Karbala University-College of veterinary medicine

Medical Physics-Lecture (4)

Heat and cold in medicine

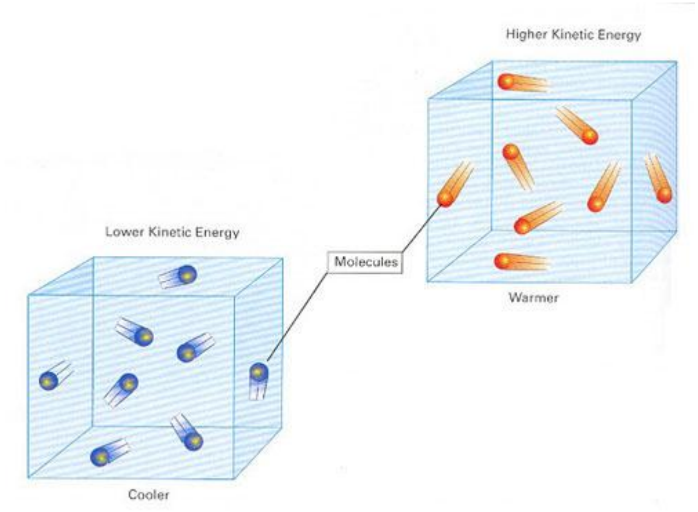
Heat and Cold in Medicine

1. Physical basis of heat and temperature

As molecules of all materials are moving so they have kinetic energy. The average kinetic energy of an ideal gas can be shown to be directly proportional with temperature. The same thing is for liquids and solids. The movement of gas molecules are freer than liquid and liquid molecules are more free than solid. An increase of temperature of any material means an increase in the energy of molecules of that material. In order to increase the temperature of a gas it is necessary to increase the average kinetic energy of its molecules by putting the gas in contact with a flame. the energy transferred from the flame to the gas causing temperature rise is called heat.

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

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



2. Thermometry and temperature scales

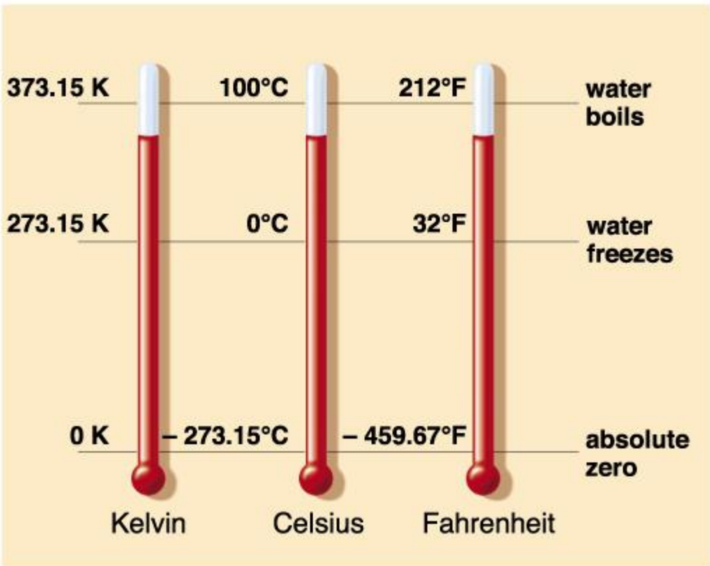
Temperature is difficult to measure directly, so we measure it indirectly by measuring one of many physical properties that change with temperature.

There are three temperature scales:

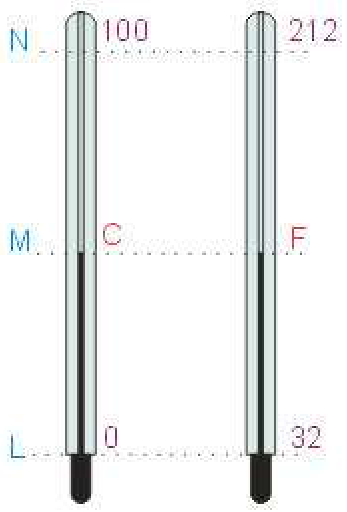
1-Fahrenheit scale (°F): in this scale the freezing temperature of water is 32°F and the boiling point is 212°F, and normal body temperature is about 98.6°F. Fahrenheit devised (أخترع) this scale in 1724 so that 100°F would represent the normal body temperature and 0°F would represent the coldest temperature man could then produce (by mixing ice and salt).

2-The Celsius (°C): the freezing point of water is 0°C and the boiling point is 100°C, and the normal body temperature is about 37°C.

