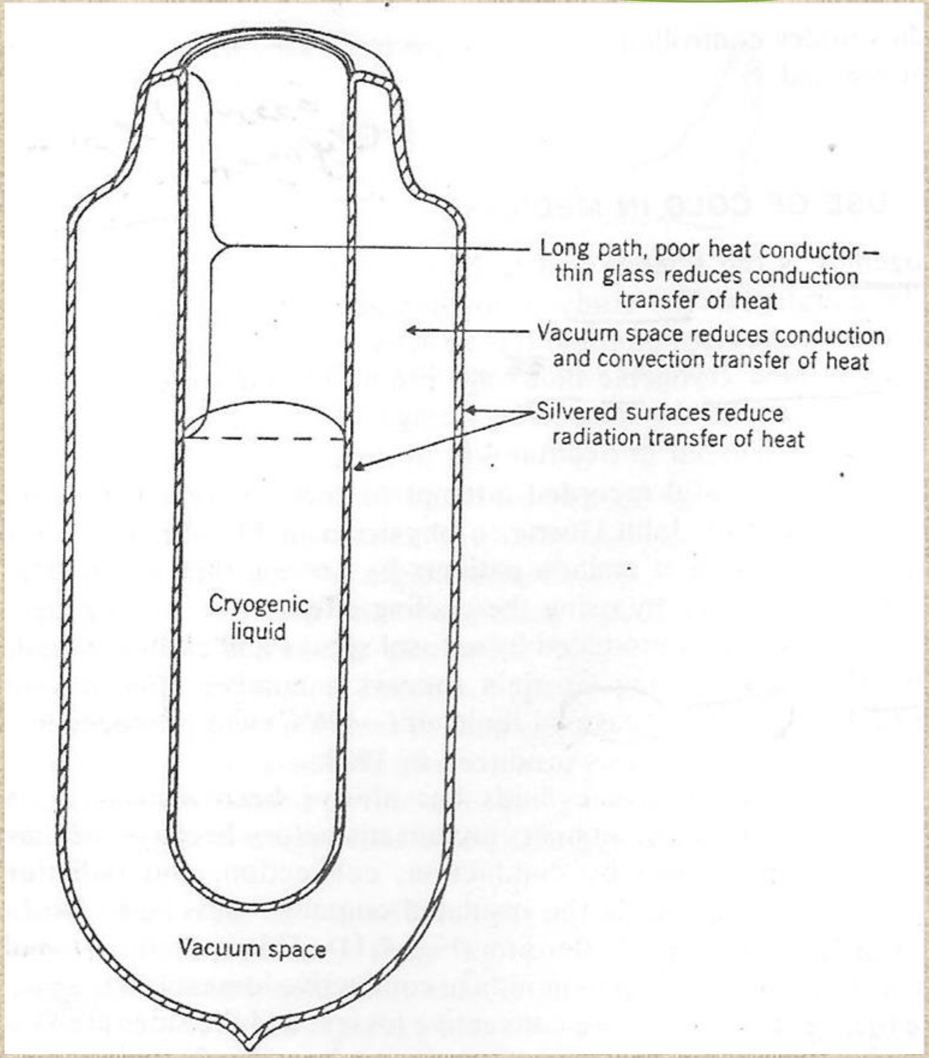
Long path, poor heat conductor—
thin glass reduces conduction
transfer of heat
Vacuum space reduces conduction
and convection transfer of heat
Silvered surfaces reduce
radiation transfer of heat
Cryogenic
liquid
Vacuum space

Figure (4-11)

- Vacuum space: minimize convective heat loss
- Silvered or polished surface: reflect radiation

❍ Transfer of cryogenic fluids: two polished concentric metal pipes with vacuum between walls

❍ Cryogenic methods in medicine

- Long-term preservation of blood, sperm, bone marrow, and tissues
- Cryonics: preservation and revival of living tissues at low T
- Survival behavior as a function of cooling rate (Fig. 4.12): different tissues show different behavior

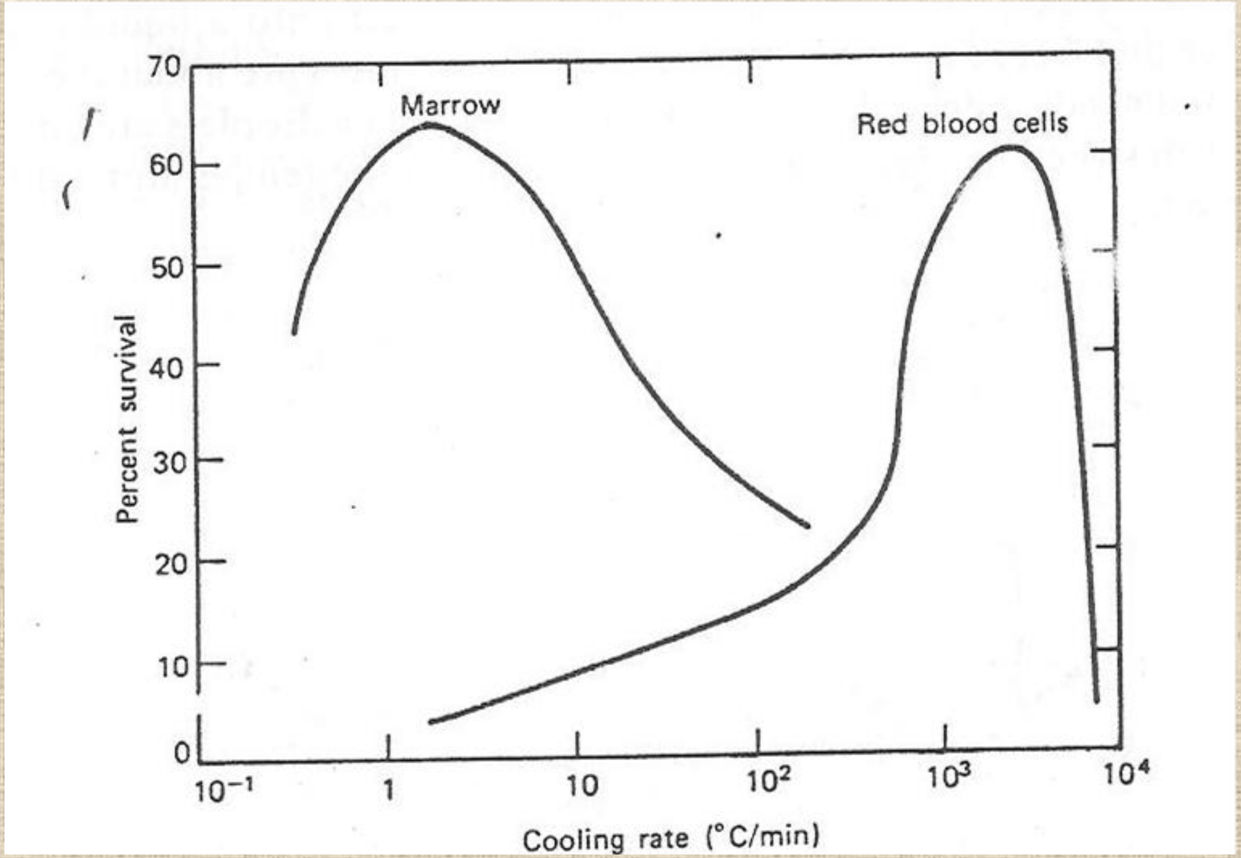
70
60
50
40
30
20
10
0
Percent survival
Marrow
Red blood cells
10⁻¹
1
10
10²
10³
10⁴
Cooling rate (°C/min)

Figure (4-12)

❍ Storage of blood

- Thin-walled container (Fig.4.13)
- Blood-sand method

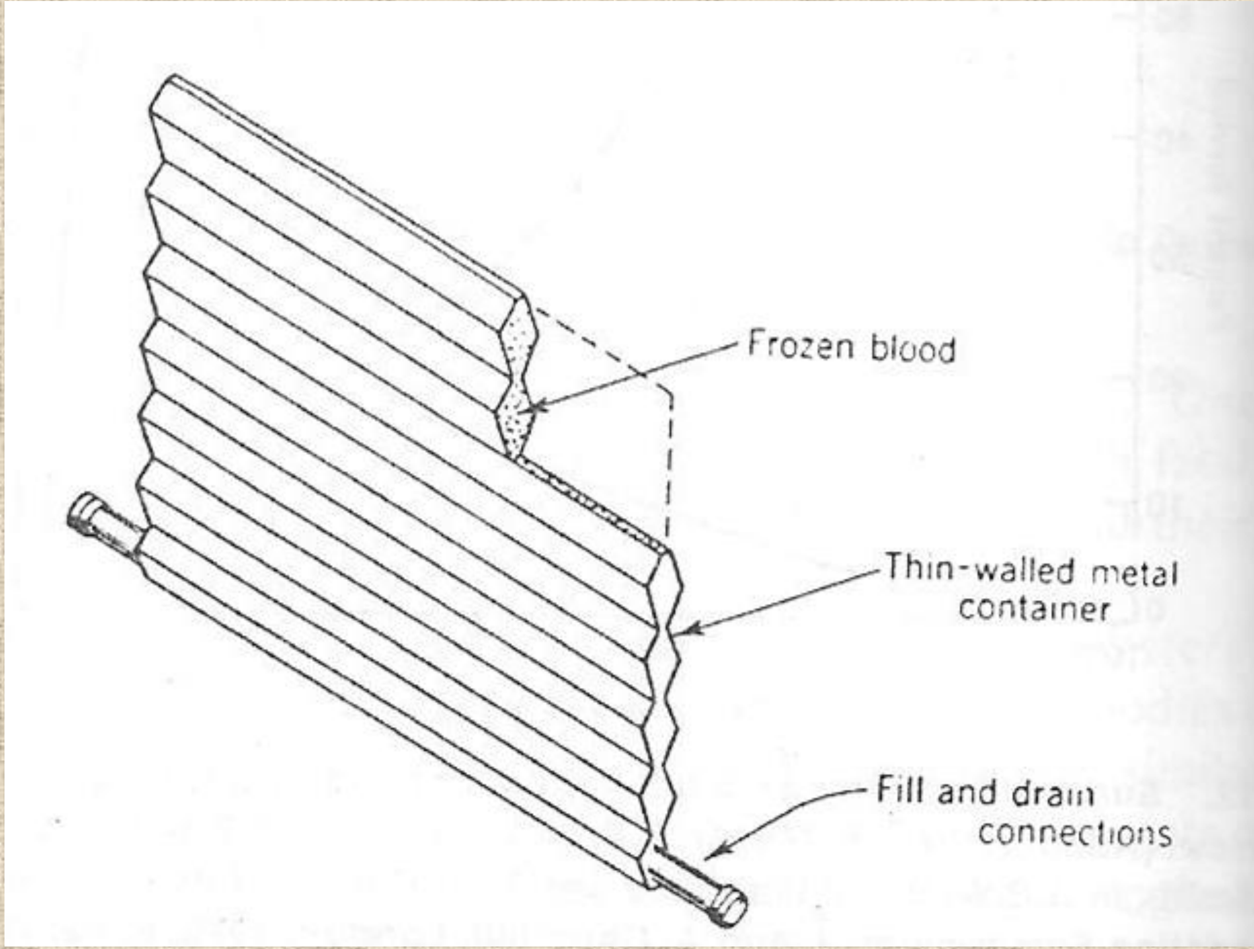
Frozen blood
Thin-walled metal
container
Fill and drain
connections

Figure (4-13)

4.6 Cryosurgery

❍ Cryosurgery: cryogenic methods to destroy cells

• Less amount of bleeding

•Volume of tissue destroyed can be controlled byT

•Little pain sensation since low T desensitize nerves

❍ Cryoknife or Cooper cryosurgery system (Fig. 4.14)

Treatment of Parkinson’s disease

Destroy a part of the thalamus in the brain

Treatment of tumors and warts

•Eye surgery

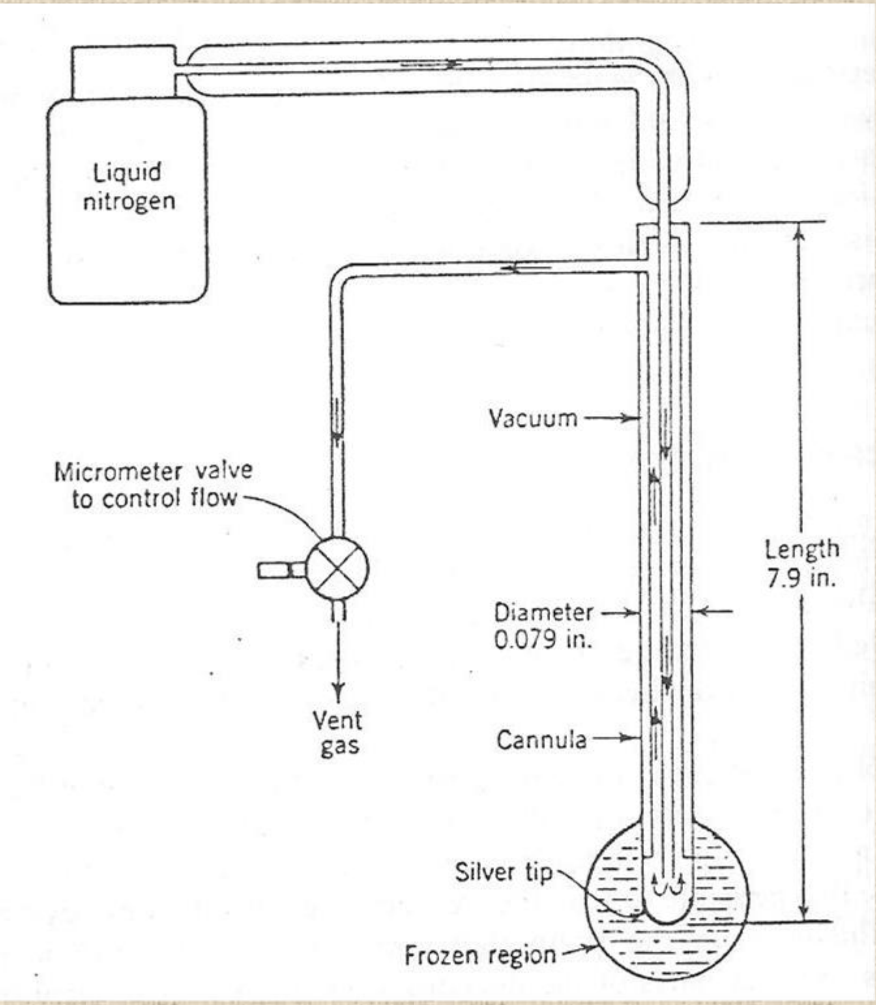
Liquid
nitrogen
Vacuum
Micrometer valve
to control flow
Length
7.9 in.
Diameter
0.079 in.
Vent
gas
Cannula
Silver tip
Frozen region

Figure (4-14)

Repair of a detached retina

Cataract surgery (removal of a darkened lens)

4.7 Safety with Cryogenics

- Containers must be securely fixed
- Pressure-reducing regulator must be used
- Cryogenic fluid causes “freeze burns”
- Adequate ventilation is required
- Open flame and smoking are prohibited
- Special care for oxygen since it is highly flammable

Physical basic of heat and cold temperature :

Heat and cold have been used for medical purposes for several thousand years . if we want to describe temperature as a physical phenomenon, however, we should try to understand it on a molecular scale .

- ✓ Matter is composed of molecules that are in motion .
- ✓ Molecules motion means that they have kinetic energy .
- ✓ Kinetic energy (K.E) is related with temperature (T) .
- ✓ K.E ↑⇔↑ T i.e.: In order to increase the temperature of gas it is necessary to increase the average kinetic energy of its molecules. this can be done by putting the gas in contact with a flame .

- *Heat :*
- The energy transferred from the flame to the (gas) molecules causing the temp. rise is called heat .
- Solid +heat liquid .
- Liquid +heat gas .
- Gas + heat ions .

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 temperature by a suitable calibration .

- All scales are based on easily states, such as, the freezing and boiling points of water (ice point , steam point) .

Ice point : a mixture of ice and water which is in equilibrium with air , saturated with vapor at 1 atmospheric pressure .

Steam point : are based on liquid water vapor (with no air) in equilibrium at 1 atmospheric pressure .

The temperature scales used in SI and English system are : (where SI is international system)

1- Celsius scales (also called the centigrade scale), which is in common use throughout most of the world : the ice and steam points are values of (0 -100°C)respectively .

** Normal body temperature $(37^{\circ}C)$.

2- Fahrenheit scale : the ice and steam points are the values of $(32 - 212\ ^{\circ}F)$ respectively .

** Normal body temperature $(98.6\ ^{\circ}F)$.

3- Absolute temperature scale: the ice and steam points are the values of $(273.15 - 373.15\ K)$respectively .

A- normal body temperature $(310K)$. we notice that in figure 1

B-The lowest temperature is the absolute zero $(0K)$ is $(-273.15^{\circ}C)$.

- The temperature unite on this scale is the **Kelvin** (K)without the degree symbol.
- In English system, the absolute temperature scale is called the **Rankin** scale .

<u>NOTICE</u> : this scale used for scientific work but it is not used in medicine .

- **The relationships between different temperature scales are :**

The **Kelvin** scale is relative to the **Celsius** scale by :

$$T_{(K)} = T_{(^\circ C)} + 273.15$$

The **Fahrenheit** scale is relative to the **Celsius** scale by :

$$T_{(^\circ C)} = \frac{5}{9}\left(T_{(^\circ F)} - 32\right)$$

Rankin scale is relative to the **Fahrenheit** scale by :

$$T_{(R)} = T_{(^\circ F)} + 459.67$$

The temperature scales in two unite system are relatively :

$$T_{(R)} = 1.8 T_{(K)}$$

And $$T_{(^\circ F)} = 1.8\, T_{(^\circ C)} + 32$$

Q1/ In a hot room, a person skin temperature is about $(35^\circ C)$,find his skin temperature on the kelvin and Fahrenheit scales ?

Sol/ from $T_{(K)} = T_{(^\circ C)} + 273.15$

$$T_{(K)} = 35 + 273.15 = 308.15\ ^\circ K$$

$T_{(^\circ F)} = 1.8\, T_{(^\circ C)} + 32 \Rightarrow T_{(^\circ F)} = 1.8 \times 35 + 32 = 95\ ^\circ F$

2/ A pan of water is heated from $(30^\circ C)$ to the boiling point. What is the change in its temperature on the Kelvin and Fahrenheit scales ?

SOL/ $T_{(K)} = T_{(^\circ C)} + 273.15 = 30 + 273.15 = 303.15$

$T_{(^\circ F)} = 1.8\, T_{(^\circ C)} + 32 = 1.8 \times 30 + 32 = 86$

$\because\ T_{(K)} = T_{(^\circ C)} + 273.15 = 100\ boiling + 273.15 = 373.15$

$\because\ T_{(^\circ F)} = 1.8\, T_{(^\circ C)} + 32 = 1.8 \times 100 boiling + 32 = 212$

$\therefore\ \Delta^\circ C = 100 - 30 = 70^\circ$

$\Delta^\circ K = 373.15 - 303.15 = 70^\circ$

$\Delta^\circ F = 212 - 86 = 126^\circ F$

Q/Calculate the normal body temperature on Kelvin, Celsius, and Fahrenheit scales ?

Q/ It is difficult to measure body temperature with the house thermometer. why ?

Ans/

A. It is difficult to place the house thermometer under the tongue .
B. The house thermometer would give a low reading because the temperature will fall when the thermometer was removed from the mouth .

Q / What is expansion value (the volume) for liquid (mercury) in a thermometer ? explain.

Ans/ The expansion of the liquid in a thermometer is not $(1cm^3)$ of mercury increases in volume by only (1.8%) in going from $(0-100\ ^\circ C)$.

in order to show this expansion, thermometers are designed so that the mercury is forced to rise from the bulb in a capillary tub with a very small diameter. the smaller the diameter of the capillary, the greater is the sensitivity of the thermometer, a fever thermometer, which needs to show fractions of degrees, requires a capillary so small-less than 0.1 mm in diameter- that it would be very difficult to read if it were not designed for visibility .

The ways to measure the body Temperature :

1- **Glass fever thermometer** :

* Contain mercury or alcohol .

Principle :

The change in temperature $(\Delta T \alpha \Delta V)$ change in volume it uses mercury because :

a. The volume expansion (ΔV) with (ΔT) is very small $(1 cm^3 Hg)$ increase volume by (1.8%) when the temperature changes from $(0 \text{ to } 100\ ^\circ C)$.
b. It`s clear color.
c. It has low adhesion force with the wall of glass .

Q/ Two things increase the visibility of the thermometer .

A. The glass acts as a magnifying glass .
B. Use an opaque white backing .

1- ***Thermistor:*** is a special resistor that changes its resistance rapidly with temperature $(\approx 5\%/^{\circ}C)$.

Principle :

The change in temperature $(\Delta T \propto \Delta R)$ change in the electrical resistance .

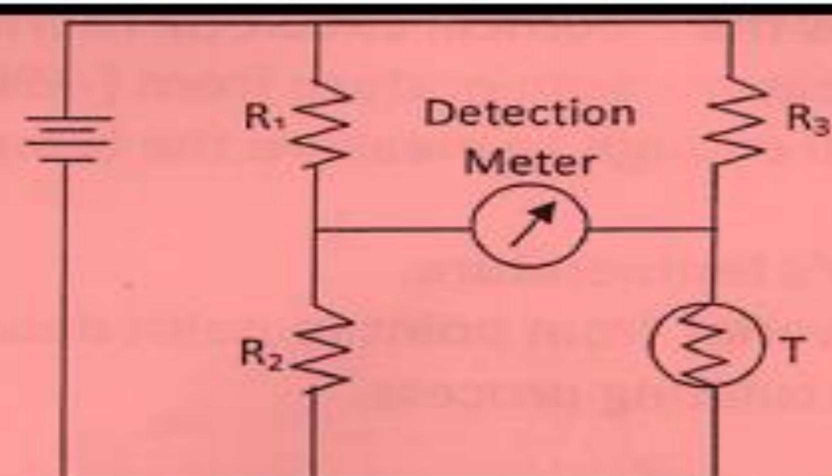

Figure Shows the electrical circuit of Thermistor

- The resistance of thermistor (T) can be measure with a simple bridge circuit to determine the temperature .
- The meter (M) can be calibrated directly in degrees Celsius or Fahrenheit .

Method :

When the bridge is balanced $(R_1, R_2, R_3, R_4 \text{ and } M)$ are equal. the meter (M) reading zero .

When the temperature is changed, it results unbalanced bridge voltage the meter .

- The meter reading can be Fahrenheit or Celsius .

Q / Thermistor is used in medicine because (Advantages) :

1- Good sensitivity .
2- Can measure temperature changes of $(0.01\ ^{\circ}C)$.
3- Small size .
4- Rapidly response to change in temperature .

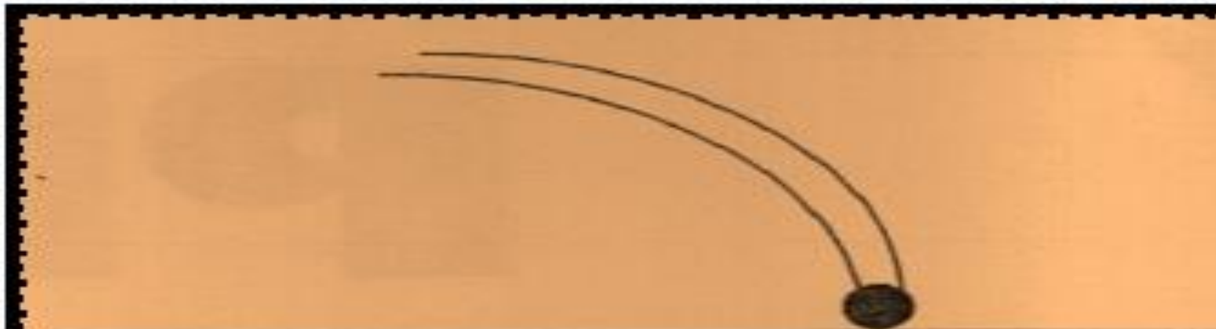

Figure shows the thermistor

<u>Medical application</u> :

Thermistor (pneumograph): is placed in the nose to monitor the breathing rate of the patient by showing the temperature rate between the inspired cold air and the expired warm air .

1- ***Thermocouple*** :

Consist of two junctions of two different metals . if the two junctions are in different temperatures, a voltage is produced that depends on the temperature difference .

Principle : voltage (e.m.f) $\propto \Delta T$.

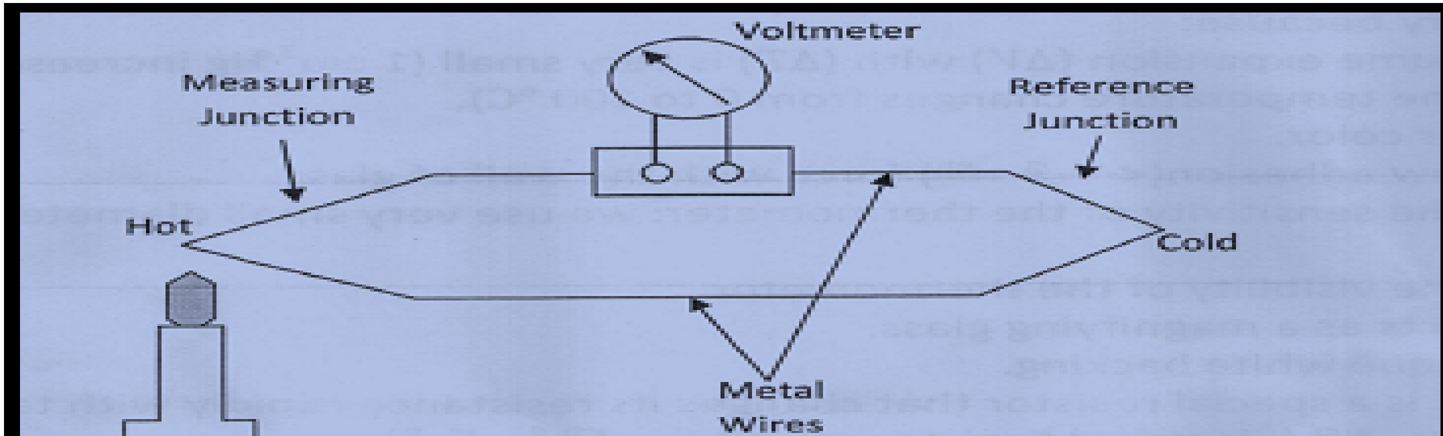

Figure shows the electrical circuit of Thermocouple

Thermocouple can be used to measure temperatures from $(-190\ ^{\circ}C\ to\ 300\ ^{\circ}C)$.

Thermocouple can be made small enough to measure the temperature of individual cells (because it has very sharp end).The metals of thermocouple must be with quite difference of atomic numbers .

❑ ***Thermograph*** : (راسم حراري)

- mapping the body`s temperature .
- The body`s surface temperature varies from point to point depending upon:

A. external physical factors .
B. internal metabolic .
C. circulatory process near the skin .

- Blood flow near the skin is the dominate factor .

❑ ***Thermogram***:(يأخذ صورة حرارية للجسم)

❖ an instrument the safest and simple routine method used to measure the surface temperature of the body .

Principle : the thermogram is used to measure radiation emitted from the body .

- At body temperature $(37°C)$ the emitted radiation is in infrared (IR) region at wave length much longer than those observable by the human eye .
- The surface temperature above a tumor was typically about (1 $°C$) higher than nearby normal tissue, therefore a very sensitive temperature measurement device had to be used (thermistor) .
- Most breasts cancers could have an elevated skin temperature in the region of the cancer .
- All object regardless of their temperature emit radiation .
- Thermogram can detect small tumor (less than 1 cm2 in diameter) in breast cancer.

Stefan – Boltzmann law :

- The basic equation describing the radiation emitted by a body is :

$$W = e\sigma T^4$$

W :the total radiation power per surface area (A), watt/cm ^{2}

T: absolute temperature ($^\circ$ C +273)

e:emissivity=1 (for radiation emitted from the body) .

σ : Stephan Boltzmann constant $= 5.7\times10^{-12}\ W/cm^2.K^4$

e.g : breast cancer

E.g/ A- what is the power radiated per cm ^{2} from skin at temperature of 33 $^\circ$C ?

$$W = e\sigma T^4$$

$$T = 33 + 273 = 306\ K$$

$$W = 1\times 5.7\times 10^{-12}\times (306)^4 = 0.05\ W/cm^2$$

B. what is the power radiated from a nude body $(1.75\times10^4\ cm^2)$ in area ?

$$W = \frac{P}{A} \quad , \quad P = W\times A$$

$$P = 0.057\ w/cm^2 \times 1.75\times10^4\ cm^2 = 875W$$

C. if the radioactive power received from the surrounding walls (background) =735 watt, what is the net power ?

875-735=140 watt

Note: the commercial instrument used in clinical thermography can measure the temperature differences of $\Delta T = 0.2\ ^\circ C$ and record a thermogram in 2 second.

To get a good thermogram :

- Before thermograph :

A. Clothes must be removed because clothing affects skin temperature .

B. It`s necessary to keep the temperature of the thermograph room at 20 C and cool uniformity to enhance the temperature difference and contrast thermograph image .

Breast cancer detection :

for breast cancer detection the steps that must be followed are :

1. Palpation (smooth touching), but it is difficult to detect a small tumor (less than 1cm diameter).

2. Thermography to detect the elevated temperature area but the results have been disappointing because of high false positive (an abnormal thermogram for a subject without cancer) and false negative (a normal thermogram for a cancer patient), due to different blood flow patterns in the two breasts (in fig) .

3. Mammography (low voltage X –ray),it is successful and much more reliable than thermography for detection of breast cancer (80% and over), but it presents a radiation hazard to the body .
4. Biopsy, it gives information only about the material excised, but some cancer tissue near the excised region can be missed .
5. Histo – pathology .

- This advantage the thermogram give false positive result due to different blood flow pattern in the two breast .

Mammography (X–ray) is more accurate than thermograph in detection of breast cancer .

Q:/ compare between mammography and thermograph

Mammography	Thermogram
It can detect 80% of breast cancer (more accurate)	Less accurate. It gives false positive result due to different blood flow pattern
Infusive less safety because it`s ionizing radiation	non infusive (more safety) because of it`s infrared (non ionizing).

medical application of thermograph :

1. Detect breast cancer .
2. Detect other type of cancer .
3. Study blood circulation in head .
4. Study blood supply in diabetic leg .

