Medical physics *1st Stage*

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HEAT AND COLD IN MEDICINE

Physical Basis of Heat and 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 .
♦ Heat :
◊ The energy transferred to the molecules causing the temp. rise .
◊ Solid +heat ⇒liquid
◊ Liquid + heat ⇒gas
◊ Gas + heat ⇒ ions

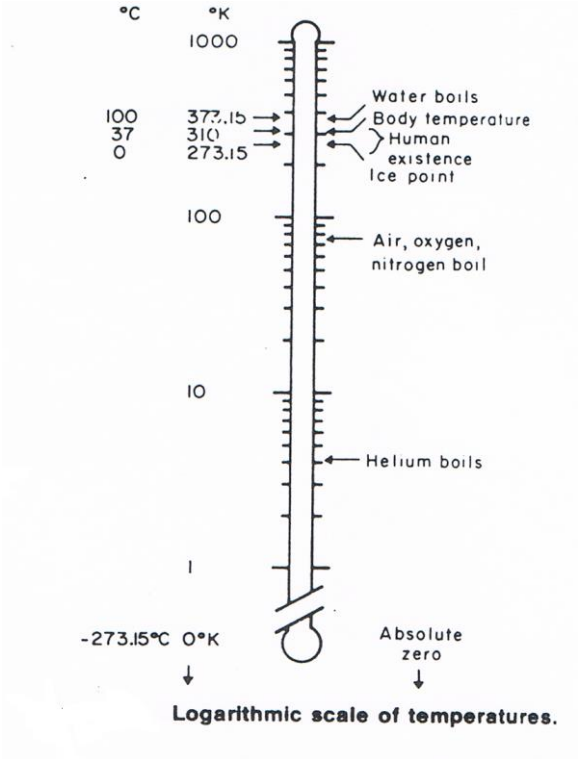
Thermometry and Temperature Scales:

♦ Temperature is difficult to measure directly , so we usually measure it indirectly by measuring one of the physical properties that change with temperature.
♦ Temperature scales :

a. Fahrenheit (°F) scale:
   ◊ water freezes at 32 °F and boils at 212 °F
   ◊ normal body temp. (rectal) is about 98.6°F
b. Celsius (°C) scale (Centigrade) :
   ◊ water freezes at 0 °C and boils at 100 °C
   ◊ normal body temp. (rectal) is about 37°C
c. Absolute (°K) scale (Kelvin) :
   ◊ water freezes at 273.15 °K and boils at 373.15 °K
   ◊ normal body temp. (rectal) is about 310 °K
   ◊ absolute zero (0°K) is –273.15 °C
   ◊ This scale used for scientific work but it is not used in medicine .

The relation ships between different temperature scales are :

1. $°F = (°C \times \frac{9}{5}) + 32$
2. $°C = (°F - 32) \times \frac{5}{9}$
3. $°K = 273.15 + °C$



Logarithmic scale of temperatures.

Example 1 :In a hot room ,a person skin temperature is about 35°C ,find his skin temperature on the Kelvin and Fahrenheit scales ?

$°K = 273.15 + °C = 273.15 + 35 = 308.15\ °K$

$°F = (°C \times \frac{9}{5}) + 32 = (35 \times \frac{9}{5}) + 32 = 95\ °F$

Example 2 :A pan of water is heated from 30 °C to the boiling point . What is the change in its temperature on the Kelvin and Fahrenheit scales