3-The Kelvin scale (°K): or the absolute scale, this scale has the same divisions as the Celsius but takes the 0° K at the absolute zero which is -273.15°C. This temperature scale is not used in medicine.



To change °C to °F: [°C= (°F-32) 5/9] or [°F=°C (9/5) +32]



أشتقاق العلاقة السابقة بين الدرجة السيليزية و الفهرنهايتية:

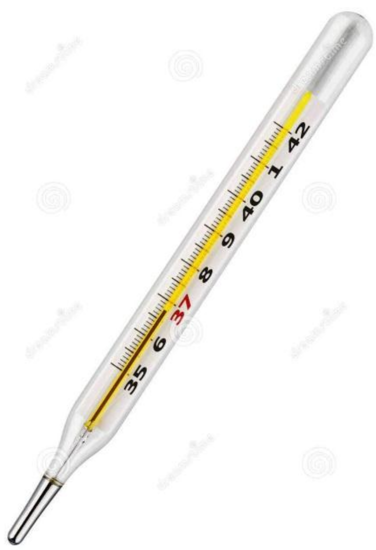
$$\frac{ML}{NL} = \frac{C-0}{100-0} = \frac{F-32}{212-32}$$

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

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

You can estimate someone else's body temperature by placing your hand on his forehead but this is not very scientific. We should use a special device to measure the body temperature. There are different types of temperature-sensitive device:

1. Glass-liquid 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 this thermometer is that an increase in temperature of different material usually causes them to expand different amount. When the thermometer is heated the liquid inside will expand more than the glass causing the liquid to rise in the capillary. The expansion of the liquid in a thermometer is not large- 1 cm^3 of mercury increases in volume by only 1.8% in going from 0 to 100°C. In order to show this expansion, thermometers are designed so that the mercury is forced to rise from the bulb in a capillary tube 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 difficult to read it was not designed for visibility. Two things increase the visibility of the capillary: the glass case acts as a magnifying glass and an opaque white backing is used.

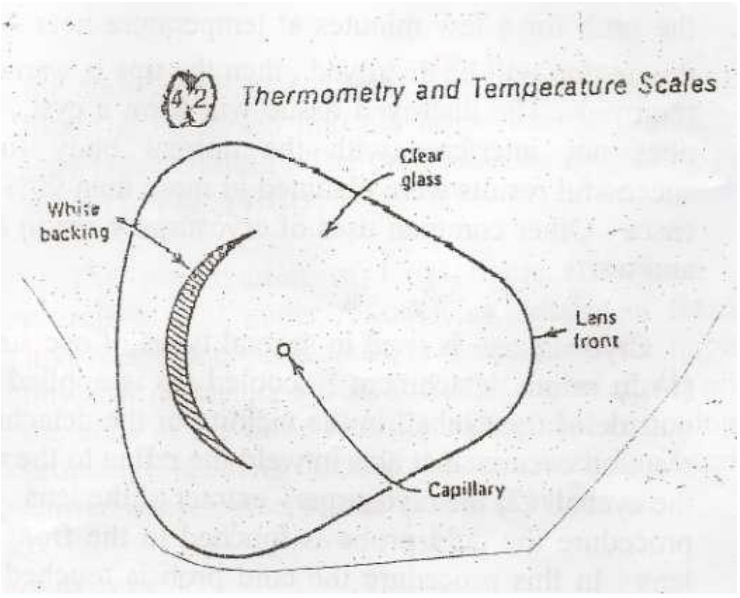
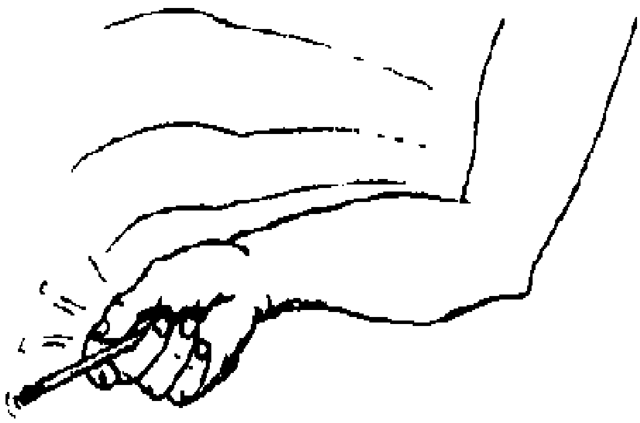


Figure: cross-section of the stem of a clinical thermometer.