Heat therapy:

Q/ Heat has two therapeutic effects :

1. **Increase in metabolism resulting in a relaxation of the capillary system (vasodilation) .**
2. **Increase in blood flow as blood moves into cool the heated area .**

Q / physical Methods of producing heat in the body:

1. Conductive heat: is based on the physical fact that if two objects at different temperature are placed in contact, heat will transfer by conduction from the warmer object to the cooler one, i.e.(hot water or hot materials can be placed in contact with the treated area (superficial area). The total heat transferred will depend upon :

- **The area of contact .**
- **The temperature difference .**
- **The time of contact (duration) .**
- **The conductivity of materials .**

Heat conduction by: hot bath, hot pack, electric heating pad, hot paraffin, etc.

Q/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. Infrared (IR) radiation heat : is also for surface heating of body .

It is the same form of heat we feel from the sun or from an open flame.

- The IR wave lengths used are between 800-40,000 nm, ($1nm=10^{-9}$).
- The waves penetrate the skin about 3mm and increase the surface temp.
- Excessive exposure causes reddening(erythema) and sometimes swelling (edema).
- This type of heating is used to treat the same condition of conductive heating, but it is considered to be more effective because the heat penetrates deeper .

3. Radio wave heating (diathermy) :

A- ***Short wave diathermy*** :

- ✓ Utilized electromagnetic waves in the radio rang (wave length~10m).
- ✓ It heats the deep tissues of the body .
- ✓ Heat from diathermy penetrates deeper in to the body than radiant and conductive heat .
- ✓ It has been used in relieving muscle spasms, pain from protruded intervertebral discs, degenerative joint disease, and bursitis.
- ✓ Two different methods are used for transferring the electromagnetic energy in to the body :

1. The first method:

The part of the body to be treated is placed between two metal plate-like electrodes energized by the high-frequency voltage (see the fig.) . The body tissue between the plates acts like an electrolytic solution. The charged particles are attracted to one plate and then the other depending upon the sign of the alternating voltage on the plates .

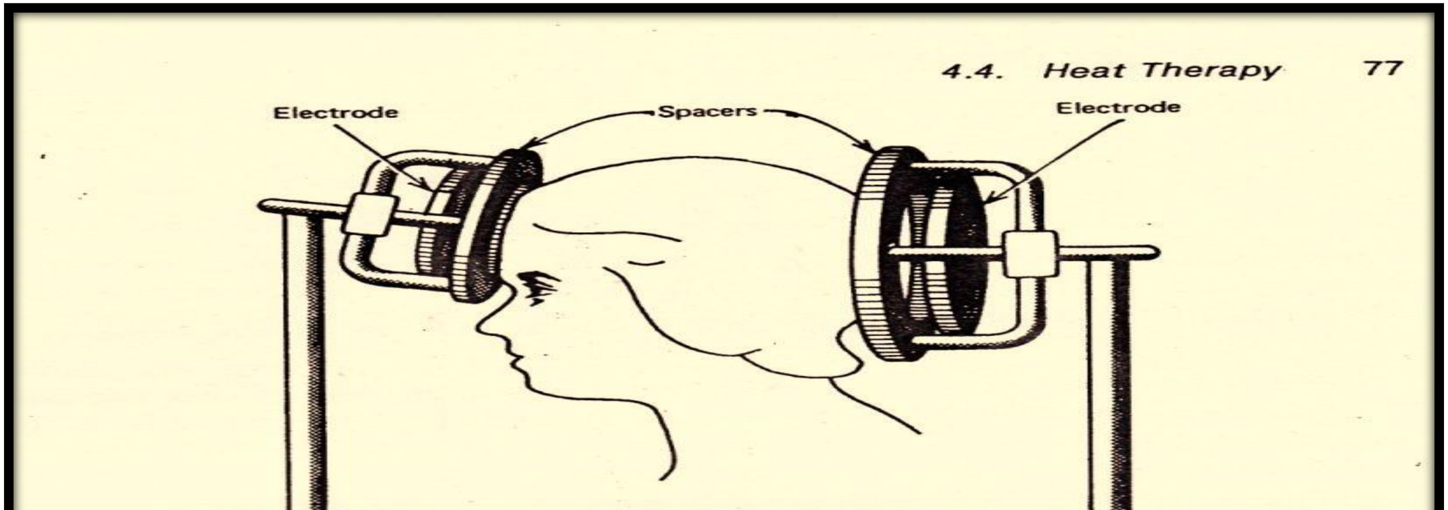

Figure 4.9. Location of capacitor plates for short wave diathermy. (Adapted from Lehmann, J.F.: "Diathermy," *in* Krusen, F.H., Kottke, F.J., and Ellwood, P.M. (Eds.): *Handbook of Physical Medicine and Rehabilitation*, 2nd edition. Philadelphia, W.B. Saunders Company, 1971, p. 286.)

2. The second method :

- It is a magnetic induction (see the blow fig.) .
- In induction diathermy, either a coil is placed around the body region to treated or a (pancake) coil is placed near that part of the body.
- The alternating current in the coil results in an alternating magnetic field in the tissues .

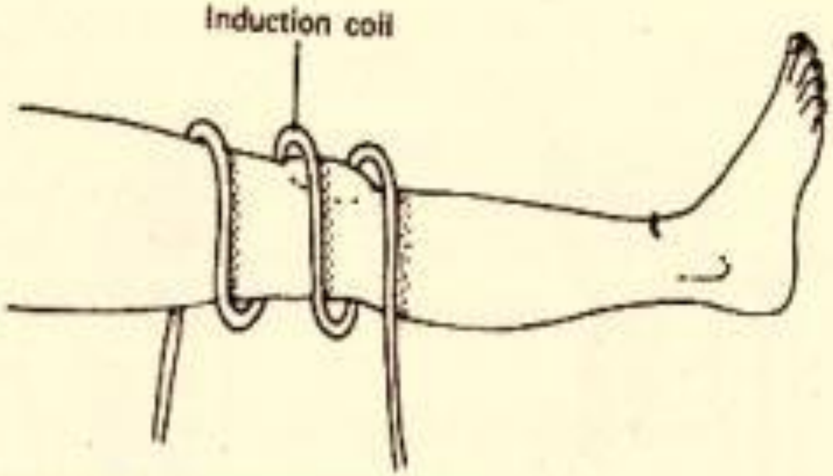

Figure 4.10. Location of induction coil around knee for short-wave diathermy.

B- Micro waves diathermy:

- It is another form of electromagnetic energy .
- It is easier to apply than short-wave diathermy .
- The frequency closer to 900 MHz is effective in therapy, causing uniform heating around body regions .
- It is used in the treatment of fractures, sprains and strains, bursitis, injuries to tendons .

4. Ultrasonic waves heating:

- US waves used for deep heating .
- US waves are completely different from the electromagnetic waves (E.M.W) diathermy .
- They produce mechanical motion like audible sound waves except the frequency is much higher (~1MHz) .
- US waves vibrate tissues producing heating .
- Ultrasonic heating has been useful in relieving the tightness and scarring that often occur in joint disease, aids joints that have limited motion .
- It is useful for deposition heat in bones because they absorb ultrasound energy more effectively than does soft tissue .

Properties of materials

Stress/strain relationships: the constitutive equation:

If we take a rod of some material and subject it to a load along its axis we expect that it will change in length. We might draw a load/displacement curve based on experimental data, as shown in figure 1.1.

We could construct a curve like this for any rod, but it is obvious that its shape depends on the geometry of the rod as much as on any properties of the material from which it is made. We could, however, chop the rod up into smaller elements and, apart from difficulties close to the ends, we might reasonably assume that each element of the same dimensions carries the same amount of load and extends by the same amount. We might then describe the **displacement in terms of extension per unit length**, which we will call **strain (ε)**, and the load in **terms of load per unit area**, which we will call **stress (σ)**. We can then redraw the load/displacement curve as a stress/strain curve, and this should be independent of the dimensions of the bar. In practice we might have to take some care in the design of a test specimen in order to eliminate end effects.

The shape of the stress/strain curve illustrated in figure 1.2 is typical of many engineering materials, and particularly of metals and/ alloys. In the context of biomechanics it is also characteristic of bone . There is a linear portion between the origin O and the point Y.

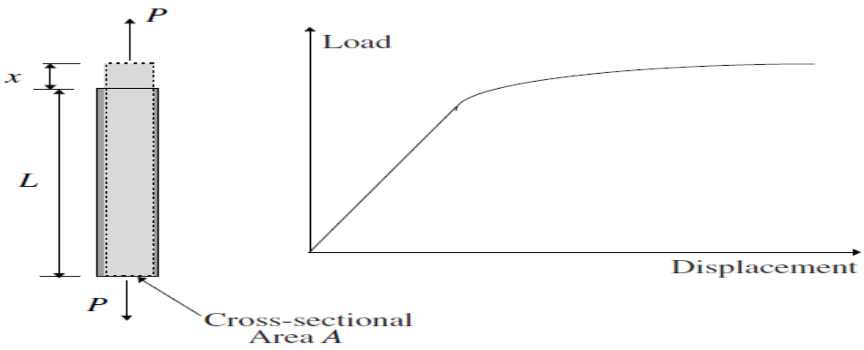

Figure 1.1. *Load/displacement curve: uniaxial tension.*

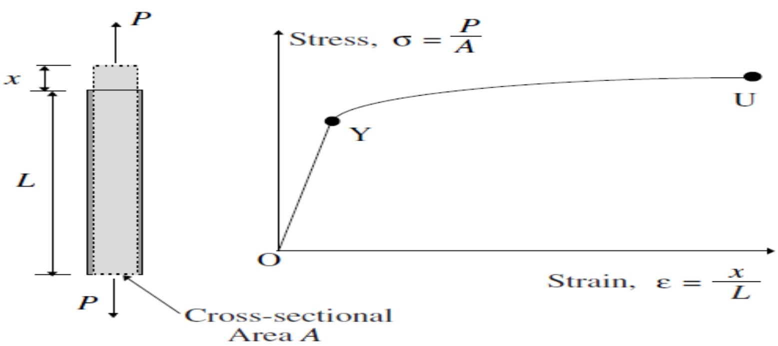

Figure 1.2. *Stress/strain curve: uniaxial tension.*

In this region **the stress is proportional to the strain. The constant of proportionality, *E*, is called *Young's modulus***,

$$\sigma = E\varepsilon$$

The linearity of the equivalent portion of the load/displacement curve is known as Hooke's law.

According **to Hook`s law** : For many materials a bar loaded to any point on the portion OY of the stress/strain curve and then unloaded will return to its original unstressed length. It will follow the same line during unloading as it did during loading. This property of the material is ***known as elasticity***. In this context it is not necessary for the curve to be linear: the important characteristic is the similarity of the loading and unloading processes. A material that exhibits this property and has a straight portion OY is referred to as *linear elastic* in this region. All other combinations of linear/nonlinear and elastic/inelastic are possible. The linear relationship between stress and strain holds only up to the point Y. After this point the relationship is nonlinear, and often the slope of the curve drops off very quickly after this point. This means that the material starts to feel 'soft', and extends a great deal for little extra load. *Typically the point Y represents a critical stress in the material.*After this point the unloading curve will no longer be the same as the loading curve, and upon unloading from a point beyond Y the material will be seen to exhibit a permanent distortion. For this reason Y is often referred to as the *yield point* (and the stress there as the yield stress), although in principle there is no fundamental reason why the limit of proportionality should coincide with the limit of elasticity. The portion of the curve beyond the yield point is referred to as the *plastic region*.

The bar finally fractures at the point U. The stress there is referred to as the (uniaxial) *ultimate tensile stress* (UTS). Often the strain at the point U is very much greater than that at Y, whereas the ultimate tensile stress is only a little greater (perhaps by up to 50%) than the yield stress. Although the material does not actually fail at the yield stress, the bar has suffered a permanent strain and might be regarded as being damaged.

Very few engineering structures are designed to operate normally above the yield stress, although they might well be designed to move into this region under extraordinary conditions. A good example of post-yield design is the 'crumple zone' of an automobile, designed to absorb the energy of a crash. The area under the load/displacement curve, or the volume integral of the area under the stress/strain curve, is a measure of the energy required to achieve a particular deformation.

On inspection of the shape of the curve it is obvious that a great deal of energy can be absorbed in the plastic region.

Materials like rubber, when stretched to high strains, tend to follow very different loading and unloading curves. A typical example of a uniaxial test of a rubber specimen is illustrated in figure 1.3. This phenomenon is known as *hysteresis*, and the area between the loading and unloading curves is a measure of the energy lost during the process. Over a period of time the rubber tends to creep back to its original length, but the capacity of the system as a shock absorber is apparent.

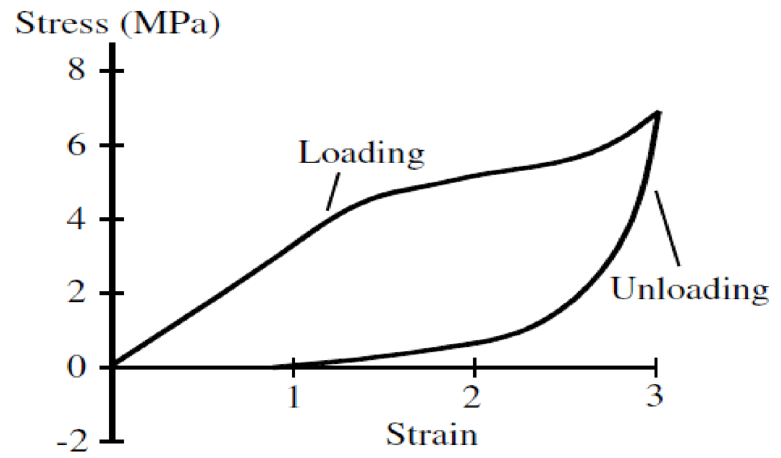

Figure 1.3. *Typical experimental uniaxial stress/strain curve for rubber.*

We might consider that the uniaxial stress/strain curve describes the behavior of our material quite adequately. In fact there are many questions that remain unanswered by a test of this type. These fall primarily into three categories: one associated with the nature and orientation of loads; one associated with time; and one associated with our definitions of stress and strain.

Bone

Bone is a composite material, containing both **organic and inorganic components**. The organic components,about one-third of the bone mass, include the cells, osteoblasts, osteocytes and osteoid. The inorganic components are hydroxyapatites (mineral salts), primarily calcium phosphates.

- The osteoid contains collagen, a fibrous protein found in all connective tissues. It is a low elastic modulus material **($E \approx 1.2$ GPa)** that serves as a matrix and carrier for the harder and stiffer mineral material.The collagen provides much of the tensile strength (but not stiffness) of the bone. **Deproteinized bone** is hard, brittle and weak in tension, like a piece of chalk.

- The mineral salts give the bone its hardness and its compressive stiffness and strength. The stiffness of the salt crystals is about 165 GPa, approaching that of steel. **Demineralized bone** is soft, rubbery and ductile .

The skeleton is composed of *cortical* (*compact*) and *cancellous* (*spongy*) bone, the distinction being made based on the porosity or density of the bone material. The division is arbitrary, but is often taken to be around 30% porosity (see figure 1.4).

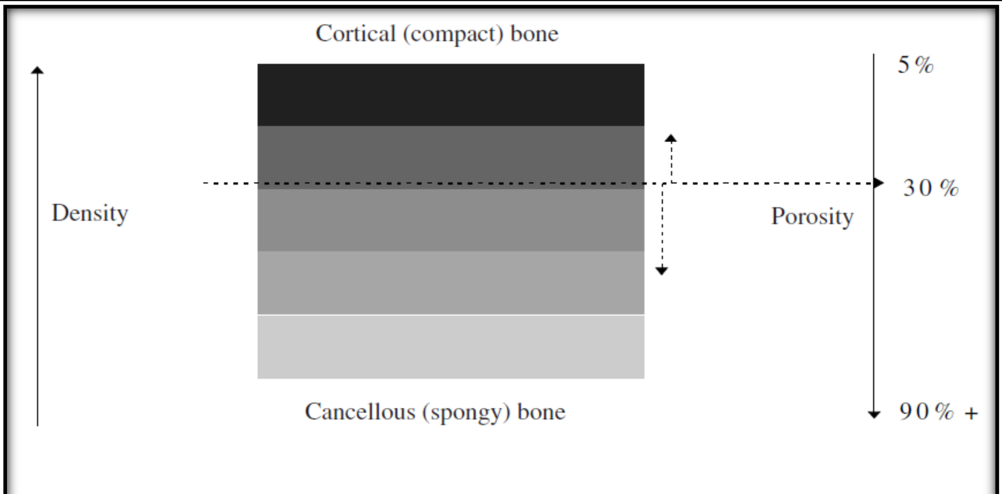

Figure 1.4. *Density and porosity of bone.*

Cortical bone is found where the stresses are high and ***cancellous bone*** where the stresses are lower (because the loads are more distributed), but high distributed stiffness is required. The aircraft designer uses honeycomb cores in situations that are similar to those where cancellous bone is found.

Cortical bone is hard and has a stress/strain relationship similar to many engineering materials that are in common use. It is anisotropic, and the properties that are measured for a bone specimen depend on the orientation of the load relative to the orientation of the collagen fibres. Furthermore, partly because of its composite structure, its properties in tension, in compression and shear are rather different. In principle, boneis strongest in compression, weaker in tension and weakest in shear. The strength and stiffness of bone alsovary with the age and sex of the subject, the strain rate and whether it is wet or dry. **Dry bone** is typically slightly stiffer (higher Young's modulus) but more brittle (lower strain to failure) than **wet bone**. A typical uniaxial tensile test result for a wet human femur is illustrated in figure 1.5. Some of the mechanical propertiesof the femur are summarized in table 1.1, based primarily on a similar table in Fung (1993).

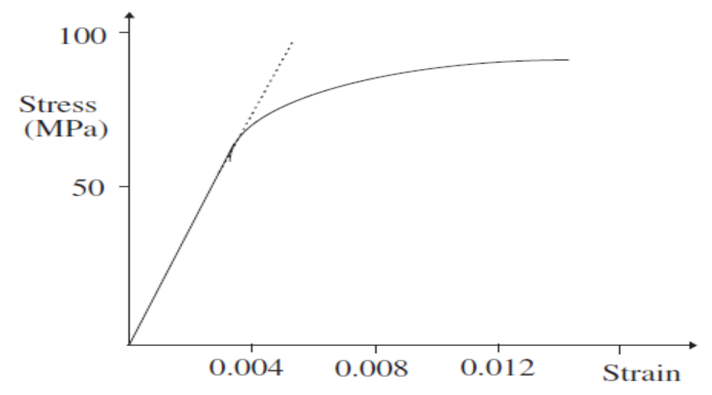

Figure 1.5. *Uniaxial stress/strain curve for cortical bone.*

Table 1.1. *Mechanical properties of bone (values quoted by Fung (1993)).*

	Tension			Compression			Shear		Poisson's ratio
Bone	σ (MPa)	ε (%)	E (GPa)	σ (MPa)	ε (%)	E (GPa)	σ (MPa)	ε (%)	ν
Femur	124	1.41	17.6	170	1.85		54	3.2	0.4

For comparison, a typical structural steel has a strength of perhaps 700 MPa and a stiffness of 200 GPa. There is more variation in the strength of steel than in its stiffness.*Cortical bone is approximately one-tenth as stiff and one-fifth as strong as steel*. Other properties, tabulated by Cochran (1982), include the yield strength (80 MPa, 0.2% strain) and the fatigue strength (30 MPa at 108 cycles).Living bone has a unique feature that distinguishes it from any other engineering material. It remodelsitself in response to the stresses acting upon it. The re-modelling process includes both a change in thevolume of the bone and an orientating of the fibres to an optimal direction to resist the stresses imposed. Thisobservation was first made by Julius Wolff in the late 19th Century, and is accordingly called Wolff 's law.Although many other workers in the field have confirmed this observation, the mechanisms by which it occursare not yet fully understood.Experiments have shown the effects of screws and screw holes on the energy-storing capacity of rabbitbones. A screw inserted in the femur causes an immediate 70% decrease in its load capacity. This isconsistent with the stress concentration factor of three associated with a hole in a plate. After eight weeks thestress-raising effects have disappeared completely due to local remodelling of the bone. Similar re-modelling processes occur in humans when plates are screwed to the bones of broken limbs.

Tissue

Tissue is the fabric of the human body. There are four basic types of tissue, and each has many subtypes and variations. The four types are:

- epithelial (*covering*) tissue;
- connective (*support*) tissue;
- muscle (*movement*) tissue;
- nervous (*control*) tissue.

In this chapter we will be concerned primarily with connective tissues such as tendons and ligaments. Tendons are usually arranged as ropes or sheets of dense connective tissue, and serve to connect muscles to bones or to other muscles. Ligaments serve a similar purpose, but attach bone to bone at joints. In the context of this chapter we are using the term tissue to describe soft tissue in particular. In a wider sense bones themselvescan be considered as a form of connective tissue, and cartilage can be considered as an intermediate stagewith properties somewhere between those of soft tissue and bone.Like bone, soft tissue is a composite material with many individual components. It is made up ofcells intimately mixed with intracellular materials. The intracellular material consists of fibres of collagen‹elastin, reticulin and a gel material called ground substance. The proportions of the materials depend onthe type of tissue. Dense connective tissues generally contain relatively little of the ground substance andloose connective tissues contain rather more. The most important component of soft tissue with respect to themechanical properties is usually the collagen fibre. The properties of the tissue are governed not only by theamount of collagen fibre in it, but also by the orientation of the fibres. In some tissues, particularly those that transmit a uniaxial tension, the fibres are parallel to each other and to the applied load. Tendons and ligamentsare often arranged in this way, although the fibres might appear irregular and wavy in the relaxed condition.In other tissues the collagen fibres are curved, and often spiral, giving rise to complex material behaviour.

The behaviour of tissues under load is very complex, and there is still no satisfactory first-principlesexplanation of the experimental data. Nevertheless, the properties can be measured and constitutive equationscan be developed that fit experimental observation. The stress/strain curves of many collagenous tissues‹including tendon, skin, resting skeletal muscle and the scleral wall of the globe of the eye, exhibit a stress/straincurve in which the gradient of the curve is a linear function of the applied stress (figure 1.6).

Viscoelasticity

The tissue model considered in the previous section is based on the assumption that the stress/strain curve is independent of the rate of loading. Although this is true over a wide range of loading for some tissue types, including the skeletal muscles of the heart, it is not true for others. When the stresses and strains are dependent upon time, and upon rate of loading, the material is described as *viscoelastic*.

The models that we shall consider are all based on the assumption that a rod of viscoelastic material behaves as a set of linear springs and viscous dampers in some combination.

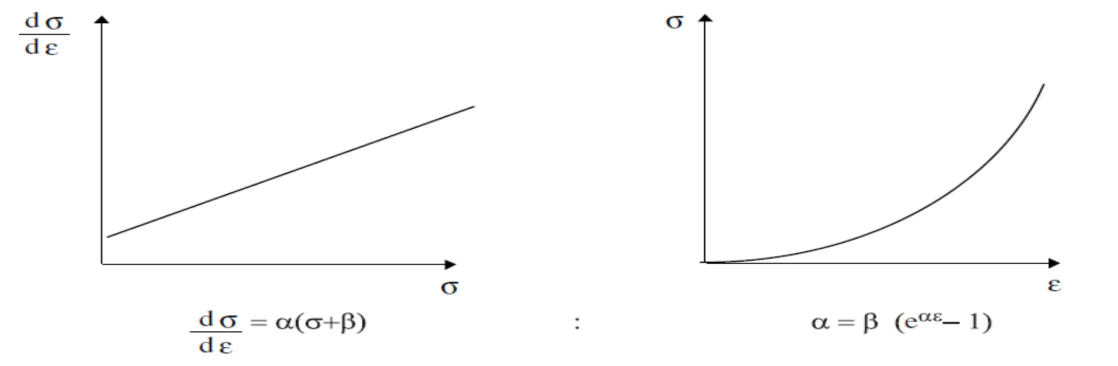

Figure 1.6. *Typical stress/strain curves for some tissues.*

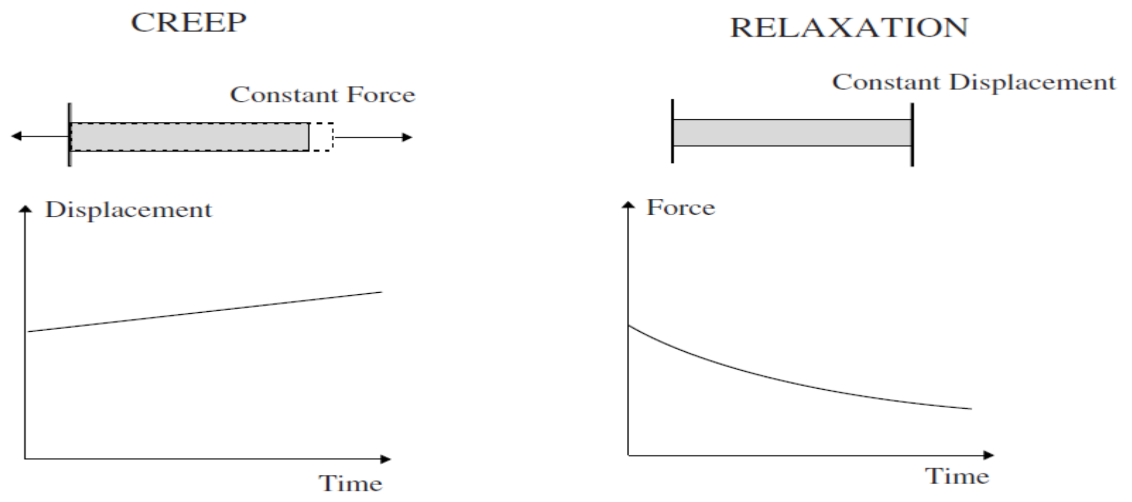

Figure 1.7. *Typical creep and relaxation curves.*

Creep and relaxation

Viscoelastic materials are characterized by their capacity to *creep under constant loads and to relax underconstant displacements* (figure 1.7).

Springs and dashpots

A linear spring responds instantaneously to an applied load, producing a displacement proportional to theload (figure 1.8).

The displacement of the spring is determined by the applied load. If the load is a function of time,$F = F(t)$, then the displacement is proportional to the load and the rate of change of displacement is

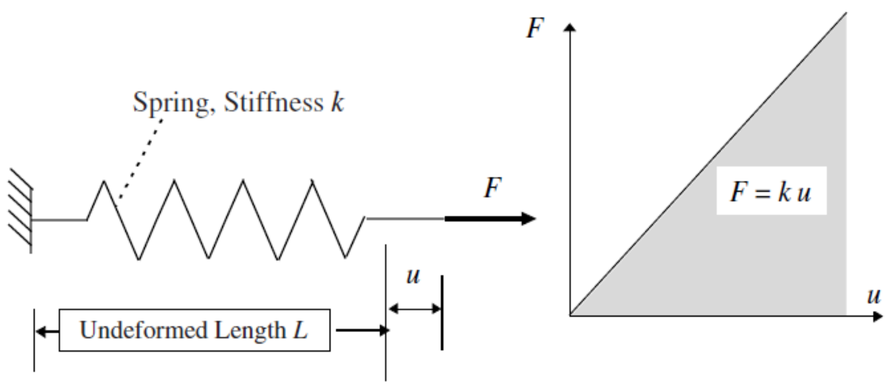

Figure 1.8. *Load/displacement characteristics of a spring.*

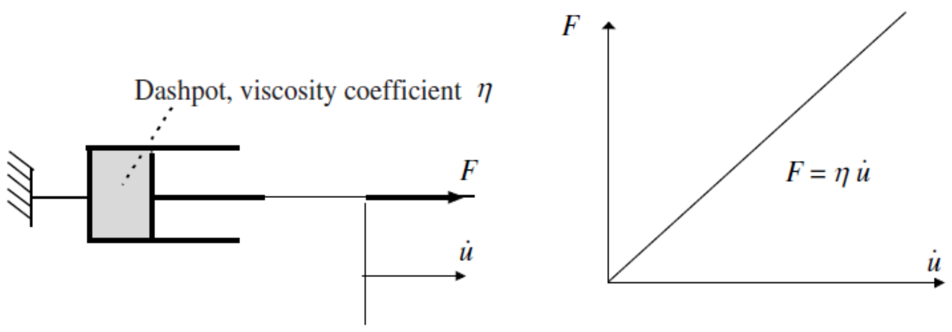

Figure 1.9. *Load/velocity characteristics of a dashpot.*

$$u_{\text{spring}} = \frac{F}{k} \qquad \dot{u}_{\text{spring}} = \frac{\dot{F}}{k}.$$

A dashpot produces a velocity that is proportional to the load applied to it at any instant (figure 1.9).

For the dashpot the velocity is proportional to the applied load and the displacement is found byintegration,

$$\dot{u}_{\text{dashpot}} = \frac{F}{\eta} \qquad u_{\text{dashpot}} = \int \frac{F}{\eta}\,\mathrm{d}t.$$

Note that the displacement of the dashpot will increase forever under a constant load.

Models of viscoelasticity

Three models that have been used to represent the behaviour of viscoelastic materials are illustrated infigure 1.10.

The *Maxwell model* consists of a spring and dashpot in series. When a force is applied the velocity isgiven by

$$\dot{u} = \dot{u}_{\text{spring}} + \dot{u}_{\text{dashpot}}$$
$$\dot{u} = \frac{\dot{F}}{k} + \frac{F}{\eta}.$$

.

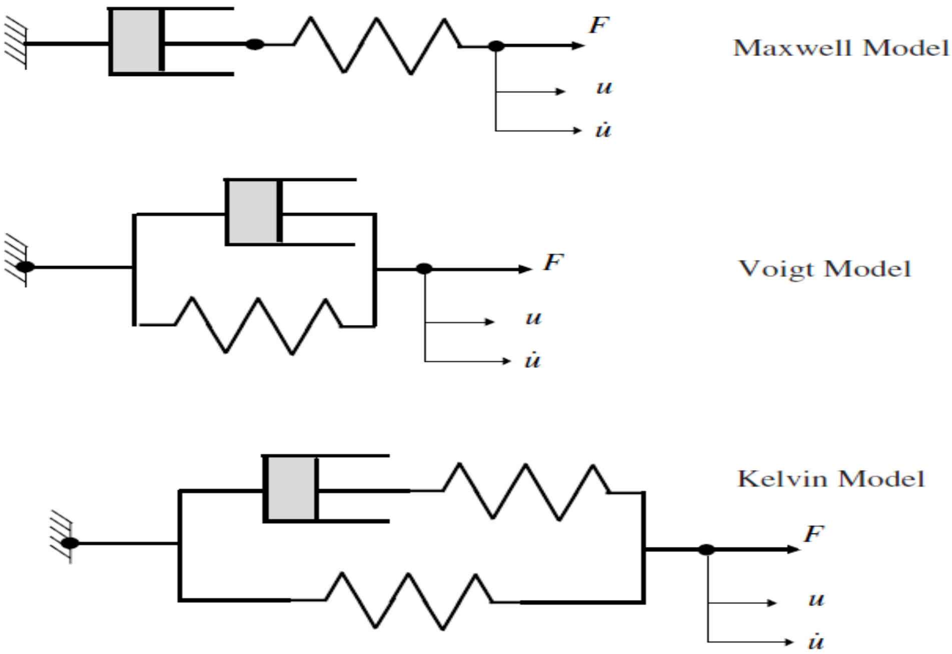

Figure 1.10. *Three 'building-block' models of viscoelasticity.*

The displacement at any point in time will be calculated by integration of this differential equation.