$\Delta°C = 100 - 30 = 70\ °C$

$\Delta°K = 373.15 - 303.15 = 70\ °K$

$\Delta°F = 212 - 86 = 126\ °F$

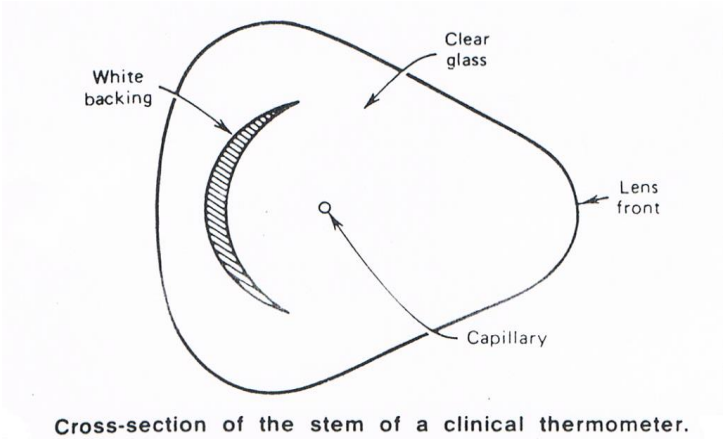
(H.W.) Calculate the normal body temperature on Kelvin , Celsius , and Fahrenheit scales consequently ?

The ways to measure the body temperature :

A number of **temperature sensitive devices** used in medicine to measure temperature (T) :

1.Glass Fever Thermometer :

- ♦ This thermometer composed of glass capillary tube ends with a bulb (a store for liquid).The liquid can be mercury or alcohol . The principle behind thermometer is that an increase in the temp. of different materials usually causes them expand different amounts .So a temp. increases causes the alcohol or mercury to expand more than the glass and thus produce an increase in the level of the liquid .
- ♦ Temperature change from 0 to 100 °C in $1cm^3$ of mercury (Hg) causes Only (1.8%) increases in volume .
- ♦ Capillary with smaller diameter (0.1 mm) causes high sensitivity .
- ♦ Magnifying glass and opaque white backing makes improved visibility
- ♦ Restriction just above the bulb hold the maximum temp. and making the mercury not to return if the thermometer is exposed to low temp.
- ♦ Temp. measurement underneath the tongue or in the rectum requires several minutes for stabilization . (Why) ?



Cross-section of the stem of a clinical thermometer.

The mercury used instead of alcohol in fever thermometer. Why?

a. It has a clear color, which can be seen easily .

b. Mercury (Hg) has low adhesion force with the wall of the glass and has high adhesive force .

It is difficult to measure body temp. with the house thermometer. Why?

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

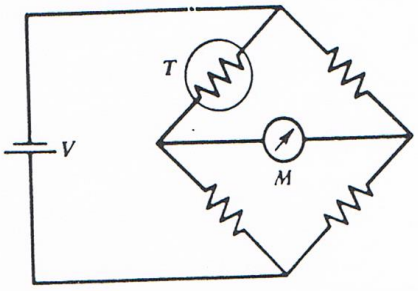
Homework: Consider a fever thermometer that contains $0.01cm^3$ of mercury. Find the diameter of the capillary if a 1^0C change corresponds to a level change of 0.5 cm. Assume the glass does not expand.

2.Thermistor :

It is a special resistor that changes its resistance rapidly with temperature (~5% / °C) . As shown in the Figure, four resistors form the bridge circuit with a thermistor (T) in one of the legs . The bridge is balanced .

The voltages at each end of the meter are equal and no current flows through the meter . A temperature change causes the thermistor (T) resistance to change,

The voltage at each end of the meter become unequal ,causing current to flow through the meter ,and the resulting meter deflection can be calibrated for temperature .



The resistance of a thermistor *T* can be measured with a simple bridge circuit to determine the temperature. The meter *M* can be calibrated directly in degrees celsius or fahrenheit.