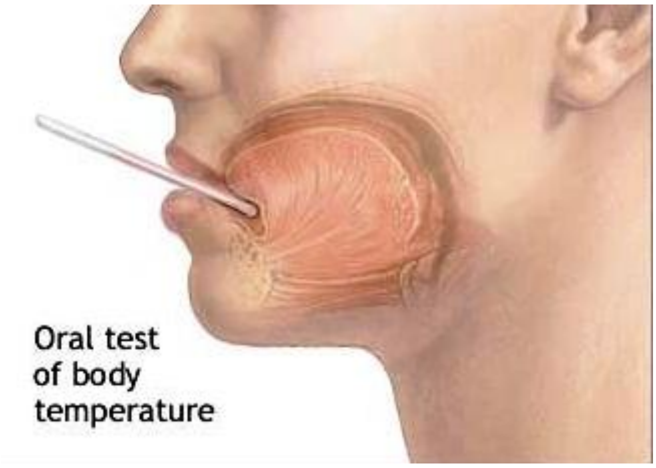
The capillary of a fever thermometer has a restriction just above the bulb making the mercury not to return if the thermometer is exposed to low temperature when it is removed outside the mouth. When the thermometer is taken from the mouth it shows the maximum temperature it reached underneath the tongue. In order to return the mercury to the bulb, the thermometer is moved rapidly with proper snap of the wrist.

لا حظ هذه الصورة : يجب رج المحرار قبل استعماله لاعادة الزئبق داخل ال (bulb) بسبب وجود تضيق يمنع رجوع الزئبق من الانبوب الشعري بسهولة. و فائدة هذا التضيق هو ثبات مستوى الزئبق عند تعرضه للبرودة خارج الفم و بالتالي تكون قراءة المحرار أكثر دقة.



The temperature is usually taken underneath the tongue or in the rectum. Since the thermometer is usually considerably colder than the body it lowers the temperature of the surrounding tissue when it is first inserted. It takes several minutes before the temperature of the tissues rises to the original value.

- عند وضع المحرار داخل الفم يجب غلق الفم جيدا و يترك المحرار مدة دقيقة الى دقيقتين على الاقل للحصول على قراءة دقيقة.



2. Thermistor:

A thermistor is a special resistor that changes its resistance rapidly with temperature (5%/^{0}C). Figure 4.3 shows a bridge circuit with a thermistor in one of the legs. Initially the four resisters shown are, that is, the bridge is balanced. By symmetry, the voltages at each end of the meter are equal and no current flows through the meter. A temperature change causes the thermistor resistance to change. This unbalances the bridge. The voltages at each end of the meter become unequal, causing a current to flow through the meter, and the resulting meter deflection can be calibrated for temperature. Thermistor are used quite often in medicine because of their sensitivity, with a thermistor it is easy to measure temperature changes of 0.01^{0}C.

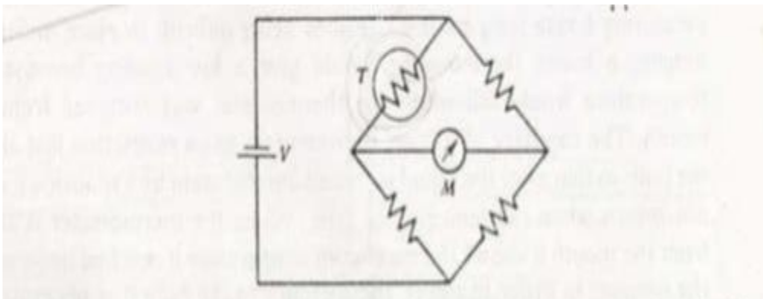


Figure 4.3. The resistance of a thermistor *T* can be measured with a simple bridge circuit to determine the temperature. The meter *M* can be calibrated directly in degrees celsius or fahrenheit.

Thermistors are occasionally placed in the nose to monitor the breathing rate of patients by showing the temperature change between

inspired cool air and expired warm air. An instrument of this type is called pneumograph.