The *Voigt model* consists of a spring and dashpot in parallel. When a force is applied, the displacementof the spring and dashpot is the same. The total force must be that applied, and so the governing equation is

$$F_{\text{dashpot}} + F_{\text{spring}} = F$$
$$\eta\dot{u} + ku = F.$$

Radiation

Physics of diagnostic x-rays :

This subject discusses the physical principles involved in the diagnostic use of x-rays in medicine .

The x-ray photon is a member of the electromagnetic family that includes light of all types (infrared, visible and ultraviolet ,radiowaves, radar and television signals and gamma rays .

Like many important scientific breakthroughs, the discovery of x-rays was accidental, in the fall of 1895. , W.C. Roentgen, a physicist at the university of Wurzburg in Germany , was studying ***cathode rays*** in his laboratory, he was using a fairly high voltage across a tube covered with black paper that had been evacuated to a low pressure .

When he "excited" the tube with high voltage , he noticed that some crystals on a nearby bench glowed and that the rays causing this fluorescence could pass through solid matter, within a few days Roentgen took the first x-ray film .

The main components of modern x-ray unit are :

1. A source of electrons – a filament or cathode .
2. An evacuated space in which to speed up the electrons .
3. A high positive potential to accelerate the negative electrons .
4. A target or anode, which the electrons strike to produce x-rays .

The unit used for radiation exposure is the Roentgen (R), a measure of the a mount of electric change produced by ionization in air :

$$1R = 2.58 * 10^{-4} \text{ C/Kg of air .}$$

x-ray slices of the body :

The radiologist often takes x-ray images from different directions, such as from the back, the side and an intermediate (oblique) angle .

taking x-ray images of slices of the body or body section radiography, better known as tomography, was first proposed in about 1930 as a better way to distinguish these shadows, both conventional tomography and computerized tomography .

axial tomography was dramatically improved in 1972 when Hounsfield developed computerized axial tomography (CAT), sometimes called computerized tomography (CT),for EMI Limited in England . Hounsfield made use of a technique for analyzing data by computer that was originally developed for use in astronomy .

physics of nuclear medicine (radioisotopes in medicine)

investigator of radioactivity discovered that certain natural elements primarily the very heavy ones, have unstable nuclei that disintegrate to emit various rays –alpha (α), beta (β) and gamma (γ) rays .

the alpha, beta and gamma rays were found to have quite different characteristics, alpha and beta particle bend in opposite directions in magnetic and electrical fields, alpha particles are positively charged and beta particles are negatively charged .

Alpha particles which stop in a few centimeters of air are the nuclei of helium atoms, ***beta rays*** are more penetrating but can be stopped in a few maters of air or a few millimeters of tissues, they are high speed electrons, ***gamma rays*** are very penetrating and are physically identical to x-rays, the usually have much higher energies than the x-rays used in diagnostic radiology .

Alpha and gamma rays from a given source have fixed energies but beta rays have a spread of energies up to a maximum characteristic of the source .

Each element has a specific number of protons in the nucleus. For example carbon has six protons, nitrogen has seven protons and oxygen has eight protons .

However, for each element, the number of neutrons in the nucleus can vary, nuclei of a given element with different numbers of neutrons are called ***isotopes*** of the element .

If they are not radioactive they are called ***stable isotopes*** and if they are radioactive they are called ***radioisotopes***, for example carbon has two stable isotopes (^{12}C and ^{13}C) and several radioisotopes (e.g, ^{11}C ,^{14}C,and ^{15}C) .

Most elements do not have naturally occurring radioisotopes, but radioisotopes of all elements can now be produced artificially, isotope mean "in the same place" and should be used when referring to a single element, the word ***radionuclides***is appropriate when several radioactive elements are involved .

There are over 1000 known radionuclides, most man-made. Heavy elements tend to have many more radioisotopes than light elements; for example, iodine has 15 known radioisotopes, while hydrogen has 1, tritium (^{3}H) . A particular radionuclide can be identified by its radioactivity alone just as human can be identified by their fingerprints.

Characteristics that help identify the radionuclide are the type and energy of its emitted particles or rays .

The most common emissions from radioactive elements are beta particles and gamma rays . since beta particles are not very penetrating, they are easily absorbed in the body and are generally of little use for diagnosis. However, some beta-emitting radionuclides such as (^{3}H and ^{14}C) play an important role in medical research .(^{23}P) is used for diagnosis of tumors in the eye because some of its beta particles have enough energy to emerge from the eye .most clinical diagnostic procedures use photon of some type- usually gamma rays with energies above 100kev can penetrate many centimeters of tissue, and a gamma emitter in the body can be located and mapped by a detector outside the body. All of the gamma-emitting radionuclides of common organic elements carbon, nitrogen, and oxygen-are short lived, which makes their use in clinical medicine difficult without an accelerator . few medical centers have installed cyclotrons for producing short-lived radionuclides.

A metastable radionuclide decays by emitting gamma rays only and daughter nucleus differs from its parent only in having less energy .

Each radionuclide decays as affixed rate commonly indicated by the half-life ($T_{1/2}$), the time needed for half of radioactive nuclei to decay .

The basic equation describing radioactive decay is

$$A = A_{\circ} e^{-\lambda t}$$

Where A is the activity in disintegrations per second, $A_{\circ}$ is the initial activity , λ is decay constant, and t is the time since the activity was $A_{\circ}$. If t measured in hours, λ must be in hours^{-1} . if λ is small, that is, less than 0.1 , it is very nearly the friction of the radionuclide that decays per unit time . for ^{198}Au, λ is 0.01 hr^{-1}, which means that 0.01(or 1%) decays per hours :

$$A = \lambda N$$

Where N is the number of radioactive atoms . equation can be used to determine that half-life of long-lived radionuclide the decay constant is related to the half-life by the simple equation

$$T_{1/2} = \frac{0.693}{\lambda}$$

The constant 0.693 is the natural logarithm of 2 . the relationship between the decay constant and the half-life is illustrated .

Second Law of Thermodynamics

There are many imaginable phenomena that are not forbidden by the First Law of Thermodynamics but still do not occur. For example, when an object falls from a table to the ground, its potential energy is first converted into kinetic energy; then, as the object comes to rest on the ground, the kinetic energy is converted into heat. The First Law of Thermodynamics does not forbid the ***reverse process***, whereby the heat from the floor would enter the object and be converted into kinetic energy, causing the object to jump back on the table. Yet this event does not occur. Experience has shown that certain types of events are ***irreversible***. Broken objects do not mend by themselves. Spilled water does not collect itself back into a container. The irreversibility of these types of events is intimately connected with the probabilistic behavior of systems comprised of a large ensemble of sub units.

The Second Law of Thermodynamics is : *The direction of spontaneous change in a system is from an arrangement of lesser probability to an arrangement of greater probability*;that is, from order to disorder (entropy).

Properties of materials

Stress/strain relationships: the constitutive equation:

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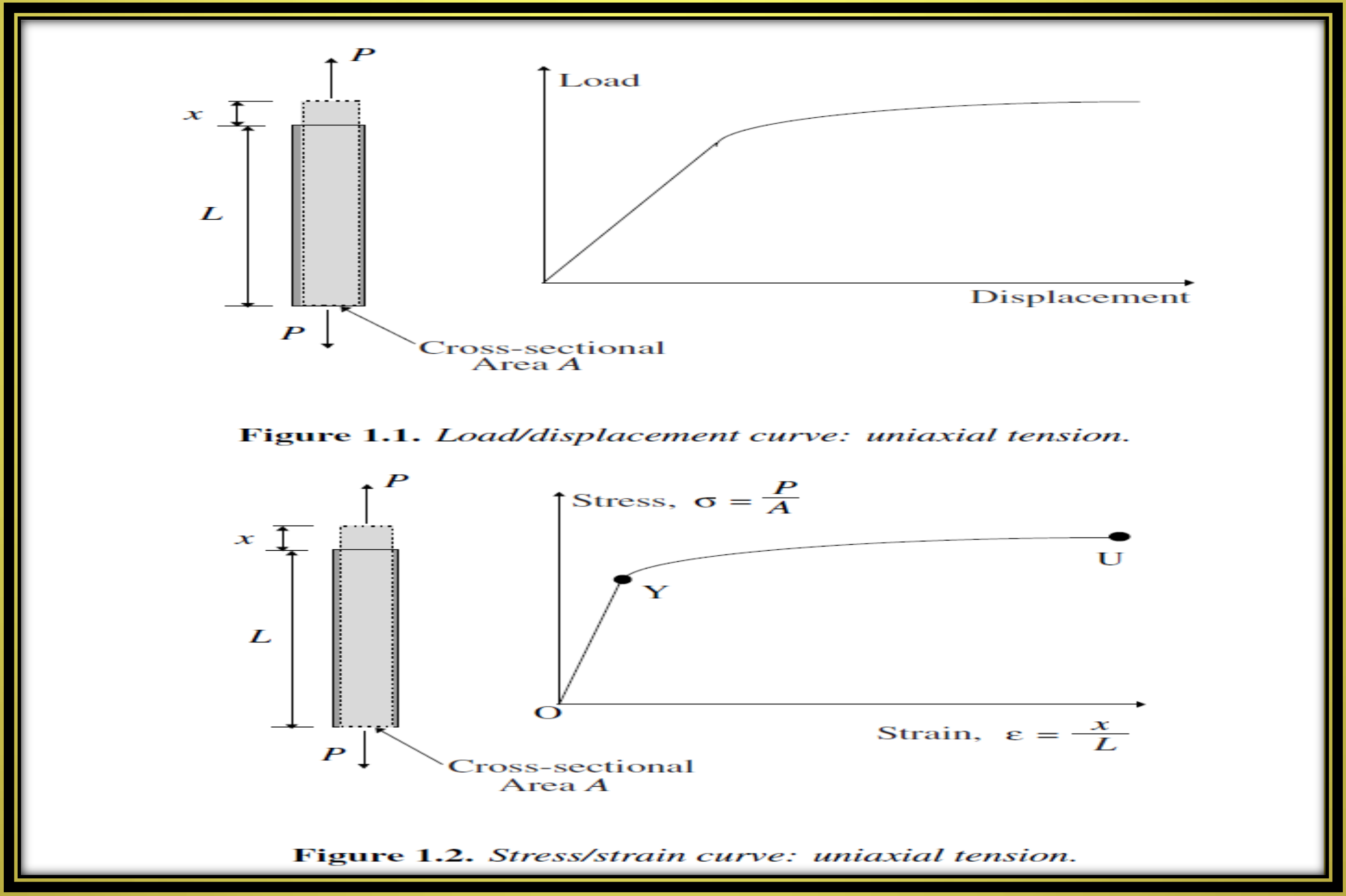
We might draw a load/displacement curve based on experimental data, as shown in figure 1.1.



We might then describe the **displacement in terms of extension per unit length**, which we will call **strain (ε)**, and the load in **terms of load per unit area**, which we will call **stress (σ)**.

We can then redraw the load/displacement curve as a stress/strain curve, and this should be independent of the dimensions of the bar.

The shape of the stress/strain curve illustrated in figure 1.2 is typical of many engineering materials, and particularly of metals and/ alloys. In the context of biomechanics it is also characteristic of bone .

In this region the stress is proportional to the strain. The constant of proportionality, *E*, is called *Young's modulus*,

$$\sigma = E\varepsilon$$

The linearity of the equivalent portion of the load/displacement curve is known as Hooke's law.

According **to Hook`s law** : For many materials a bar loaded to any point on the portion OY of the stress/strain curve and then unloaded will return to its original unstressed length. It will follow the same line during unloading as it did during loading. This property of the material is ***known as elasticity***.

In this context it is not necessary for the curve to be linear: the important characteristic is the similarity of the loading and unloading processes. A material that exhibits this property and has a straight portion OY is referred to as *linear elastic* in this region. All other combinations of linear/nonlinear and elastic/inelastic are possible. The linear relationship between stress and strain holds only up to the point Y.

After this point the relationship is nonlinear, and often the slope of the curve drops off very quickly after this point. This means that the material starts to feel ‘soft’, and extends a great deal for little extra load. *Typically the point Y represents a critical stress in the material.*After this point the unloading curve will no longer be the same as the loading curve, and upon unloading from a point beyond Y the material will be seen to exhibit a permanent distortion. For this reason Y is often referred to as the *yield point* (and the stress there as the yield stress), although in principle there is no fundamental reason why the limit of proportionality should coincide with the limit of elasticity. The portion of the curve beyond the yield point is referred to as the *plastic region*.

The bar finally fractures at the point U. The stress there is referred to as the (uniaxial) *ultimate tensile stress* (UTS).

Materials like rubber, when stretched to high strains, tend to follow very different loading and unloading curves. A typical example of a uniaxial test of a rubber specimen is illustrated in figure 1.3. This phenomenon is known as *hysteresis*, and the area between the loading and unloading curves is a measure of the energy lost during the process. Over a period of time the rubber tends to creep back to its original length, but the capacity of the system as a shock absorber is apparent.

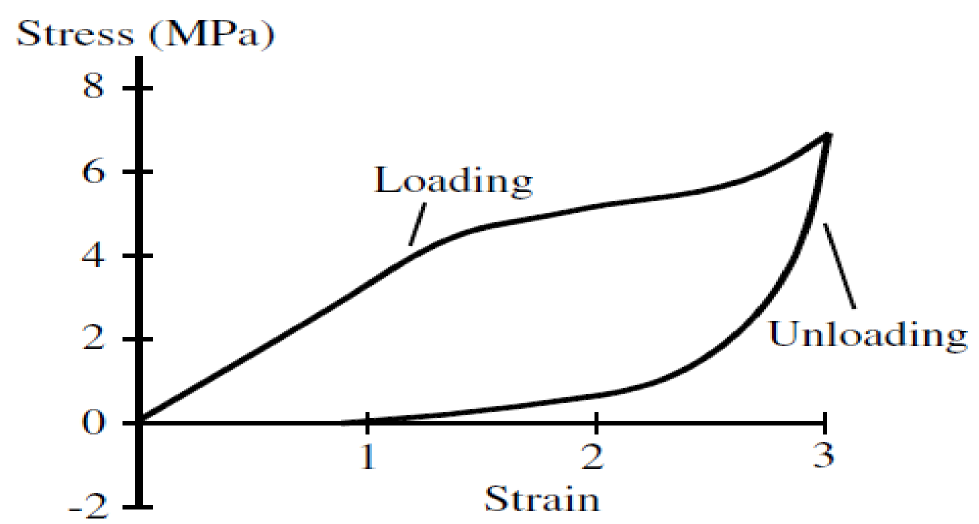


Figure 1.3. *Typical experimental uniaxial stress/strain curve for rubber.*

In fact there are many questions that remain unanswered by a test of this type. These fall primarily into three categories: one associated with the nature and orientation of loads; one associated with time; and one associated with our definitions of stress and strain.

Bone

Bone is a composite material, containing both **organic and inorganic components**. The organic components,about one-third of the bone mass, include the cells, osteoblasts, osteocytes and osteoid. The inorganic components are hydroxyapatites (mineral salts), primarily calcium phosphates.

•The osteoid contains collagen, a fibrous protein found in all connective tissues. It is a low elastic modulus material **($E \approx 1.2$ GPa)** that serves as a matrix and carrier for the harder and stiffer mineral material.The collagen provides much of the tensile strength (but not stiffness) of the bone. **Deproteinized bone** is hard, brittle and weak in tension, like a piece of chalk.

•The mineral salts give the bone its hardness and its compressive stiffness and strength. The stiffness of the salt crystals is about 165 GPa, approaching that of steel. Demineralized bone is soft, rubbery and ductile .

The skeleton is composed of *cortical* (*compact*) and *cancellous* (*spongy*) bone, the distinction being made based on the porosity or density of the bone material. The division is arbitrary, but is often taken to be around 30% porosity (see figure 1.4).

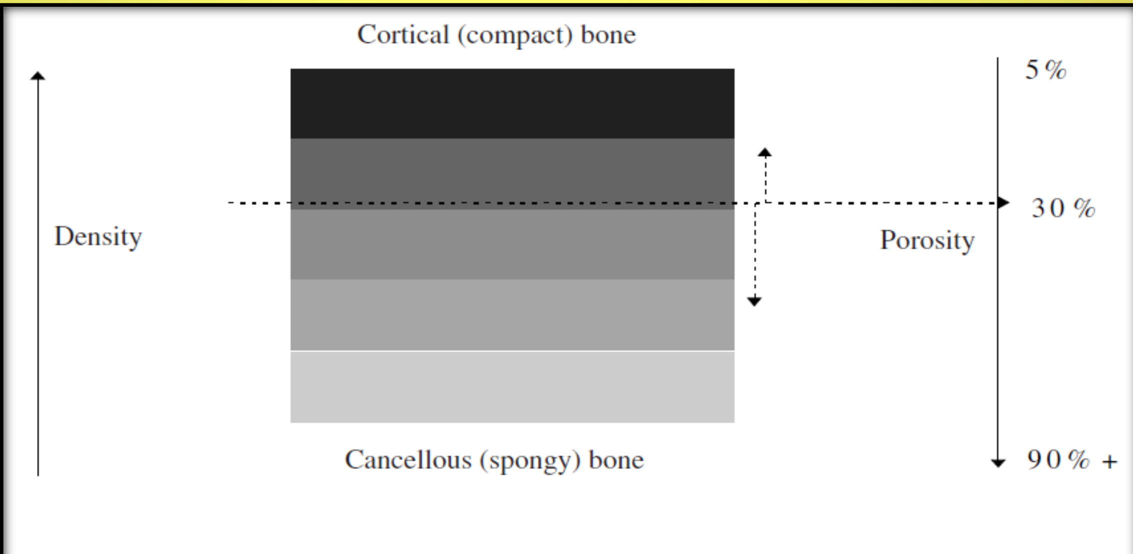


Figure 1.4. *Density and porosity of bone.*

Cortical bone is found where the stresses are high and ***cancellous bone*** where the stresses are lower (because the loads are more distributed), but high distributed stiffness is required. The aircraft designer uses honeycomb cores in situations that are similar to those where cancellous bone is found.

Dry bone is typically slightly stiffer (higher Young's modulus) but more brittle (lower strain to failure) than **wet bone**. A typical uniaxial tensile test result for a wet human femur is illustrated in figure 1.5.

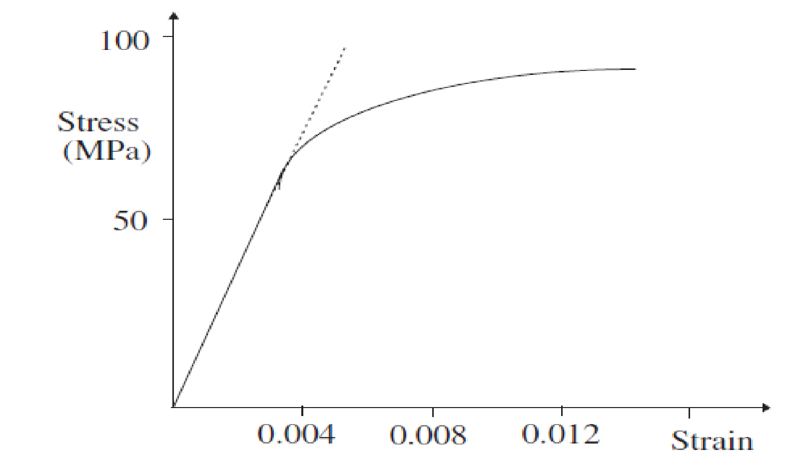


Figure 1.5. *Uniaxial stress/strain curve for cortical bone.*

Table 1.1. *Mechanical properties of bone (values quoted by Fung (1993)).*

	Tension			Compression			Shear		Poisson's ratio
Bone	σ (MPa)	ε (%)	E (GPa)	σ (MPa)	ε (%)	E (GPa)	σ (MPa)	ε (%)	ν
Femur	124	1.41	17.6	170	1.85		54	3.2	0.4

Tissue

Tissue is the fabric of the human body. There are four basic types of tissue, and each has many subtypes and variations. The four types are:

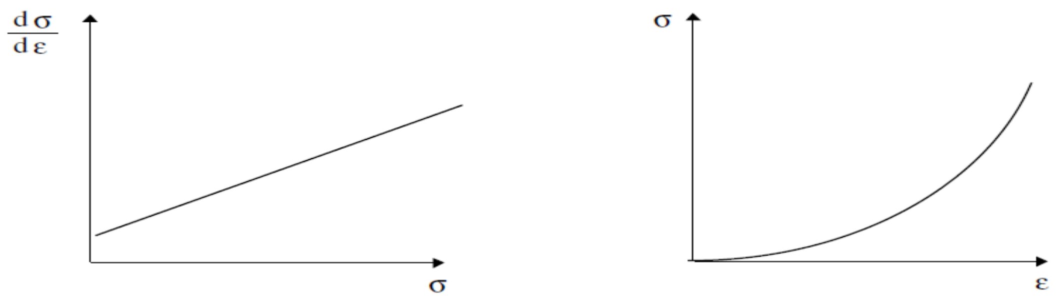
- epithelial (*covering*) tissue;
- connective (*support*) tissue;
- muscle (*movement*) tissue;
- nervous (*control*) tissue.

In this chapter we will be concerned primarily with connective tissues such as tendons and ligaments. Tendons are usually arranged as ropes or sheets of dense connective tissue, and serve to connect muscles to bones or to other muscles. Ligaments serve a similar purpose, but attach bone to bone at joints. In the context of this chapter we are using the term tissue to describe soft tissue in particular.

Viscoelasticity

The tissue model considered in the previous section is based on the assumption that the stress/strain curve is independent of the rate of loading. Although this is true over a wide range of loading for some tissue types, including the skeletal muscles of the heart, it is not true for others. When the stresses and strains are dependent upon time, and upon rate of loading, the material is described as *viscoelastic*.

The models that we shall consider are all based on the assumption that a rod of viscoelastic material behaves as a set of linear springs and viscous dampers in some combination.



$$\frac{d\sigma}{d\varepsilon} = \alpha(\sigma+\beta) \quad : \quad \alpha = \beta\ (e^{\alpha\varepsilon} - 1)$$

Figure 1.6. *Typical stress/strain curves for some tissues.*

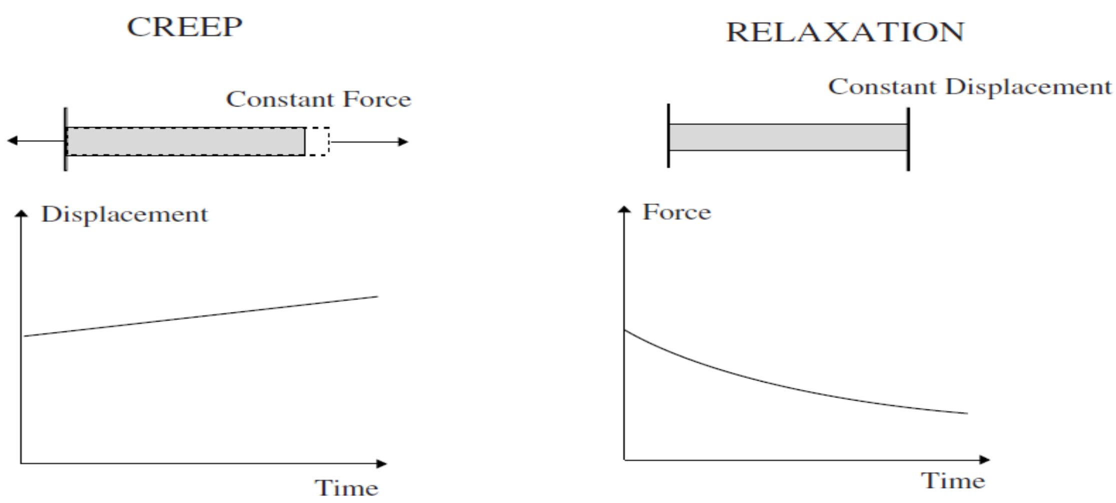


Figure 1.7. *Typical creep and relaxation curves.*

Physical basic of heat and cold temperature :

Heat and cold have been used for medical purposes for several thousand years . if we want to describe temperature as a physical phenomenon, however, we should try to understand it on a molecular scale .

- ✓ Matter is composed of molecules that are in motion .
- ✓ Molecules motion means that they have kinetic energy .
- ✓ Kinetic energy (K.E) is related with temperature (T) .
- ✓ K.E $\uparrow \Leftrightarrow$ T $\uparrow$ i.e.: In order to increase the temperature of gas it is necessary to increase the average kinetic energy of its molecules. this can be done by putting the gas in contact with a flame .

○ *Heat :*

The energy transferred from the flame to the (gas) molecules causing the temp. rise is called heat .

- Solid +heat $\Rightarrow$ liquid .
- Liquid +heat $\Rightarrow$ gas .
- Gas + heat $\Rightarrow$ ions .

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 temperature by a suitable calibration .

- All scales are based on easily states, such as, the freezing and boiling points of water (ice point , steam point) .

Ice point : a mixture of ice and water which is in equilibrium with air , saturated with vapor at 1 atmospheric pressure .

Steam point : are based on liquid water vapor (with no air) in equilibrium at 1 atmospheric pressure .

The temperature scales used in **SI** and English system are : (where **SI** is international system)

1- Celsius scales (also called the centigrade scale), which is in common use throughout most of the world : the ice and steam points are values of (0 -100 $^{\circ}C$)respectively .

** Normal body temperature $\left(37^{\circ}C\right)$.

2- Fahrenheit scale : the ice and steam points are the values of $\left(32-212\ ^{\circ}F\right)$ respectively .

** Normal body temperature $\left(98.6\ ^{\circ}F\right)$.

3- Absolute temperature scale: the ice and steam points are the values of $(273.15-373.15\ K)$respectively .

A- normal body temperature $(310K)$. we notice that in figure 1

B-The lowest temperature is the absolute zero$(0K)$ is $\left(-273.15^{\circ}C\right)$.

- The temperature unite on this scale is the **Kelvin**(K)without the degree symbol.
- In English system, the absolute temperature scale is called the **Rankin** scale .

<u>NOTICE</u> : this scale used for scientific work but it is not used in medicine .

- **The relationships between different temperature scales are :**

The **Kelvin** scale is relative to the **Celsius** scale by :

$$T_{(K)} = T_{\left(^{\circ}C\right)} + 273.15$$

The **Fahrenheit** scale is relative to the **Celsius** scale by :

$$T_{\left(^{\circ}C\right)} = \frac{5}{9}\left(T_{\left(^{\circ}F\right)} - 32\right)$$

Rankin scale is relative to the **Fahrenheit** scale by :

$$T_{(R)} = T_{(^\circ F)} + 459.67$$

The temperature scales in two unite system are relatively :

$$T_{(R)} = 1.8T_{(K)}$$

And $$T_{(^\circ F)} = 1.8T_{(^\circ C)} + 32$$

Q1/ In a hot room, a person skin temperature is about $(35^\circ C)$,find his skin temperature on the kelvin and Fahrenheit scales ?

Sol/ from $T_{(K)} = T_{(^\circ C)} + 273.15$

$$T_{(K)} = 35 + 273.15 = 308.15\ ^\circ K$$

$$T_{(^\circ F)} = 1.8T_{(^\circ C)} + 32 \Rightarrow T_{(^\circ F)} = 1.8 \times 35 + 32 = 95\ ^\circ F$$

Q2/ A pan of water is heated from $(30^\circ C)$ to the boiling point. What is the change in its temperature on the Kelvin and Fahrenheit scales ?

SOL/ $T_{(K)} = T_{(^\circ C)} + 273.15 = 30 + 273.15 = 303.15$

$$T_{(^\circ F)} = 1.8T_{(^\circ C)} + 32 = 1.8 \times 30 + 32 = 86$$

$$\because\ T_{(K)} = T_{(^\circ C)} + 273.15 = 100\ \textit{boiling} + 273.15 = 373.15$$

$$\because\ T_{(^\circ F)} = 1.8T_{(^\circ C)} + 32 = 1.8 \times 100 \textit{boiling} + 32 = 212$$

$$\therefore\ \Delta^\circ C = 100 - 30 = 70^\circ$$
$$\Delta^\circ K = 373.15 - 303.15 = 70^\circ$$
$$\Delta^\circ F = 212 - 86 = 126^\circ F$$

We can see this degree on thermometer in figure 1

Q/Calculate the normal body temperature on Kelvin, Celsius, and Fahrenheit scales ?

Q/ It is difficult to measure body temperature with the house thermometer. why ?

Ans/

a- It is difficult to place the house thermometer under the tongue .
b- The house thermometer would give a low reading because the temperature will fall when the thermometer was removed from the mouth .

Q / What is expansion value (the volume) for liquid (mercury) in a thermometer ? explain.

Ans/ The expansion of the liquid in a thermometer is not $(1cm^3)$ of mercury increases in volume by only (1.8%) in going from $(0-100\ ^\circ C)$.

in order to show this expansion, thermometers are designed so that the mercury is forced to rise from the bulb in a capillary tub with a very small diameter. the smaller the diameter of the capillary, the greater is the sensitivity of the thermometer, a fever thermometer, which needs to show fractions of degrees, requires a capillary so small-less than 0.1 mm in diameter- that it would be very difficult to read if it were not designed for visibility .

The ways to measure the body Temperature :

1- ***Glass fever thermometer*** :

* Contain mercury or alcohol .

Principle :

The change in temperature $(\Delta T\ \alpha\ \Delta V)$ change in volume it uses mercury because :

a. The volume expansion (ΔV) with (ΔT) is very small $(1cm^3 Hg)$ increase volume by (1.8%) when the temperature changes from $(0\ to\ 100\ ^\circ C)$.
b. It`s clear color.

c. It has low adhesion force with the wall of glass .

Q/ Two things increase the visibility of the thermometer .

A. The glass acts as a magnifying glass .
B. Use an opaque white backing .

2- ***Thermistor:*** is a special resistor that changes its resistance rapidly with temperature $(\approx 5\% / ^{\circ}C)$.

Principle :

- The change in temperature $(\Delta T \, \alpha \, \Delta R)$ change in the electrical resistance .