The thermistor advantages :

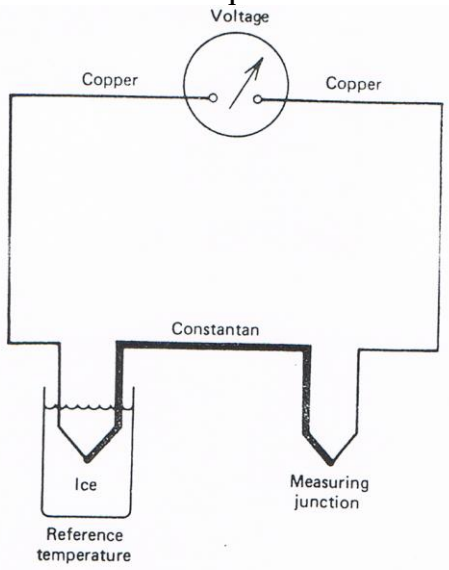
a. **Very sensitive** ,it is easy to measure temp. changes of (0.01°C) .
b. **Small mass** ,thermistor has little effect on the temp. of the surrounding tissues and responds rapidly to temp. change .
c. Breathing rate temperature measurement (**Pneumograph**) .

Pneumograph : It is a thermistor placed in the nose to monitor the breathing rate of patients by showing the temp. change between inspired cool air and expired warm air .

3.Thermocouple :

A thermocouple consists of two junctions of two different metals .If the two junctions are at different temp. ,a voltage is produced that depends on the temp. difference .Usually one of the junction is kept at a reference temp. such as in an ice water bath .The copper – constantan thermocouple shown in the Figure can be used to measure temperatures from{ –190 to 300 °C} . For a 100 °C temp. difference ,the voltage produced is only about (4 mV).

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



Schematic diagram of a thermocouple. The voltage is measured by a potentiometer.

4.Thermography :

- It is mapping the body's temperature . Measurements of body surface temp. indicate that the surface temp. 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 :

- It is the safest and simple routine method of obtaining a surface temperature .
- Most breasts cancers could have an elevated skin temp. in the region of the cancer .

- ♦ The surface temp. above a tumor was typically about (1°C) higher than the above nearby normal tissue ,therefore a very sensitive temp. measuring device had to be used (thermistor)
- ♦ Thermogram is done by measuring the radiation emitted from the human body .
- ♦ All objects regardless of their temp. emit radiation .
- ♦ At body temp. the emitted radiation is in the far infrared (IR) region of wave lengths much longer than those observable by the eye .

Stefan – Boltzman Law :

One very appealing method of obtaining a Thermogram is to measure the radiation emitted from the body .The basic equation described the radiation emitted by a body was given by Max Plank in 1901. For our purposes the Stefan –Boltzman law for the total radiative power per surface area (W) is more useful .It is : $W = e\sigma T^4$ Where

T : is the absolute temp.(°K)

e : is the emissivity

σ : is the Stefan-Boltzman constant

Notes :

1. e : is depending upon the emitter material and its temp. .For radiation from body (e) is almost **one** .
2. $\sigma = 5.7\times10^{-12}$ watt /cm^2

$\lambda_{max} = \frac{2898}{T}$:Wien`s displacement law .

T =300 °K $\Rightarrow \lambda_{max}$ = 9.66 μm (infrared region ,not visible)

Ex. :

a. What is the power radiated per square centimeter from skin at temp. of (~33 °C)?

°K = 273.15 + °C =273.15 +33 $\approx$306 °K

$W = e\sigma T^4 = 1\times5.7\times10^{-12}\times(306)^4 \approx 0.05$ watt/cm^2

b. What is the power radiated from a nude body $1.75m^2\left(1.75\times10^4 cm\right)$ in area?

$W \approx (0.05)\left(1.75\times10^4 cm^2\right) = 875$ watt .

To get a good Thermogram :

1. Clothes must be removed before thermography because clothing affects skin temp.
2. It necessary to permit the region to be mapped to adapt to room temp. and cool uniformly because this enhances the temp. differences and contrast in thermography .
3. A drafty examination area must be avoided.