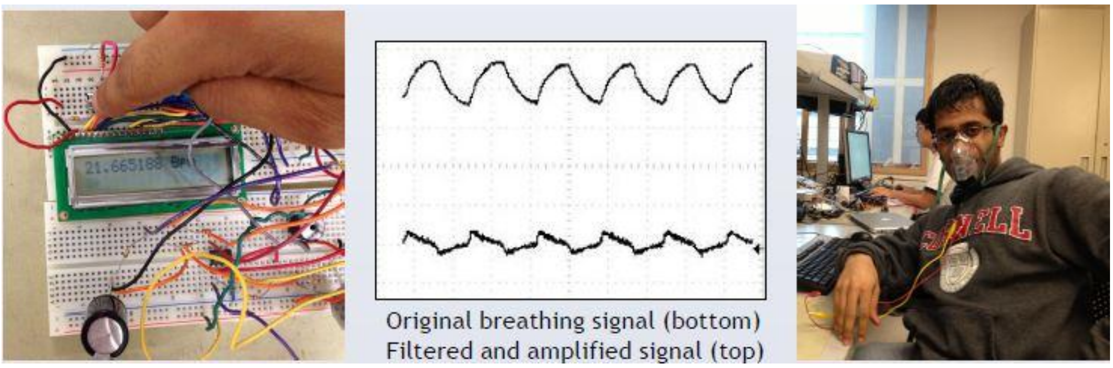


Figure: Thermistor-Based Respiration Monitor

3. Thermocouple:

A thermocouple consists of two junctions of two different metals. If the two junctions are at different temperature, a voltage is produced that depends on the temperature difference. Usually one of the junctions is kept at a reference temperature such as in an ice-water bath.

The copper-constantan thermocouple can be used to measure temperature from -190 to 300°C. For 100°C temperature difference, the voltage produced is only about 0.004V.

Thermocouple can be made small enough to measure the temperature of individual cells.

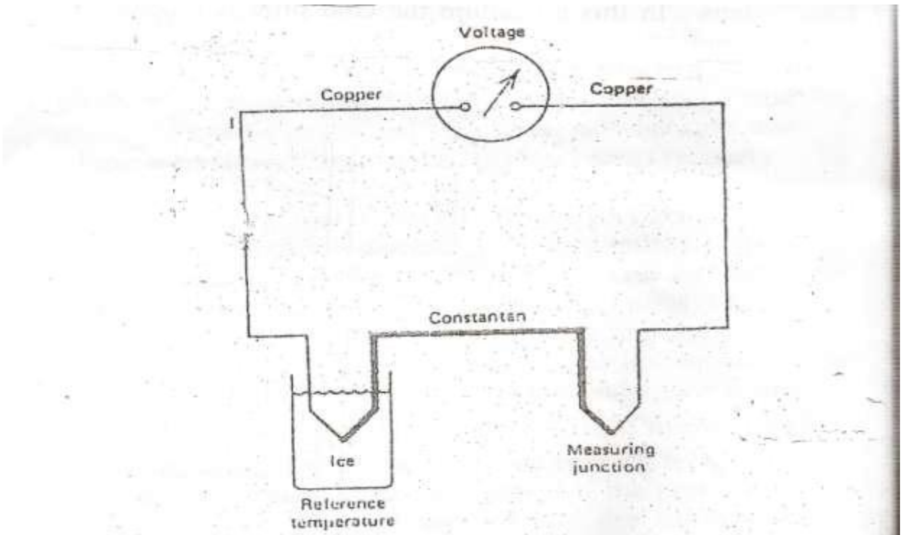


Figure 4.4. Schematic diagram of a thermocouple. The voltage is measure potentiometer.

3. Thermograph-mapping the body's temperature:

Measurement of body surface temperature indicates that the surface temperature varies from point to point depending upon external physical factors and internal metabolic and circulatory processes near the skin- blood flow near the skin is dominant factor. Since variations in these internal processes may be symptomatic (دال على،عرض)of abnormal conditions, many researchers have attempted to accurately measure the surface temperature of the body and relate it to pathologic conditions(حالات مرضية).

All objects regardless of their temperature emit radiation. If the temperature is sufficiently high (red hot), the radiation is visible. At body temperature the emitted radiation is in the far infrared (IR) region at wavelengths much longer than those observable by the human eye.