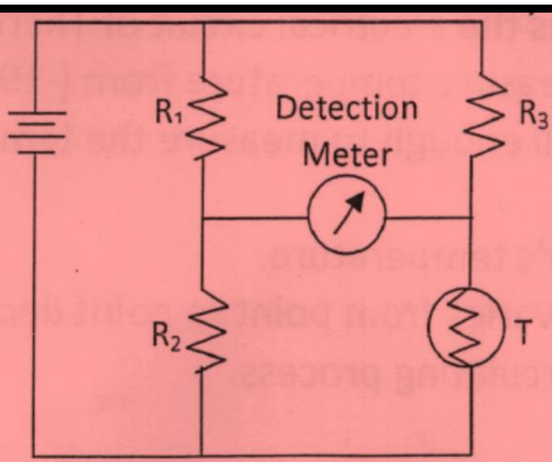


Figure Shows the electrical circuit of Thermistor

- The resistance of thermistor (T) can be measure with a simple bridge circuit to determine the temperature .

- The meter (M) can be calibrated directly in degrees Celsius or Fahrenheit .

Method :

When the bridge is balanced $(R_1, R_2, R_3, R_4 \; and \; M)$ are equal. the meter (M) reading zero .

When the temperature is changed, it results unbalanced bridge voltage the meter .

- The meter reading can be Fahrenheit or Celsius .

Q / Thermistor is used in medicine because (Advantages) :

1- Good sensitivity .
2- Can measure temperature changes of $(0.01\ ^{\circ}C)$.
3- Small size .
4- Rapidly response to change in temperature .

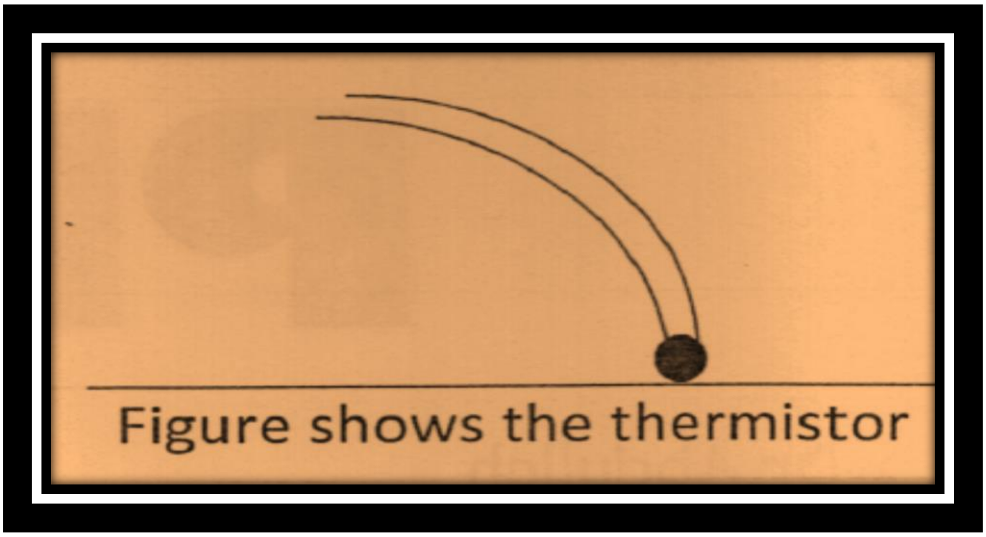


Figure shows the thermistor

<u>Medical application</u> :

Thermistor (pneumograph): is placed in the nose to monitor the breathing rate of the patient by showing the temperature rate between the inspired cold air and the expired warm air .

3- ***<u>Thermocouple</u>*** :

Consist of two junctions of two different metals . if the two junctions are in different temperatures, a voltage is produced that depends on the temperature difference .

Principle : voltage (e.m.f) $\alpha \ \Delta T$.

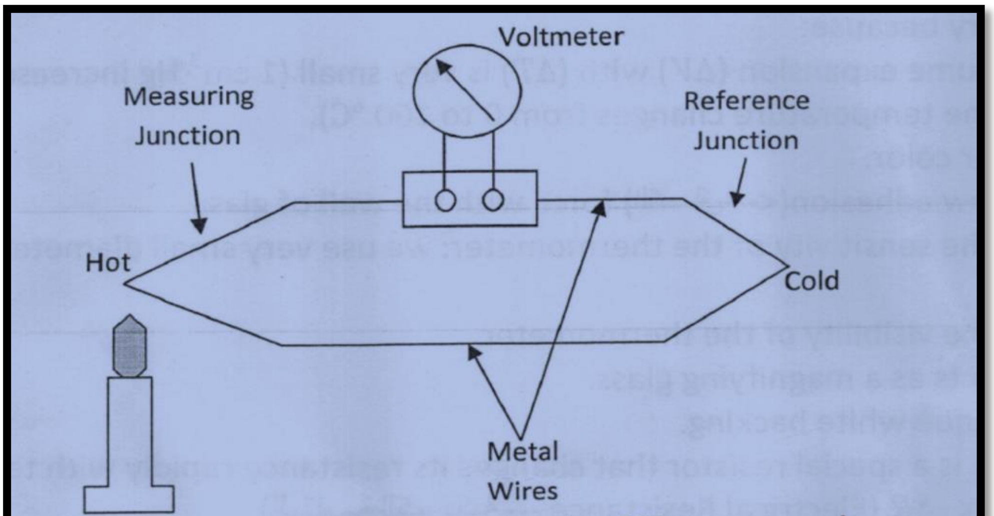


Figure shows the electrical circuit of Thermocouple

Thermocouple can be used to measure temperatures from $\left(-190\ ^{\circ}C\ to\ 300\ ^{\circ}C\right)$.

Thermocouple can be made small enough to measure the temperature of individual cells (because it has very sharp end).The metals of thermocouple must be with quite difference of atomic numbers .

Thermograph : (راسم حراري)

- mapping the body`s temperature .
- The body`s surface temperature varies from point to point depending upon:
  a. external physical factors .
  b. internal metabolic .
  c. circulatory process near the skin .
- Blood flow near the skin is the dominate factor .

Thermogram:(يأخذ صورة حرارية للجسم)

- an instrument the safest and simple routine method used to measure the surface temperature of the body .

Principle : the thermogram is used to measure radiation emitted from the body .

- At body temperature $(37^{\circ}C)$ the emitted radiation is in infrared (IR) region at wave length much longer than those observable by the human eye .
- The surface temperature above a tumor was typically about (1 $^{\circ}C$) higher than nearby normal tissue, therefore a very sensitive temperature measurement device had to be used (thermistor) .
- Most breasts cancers could have an elevated skin temperature in the region of the cancer .
- All object regardless of their temperature emit radiation .
- Thermogram can detect small tumor (less than 1 cm^2 in diameter) in breast cancer.

Stefan – Boltzmann law :

- The basic equation describing the radiation emitted by a body is :

$$W = e\sigma T^4$$

W :the total radiation power per surface area (A), watt/cm^2

T: absolute temperature ($^{\circ}$ C +273)

e:emissivity=1 (for radiation emitted from the body) .

σ : Stephan Boltzmann constant = $5.7 \times 10^{-12}\ W/cm^2.K^4$

e.g : breast cancer

e.g/ A- what is the power radiated per cm^2 from skin at temperature of $33^\circ C$?

$$W = e\sigma T^4$$

$$T = 33 + 273 = 306\,K$$

$$W = 1 \times 5.7 \times 10^{-12} \times (306)^4 = 0.05\ W/cm^2$$

B. what is the power radiated from a nude body $\left(1.75 \times 10^4\ cm^2\right)$ in area ?

$$W = \frac{P}{A} \quad , \quad P = W \times A$$

$$P = 0.057\ w/cm^2 \times 1.75 \times 10^4\ cm^2 = 875W$$

C. if the radioactive power received from the surrounding walls (background) =735 watt, what is the net power ?

875-735=140 watt

Note: the commercial instrument used in clinical thermography can measure the temperature differences of $\Delta T = 0.2\ ^\circ C$ and record a thermogram in 2 second.

To get a good thermogram :

- Before thermograph :

a. Clothes must be removed because clothing affects skin temperature .
b. It`s necessary to keep the temperature of the thermograph room at $20^\circ C$ and cool uniformity to enhance the temperature difference and contrast thermograph image .

Breast cancer detection :

for breast cancer detection the steps that must be followed are :

1. **Palpation** (smooth touching), but it is **difficult** to detect **a small tumor (less than 1cm diameter)**.
2. **Thermography** to detect the **elevated temperature area** but the results have been **disappointing** because of high **false positive** (an abnormal thermogram for a subject without cancer) and **false negative** (a normal thermogram for a cancer patient), due to **different blood flow** patterns in the two breasts (in fig) .

3. **Mammography** (low voltage X –ray),it is **successful** and much more reliable than thermography for detection of breast cancer **(80% and over)**, but it presents a **radiation hazard** to the body .

4. **Biopsy**, it gives information only about the material excised, but some cancer tissue near the excised region can be missed .
5. **Histo – pathology** .

- This advantage the thermogram give false positive result due to different blood flow pattern in the two breast .

Mammography (X–ray) is more accurate than thermograph in detection of breast cancer .

Q:/ compare between mammography and thermograph

Mammography	***Thermogram***
It can detect 80% of breast cancer (more accurate)	Less accurate. It gives false positive result due to different blood flow pattern
Infusive less safety because it`s ionizing radiation	non infusive (more safety) because of it`s infrared (non ionizing).

medical application of thermograph :

1. Detect breast cancer .
2. Detect other type of cancer .
3. Study blood circulation in head .
4. Study blood supply in diabetic leg .

Heat therapy:

Q/ Heat has two therapeutic effects :

1. Increase in metabolism resulting in a relaxation of the capillary system (vasodilation) .
2. Increase in blood flow as blood moves into cool the heated area .

Q / physical Methods of producing heat in the body:

1. **Conductive heat**: is based on the physical fact that if two objects at different temperature are placed in contact, heat will transfer by conduction from the warmer object to the cooler one, i.e.(hot water or hot materials can be placed in contact with the treated area (superficial area). The total heat transferred will depend upon :

a. The area of contact .
b. The temperature difference .
c. The time of contact (duration) .
d. The conductivity of materials .

Heat conduction by: hot bath, hot pack, electric heating pad, hot paraffin, etc.

Q/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. **Infrared (IR) radiation heat** : is also for surface heating of body .

It is the same form of heat we **feel from the sun** or from an open flame.

- The IR wave lengths used are between 800-40,000 nm, (1nm=10^{-9}).
- The waves penetrate the skin about 3mm and increase the surface temp.
- Excessive exposure causes reddening(erythema) and sometimes swelling (edema).
- This type of heating is used to treat the same condition of conductive heating, but it is considered to be more effective because the heat penetrates deeper .

3. **Radio wave heating (diathermy)** :

A- ***Short wave diathermy*** :

- ✓ Utilized electromagnetic waves in the radio rang (wave length~10m).
- ✓ It heats the deep tissues of the body .
- ✓ Heat from diathermy penetrates deeper in to the body than radiant and conductive heat .
- ✓ It has been used in relieving muscle spasms, pain from protruded intervertebral discs, degenerative joint disease, and bursitis.
- ✓ Two different methods are used for transferring the electromagnetic energy in to the body :

1. ***The first method:***
   - ❖ The part of the body to be treated is placed between two metal plate-like electrodes energized by the high-frequency voltage (see the fig.) .
   - ❖ The body tissue between the plates acts like an electrolytic solution.

- The charged particles are attracted to one plate and then the other depending upon the sign of the alternating voltage on the plates .

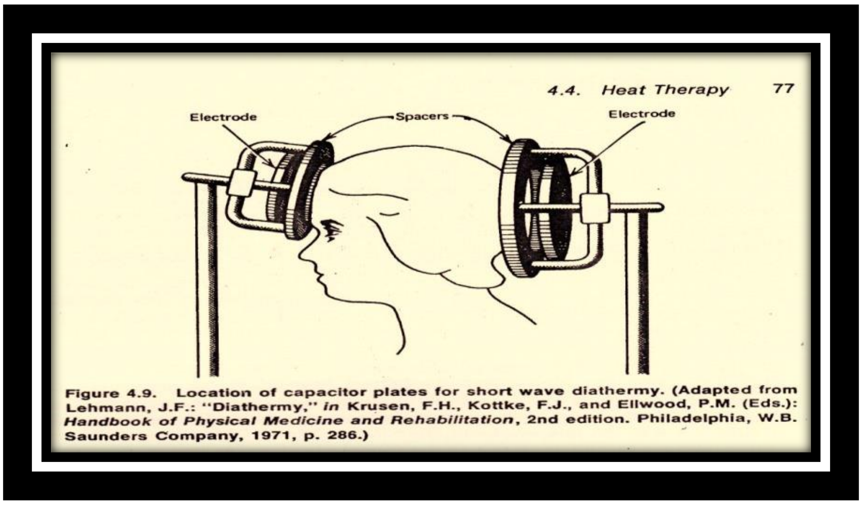


Figure 4.9. Location of capacitor plates for short wave diathermy. (Adapted from Lehmann, J.F.: "Diathermy," *in* Krusen, F.H., Kottke, F.J., and Ellwood, P.M. (Eds.): *Handbook of Physical Medicine and Rehabilitation*, 2nd edition. Philadelphia, W.B. Saunders Company, 1971, p. 286.)

2. ***The second method*** :
   - It is a magnetic induction (see the blow fig.) .
   - In induction diathermy, either a coil is placed around the body region to treated or a (pancake) coil is placed near that part of the body.
   - The alternating current in the coil results in an alternating magnetic field in the tissues .

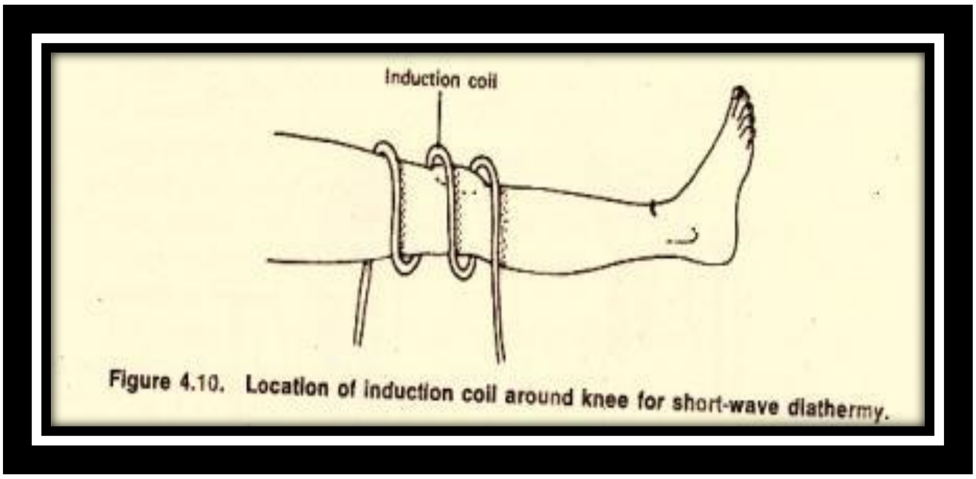


Figure 4.10. Location of induction coil around knee for short-wave diathermy.

B- Micro waves diathermy:

- It is another form of electromagnetic energy .
- It is easier to apply than short-wave diathermy .
- The frequency closer to 900 MHz is effective in therapy, causing uniform heating around body regions .

- It is used in the treatment of fractures, sprains and strains, bursitis, injuries to tendons .

4. Ultrasonic waves heating:

- US waves used for deep heating .
- US waves are completely different from the electromagnetic waves (E.M.W) diathermy .
- They produce mechanical motion like audible sound waves except the frequency is much higher (~1MHz) .
- US waves vibrate tissues producing heating .
- Ultrasonic heating has been useful in relieving the tightness and scarring that often occur in joint disease, aids joints that have limited motion .

- It is useful for deposition heat in bones because they absorb ultrasound energy more effectively than does soft tissue .

Pressure

Typical pressure in human body :

Typical pressure in human body	Typical pressure (mm Hg)
▪ **Arterial blood pressure** Maximum (systole) Minimum(diastole)	 100 – 140 60 – 90
▪ Venous blood pressure	3 -7
▪ Great veins	〈 1
▪ Capillary blood pressure	30
▪ Middle ear pressure	〈 1
▪ Eye pressure (aqueous humor) Gastrointestinal pressure	20 10-20
▪ Intrathoracic pressure (between lung and chest wall)	-10

Biofluids mechanics :

In this chapter we will discuss the concept of pressure as it relates to fluids in the body .

Pressure: is defined as the force per the quantity force per unit area referred to as stress .

There are many units which the pressure measured with them .

- ✓ In SI units:

$1N/m^2$=1Pascal (Pa)

1atm (atmosphere)=$1.03*10^{-5}$ Pa=760mmHg=1033cmH_2O

1Pas=$0.987*10^{-5}$atm=0.0075mmHg=0.0102cmH_2O

The pressure "P" under a column of liquid can be calculated from :

$$P = \rho gh$$

Where ρ : is the density of liquid .

g : is the gravitational acceleration .

h : is the height of column .

- The density of mercury is about ($13600kg/m^3$) or ($13.6gm/cm^3$) .
- The density of water is ($1000kg/m^3$) or ($1gm/cm^3$) .
- A column of water has to be (13.6) times higher than column of mercury in order to produce the same pressure .
- The density of whole blood is a bit higher ($1.06gm/cm^3$) at $(37^\circ C)$.

There are two types of pressure :

1. **Absolute pressure** : is the pressure of the fluid inside the container plus (+) the atmospheric pressure for example, the pressure inside the tire of the bicycle is ($4.13*10^{-5}$ N/m^2), so the absolute pressure is ($4.13*10^{-5}+1.01*10^{-5}$ N/m^2)=$5.14*10^{-5}$ N/m^2 .
2. **Gauge pressure** : is the absolute pressure minus (–)atmospheric pressure .

Note/All the pressures used in this chapter are gauge pressures .

Negative pressure :

There are a number of places in the body where the pressures are lower than atmospheric or negative ,.. for example, when we breathe in (inspire) the pressure in lungs must be somewhat lower than atmospheric pressure or the air would not flow in .

The lung pressure during inspiration is typically a few centimeters of water negative .

When a person drinks through a straw the pressure in his mouth must be negative by amount equal to the height of his mouth above the level of the liquid he is drinking .

EX/**Calculate the pressure in millimeters of mercury equal to a pressure of 20 cmH_2O ?**

Sol/ 760 mmHg → 1033 cmH_2O

X→20 cmH_2O

Then the pressure (X)=14.7 mmHg

Or 1.36cmH_2O→1mmHg

20 cmH_2O→X

Then the pressure (X) =14.7 mmHg

Q/ prove that :

$$P = \rho gh$$

Sol /

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

$$\rho = \frac{M}{V}$$

$$P = \frac{F}{A} = \frac{Mg}{A} = \frac{\rho Vg}{A}$$

$$but \Rightarrow V = Ah$$

$$\therefore P = \frac{\rho Ahg}{A} = \rho gh$$

Ex/ suppose you are a deep-sea preparing for a dive to (30m), what absolute pressure and gauge pressure will you experience ?

Solu/ all 1 atm=10.33m(H_2O)

X=30m

X=3 atm(gauge pressure)

Absolute pressure =3+1=4 atm

Ex/ calculate atmospheric pressure in day was the height of mercury is (76cm) ?

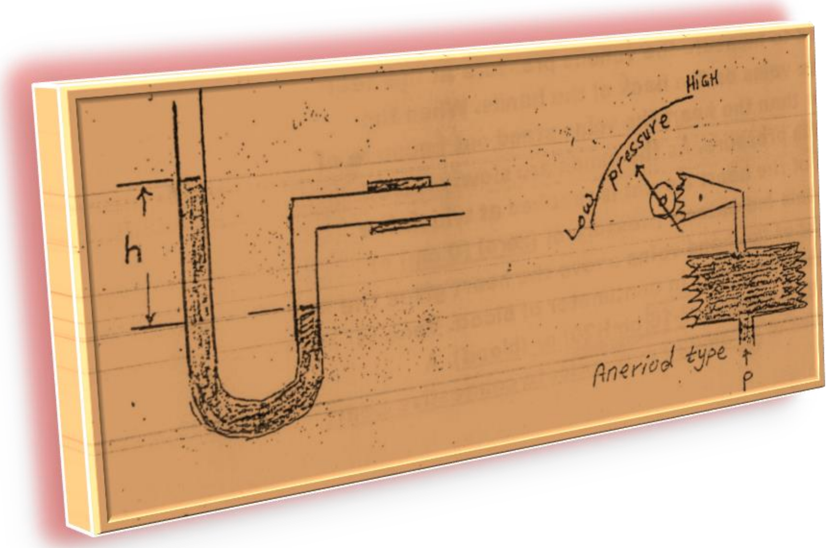
Solu/ ρgh =13.6gm.sec^{-3}*980cm.sec^{-2}*76cm

=1.01*10^6dyne/cm^2=1.013*10^5 N/m^2

Measurement of pressure in the body :

1. **Manometer :**
   - It is a **U** –tube .
   - Containing fluid (Hg,or H_20) **.**

- Connected to the pressure to be measured .
- Can measure both positive and negative pressure .



2. ***Sphygmomanometer***
   - It`s the most common clinical instrument used in measuring blood pressure .
   - The types of sphygmomanometer are :

   A. Mercury manometer : the pressure is indicated by the height of column of mercury inside glass tube .
   B. Aneroid type :the pressure changes the shape of a sealed flexible container which causes a needle to move on a dial .
   C. Electronic system: contains a digital screen .

Some parts of the body can be act like crude pressure indicators .

Example :

1. **Ear**: is very sensitive to pressure .

   A person going up or down in an elevator or an airplane is often aware of the change in atmospheric pressure on the ears .

2. **Veins**: as a hand is raised slightly above the level of the heart these veins become smaller due to the lower venous blood pressure .

Method :

A simple method to measure the venous pressure at the heart is to observe the veins on the back of the hands . when the hands are lower than the heart the veins standout because of increased venous pressure. As the hands are slowly raised above the level of the heart a point is reached at which the veins collapse :this indicates a pressure of (zero) (0 cm) of blood . the height of the hand veins above the heart gives the venous pressure at the heart in centimeter of blood . venous pressure normally averages (8-16cmH20) or(blood).a pressure in excess of 16cmH20 may indicate congestive heart failure .

***Pressure inside the skull*:**

The brain contains approximately 150 ml (cm^3)of cerebrospinal fluid (CSF) a series of interconnected openings called ventricles. one of the ventricles,(the aqueduct), is especially narrow .

If at (birth) this opening (aqueduct) is blocked for any reason, the (CSF) trapped inside the skull and measure the internal pressure .

The increased pressure causes the skull to enlarge. this condition called hydrocephalus (water-head). Hydrocephalus occurs in infants .

To measure hydrocephalus .

1. **Crude method**
    - Measure the circumference of the skull just above the ear .
    - The normal values for newborn =32-37 cm .
    - Larger value than (32-37cm) may indicate hydrocephalus.
2. **Transillumination**
    - Use of the light scattering properties of the rather clear CSF inside the skull .

3. **Ultrasound**

Eye- pressure

The clear-fluids (water) in the eyeball that transmit the light to the retina in eyeball (called aqueous humor) maintains the internal pressure of eye .

The pressure in normal eyes range (12-23mmHg) .

The eye continuously produces aqueous humor and a drain system allows the surpluses to escape. If a partial blockage of this drain system occurs, the pressure increases and the increased pressure can restrict the blood supply to the retina and thus affect the vision, this condition, called glaucoma .

Eye –pressure measurements .

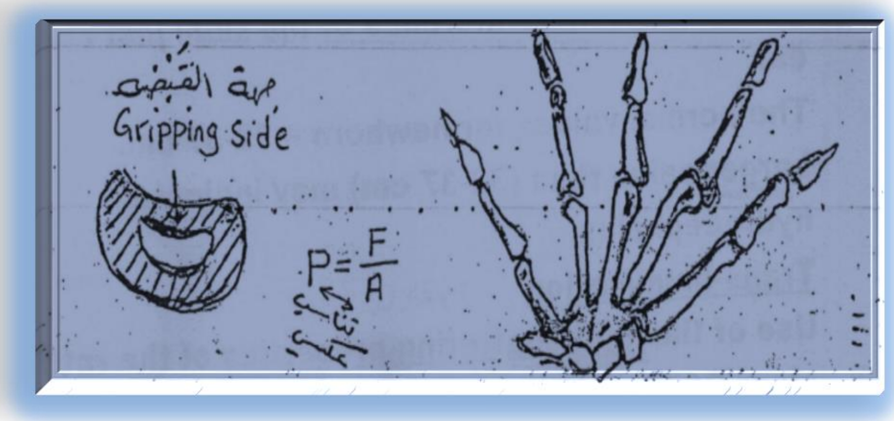
1. **By feel**
   - ✓ Estimated the pressure inside the eye by (feel) as they passed on the eye with their fingertips .
   - ✓ **Tonometer .**

   Is An instrument used to measure the eye pressure in arbitrary units rather than in mmHg .

Pressure in the skeleton

- The highest pressure in the body is found in the weight-bearing bone joints .
- When walking, the pressure is reduced as the area increased to reduce pressure :

A. Bone joint lubrication (the higher the pressure, the better the lubrication).
B. The finger bones are flat rather than cylindrical on the gripping side ; the force is spread over a large surface : this reduces the pressure in the tissues over the bones .

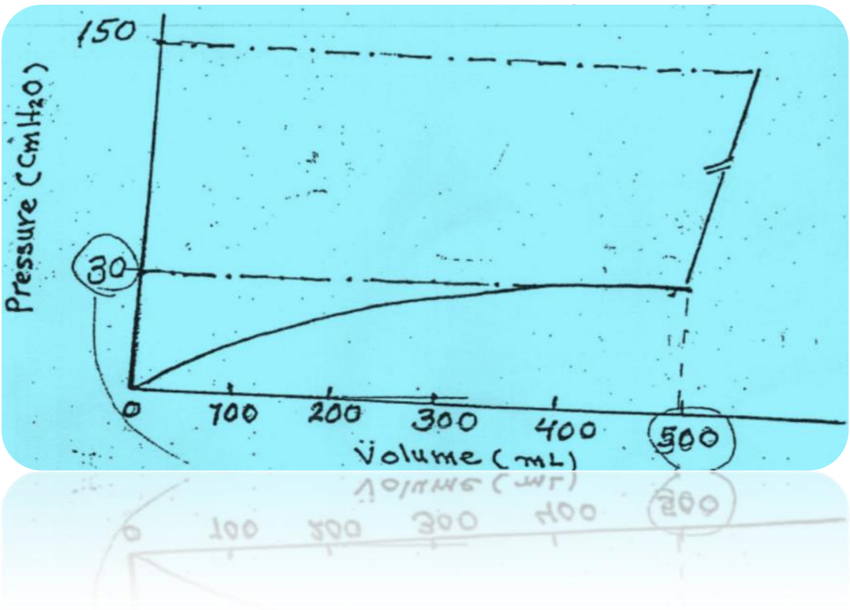


Pressure in the urinary bladder

1. Internal pressure in the bladder is due to accumulation of urine .
2. The typical (***P-V)***relationship in the urinary shows in fig .
3. When the bladder is filled with urine, the volume of the bladder $= 3/4\pi R^3$ is increase . (this mean : for a given increase in (R) the volume increase as (R^3) while the pressure $\left(P = F/A = F/\pi R^2\right)$ only increases as $\left(R^2\right)$.
4. For adult, the maximum volume in bladder before voiding=500ml, at pressure=30 $cm\,H_2O$.

   When the micturation reflex occurs, the resulting sizable muscular contraction in the bladder wall produces a momentary pressure of up to 150 $cm\,H_2O$. see fig .

5. Normally voiding pressure =20-40 $cm\,H_2O$.
6. For men who suffer from prostates obstruction of the urinary passage it may be over 100 $cm\,H_2O$.
7. The bladder pressure increases during : (a). coughing, (b). straining, (c). sitting, (d). during pregnancy. (e). stress situation.



Bladder pressure measurement :

a. indirect method (catheter)

b . direct method (cystometer)

Direct Cystometry: The pressure is measured by a needle inserted through the wall of the abdomen into the bladder. this technique gives information of the function of the exit values that cannot be obtained with the catheter technique .

pressure effect while diving

Boyles law : for a fixed (mixture) quantity of gas at a fixed temperature the product of the absolute pressure and volume is constant .

PRESSURE * VOLUME =Constant

$$P \times V = C$$

Note :this means , if the absolute pressure is doubled, the volume is decreased to half . $\left(P \propto \frac{1}{V}\right)$

Eg/ What volume of air at an atmospheric pressure of $1\times10^5\ N/M^2$ needed to fill a 14.2 liter tank to pressure of $1.45\times10^7\ N/M^2$

Solution :

$$P_1V_1 = P_2V_2$$

$$(1\times10^5)(V_1) = (1.45\times10^7)(14.2)$$

$$V_1 = 2\times10^3\ LITER$$

E.g/ **middle ear is an air cavity** .

- (for comfort ,pressure in middle ear = pressure outside)
- When diving , it`s very difficult to get equalization and feel pressure in ears .
- If the pressure across the eardrum =120 mmHg , that will cause the eardrum to rupture .

Henry`s law :

States : the amount of gas that will dissolve in a liquid is proportional to the partial pressure of the gas in contact with the liquid .

E.g/ - **At sea level** :

The air contain 20% O_2 and 80% N_2

The partial pressure of Oxygen is $(P_{O_2}) = \left(\frac{20}{100}\times760\right) = 150\,mmHg$

The partial pressure of Nitrogen is $(P_{N_2}) = \left(\frac{80}{100}\times760\right) = 610\ mmHg$

- **Under water (30M depth)**:

The pressure in the lung at any depth in water is too much greater that (which is denoted by) the pressure in the lungs at sea level .

This means: that the air in the lungs is dense under water and that the partial pressures of $(O_2)$and $(N_2)$are higher than 150 and 610 mmHg at sea level , this will result :

1. The higher pressure oxygen causes more(O_2)molecules to be transferred (dissolved) into the blood, and the (O_2) poisoning results if partial pressure of oxygen gets too high .

2. O_2 poisoning occurs when (P_{O_2})=0.8 atm, and this occurs at depth about 30M.

3. According to the henry`s law , excess in N_2 dissolved in blood and tissue, this can produce 2 problems :

A - Nitrogen necrosis (intoxication effect)

B - bends (decompression)

hyperbaric oxygen therapy (hot) :

In some medical application, it`s useful to increase the percentage of $O_2$, in order to provide more$O_2$ to the tissue . it`s used hyper-oxygen chamber .

- medical application :

1. Gas gangrene : is a disease due to bacteria (bacillus) it cannot be survived in present of O_2, patient treatment with hot and without the need for amputation .

