Karbala University-College of Dentistry
Medical Physics-Lecture (4)

Heat and cold in medicine

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. then relate the physical property to temperature by a suitable calibration.

In the United States, the most common temperature scale is the Fahrenheit (^oF) scale. Water freezes at 32^oF and boils at 212^oF, and the normal body temperature (rectal) is about 98.6^oF. Fahrenheit devised this scale in 1724 . Most scientists in the United States use the **Celsius** (**^oC**) **scale** (**formerly called centigrade scale**), which is in common use throughout most of the world. Water freezes at **0^oC** and boils at **100^oC**, and the normal body temperature (**rectal**) is about **37^oC**.

Another important temperature scale used for scientific work is the **Kelvin** (**^oK**), or absolute scale, <u>which has the same degree intervals as the **Celsius scale**</u>; **$0\ ^oK$** (**absolute zero**) is **$-273.15\ ^oC$**. On the absolute scale, water freezes at **273.15^oK** and boils at **373.15^oK**, and the normal body temperature (**rectal**) is about **310^oK**. This temperature scale is not used in medicine.

<u>**The relationships between the different temperature scales are: -**</u>

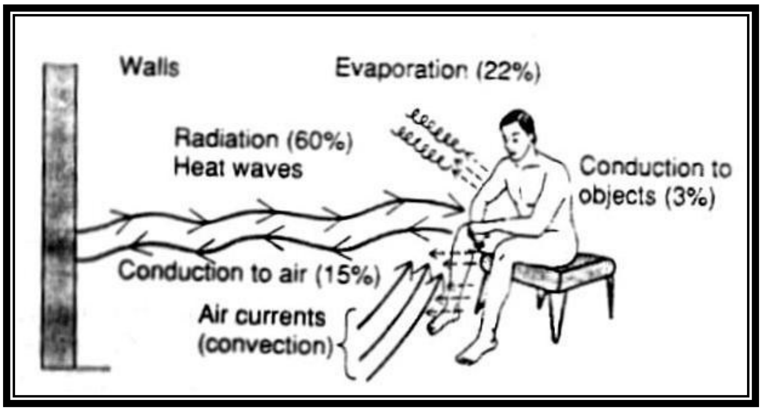
$$^oK = 273.15 + {^oC}$$

$$^oC = (5/9)\times({^oF} - 32)$$

$$^oF = (9/5)\ {^oC} + 32$$

How does Heat Travel?

Heat can be transferred from one place to another by four methods: -
Conduction.
Convection.
Evaporation.
Radiation.



The method used to transfer heat is usually the one that is the most efficient. If there is a temperature difference in a system, heat will always move from higher to lower temperatures.

Heat Verses Temperature

We have all noticed that when you heat something up, its temperature rises. Heat and temperature are related to each other, but are different concepts.

Heat: Is the total energy of molecular motion in a substance.

Temperature: The molecules move means that they have kinetic energy and this kinetic energy is related to the temperature.

Heat energy depends on the speed of the particles, the number of the particles (the size or mass), and the type of particles in an object.

Temperature does not depend on the size or type of object. *For example*, the temperature of a small cup of water might be the same as the temperature of a large tub of water, but the tub of water has more heat because it has more water and thus more total thermal energy.

Heat Detecting

There are many ways to detect heat. The method chosen often depends on what heat source we are trying to measure. *For example*, the way we detect the heat in the air is different from how we detect heat from a fire or heat from objects in deep space. We have all felt various levels of heat. Our skin is a good detector of heat and

we interpret the average molecular motion within an object as a feeling that the object is hot or cold. However, our skin does not always give us consistent measurements of heat energy. For this, we need special instruments, which can accurately measure temperature, like a thermometer.

The Mercury Thermometer (glass liquid thermometer)

The most common way to measure temperature is with a glass fever thermometer containing mercury or alcohol(figure 1). The principle behind this thermometer is that an increase in the temperature of different materials usually causes them to expand different amounts. In a **fever thermometer**, a temperature increase causes the alcohol or mercury to expand more than the glass and thus produces an increase in the level of the liquid. The expansion of the liquid in a thermometer is not large " $1cm^3$ of mercury increases in volume by only 1.8% in going from 0 to 100 ^0C "

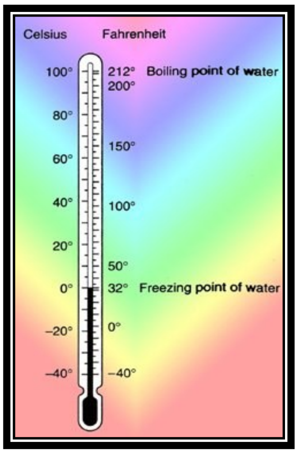
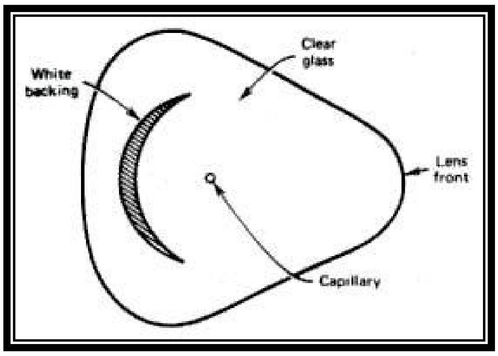


Figure (1): Scale of temperature in a mercury thermometer.