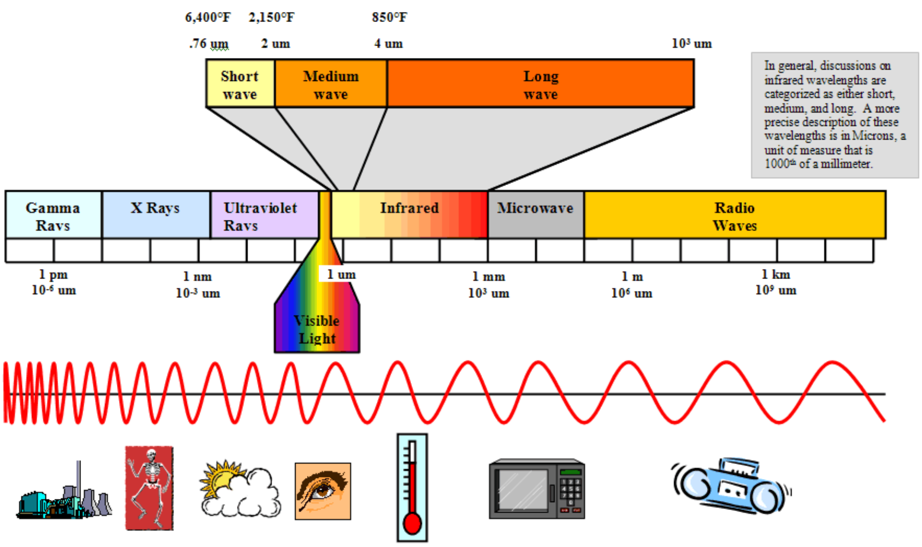


Figure: electromagnetic spectrum showing the infrared region

We use the Stefan-Boltzmann law to describe the radiation emitted by the body.

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

Where

W: is the total radiative power per surface area,

T: is the absolute temperature of the body

e: is the emissivity depends upon the emitter material and its temperature. For radiation from body e is almost 1,

σ: is the Stefan –Boltzmann constant=5.7×10^{-12} W/cm^2 °K^4

Example:

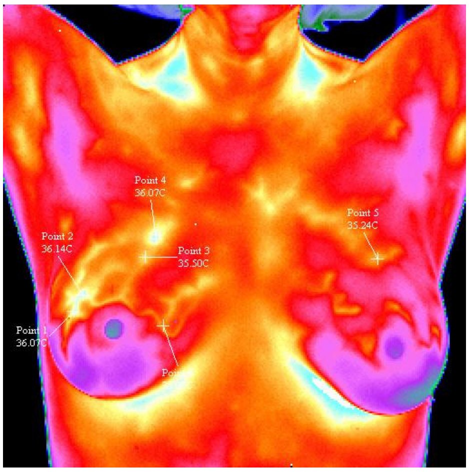
a) What is the power radiated per square centimeters from skin at a temperature of 306°K?

$W= e\,\sigma T^4= (5.7\times10^{-12})\,(306)^4= 0.05\ W/cm^2$

b) What is the power radiated from a nude body 1.75 m^2 (1.75 × 10^4 cm^2) in area?

$W= (0.05)\,(1.75\times10^4\ cm^2) = 875\ W$

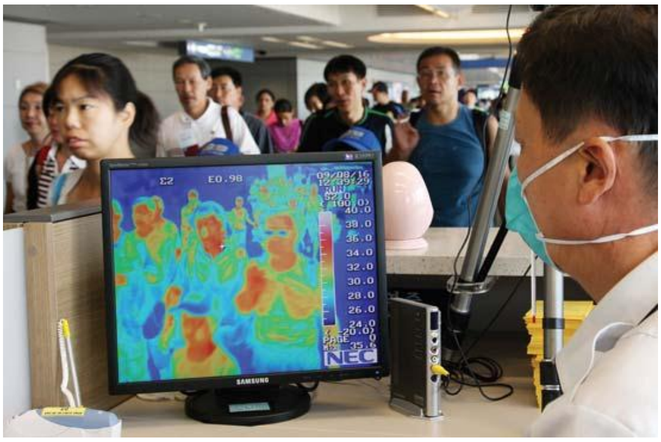
It was found that the most breast cancers has 1°C higher than that the other healthy side (since the tumor has high blood flow) and it was thought that breast thermogram will be a good procedure for early breast cancer detection. Unfortunately, the results of using thermography for breast cancer have been disappointing. If 1000 random women of age 45 are studied, about one-third will have abnormal thermograms of the breast, although less than 1% of them have cancer.



Right breast cancer

X-ray mammography has shown much more successful results to detect breast tumor of less than 1cm in diameter, but they present a radiation hazard to the body.

During the attack of swine flu (انفلونزا الخنازير), some airports use thermal imaging cameras to see whether travelers have fevers, without having to stick thermometers in their mouths. These cameras were very sensitive, measuring temperatures down to a fraction of a degree Fahrenheit.



Thermal camera in the airport

4. Heat therapy:

Heat was recognized as therapeutic agent several thousand years ago. It has two primary therapeutic effects:

a) An increase in metabolism resulting in relaxation of the blood capillaries (vasodilation).

b) An increase in blood flow as blood moves in to cool down the heated area.

The vasodilation and increased blood flow are beneficial to the damaged tissue. In this section we briefly consider the physical methods of producing heat in the body. These methods are conductive heating, infrared (IR) radiant heating, radio wave heating (diathermy), and ultrasonic wave heating (ultrasonic diathermy).