2. Carbon monoxide poisoning :

- the presence of a few (CO) on red blood cells (**RBCs**) greatly reduce the ability of **RBCs** to transportO_2 to the tissue .

- **Normally**, the amount ofO_2dissolved in blood is 2% that carried by **RBC**.

- **Treatment with hot**: the partial pressureO_2 can be increased by factor of 15 according to henry`s law allowing enoughO_2 to be dissolved to fill the body's needs .

Hot in radio therapy :

Theory : the tumor consist of :

a. **Normal tissue** : which is well oxygenated (Rich in O_2)

b. Malignant (cancer cell) : which is poor in O_2

c. The normal cells well oxygenated are more sensitive to the (ionizing radiation RAY) than the cancer cells . X - RAY and γ - Ray

d. This is mean the radio therapy may cause damage to the normal tissue

e. To improve the radiotherapy treatment we use (hot) .

Treatment

1. The patient is placed inside a transparent plastic tank .

2. The pressure inside the tank is about 3 atm. .

3. The ionizing radiation is beam through the wall of the tank .

4. The treatment takes about 10 minutes .

E.g / Assume you are a shallow – water diver preparing for 10M dive into salt water .

a. What absolute pressure and gauge pressure will you experience ?
b. Normally, your lungs have an available volume of (6L) what will happen to that volume ?
c. Suppose you can`t equalize the pressure in your middle ear . what will happen during the dive ?

Sol/

a. Gauge Pressure (ΔP)=Absolute pressure – atmospheric pressure

$$\Delta P = \rho g h = 1000 \times 10 \times 10 = 10^5 \; N/M^2$$

$$10^5 \; KPa = absolute\ pressure - 1atm$$

1 atm = absolute pressure – 1 atm

Absolute pressure =2 atm

b. $$P_1V_1 = P_2V_2$$

$$1atm \times 6L = 2\,atm \times V_2$$

$$V_2 = 3L\left(Decreased\ as\ the\ pressure\ increase\right)$$

c. **If it is not equalized, that will cause eardrum rupture.**

EX/ Negative pressure or suction is often used to drain body cavities. In the drainage arrangement for the gastrointestinal region show, the negative pressure supplied to the collection bottle is (100 mmHg) and the top end of the tub is (37cm) above the end of the tub in the body. Find the negative pressure at the lower end of the tub .

SOL:/

If negative pressure supplied to the collection bottle is =100 mmHg .

The Pressure in the bottle $P = \rho h g = 1 \times 980 \times 37 = 36260 \; dyn/cm^3$

$$36260 = 13.6 \times 980 \times h$$

$h = 27 \; mmHg$ (the negative pressure of the top end of the tub)

Net pressure =100-27=73 mmHg

Equation of state :

Any equation that relates the pressure (P),temperature (T) and specific volume (V) of a substance is called an equation of state .

Ideal gas equation of state :

- ✓ It`s the simplest and best known equations of state for substances in the gas phase .
- ✓ This equation predicts the (P, V, T) behavior of a gas .
- ✓ At low pressure, the volume of a gas is proportional to its temperature .

That is $P = R\left(\frac{T}{V}\right)$

$PV = RT$ IDEAL GAS EQUATION OF STATE .

Where R : gas constant

P :absolute pressure

T : Temperature

V :specific volume

$$R = \frac{R_U}{M} \qquad K\,J/(Kg.K)$$

R_U : universal gas constant and $R_U = 8.314 \quad KJ/(K\,mol.K)$

M : Molar mass "molecular weight"

- ✓ The mass of the system is equal to the product of its molar mass "M" and the moles number "N" .

$$m = MN \qquad (Kg)$$

- ✓ **The ideal gas equation can be written in different forms** :

$PV' = RT$ Where $(V' = \frac{V}{m})$

$$P\frac{V}{m} = RT$$

$$PV = mRT \qquad Where \qquad (m = MN)$$

$$PV = MNRT \qquad Where \qquad (RM = R_U)$$

- ✓ ***When we fixed mass of system, the properties of an ideal gas at two different states are related to each other .***

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad general\ lawes\ of\ gases$$

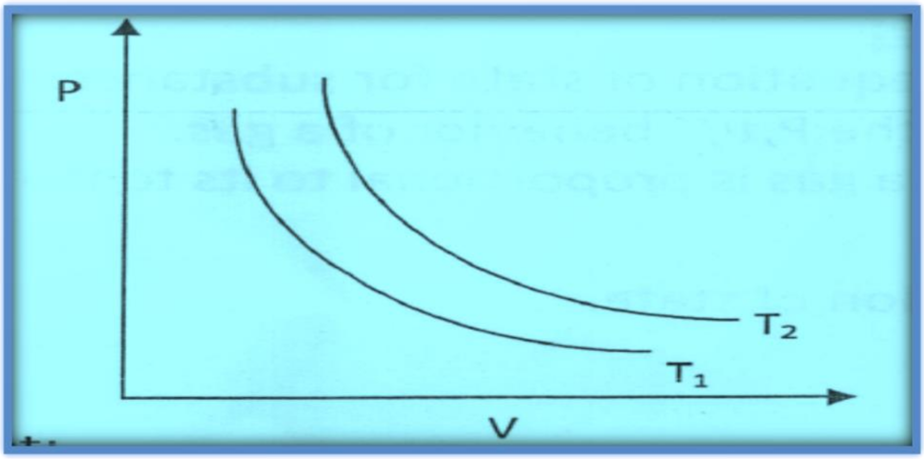
- ✓ ***When T is constant, the cross product of pressure and specific volume is constant. that mean : as the mass is constant "as denoted before " the specific volume will equal the volume .***

Because $v = \frac{V}{m}$

Where T: constant

Then

$$P_1V_1 = P_2V_2 = P_3V_3 \qquad [Boyels\ \ law\ ]$$



- ***When the pressure is constant*** :

P: constant

Then : $\frac{V_1}{T_1} = \frac{V_2}{T_2}$	Charles`s law

Eg/ Determine the mass of the air in a room whose dimension are $(4 \times 5 \times 6)$ at $(100\, KPa)$ and $(25^{\circ} C)$.

Sol / Absolute temperature (T) = $25^{\circ} C + 273 = 298\, K$

The volume of the room = $(4 \times 5 \times 6)$=$120 \;\; m^3$

From the table, the gas constant for air is :

$$R = 0.287 \quad KPa . M^3 / (Kg . K)$$

By substitute these values in the equation :

$$PV = m RT$$

$$m = \frac{PV}{RT} = \frac{100 \times 120}{0.287 \times 298} = 140.3\ Kg$$

$$PVN = mRT$$

- **The ideal gas law can be expressed in terms of the total number of molecules "N" where** :

$$N = n\ Na$$

$N = Total \;\; no. \;\; of \;\; moles, \qquad n = no. \; of \; moles$

$Na = Avogadro`s \;\; no. = 6.022 \times 10^{23} \;\; molecules \;\; / mole$

$$= 6.022 \times 10^{26} \ molecules \ / K.mole$$

$$PV = nRT \Rightarrow PV = \frac{N}{Na} RT$$

$$Where \qquad K = \frac{R}{Na}$$

$$Boltzman\, const. = 1.38 \times 10^{-23} \ J/molecules\,.K$$

$$= 8.63 \times 10^{-5} \ e.v/molecules\,.K$$

$$substite \ \ in \qquad PV = NKT$$

One mole of a substance is that mass that contain Avogadro`s no. of molecules .

E.g/ An ideal gas occupies a volume of $(100\,cm^3)$ at $(20^\circ C)$and pressure of $(100\,KPa)$. determine the no. of moles a gas in the container .

Sol/ $PV = NKT$

Equation of state in real gas ;

Real gas : gas have a distance between his molecules .

In real gas we have two equation:

a. Clauses equation :

$$P(V - nb) = NRT$$

b. Vander Waals equation :

$$\left(P + \frac{a}{v^2}\right)(v - b) = RT$$

Where **a** and **b** : constant for any one gas but differs for different gasses .

NOTE / $P_{real} < P_{ideal}$

Relative Density: Ratio of the density of substance of some standard substance at a specified temperature.

{ Note: Usually water at 4°C for which $\rho_{H_2O} = 1000\ Kg/M^3$ }

$$\rho_s = \frac{\rho}{\rho_{H_2O}}$$

Specific Volume: The volume per unit mass.

$$\mathcal{V} = \frac{V}{m} = \frac{1}{\rho}\ (M^3/Kg)$$

Intensive Properties(الخصائص الضمنية): Properties which are independent of the size of the system such as T,P and ρ.

Extensive Properties(الخصائص اللاضمنية): Properties of very directly with size of the system Such as (Mass "m" ,Volume "V" ,total energy "E").

Thermodynamic Coordinate(احداثيات ثيرموديناميكية):

(P,V,T) or (P,ρ,T) are thermodynamic Coordinates. Any change of this three coordinates we have thermodynamic process.

If T: is constant -----> We have isotherm process.

If P: is constant -----> Isobaric process.

If V: is constant -----> Isochoric or Isometric process.

Adiabatic Process(العمليات الديناميكية الكظمة): In this process no change in energy. The quantity of thermal energy is constant.

$Q_1 = Q_2$

$Q\ is\ consant$ (ثابت)

$dQ = zero$(مشتقة الثابت صفر)

Process: Any change that a system undergoes from one equilibrium state to another.

Path: Series of states through which a system passes during process.

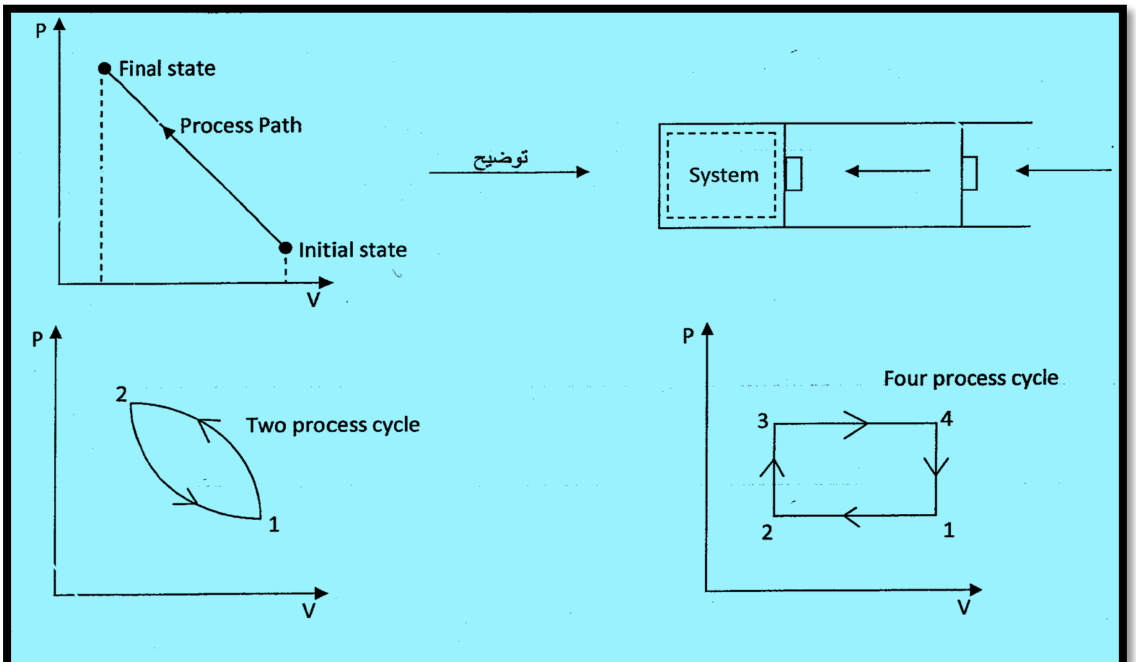


Figure Shows two ideal thermodynamic cycle

Energy, Work and heat , power of the body:

Heat : The form of energy that transferred between two systems by a temperature differences .

- ❖ Heat transferred during the process between two states (state1and state 2) is denoted by Q_{12} .
- ❖ Heat has energy unit (KJ) .(Kilojoules) .
- ❖ $q = \frac{Q}{M}(KJ/Kg)$ heat transferred per unit mass .

Note -1/Heat and internal energy are two different things .

Energy is associated with **a state** .

Heat is associated with **a process** .

Note -2/Heat is a directional quantity .

Heat transferred to a system (+) .

Heat transferred from a system (-) .

The direction of energy $\rightarrow$ from higher temperature body to lower .

Work **: is an energy interactions between a system and its surrounding.**

- Work is form of energy like heat .
- Work has energy unit such as (KJ) .

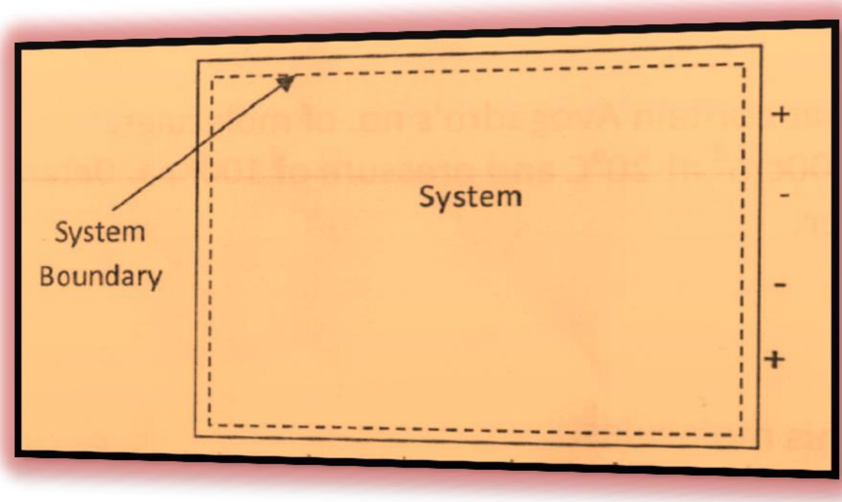
The work done during the process between state 1 and state 2 (or initial and final state) is denoted by W_{12} or W

- $W = \frac{w}{m} \ (KJ/Kg)$:**work done per unit mass** .

Power: **workdone per unit time .**

- The Power law: $p = \frac{w}{t} \left(\frac{KJ}{s} or \ Kw \right)$.
- The work done by a system is (+) .
- The work done on a system is (-) .

The figure below show the sign convertion for heat and work



1. Both heat and work are boundary phenomena .
2. Both heat and work are transient phenomena .
3. Both are path functions .

Mechanical forms of work:

The work done by constant force ***(F)*** on a body is displaced a distance ***(S)*** in the direction of force is :

$$W = F.S \qquad ......(1)$$

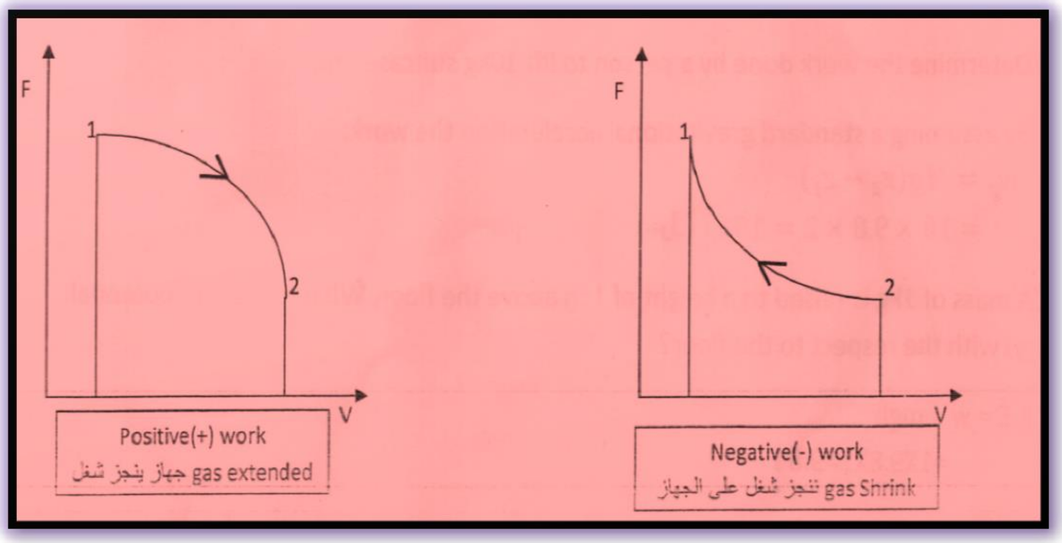
If the force is not constant, the work done is obtained by the differential amount of work :

$$W = \int_1^2 F.dS \qquad ......(2)$$

Equation no.1 and equation no.2 give only the magnitude of the work .

- Work done by a system against external force acting in the direction of the motion(-) .
- Work done by a system against external force acting in the opposite direction of the motion(+) .

The figures below show the positive and negative work :



Gravitational work :

The work done by or against a gravitation force .

The force acting on body is :

$$F = m g$$

Where m=mass of the body, g=acceleration of gravity .

When the work required to raise the body from level Z_1 *to* Z_2 is :

$$W_g = \int_1^2 F . dz = \int_1^2 mg . dz = mg \int_{z_1}^{z_2} dz = mg(z_2 - z_1)$$

Figure

Note / The gravitational work depend on the end state and is independent of the path .

- The work done is equal "in magnitude " to the change in the potential energy of the system .

The sign of the gravitational work :

(+) if done by the system. (the system falls) .

(-) if done on the system. (the system raised) .

Note : potential energy (P.E) = work done to put body in position .

$$P.E = work = Fh = mgh$$

Ex.1 / Determine the work done by a person to lift 10 kg suitcase 2m .

Sol./ by assuming a standard gravitational acceleration the work :

$$W_g = Mg\,(z_2 - z_1)$$

$$= 10 \times 9.8 \times 2 = 196\,J$$

EX/ A mass of 1kg is raised to a height of 1m above the floor . what is the P.E (potential energy) with the respect to the floor ?

Sol./ $$P.E = W = mgh$$

$$= 1 \times 9.8 \times 1 = 9.8\,J$$

Acceleration work :

The work associated with the change in velocity of a system .

$$F = m \times a \qquad Newten\ \ 2^{nd}\ law$$

$$a = \frac{dv}{dt} \Rightarrow\ F = m \times \frac{dv}{dt}$$

The differential displacement (ds) is reacted to velocity V by :

$$v = \frac{ds}{dt} \Rightarrow\ ds = Vdt$$

Substituting the ***F*** and ***ds*** relation in the equation :

$$W = \int_1^2 F.ds \quad \Rightarrow W_a = \int_1^2 F.ds = \left(\frac{mdv}{dt}\right)(Vdt)$$

$$W_a = m\int_1^2 Vdv = m\left(\frac{V_2^2 - V_1^2}{2}\right) \Rightarrow W_a = \frac{1}{2}m\left(V_2^2 - V_1^2\right)$$

Where $\frac{1}{2}mV^2 = W_a =$ kinetic energy of a body

The work done to accelerate body is independent of path, the work equivalent to the change in the kinetic energy of the body .

The sign of work acceleration is :

(+) if done by the system .

(-) if done on the system .

Ex/ Determine the power required to accelerate 900kg car from restto velocity 80km/h in 20 seconds, on a level road .

Sol/

$$W_a = \frac{1}{2} m\left(V_2^2 - V_1^2\right)$$

$$= \frac{1}{2} \times 900\left[(80)^2 - 0\right] = 222.2\ KJ$$

$$W = power = \frac{W_a}{\Delta t} = \frac{222.2}{20} = 11.1KW$$

Shift work:

A force acting ***(F)*** through a moment arm ***(r)*** generates a torque ***(T)*** which is determined from :

$$T = Fr$$

This force is act through distance ***(S)*** which is related to the radius **(r)** by :

$$S = (2\pi r) \times n$$

r=revolution

the shift work :

$$W_{sh} = FS$$

$$W_{sh} = \frac{T}{r} \times 2\pi n r = 2\pi nT$$

The power : **the shift work done per unit time** .

$$W_{sh}^{\circ} = \frac{W_{sh}}{t} = 2\pi n^{\circ} T$$

Where $n^{\circ} = \frac{n}{t} = No.\ of\ revolution\ per\ unit\ temp.$

Rpm=revolution per minute .

Ex/Determine the power transmitted through the shift of a car when the torque applied is 200(N.M) and the sniff rotates at a rate of 4000 Rpm .

SOL/ $W = 2\pi n^{\circ} T$

$$= 2\pi \times 4000 \frac{1}{\min.} \times 200\ N.M = ????$$

Spring work :

When a force is applied or a spring the length of the spring change when the length of the spring change by differential amount (dx) under influence of a force (F1,the work done is:

$$W_{Spring} = F.dx \qquad ....(1)$$

For linear elastic spring, the displacement (x) is proportional to the force applied, that is :

$$F \propto x$$

$$F = Kx \qquad ....(2)$$

Where K=Spring constant , x=is displacement

x=is measured from the undisturbed position of the spring .(x=0 when F=0)

substitute equation (2) in equation(1) and integrating, yield :

$$W_{spring} = \frac{1}{2}K\left(x_2^2 - x_1^2\right)$$

$$\Delta W = \int_1^2 K\,x\,dx$$

$$= K\int_1^2 x\,dx$$

$$= \frac{1}{2}K\left(x_2^2 - x_1^2\right)$$

Where x_1,x_2 are the initial and final displacement.

Both x_1,x_2 are measured from the undisturbed position of spring .

Q/ PROVE THAT

Prove that :

$$1.\ W = RT\ lin\frac{V_f}{V_i}$$

$$2.\ W = RT\ lin\frac{P_1}{P_2}$$

SOL/ for ideal gas $PV = RT$

$T = const.$

1. $dW = PdV \Rightarrow W = \int_{V_i}^{V_f} Pdv$

For ideal gas :

$$PV = RT \Rightarrow P = \frac{RT}{V}$$

$$W = \int_{V_i}^{V_f}\frac{RT}{V}dV = RT\int_{V_i}^{V_f}\frac{dV}{V}$$

$$W = RT\left\lfloor linV_f - linV_i\right\rfloor$$

$$W = RT\ lin \frac{V_f}{V_i}$$

2. $P_1V_1 = RT\ \ and\ \ P_2V_2 = RT$

$$\therefore \quad P_1V_1 = P_2V_2$$

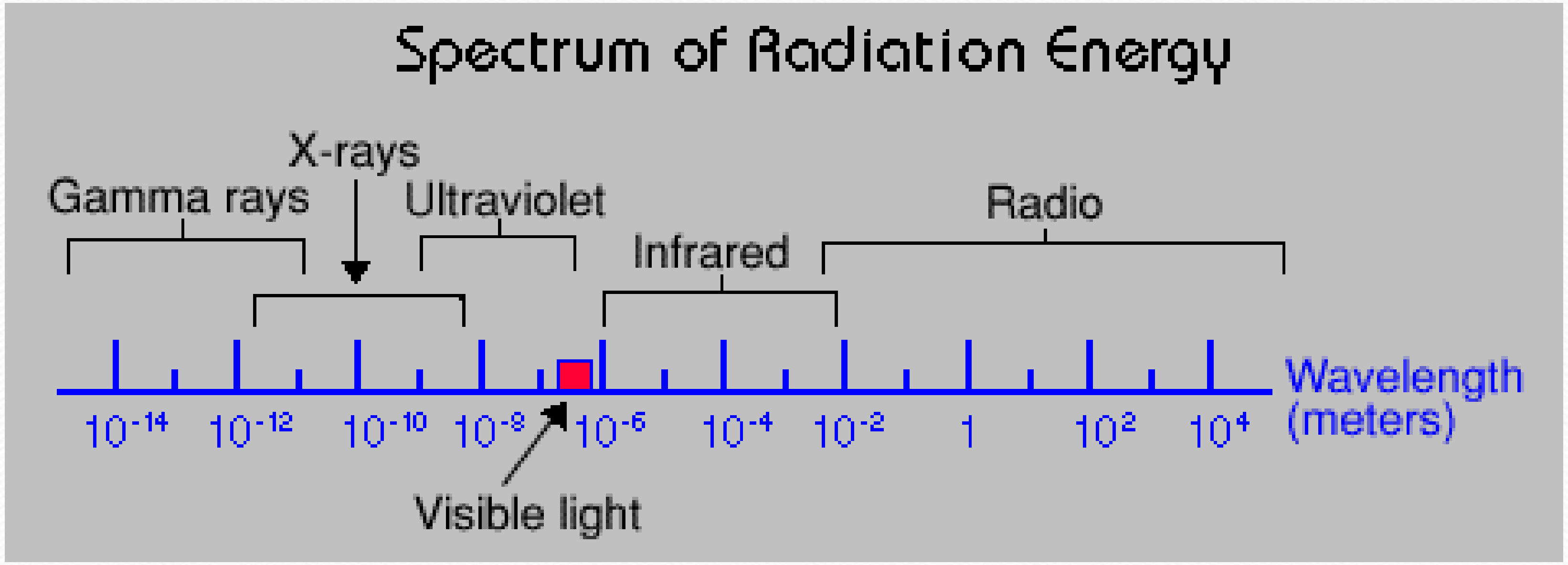
$$\frac{P_1}{P_2} = \frac{V_1}{V_2}$$

$$W = RT\ lin\ \frac{P_1}{P_2}$$

Physics of Diagnostic X-rays


What are x-ray

What are X-rays?



What are X-rays?

Made of photons

Travel at speed of light

Travels in a straight line

Has no mass nor charge (cannot be focused by magnets)

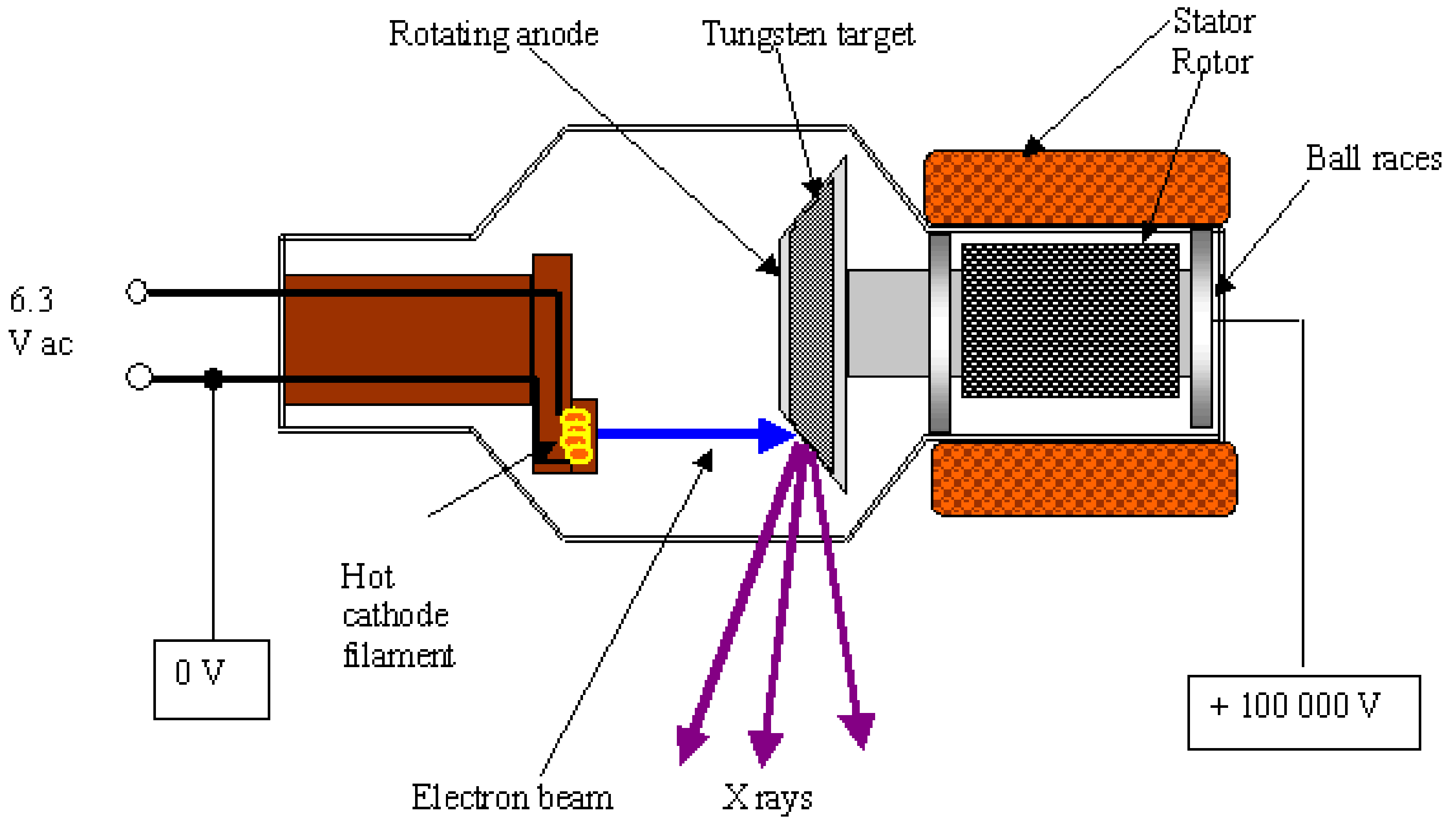
X-ray beam has a mix of energies

Maximum energy in a beam = kVp

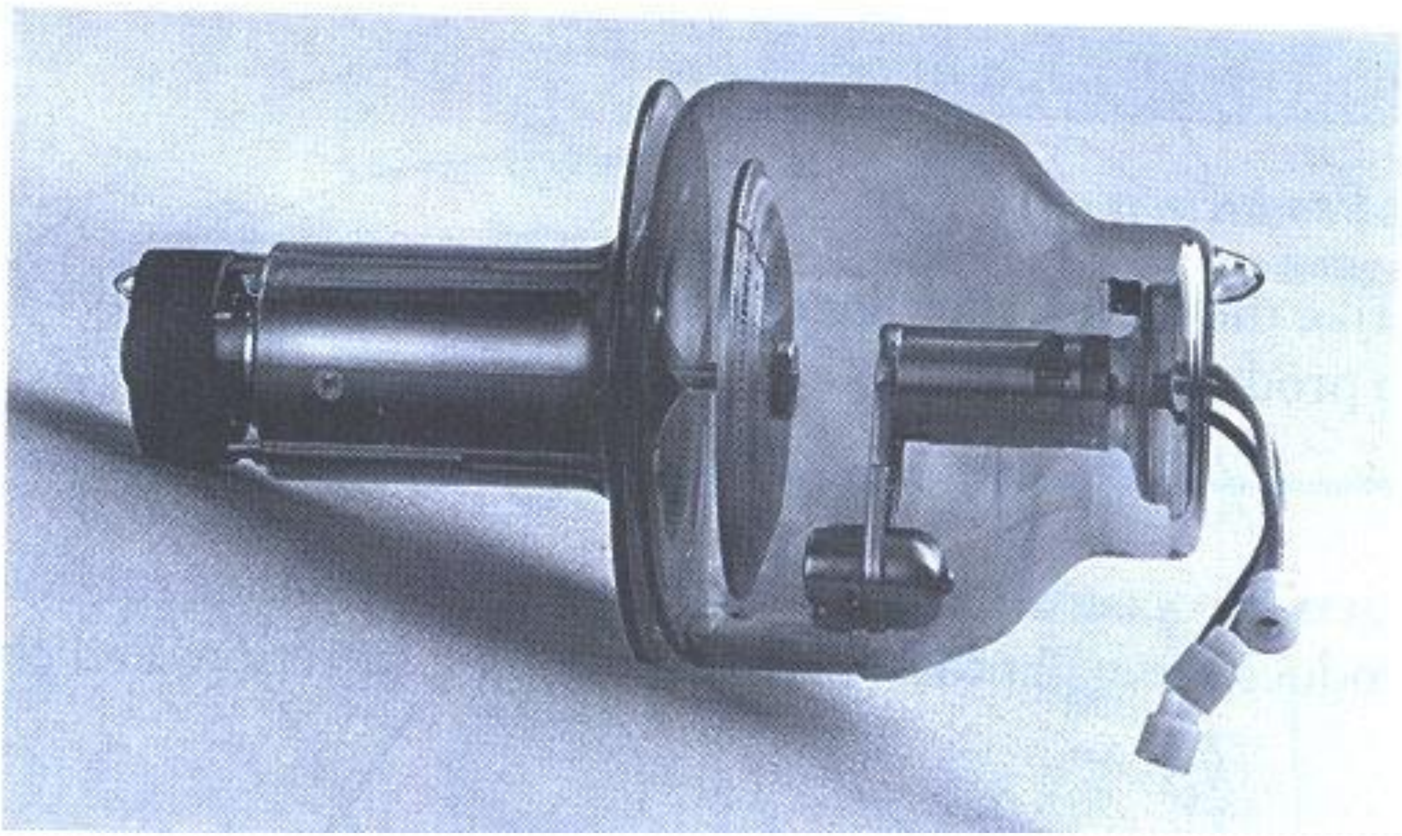
Diagnostic X-ray range 20-150 kVp

- **X-ray production:**
- To produce photons of x-ray we need:

1. A filament (Cathode): This is a source of electrons.
2. An evacuated space in which to speed up the electrons.
3. A high positive potential to accelerate the negative electrons.
4. A target ((anode)): which the electrons strike to produce x-rays.