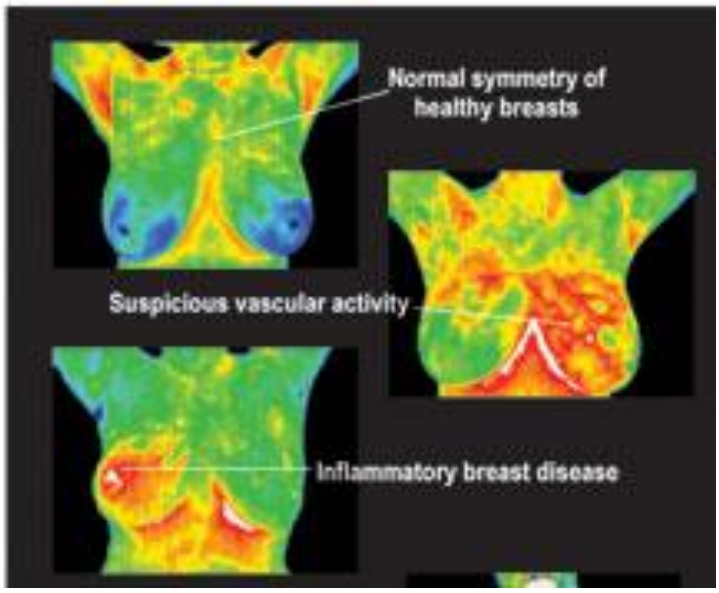
Thermography can be used in :

1. Aid in detecting breast cancer .
2. Detect other type of cancer .
3. Study the circulation of blood in the head .
4. Reduce leg amputation in diabetics .

Breast cancer detection :

For breast cancer detection the steps that must be followed respectively are :

1. **Palpation** (smooth touching) ,but it is difficult to detect a small tumor (less than 1 cm 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 with out cancer) and false negative (a normal Thermogram for a cancer patient), due to different blood flow patterns in the two breasts (below 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 .



Heat Therapy :

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 in to cool the heated area .

Physical methods of producing heat in the body :

1- Conductive heat : is based on the physical fact that if tow 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 :

1- The area of contact.
2- The temperature difference.
3- The time of contact (duration) .
4- The conductivity of material .

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

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} m)
- The waves penetrate the skin about 3mm and increase the surface temp.
- Excessive exposure causes reddening (erythema) and some times swelling (edema) .
- This type of heating is used to treat **the same** condition of conductive heating ,but it is considered to be moor effective because the heat penetrates deeper .

3- Radio wave heating (diathermy) :

A- Short wave diathermy :

- **U**tilized electromagnetic waves in the radio rang (wave length ~10 m).
- 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 .

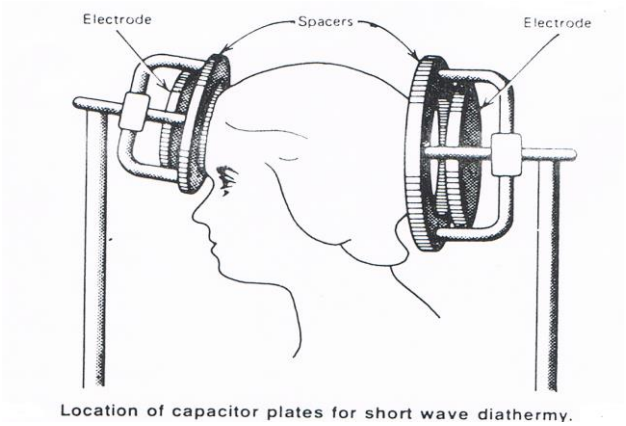
♦ Two different methods are used for transferring the electromagnetic energy in to the body

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 .