1- The conductive method:

This 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. The total of heat transferred depends on the temperature difference, the time of contact, the area of

contact, and the thermal conductivity of the materials. This can be done by several ways such as hot bath, hot packs, and electric heating pad. This will lead to local surface heating. Conductive heating is used in the treatment of arthritis (التهاب المفاصل), strains (تمزق), and back pain.

2-Radiant heat (IR):

This is the same form of heat we feel from the sun or from an open flame. Man-made sources of radiant heat are glowing wire coils and 250 Watts incandescent (متوهج) lamps. The wavelengths used are between (800-40000nm). The waves penetrate about 3mm in the skin. It can be produced. An excessive exposure can cause reddening and sometimes swelling (edema). longer exposure can cause skin browning or hardening. It is considered to be more effective than conductive heating because it can penetrate deeper.

Effect of prolong exposure to heat (IR)

3-Diathermy:

Short wave diathermy utilizes electromagnetic waves in radio range (wavelength≈10m), microwave diathermy uses waves in radar range (wavelength≈12cm).

Heat from diathermy penetrates deeper into the body than radiant and conductive heat, thus it is useful for internal heating and has been used in the treatment of inflammation of skeleton, bursitis, and neuralgia.

Two different methods are used for transferring the electromagnetic energy into the body in short-wave diathermy:

A- The part of the body to be treated is placed between two metal plates (electrodes) connected with high frequency power supply. The body tissue between the plates acts like an electrolytic solution. The charged particles of the tissue will be attracted to one plate and then the other depending upon the sign of the alternating voltage on the plates. This movement of charges will produce resistive (joule) heating.

B- The second method of transferring short wave energy into the body is magnetic induction. In induction diathermy, either a coil is placed around the region to be treated (fig 4.10) or a (pancake) coil is placed near that part of the body. The alternating current in the coil produces an alternating magnetic field in the tissue; consequently alternating (eddy) currents are induced, producing joule heating in the region being treated.

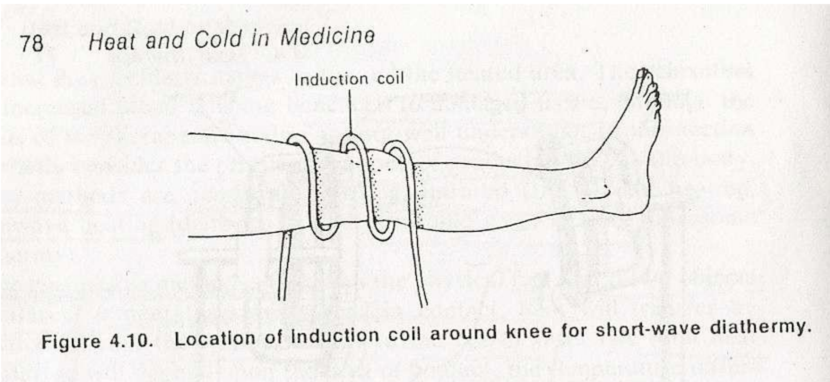


Figure 4.10. Location of induction coil around knee for short-wave diathermy.

Short wave diathermy can penetrate deep into tissues. It can be used in relieving muscle spasms(تشنّج), pain from protruded intervertebral disc, joints with minimal soft tissue coverage such as knee and elbow.

Microwave diathermy, another form of electromagnetic energy, is usually easier to apply than short wave diathermy. The microwaves are produced in a special tube called a (magnetron) and are then emitted from the applicator (antenna) which can be placed several inches from the region to be treated. The microwaves can penetrate deeper into the tissues causing deep heating. Microwave diathermy is used in the treatment of fractures, sprains, strains, bursitis, injuries to tendons and arthritis(إلتهاب المفاصل).

4-Ultrasonic waves:

These waves are completely different from electromagnetic waves. they produce mechanical vibration inside tissue. They are the same as the sound waves but they have much higher frequencies about 1MHz. In ultrasonic diathermy, power levels of several watts per square centimeter are usually used and the sound source is directly in contact with body. As the ultrasonic waves move through the body, the particles in the tissues move back and forth. The movement is similar to a micromassage and results in heating of the tissues. Ultrasonic heating is used for reliving tightness(تصلب) and scarring (تليف) occurring in joint disease. It greatly aids joint that have limited motion. It can dispose more heat in bones, as bones are better absorber for ultrasonic energy than soft tissue.

- Heat therapy has also been used in cancer treatment in combination with radiotherapy. The tumor is heated about 42°C for approximately 30 minutes, and the radiation treatment is given after the heat treatment.