Rotating anode
Tungsten target
Stator
Rotor
Ball races
6.3
V ac
0 V
Hot
cathode
filament
Electron beam
X rays
+ 100 000 V

The X-ray tube



The X-ray tube parts:

Cathode (-)

- Filament made of tungsten

Anode (+) target

- Tungsten disc that turns on a rotor

Stator

- motor that turns the rotor

Port

- Exit for the x-rays

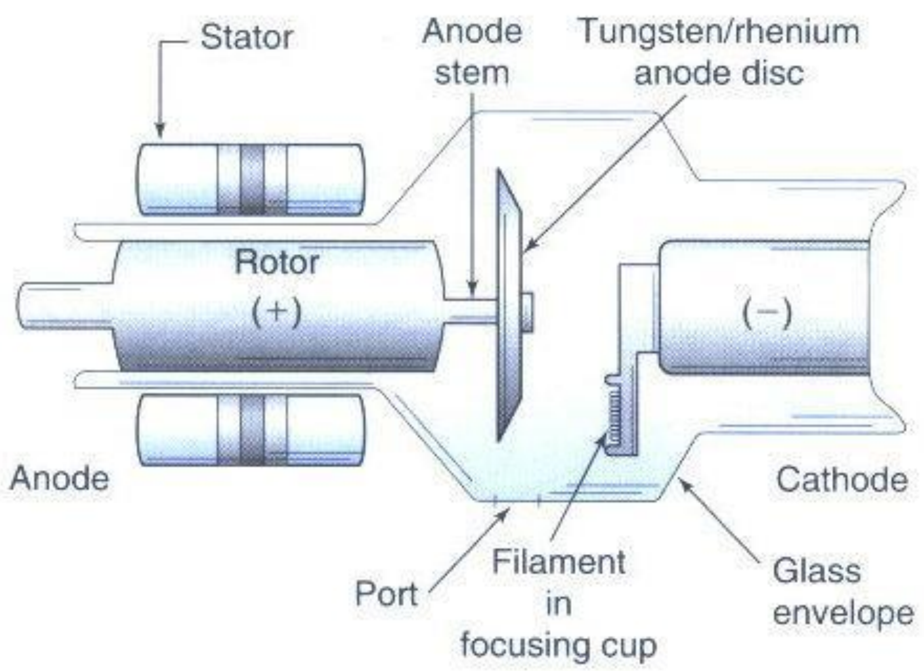
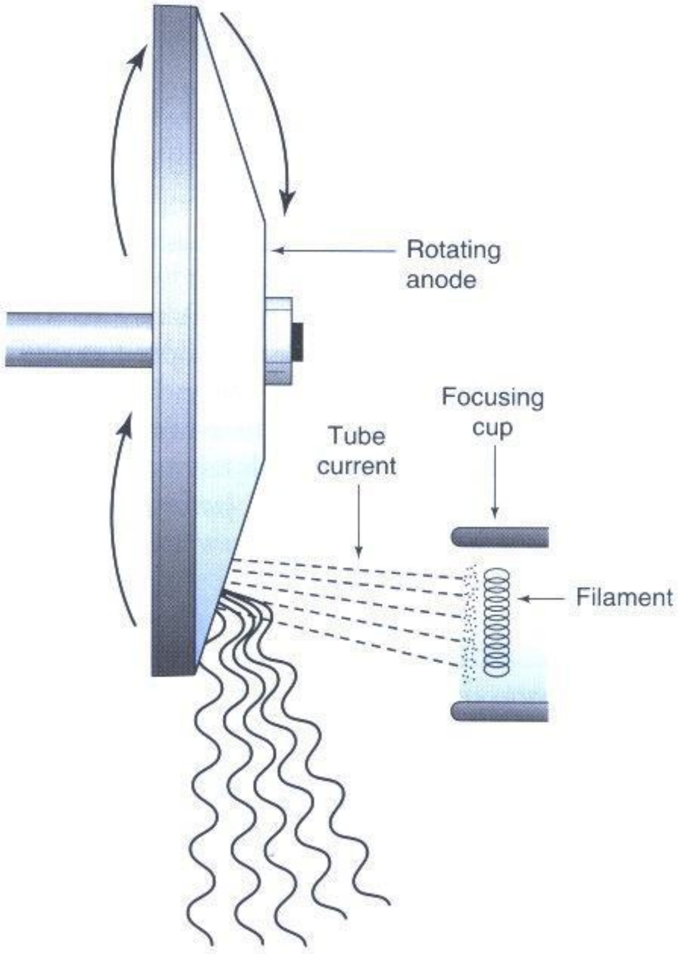


FIGURE 2-5 Structure of a typical x-ray tube, including the major operational parts.

X-ray production

- Push the "rotor" or "prep" button
  - Charges the filament – causes thermionic emission (e- cloud)
  - Begins rotating the anode.
- Push the "exposure" or "x-ray" button
  - e-'s move toward anode target to produce x-rays



Hitting the target

e-'s hitting the target creates x-rays two different ways:

Characteristic x-rays – are due to the material the e-'s hit (tungsten). Only occurs above 70 kVp

Bremsstrahlung (braking) x-rays – due to slowing down of e- beam.

< 70 kVp – 100% of X-rays are of this type

> 70 kVp – 85% of X-rays are of this type

* ***Some notes about x-ray generation:***

1- High speed electron can convert some or all it's energy into an x-ray photons when it strikes an atom, and thus we need to speed up electrons to produce x-rays.

2- An x-ray tube that produced electrons by "boiling" them off a red-hot filament.

3-The intensity of the x-rays beam produced is highly depend on the anode material, which preferred to has:

a. high atomic number. b. high melting point.

- Example: Tungsten is more preferred:

I. It's atomic number (z) =74.

II. It's melting point = 3400c.

4-The number of electrons accelerated towards the node depend on: Temperature of the filaments.

5-The kilovolt peak used for an x-ray study depends on:

a- Thickness of the patient.

b- Type of study being done.

6- The advantage of the rotating of the node is to avoid overheating of the anode, because the overheating produce a damage of the node.

Types of x-ray:

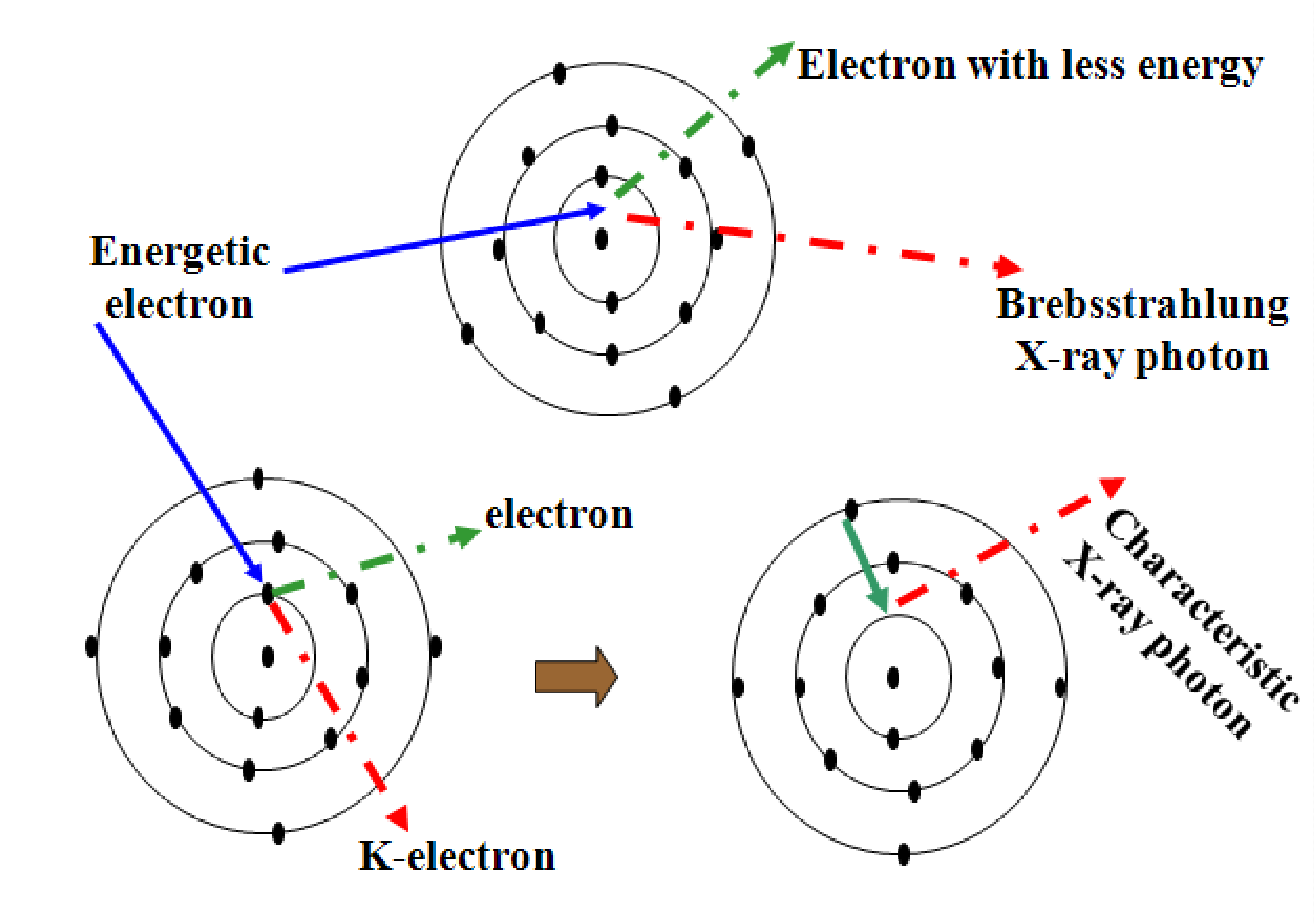
There are two types of x-rays:

1-***Characteristic x-ray***:

2- Bremsstrahlung x-ray:

1-***Characteristic x-ray***:

- A fast electron strikes a K electron in a target atom and knocks its out orbit and free of the atom. The vacancy in the K-shell is filled almost immediately when an electron from an outer shell of the atom falls into it, and in the process. a characteristic K x-ray photon is emitted.



Electron with less energy
Energetic electron
Brebsstrahlung X-ray photon
electron
K-electron
Characteristic X-ray photon

- The emitted photon is named according to the shell of the stroked electron. For example: - K characteristic x-ray or L characteristic x-ray.

An x-ray photon emitted when:

1. An electron falls from the L-level to the K-level is called Kα characteristic x-ray.
2. An electron falls from the M-level to the K-level is called K_{β} characteristic x-ray

- The energy of the emitted photon depends on the energy difference between the shell that have the vacancy and the outer shell (which the electron fills from it).

- ***Bremsstrahlung x-ray:***

  This type of x-ray is produced by the sudden deaccelerating of high energy electron. When the electron gets close enough to the nucleus of the target atom to be diverted from its path.

- This type also called "white radiation" because it's analogous to white light and has a range of wave length.

It depend on:

A: 1- Z of the target.

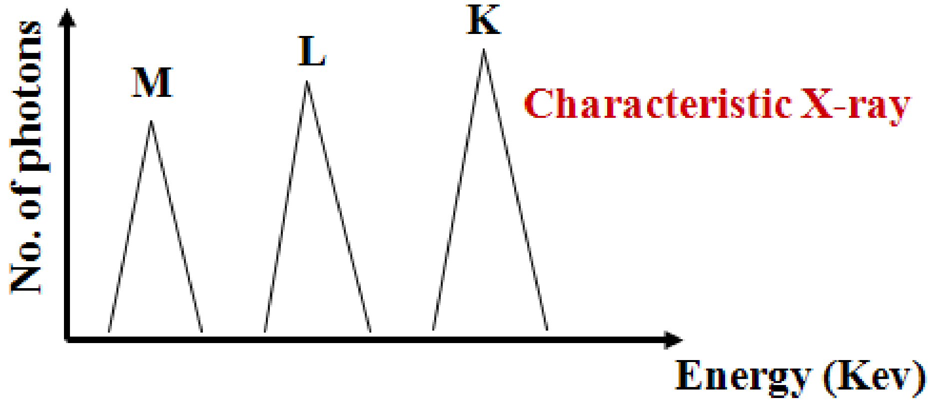
2- The more protons in the nucleus.

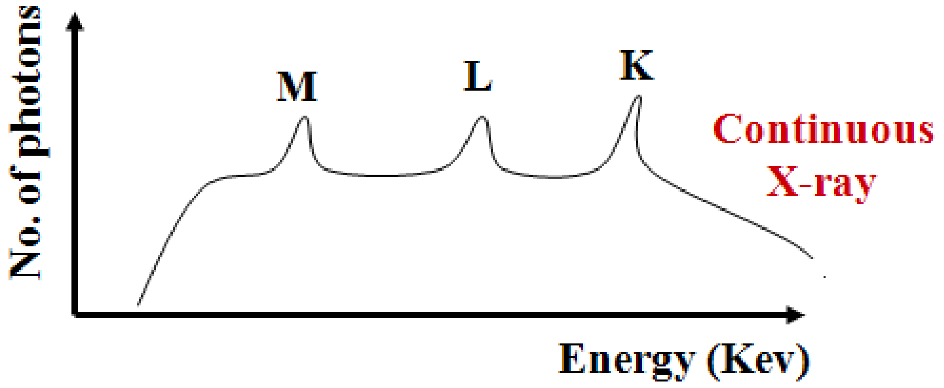
3- The greater acceleration of the electrons.

B: The kilovolt peak: The faster electrons are more likely to penetrate to the nucleus region.

The spectrum of x-rays produced by x-ray generator is shown in figure 16.8, page: 395. The broad smooth curve is due to the bremsstrahlung, and the spikes represent the characteristic x-rays.

X-ray spectrum





- **How x-rays are absorbed:**
- X-ray are not absorbed equally well by all materials. Heavy elements such as calcium are much better absorbers of x-rays than light elements such as Carbon.
- To understand the absorption of x-ray, we need to study the properties of the x-ray.

1- The attenuation:

It's the reduction of an x-ray beam due to the absorption and scattering of some of the out the beam. To measure the attenuation beam intensity I_o we use:

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

where:

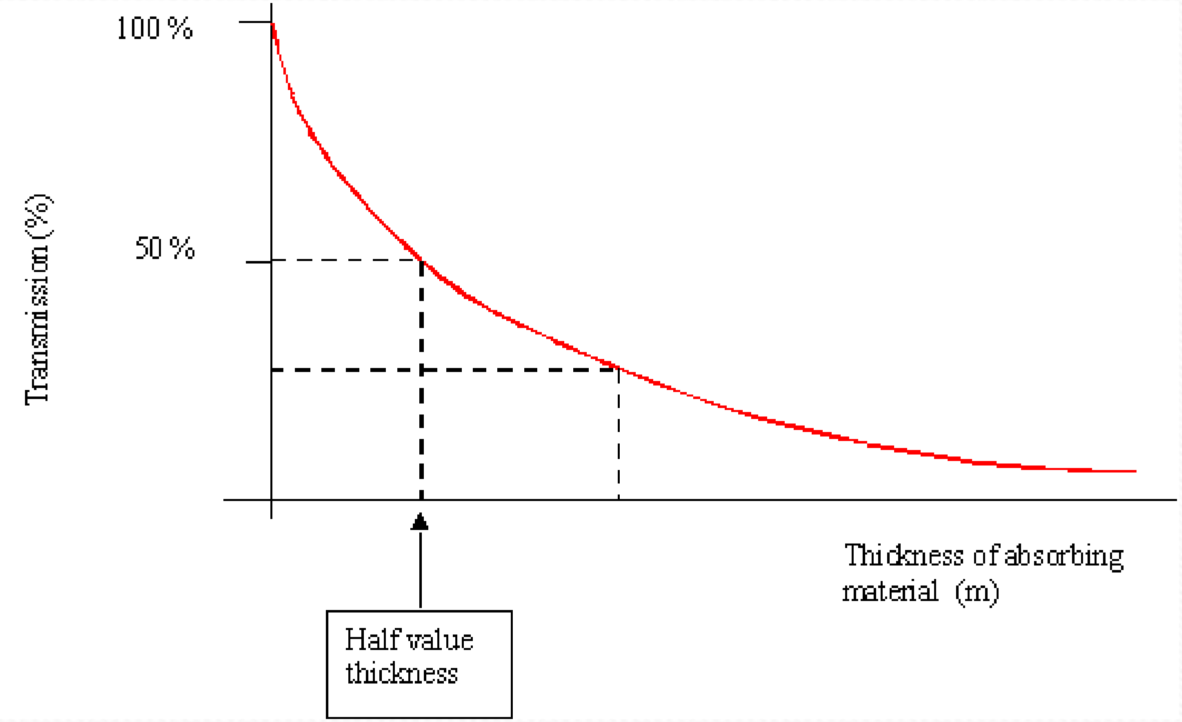
e: Base of natural logarithm = 2.7

I: The final intensity of x-rays beam.

I_o: attenuated intensity. (original intensity).

x: Thickness of the attenuator (The target).

μ: The linear attenuation coefficient of the attenuator (which is depend on the energy of x-ray photon).


100 %
50 %
Transmission (%)
Thickness of absorbing material (m)
Half value thickness

The linear attenuation coefficient of the attenuator (μ) was related with half-value layer according to this equation:

$$\mu = 0.693 / HVL$$

HVL: The thickness of a given material that will reduce the beam intensity by one half.

2- Biological effect of an x-rays beam.

- Mass attenuation coefficient: it's used to remove the effect of density when comparing attenuation in several materials.

- Mass attenuation coefficient= Linear atten. coeff. / density of material

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

- μ_m will be in cm^2 /gm

- Then $I = I_o\ e^{-(\mu/\rho)\rho x}$
- Therefore $I = I_o\ e^{-\mu m\ \rho x}$

X-ray interaction with matter:

- There are three types of interaction between the x-rays and matter. Or x-rays lose energy in three ways:

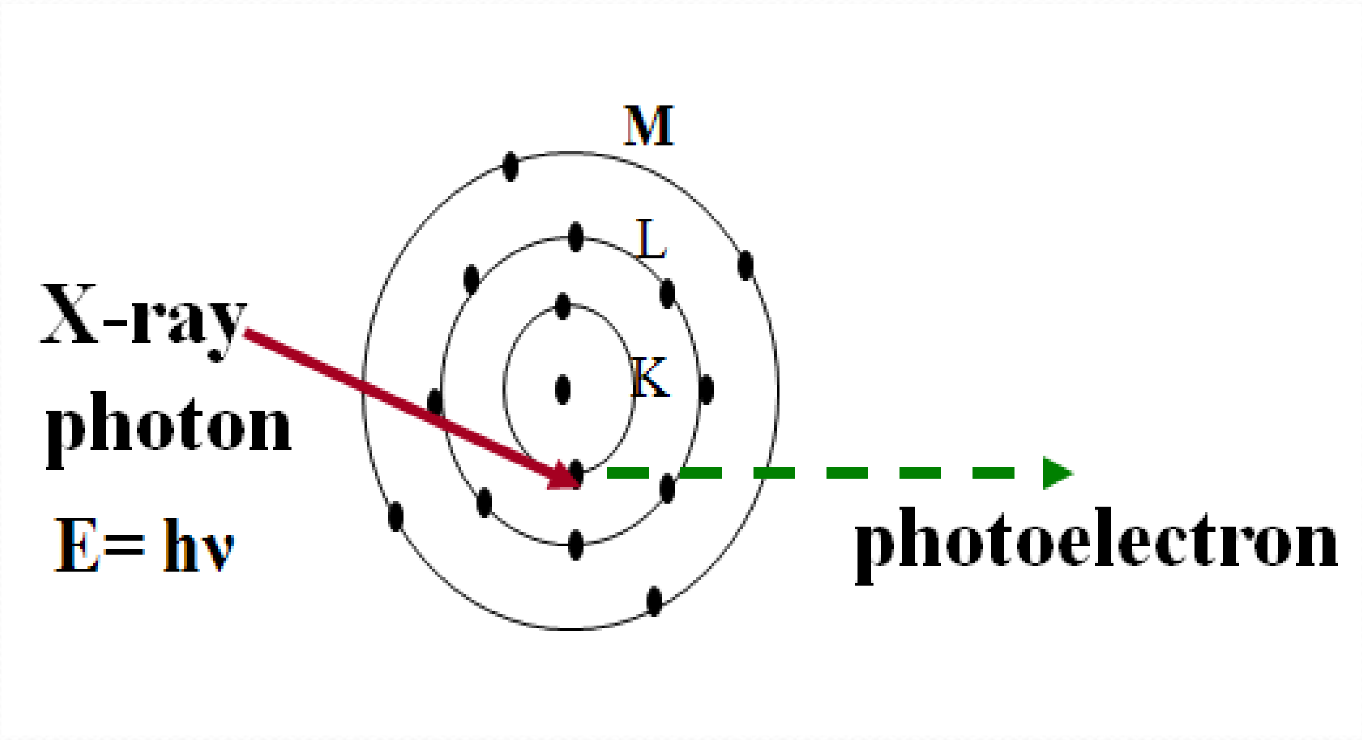
1-**Photoelectric effect**

2- **Compton effect**

3- **Pair-production**

1- Photoelectric effect

Its occurs when the incoming x-ray photon transfer all of its energy to an electron which then escapes from the atom.



Characteristics of Photoelectric effect:

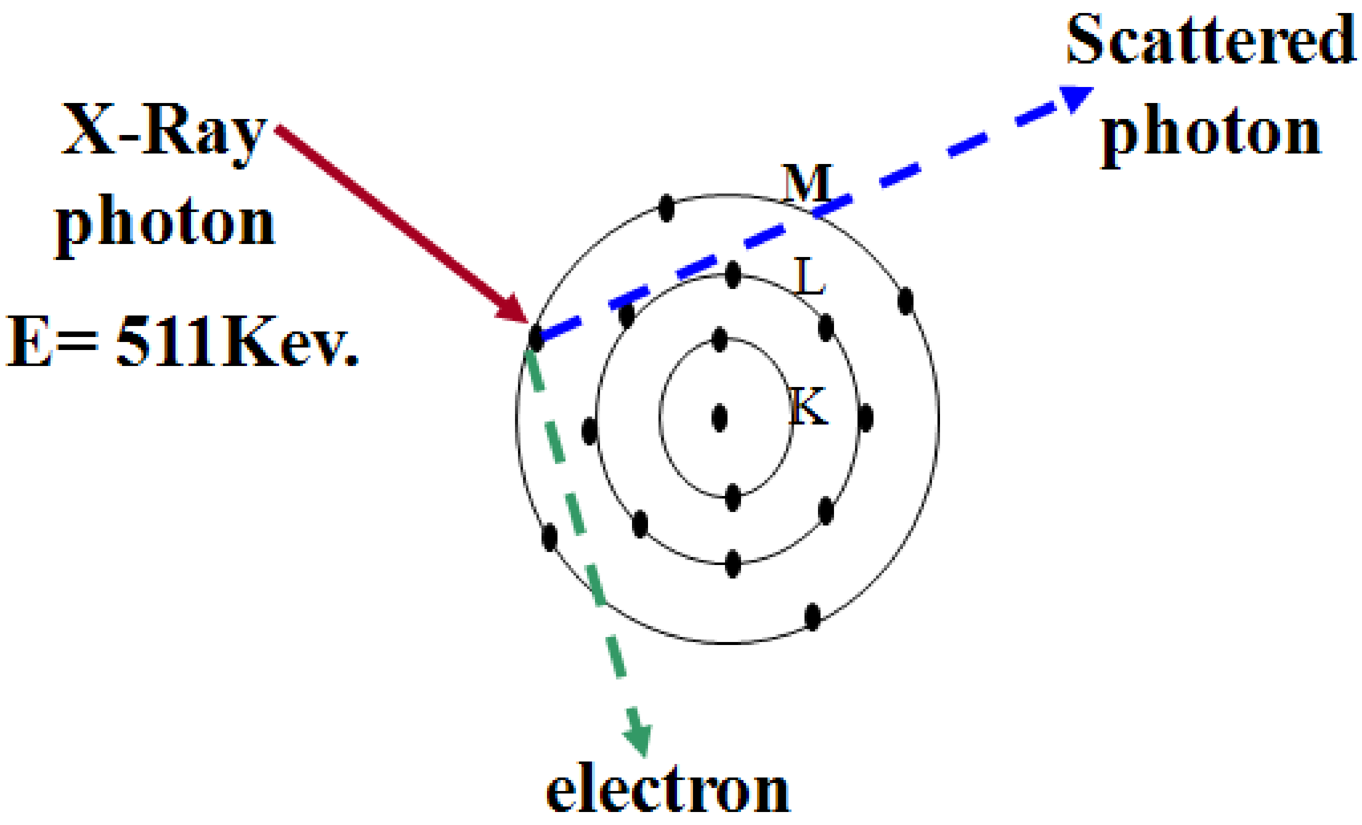
1. It's more apt to occur in the intense electric field near the nucleus.
2. It's more common in elements with high Z than in those with low Z.
3. The photoelectron uses some of its energy (the binding energy) to get away from the positive nucleus and the reminder will be as a kinetic energy for the electron.

4. The energy used about 30 Kev of x-ray photons.

5. Used more than Compton effect in diagnosis. Especially the bones and heavy materials such as bullets in the body.

2- Compton effect

1. It occurs by collision of an x-ray photon with an loosely bounded electron.
2. More apt to occurs at the outer electrons.
3. The energy used usually more than 100 Kev.
4. It usually done at low atomic number (Z) materials.
5. Used also in diagnosis especially the soft tissue.

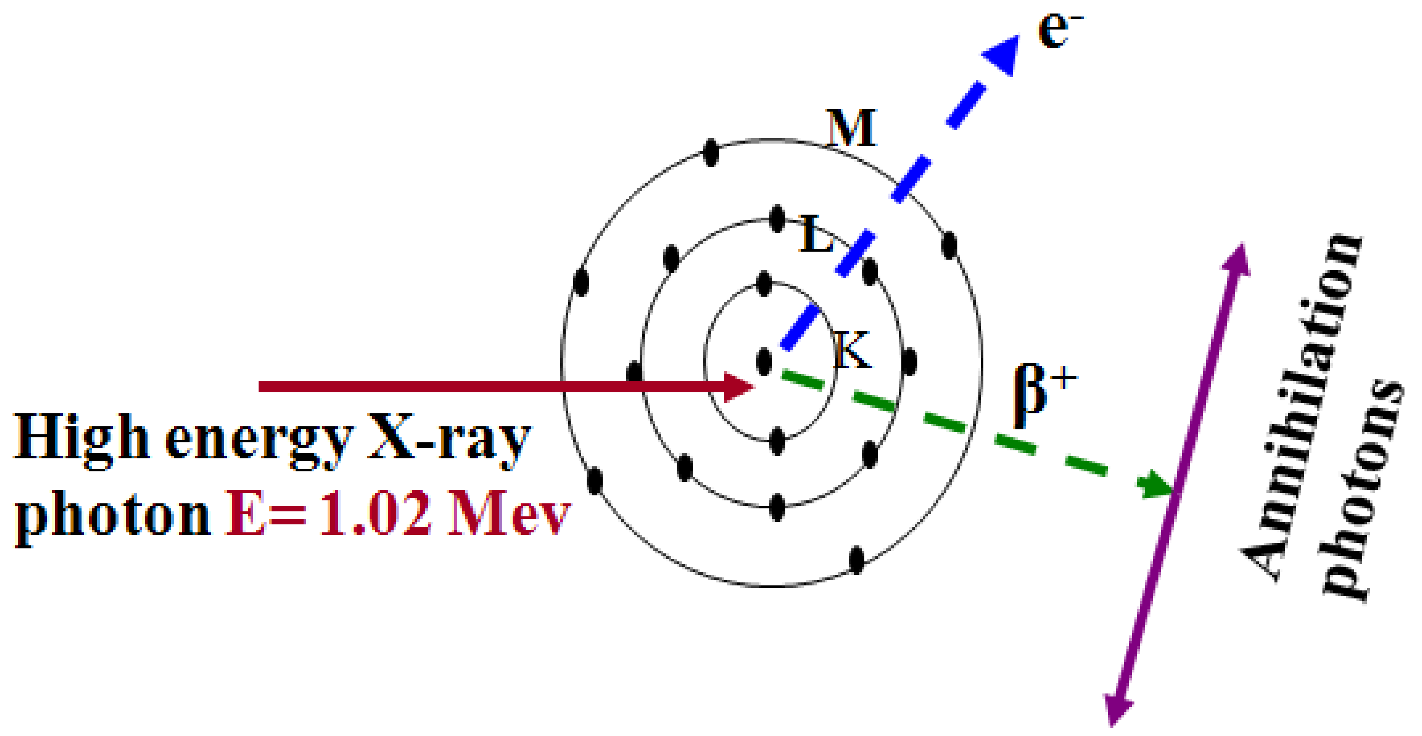

Scattered
photon
X-Ray
photon
E= 511Kev.
M
L
K
electron

3- Pair-production

Its occur when:

1. A very energetic photon enters the intense field of the nucleus, and converted into two particles: an electron and a positron (β^+), or positive electron.