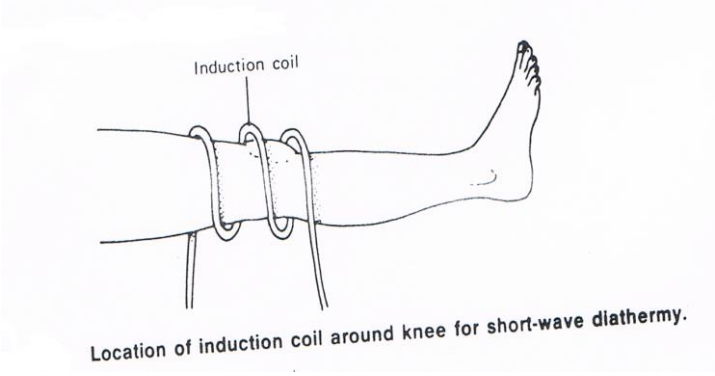
Location of capacitor plates for short wave diathermy.

2-**The second method :**

◊ It is a magnetic induction (see the below 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 .



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

B- Micro wave 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 heat .
- ♦ Ultrasonic heating has been found useful in relieving the tightness and scarring that often occur in joint disease ,aids joints that have limited motion .
- ♦ It is useful for depositing heat in bones because they absorb Ultrasound energy more effectively than does soft tissue .

Heat and radiation therpy combination:

Heat therapy may be beneficial in the treatment of cancer when it is combined with radiation therapy .The tumor is heated by diathermy to about 42 ^{o}C for 20-30 min, and the radiation treatment is given after the heat treatment.

Use of cold in medicine :

- ♦ **Cryogenics :**The science and technology of producing and using very low temperatures .

- ♦ **Cryobiology :** The study of low-temperature effects in biology and medicine .

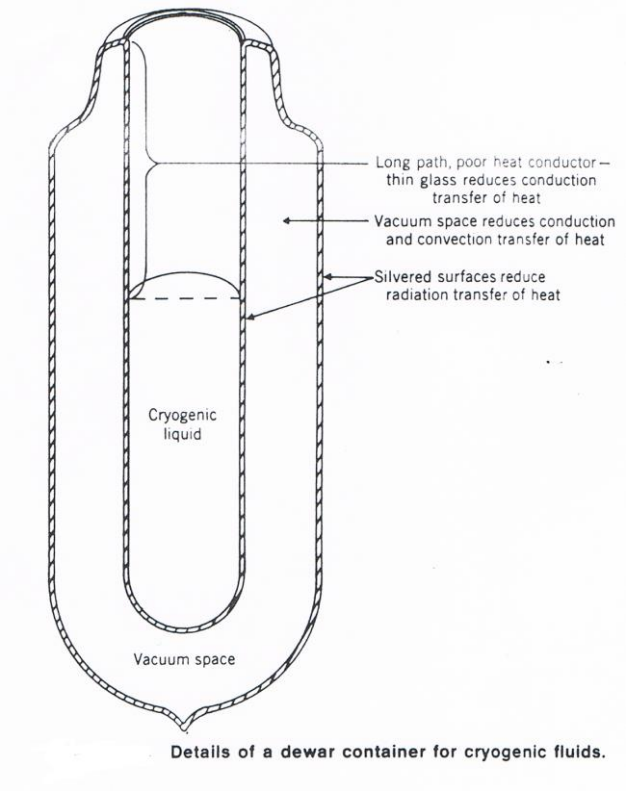
- ♦ **Cryogenic fluids :**

◊ Liquid helium (-269 ^{o}C)

◊ Liquid nitrogen (-196 ^{o}C)

◊ The storage of liquid gas (cryogenic fluids) is rather difficult because it can take heat rapidly from the environment due to the large differences in temp. .

♦ **Dewar container (vessels) :**
A special container has been designed by Dewar .This container was composed from two cylindrical bottles made of glass or stainless steel to minimize conductive losses ,one inside the other and vacuum in between to essentially eliminate convection losses, and the sides are silvered or polished, so that radiation striking the surface is reflected rather than absorbed. (see the next figure). Low temp. has been used for long-term preservation of blood, sperm, bon marrow and tissues.