5. Use of cold in medicine:

Cryogenics is the science and technology of producing and using very low temperature, it is used in biology and medicine and called cryobiology.

Low temperature can be produced by liquefying gases (تسييل الغازات). It was succeeded to produce liquid air (-196 °C) in 1877 and liquid helium (-269°C) in 1908. For liquid nitrogen it is (-196°C).These cold liquids have many medical and biological advantages. The storage of liquefied gases is rather difficult because it can absorb heat rapidly from the environment by conduction (توصيل), convection (حمل), and radiation (أشعاع). A special container has been designed by Dewar (1892) and named after him. This container is made of two cylindrical bottles which are made of glass or stainless steel one inside the other and a vacuum in between. This can prevent heat transfer by conduction and convection. The sides of the two bottles are silvered so that radiation striking the surface is reflected rather than absorbed; so they are good reflector and poor radiator for heat. The contact between them is made only at the top to minimize heat losses by conduction.

The container resembles the familiar thermos bottle used to store hot and cold drinks.

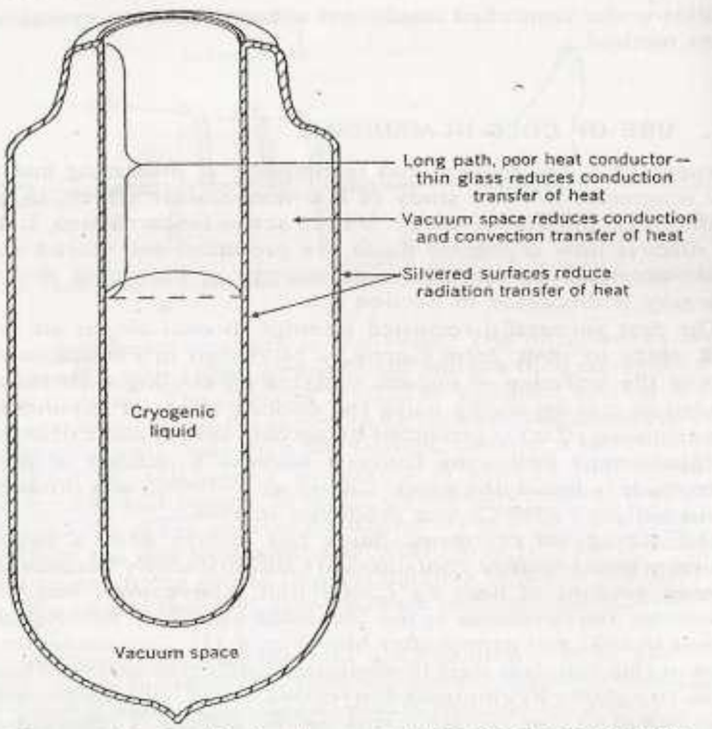


Figure 4.11. Details of a dewar container for cryogenic fluids.

Low temperatures have been used in medicine for long term preservation (حفظ) of blood, sperm, bone marrow and tissues.

Much interest has been aroused by the idea of using cryogenic methods to cool the body into a state of suspended animation (حياة معلقة) so it can pass time without aging. This science is called cryonics. One goal of cryonics is to preserve people with fatal diseases at a low temperature with the hope that in the future they could be revived (ينعشون) and their diseases cured.

Some successful work has been done with cooling hamsters(قوارض) down to (-5°C) by freezing 50 to60 % of the water in their bodies, and then reviving them. However, the present technology excludes similar cooling of smoothing as complex as man. Some simpler human biological systems such as blood, semen and tissue have successfully been cooled, stored and revived. It has been found that for long-term survival, the tissues should be stored at very low temperatures. Since the biochemical and physical processes that sustain life are temperature dependent, lowering the temperature reduces the rates of the processes. Preservation is much better at the temperature of liquid nitrogen (-196 °C) than at the temperature of solid carbon dioxide (-79°C).

Another important finding involves the freeze-thaw cycle (دورة التجميد و التذويب). Survival rate is more dependent on the cooling rate during the freezing cycle than on the warming rate during the thawing cycle.

Measurement of the survival of two biomaterials as a function of cooling rate freezing and thawing the materials gives the results shown is figure below.

There is no unique cooling rate that will ensure cell survival for all materials. This puts a severe limitation on preserving biomaterials composed of many different cell types.