2. This energetic photon providing the mass for the two particles requires a photon with energy of at least 1.02 Mev and the remainder of the energy over 1.02 Mev is given to the particles as a kinetic energy.



e⁻
M
L
K
β⁺
High energy X-ray
photon E=1.02 Mev
Annihilation
photons

3. The positron is a piece of antimatter. After it has spent its kinetic energy in ionization it does death dance with an electron.

4. Both then vanish, and their mass energy usually appears as two photons of 511 kev each called (annihilation radiation).

5. Pair-production is more apt to occur in high Z elements than in low Z elements.

Contrasting:

This technique is made to make further use of the photoelectric effect. This done by injected high Z material into different parts of the body which are called (Contrasting media).

Examples:

1. Compound containing iodine is injected into a blood stream to show the arteries.
2. Oily mist containing iodine is sometimes sprayed into the lungs to make the airways visible.
3. Barium enemas to view lower GI system.
4. Barium compound is given orally to see parts of the upper gastrointestinal tract.

X-ray slices of the body

- On an ordinary x-ray image the shadows of all the objects in the path of x-ray beam are superimposed, and thus the shadows of normal structures may mask or interface with the shadows that indicate disease.

- In order to distinguish the shadows indicating disease (so, avoid problem above) the radiologist often takes x-ray images from different directions, such as from the back, the side, and an intermediate angle.

- The ways that used for taking x-ray image of slices are:

1- **Tomography: -** x-ray images of slices of the body, or body section radiography.

2- **Axil tomograph:-** is an image of slice across the body and is taken by rotating the x-ray tube and film around the patient.

3- **Computerized axil tomography (CAT)** or Computerized tomography (CT): It ◌s use of a technique for analyzing data by computer.

The technique for (CAT) is:

1. The original CAT unit designed to be used on the head.

2. An x-ray tube is collimated to produce 2-narrow x-ray beams that scan across the head, and the intensities of the transmitted beams are measured by 2 detectors moving with the beam.

3. The data from the scan are stored in the memory of the computer.

4. The tube and the detector are then rotated 1 ° and the process repeated.

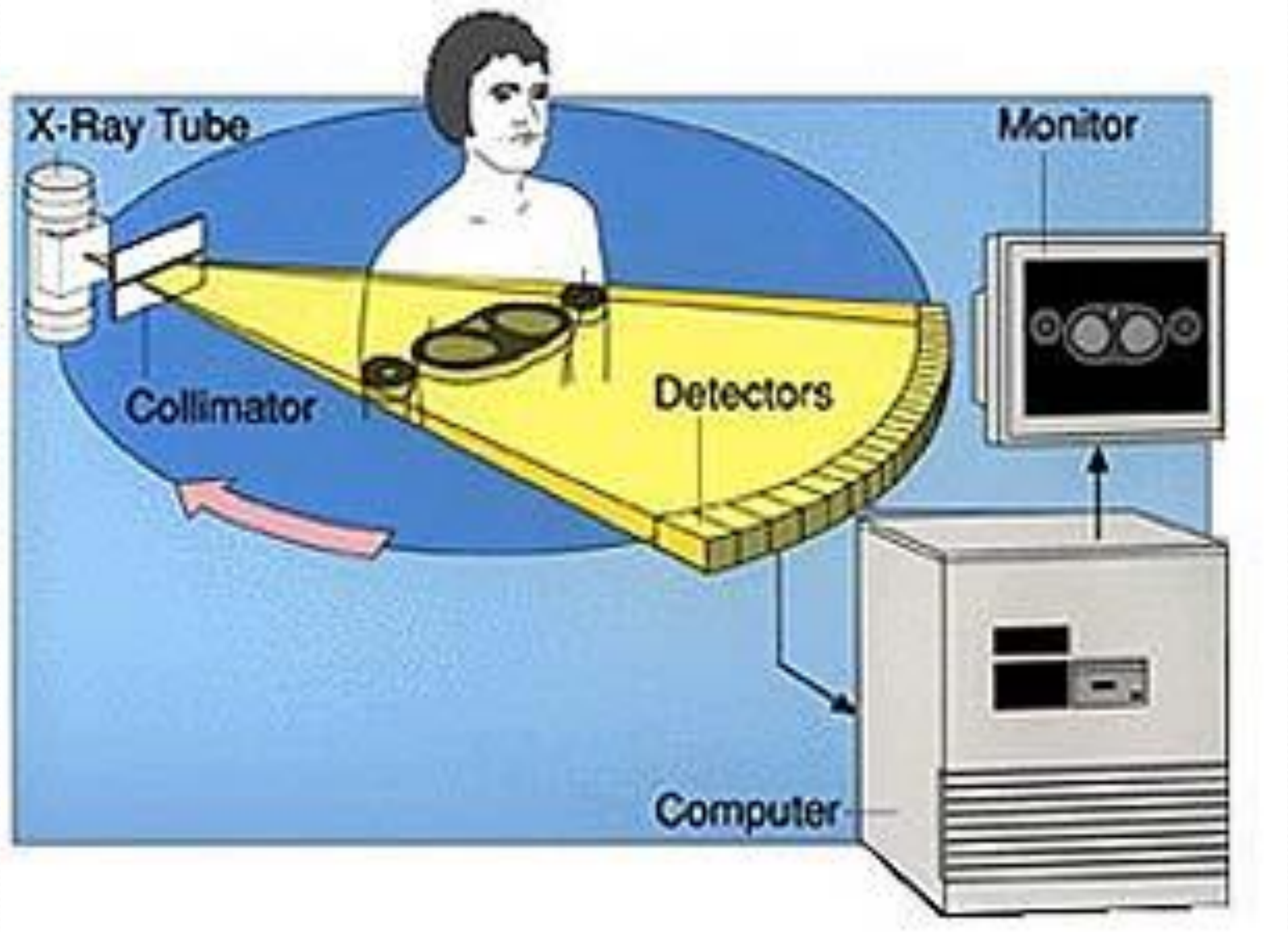
5. This process is repeated until. 180 scan have been obtained, which require about 4 min.

6. The computer analyzes the data to determine the distribution of densities in the slice.

7. The operator have these densities that represented by shades of gray to produce an image.

__Note1:__

CAT scanners that could be used on any portion of the body were developed.


X-Ray Tube
Monitor
Collimator
Detectors
Computer

<u>Note2:</u> When the scan is made for the thorax:

The patient should not breathe during the test in order to eliminate blurring on scan, and it's difficult for the patient for holding the breath for more than 30 sec. therefore:

The time of the test must be reduced from 4 min. to 20 sec. by using x-rays beam collimated in a fan shape and many detectors to measure the transmitted segments of the beam.

Fluorescence:

The production of light by bombarding certain materials with other form of radiation. Its property of x-ray.

X-ray image images could be viewed directly on a sheet coated with fluorescent material, or a fluorescent screen. Fluoroscopic techniques are useful where motion, such as the movement of contrast media in the digestive tract.

Computed Tomography

Basic principles

Geometry and historical development

Basic principles

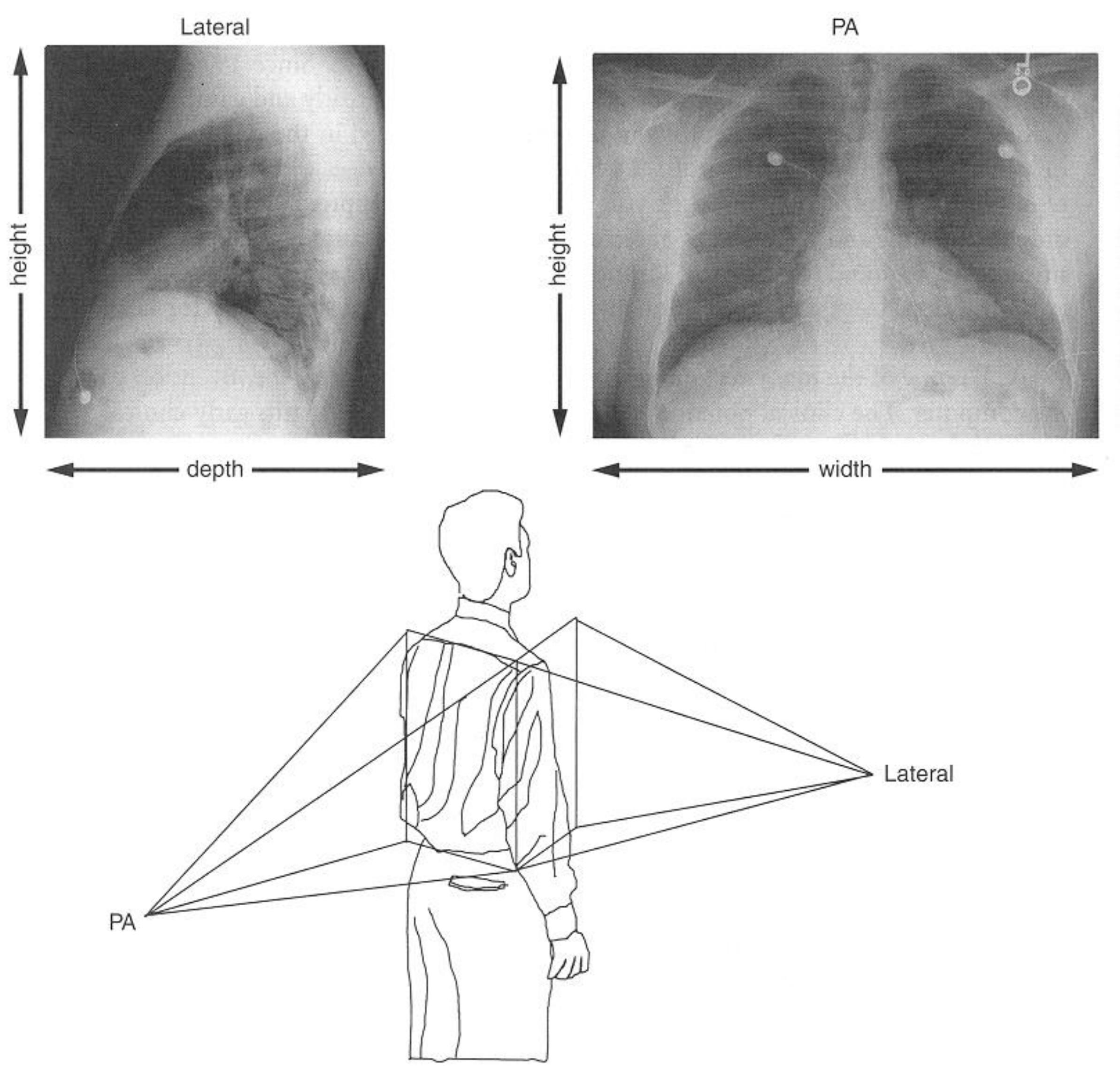
- Mathematical principles of CT were first developed in 1917 by Radon
- Proved that an image of an unknown object could be produced if one had an infinite number of projections through the object

Basic principles (cont.)

- Plain film imaging reduces the 3D patient anatomy to a 2D projection image
- Density at a given point on an image represents the x-ray attenuation properties within the patient along a line between the x-ray focal spot and the point on the detector corresponding to the point on the image

Basic principles (cont.)

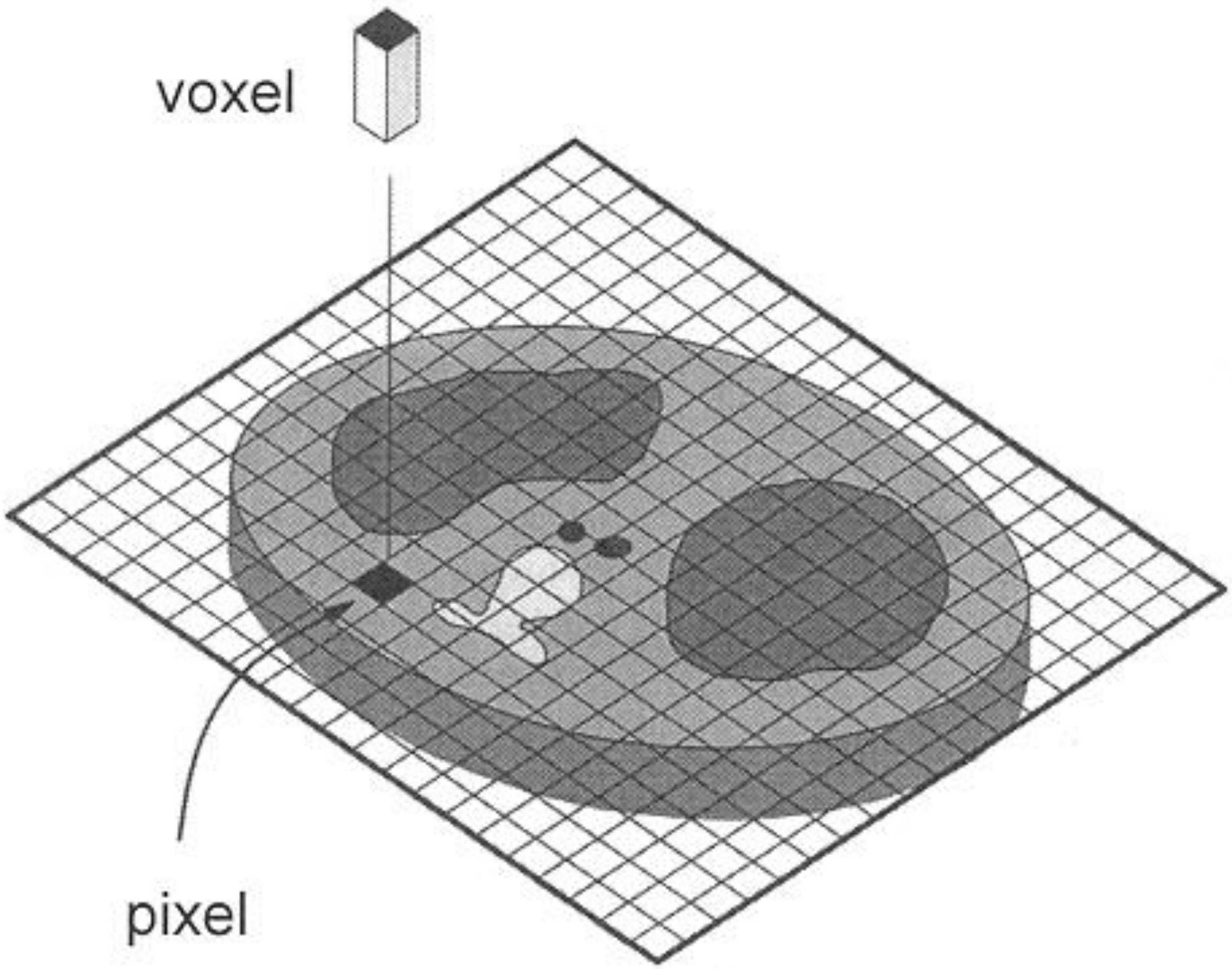
- With a conventional radiograph, information with respect to the dimension parallel to the x-ray beam is lost
- Limitation can be overcome, to some degree, by acquiring two images at an angle of 90 degrees to one another
- For objects that can be identified in both images, the two films provide location information



Lateral
PA
height
height
depth
width
Lateral
PA

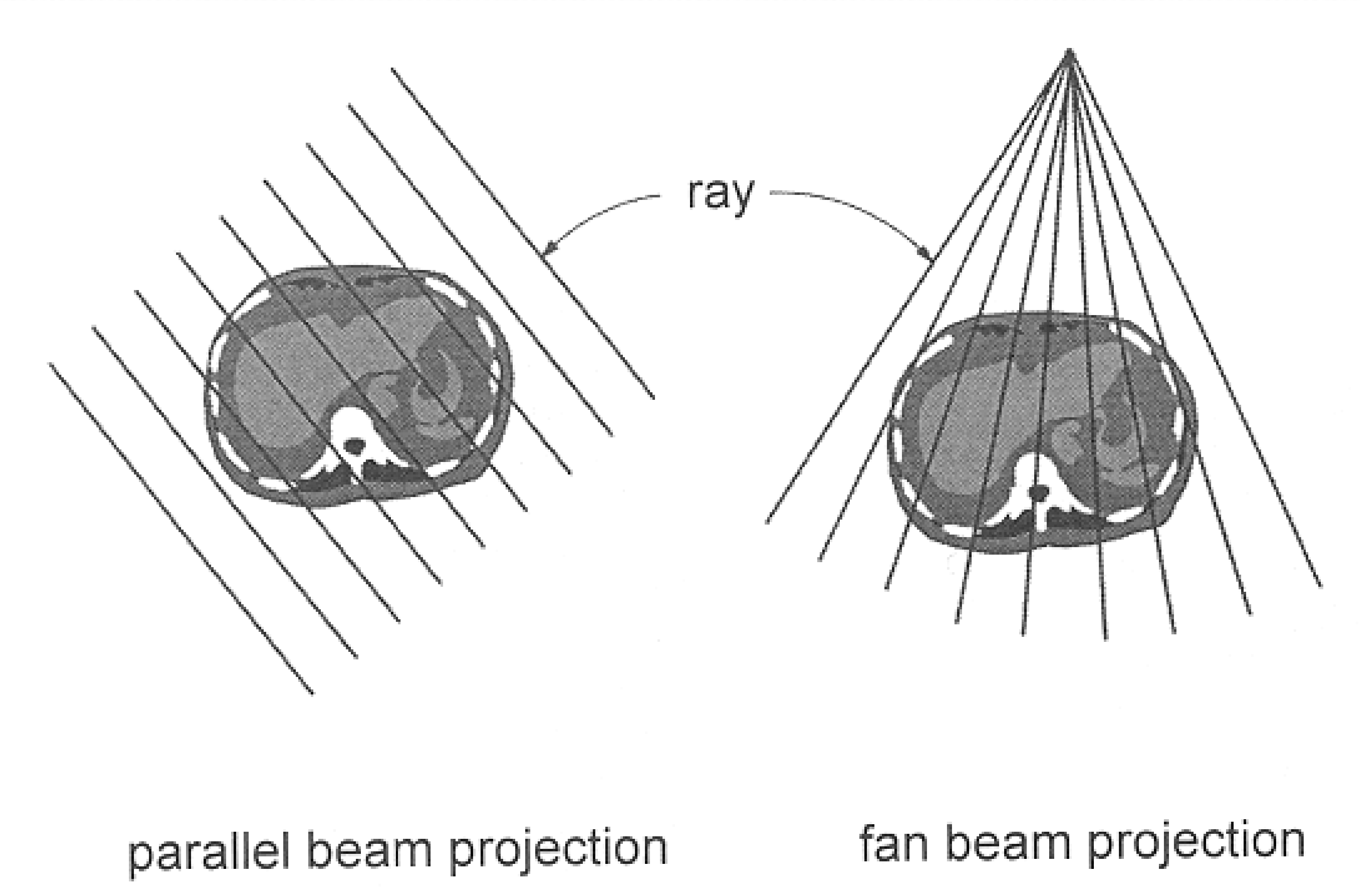
Tomographic images

- The tomographic image is a picture of a slab of the patient's anatomy
- The 2D CT image corresponds to a 3D section of the patient
- CT slice thickness is very thin (1 to 10 mm) and is approximately uniform
- The 2D array of pixels in the CT image corresponds to an equal number of 3D voxels (volume elements) in the patient
- Each pixel on the CT image displays the average x-ray attenuation properties of the tissue in the corrsponding voxel


voxel
pixel

Tomographic acquisition

- Single transmission measurement through the patient made by a single detector at a given moment in time is called a *ray*
- A series of rays that pass through the patient at the same orientation is called a *projection* or *view*
- Two projection geometries have been used in CT imaging:
  - *Parallel beam geometry* with all rays in a projection parallel to one another
  - *Fan beam geometry*, in which the rays at a given projection angle diverge


ray
parallel beam projection
fan beam projection

Acquisition (cont.)

- Purpose of CT scanner hardware is to acquire a large number of transmission measurements through the patient at different positions
- Single CT image may involve approximately 800 rays taken at 1,000 different projection angles
- Before the acquisition of the next slice, the table that the patient lies on is moved slightly in the cranial-caudal direction (the “z-axis” of the scanner)

Tomographic reconstruction

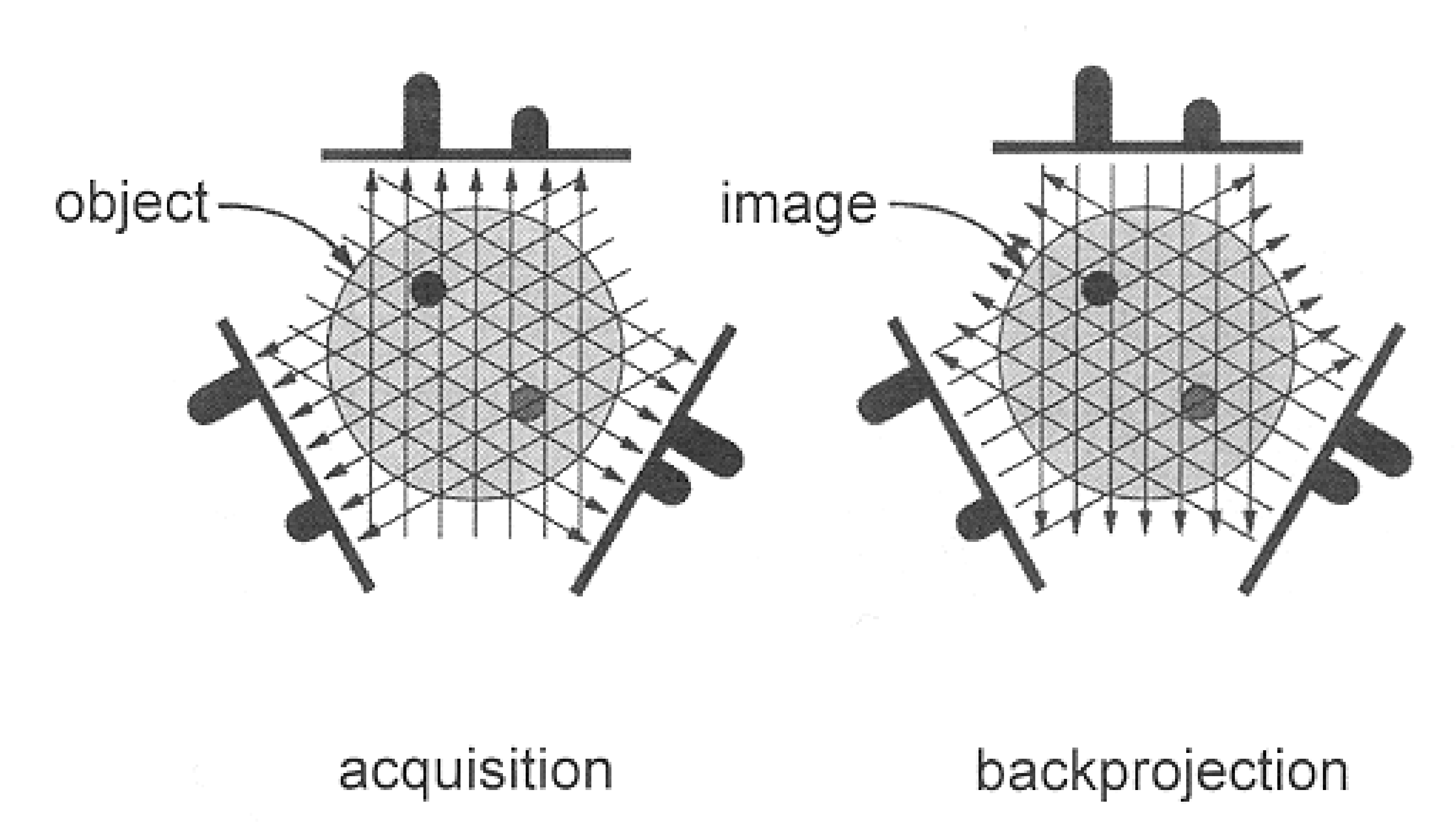
- Each ray acquired in CT is a transmission measurement through the patient along a line
- The unattenuated intensity of the x-ray beam is also measured during the scan by a reference detector

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

$$\ln(I_0 / I_t) = \mu t$$

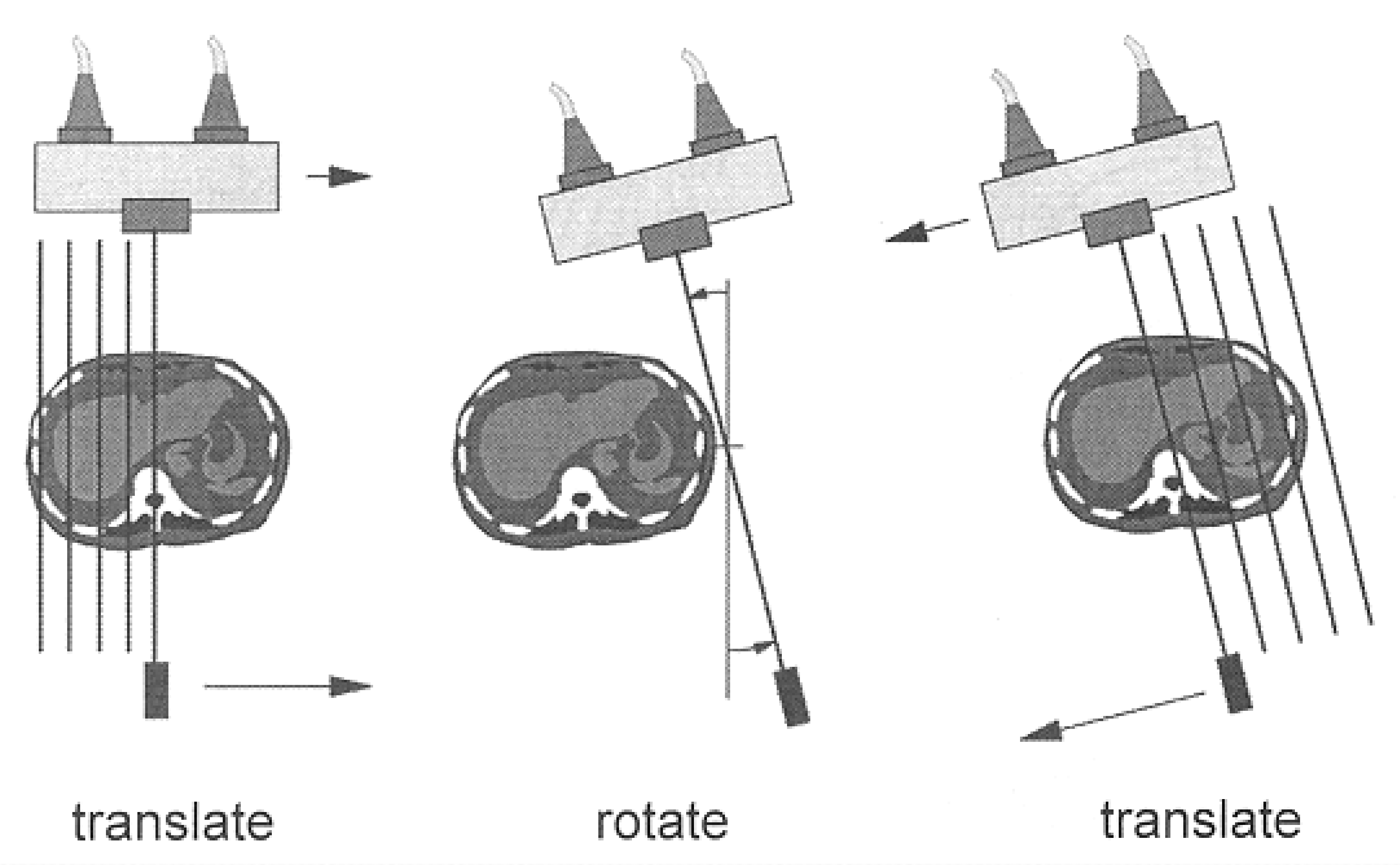
Reconstruction (cont.)