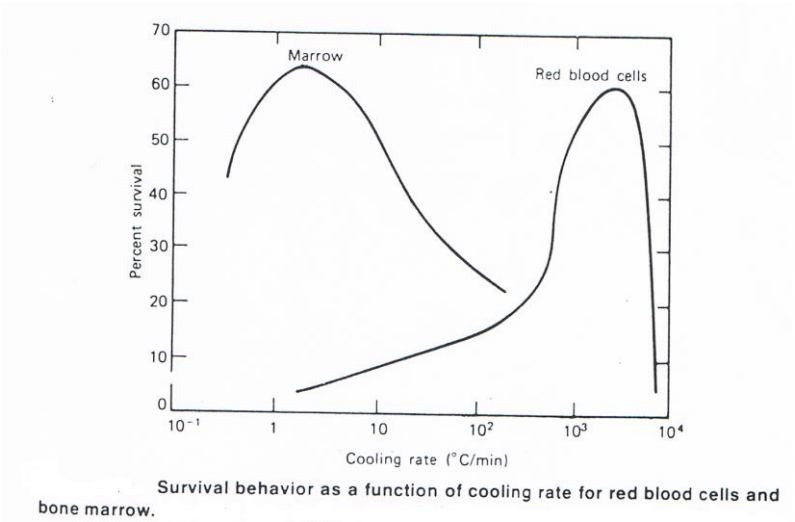


Details of a dewar container for cryogenic fluids.

♦ **Cryonics :**The science of using cryogenic methods to cool the body in to a state of(suspended animation)so that it can pass time without aging.
◊ The aim of cryonics is to preserve at low temperature people with fatal diseases with the hop that in the future they could be revived and their diseases cured .
◊ Some simpler human biological systems such as blood, semen, and tissue have successfully been cooled, stored, and revived .

♦ The survival curves of different biomaterials as a function of cooling rate have similar shapes, but there is no unique cooling rate that will ensure cell survival for all materials .

♦ The (next Figure) shows survival behavior as a function of cooling rate for red blood cells and bon marrow .



Survival behavior as a function of cooling rate for red blood cells and bone marrow.

Ex. :

If you know that the optimum cooling rate for preserving red blood cells is 2×10^3 ^oC/min , how long would it take to cool red blood cells from 37 to –196 ^oC .

Solu. :

$$^oC = 37 + 196 = 233\ ^oC$$

$$t = \frac{233}{2\times10^3} = 0.116 \text{ min} \sim 7 \text{ sec}$$

♦ Experimental work is under way to form banks for skin, muscle, and organs .These substantances are harder to preserve than simple cell such as blood cells for a number of reason :

1. The large physical dimensions limit the cooling rate .
2. Adding and removing protective agents is difficult .

♦ Even so, some work has successfully been carried out with cornea and skin preservation.

♦ Organ preservation and re-use is still in the experimental stage .

♦ **Cryosurgery :**The use of cryogenic methods to destroy cells .

It has several advantages :

1. Cause a little bleeding in the destroyed area .
2. The volume of the tissues destroyed can be controlled .
3. Little pain because low temp. tend to desensitize the nerves .
4. Very short recovery time .
5. Successful results ware obtained in more than 90% of cases .

♦ **Treatment with Cryosurgery :**

◊ One of the first uses of Cryosurgery is in treatment of **Parkinson's disease** (shaking palsy) .This disease causes uncontrolled tremors in the arms and legs .It is possible to stop it by destroying the part of the thalamus in the brain that controls the transmission of nerve impulses to other parts of the nervous system.

◊ Other common uses of Cryosurgery are in tumors, warts.

Ink markings illustrate the desirable halo around a benign lesion.

◊ Cryosurgery is used in several types of eye surgery:

1. In **retina detachment**, a cooled tip is applied to the outside of the eye ball in the vicinity of the detachment a reaction occurs that acts to weld the retina to the wall of the eye boll.

2. The **cryosurgical extract of the lens**, in this procedure the cold probe is touched to the front of the lens. The probe sticks to the lens making the lens easy to remove.