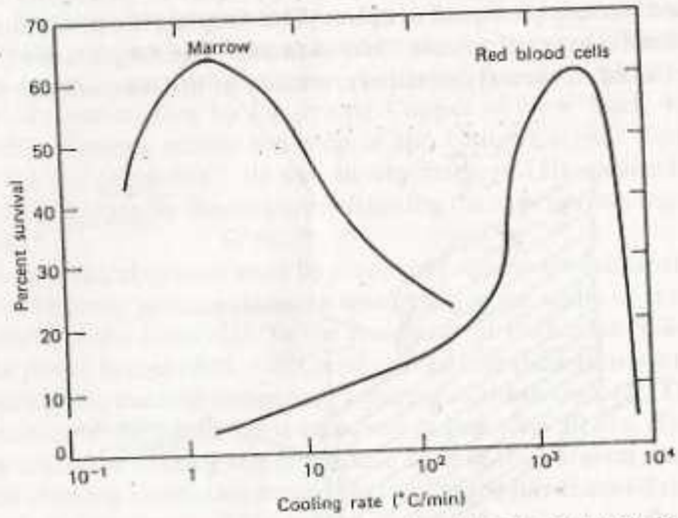


Figure 4.12. Survival behavior as a function of cooling rate for red blood cells and bone marrow. (Adapted from P. Mazur, S.P. Leibo, J. Farrant, E.H.Y. Chu, M.G. Hanna, and L.H. Smith, in G.E.W. Wohlstenholme and M. O'Connor (Eds.), *The Frozen Cell*, A Ciba Foundation Symposium, J. and A. Churchill, London, 1970, p. 82. The red blood cell curve is redrawn from data of G. Rapatz, J.J. Sullivan, and B. Luyet, *Cryobiology*, 5, 1968, pp. 18–25.)

Some protective agents added such as glycerol improve the cell survival. Sometimes and especially in blood these materials present problems because the removal of them from the blood is very difficult.

The conventional non-cryogenic method of blood storage involves mixing whole blood with an anticoagulant (مضاد تخثر) and storing it at 4°C. About 1% of the red blood cells hemolyze (break) each day, so the blood will not be suitable for use after 21 days. For rare blood types this storage time is insufficient making maintaining an adequate supply is difficult. Other procedures are used.

Blood can be stored for much longer time if it is frozen rapidly. There are two ways to freeze the blood to (-196°C) in liquid nitrogen:

1) Thin walled containers: it is made of highly heat conductive material. The container with thin metal walls is constructed so that the blood volume between the walls is small. After it is filled with blood it is quickly inserted into a liquid nitrogen bath.

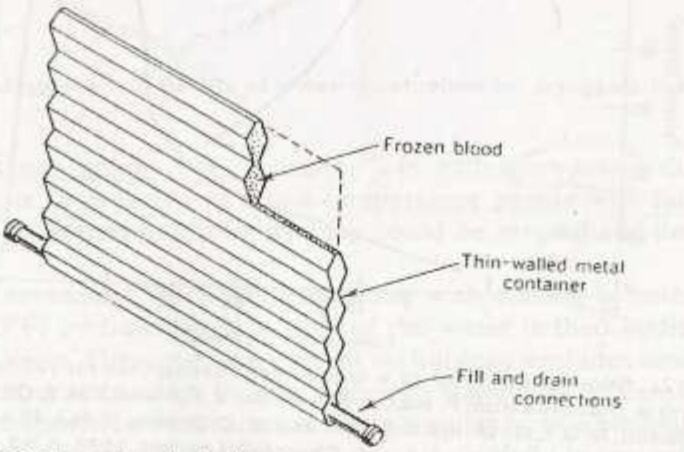


Figure 4.13. Container for whole-blood freezing at cryogenic temperatures. (From *Cryogenic Systems* by R. Barron. Copyright © 1966, McGraw-Hill, New York. Used with permission of McGraw-Hill Book Company.)

2) Blood-sand method: the blood is sprayed onto a liquid nitrogen surface and freezes into small droplets. The droplets are about the size of grains of sand-hence the name blood-sand. The droplets are collected and then stored in special containers, usually at the temperature of liquid nitrogen.

The preservation of large tissue like bone, muscles is still under searches as storage of them involves some problems:

1- Because of its large physical dimensions it is difficult to cool down all the cells at the same rate.

2- Adding and removing protective agents is difficult.

Some work has been carried out to preserve cornea and skin.

6. Cryosurgery:

The cryogenic methods are also used to destroy cells, this application is called cryosurgery. It has several advantages:

1-There is little bleeding in the destroyed area.

2-The volume of tissue destroyed can be controlled by the temperature of the cryosurgical probe

3-There is little pain because low temperatures desensitize (تخدر) the nerves.

Cryosurgery is used in the treatment of tumors (الاورام), warts (فالول بالعامية) and other diseases.

Cryosurgery for warts