- There are numerous reconstruction algorithms
- *Filtered backprojection* reconstruction is most widely used in clinical CT scanners
- Builds up the CT image by essentially reversing the acquistion steps
- The μ value for each ray is smeared along this same path in the image of the patient
- As data from a large number of rays are backprojected onto the image matrix, areas of high attenutation tend to reinforce one another, as do areas of low attenuation, building up the image


object
image
acquisition
backprojection

1^{st} generation: rotate/translate, pencil beam

- Only 2 x-ray detectors used (two different slices)
- Parallel ray geometry
- Translated linearly to acquire 160 rays across a 24 cm FOV
- Rotated slightly between translations to acquire 180 projections at 1-degree intervals
- About 4.5 minutes/scan with 1.5 minutes to reconstruct slice

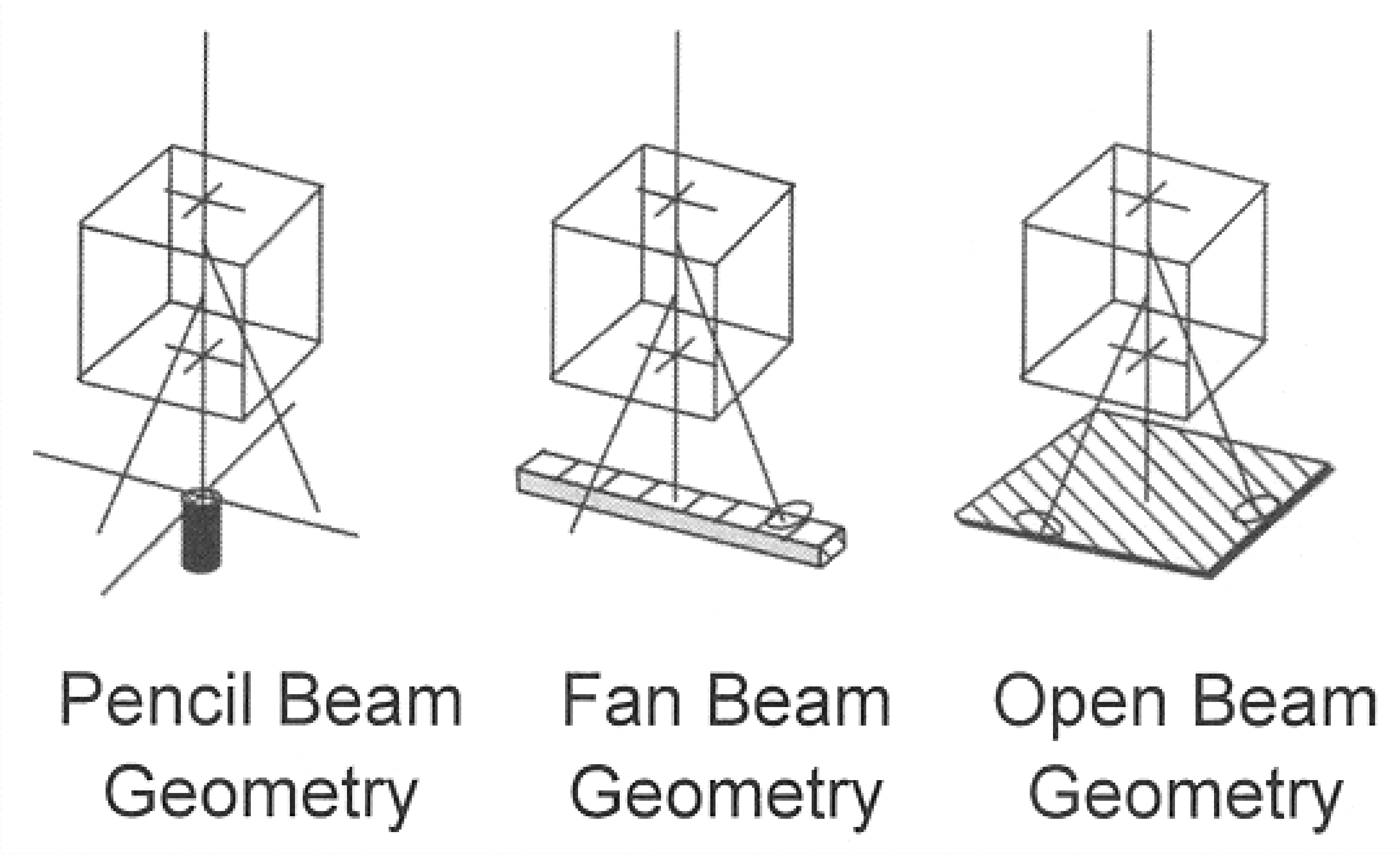

translate
rotate
translate

1st generation (cont.)

- Large change in signal due to increased x-ray flux outside of head
  - Solved by pressing patient's head into a flexible membrane surrounded by a water bath
- NaI detector signal decayed slowly, affecting measurements made temporally too close together
- Pencil beam geometry allowed very efficient scatter reduction, best of all scanner generations

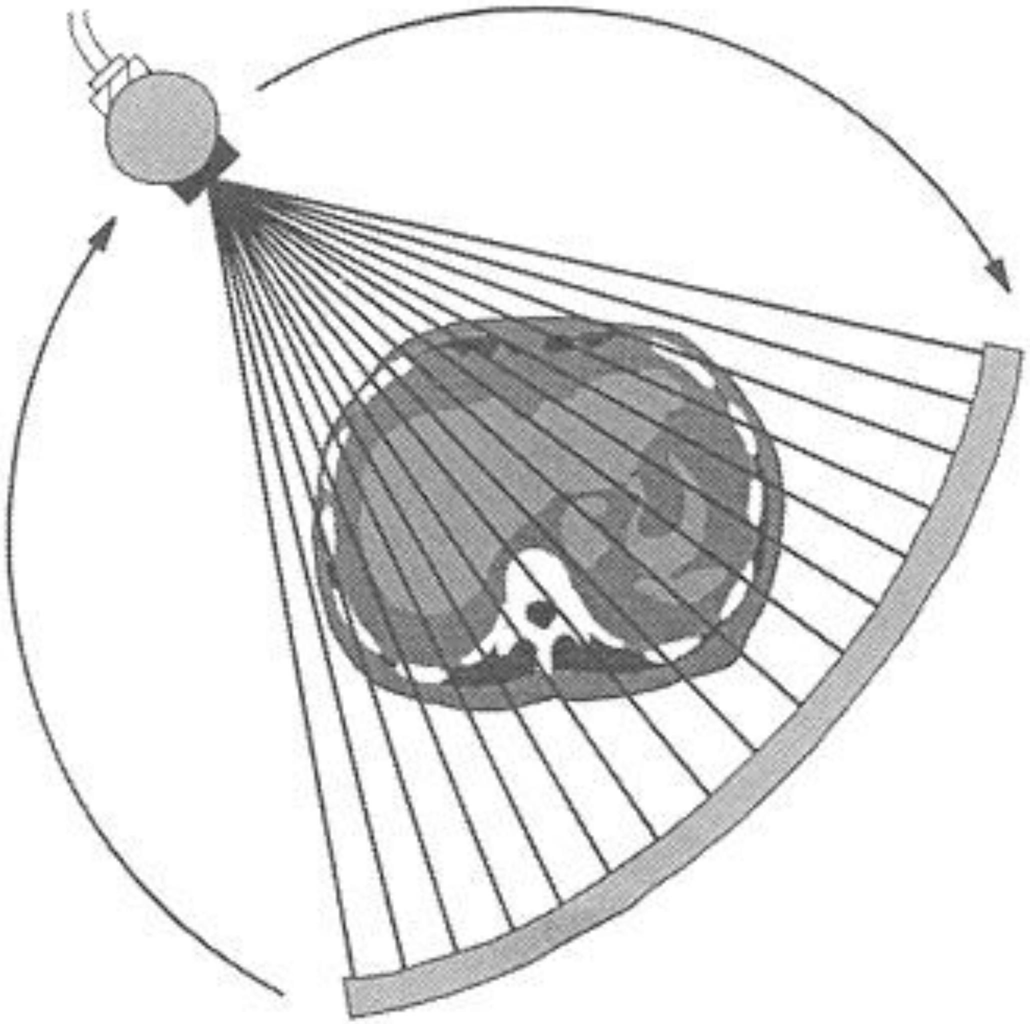
2nd generation: rotate/translate, narrow fan beam

- Incorporated linear array of 30 detectors
- More data acquired to improve image quality (600 rays x 540 views)
- Shortest scan time was 18 seconds/slice
- Narrow fan beam allows more scattered radiation to be detected


Pencil Beam Geometry
Fan Beam Geometry
Open Beam Geometry

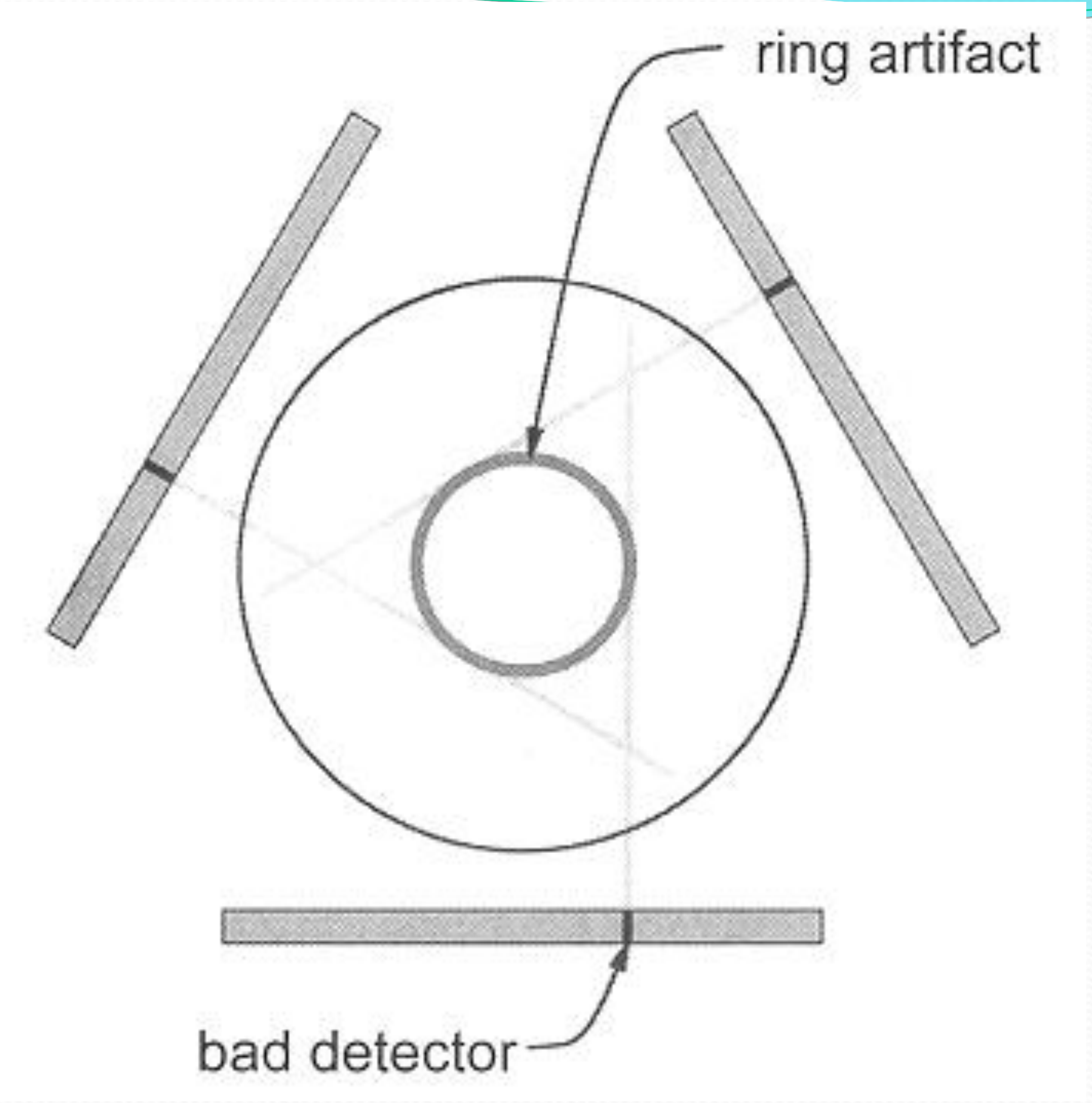
3^{rd} generation: rotate/rotate, wide fan beam

- Number of detectors increased substantially (to more than 800 detectors)
- Angle of fan beam increased to cover entire patient
  - Eliminated need for translational motion
- Mechanically joined x-ray tube and detector array rotate together
- Newer systems have scan times of ½ second



Ring artifacts

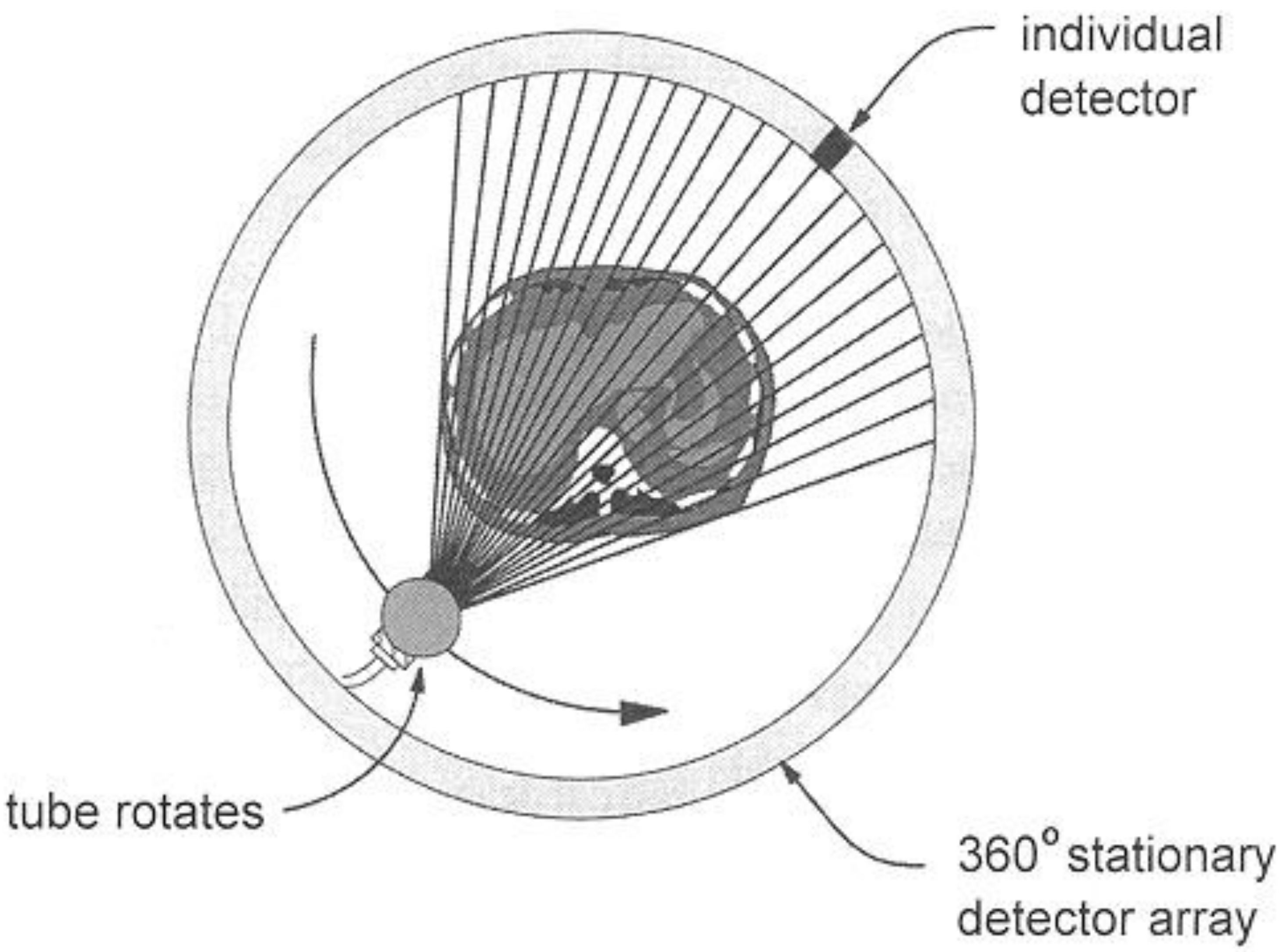
- The rotate/rotate geometry of 3rd generation scanners leads to a situation in which each detector is responsible for the data corresponding to a ring in the image
- Drift in the signal levels of the detectors over time affects the μt values that are backprojected to produce the CT image, causing ring artifacts



ring artifact
bad detector

4th generation: rotate/stationary

- Designed to overcome the problem of ring artifacts
- Stationary ring of about 4,800 detectors

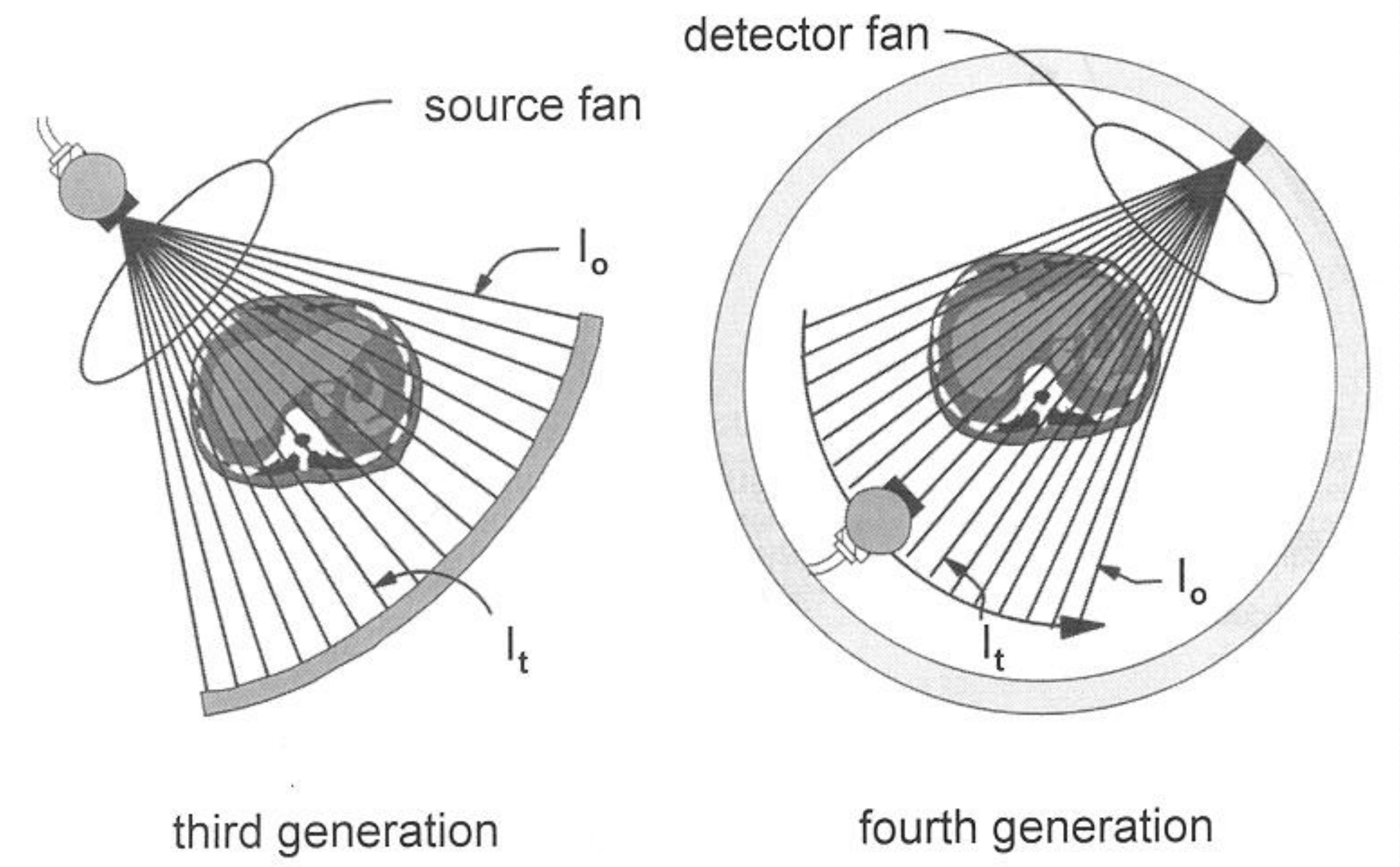

individual
detector
tube rotates
360° stationary
detector array

3rd vs. 4th generation

- 3rd generation fan beam geometry has the x-ray tube as the apex of the fan; 4th generation has the individual detector as the apex

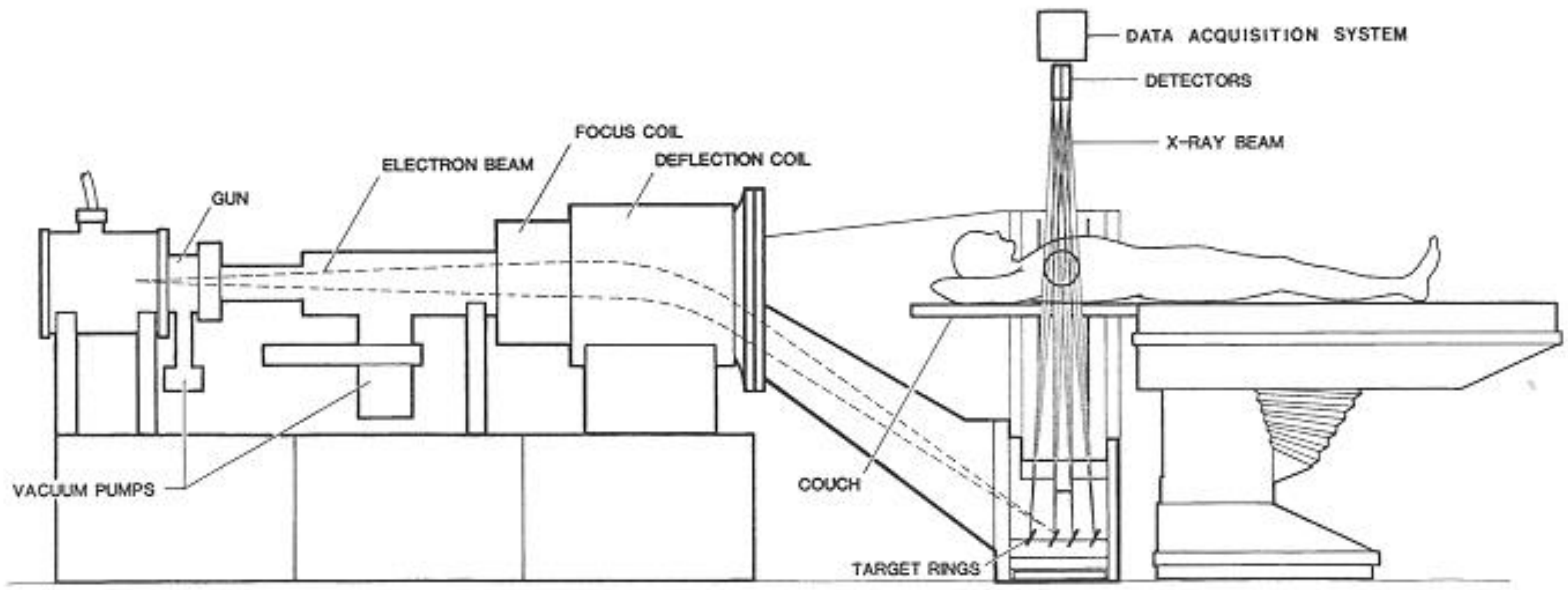
$$3^{rd}\ \text{gen}: \ln(g_1 I_0 / g_2 I_t) = \mu t$$

$$4^{th}\ \text{gen}: \ln(g I_0 / g I_t) = \mu t$$


detector fan
source fan
Io
It
Io
It
third generation
fourth generation

5th generation: stationary/stationary

- Developed specifically for cardiac tomographic imaging
- No conventional x-ray tube; large arc of tungsten encircles patient and lies directly opposite to the detector ring
- Electron beam steered around the patient to strike the annular tungsten target
- Capable of 50-msec scan times; can produce fast-frame-rate CT movies of the beating heart


DATA ACQUISITION SYSTEM
DETECTORS
X-RAY BEAM
FOCUS COIL
DEFLECTION COIL
ELECTRON BEAM
GUN
VACUUM PUMPS
COUCH
TARGET RINGS

6th generation: helical

- Helical CT scanners acquire data while the table is moving
- By avoiding the time required to translate the patient table, the total scan time required to image the patient can be much shorter
- Allows the use of less contrast agent and increases patient throughput
- In some instances the entire scan be done within a single breath-hold of the patient

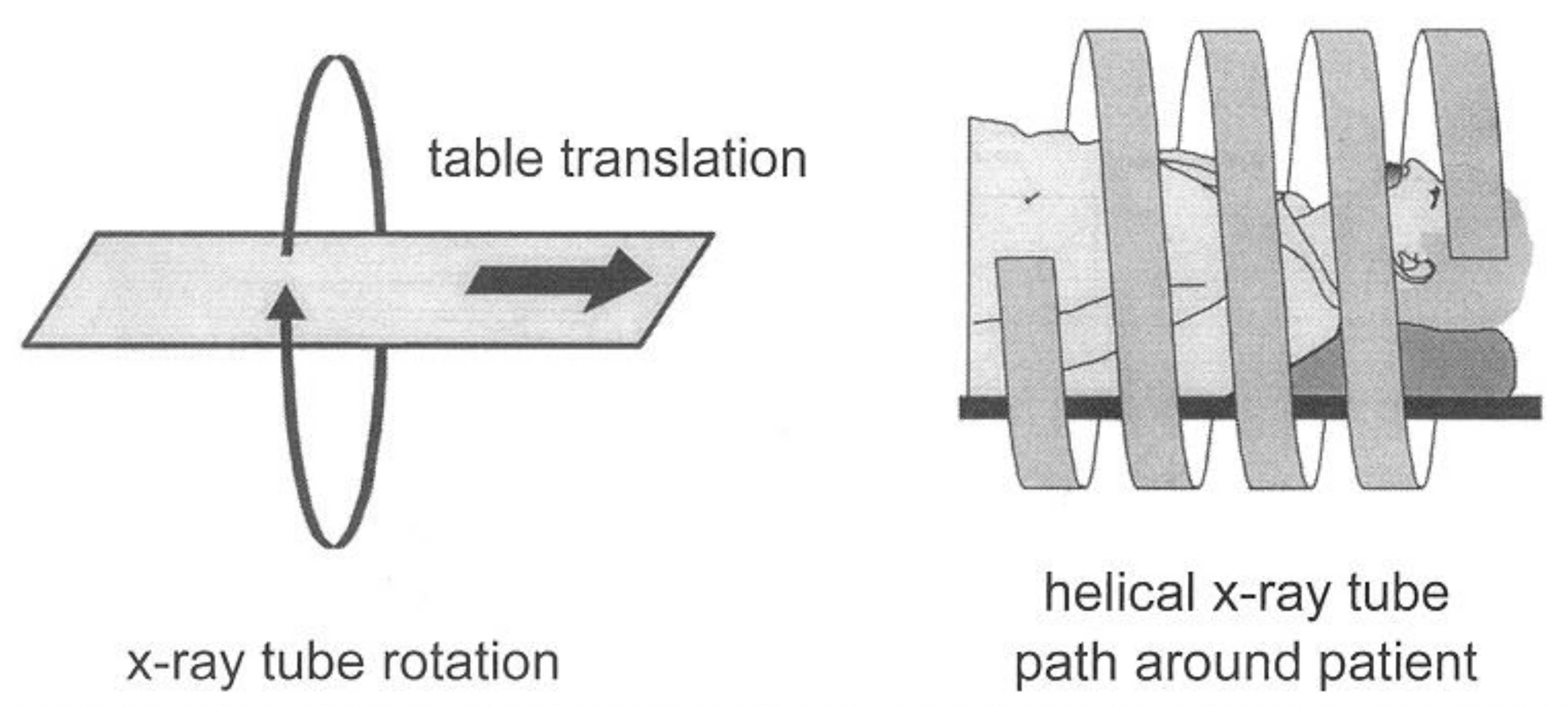
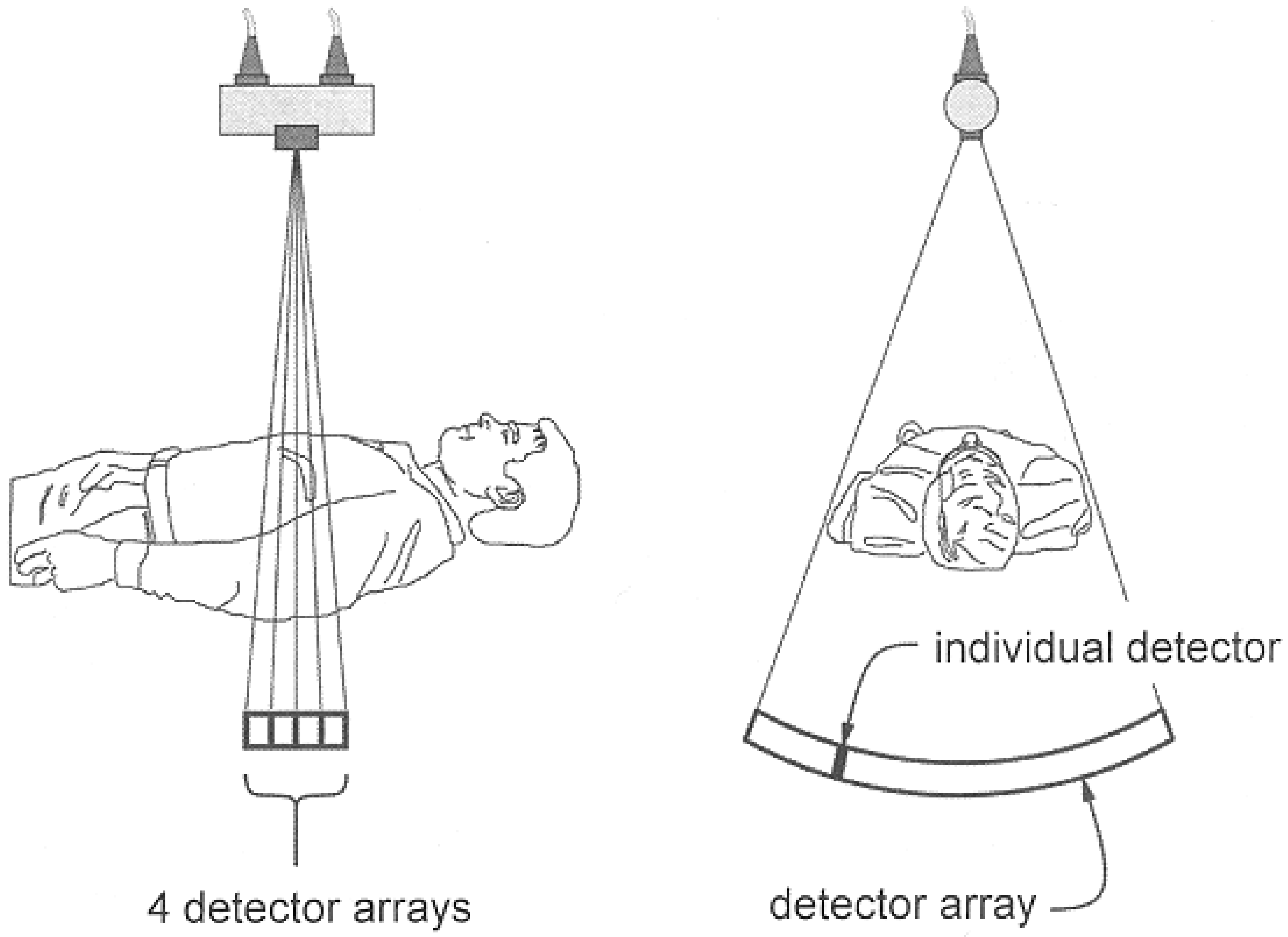


table translation
x-ray tube rotation
helical x-ray tube
path around patient

7th generation: multiple detector array

- When using multiple detector arrays, the collimator spacing is wider and more of the x-rays that are produced by the tube are used in producing image data
  - Opening up the collimator in a single array scanner increases the slice thickness, reducing spatial resolution in the slice thickness dimension
  - With multiple detector array scanners, slice thickness is determined by detector size, not by the collimator


4 detector arrays
individual detector
detector array