Figure(2) :Cross section of the stem of a clinical thermometer.

Two things increase the visibility of the capillary: -

1. The glass case acts as a magnifying glass.
2. An opaque white backing is used (see figure 2).

In order to return the mercury to the bulb it is necessary to take advantage of some elementary physics involving centrifugal forces. A number of temperature sensitive devices other than the glass liquid thermometer are used in medicine. Two of them are thermistor and thermocouple.

Thermistor

Thermistor is a special resistor that changes its resistance rapidly with temperature (~ 5%/ ^{o}C). figure 3 shows a bridge circuit with a thermistor in one of the legs. Initially the for resistors shown are equal, that is the bridge is balanced. A temperature change caused the thermistor resistance to change. This unbalances, the voltages at each end of the meter become unequal, caused a current to flow through the meter, and the resulting meter deflection can be calibrated for temperature. Thermistors 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 . The meter of figure 3 can be located some distance from the patient, for example at a nursing station, this permits easy monitoring.

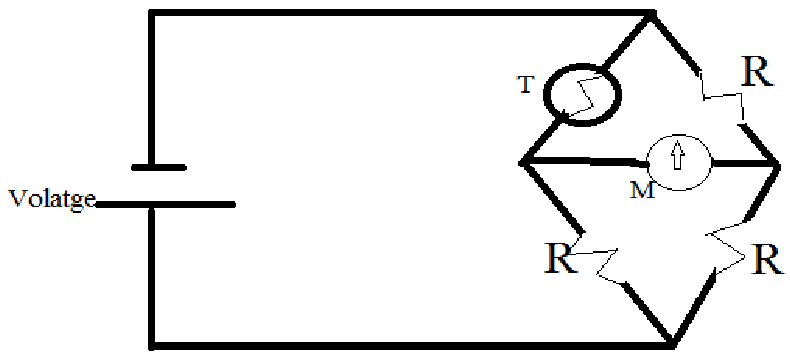


Figure 3: the resistance of a thermistor T can be measured with a simple bridge circuit to determine the temperature. The meter M can be calibrated directly in a degrees Celsius or Fahrenheit.

The Thermocouple

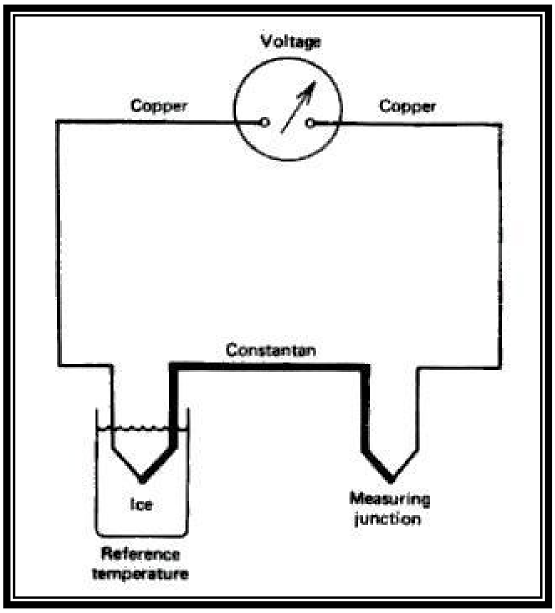


Figure (4) : Schematic diagram of a thermocouple.

A **thermocouple** consists of two junctions of two different metals. If the two junctions are at different temperatures, 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 shown in figure (4) can be used to measure temperatures from (**-190 to 300 °C**). **Thermocouples** can be made small enough to measure the temperature of individual cells.

Core Temperature and Skin Temperature

The temperature of the deep tissues of the body "core" remains almost exactly constant, within ±1°F (±0.6°C). The skin temperature, in contrast(بالمقارنة) to the core temperature, rises and fills with the temperature of the surroundings. The basic equation describing the radiation emitted by a body was given by Max Planck in 1901. For our purposes the Stefan-Boltzmann law for the total radiate power per surface area *W* is more useful. It is:

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

Where T is the absolute temperature , e is the emissivity, which depends upon the emitter material and its temperature, and σ is Stefan-Boltzmann constant 5.7×10^{-12} $w/cm^2\ K^4$. For radiation from the body **e** is almost 1

Example:

a. What is the power radiated per square centimeter from skin at a temperature of 33 ^{0}C ?

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

W= 5.7× 10^{-12} $(33+273)^4$

W= 0.05w/cm^2

b. What is the power radiated from the a nude body 1.75m^2 in area?

W= 0.05w/cm^2×1.75×$10^4$$cm^2$ =875watt

The radiate power received from the surrounding walls at 293K (~20 ^{0}C) would be about 735w ,for a net loss of 140watt.

Normally most of the body is clothe , the loss is considerably smaller than 140w, but it is still significant.

Heat Therapy

Two primary therapeutic effects take place in a heated area: there is an increase in metabolism resulting in a relaxation of the capillary system and there an increase in blood flow moves in to cool the heated area.

physical methods of producing heat in the body. These methods are **conductive heating**, **infrared (IR) heating**, **short-wave diathermy**, **radio wave heating (diathermy)** and **ultrasonic wave heating (ultrasonic diathermy)**

The **conductive method** is based on the physical fact that if two objects at different temperatures are placed in contact, heat will transfer by conduction from the warmer object to the cooler one. The total heat transferred will depend upon the area of contact, the temperature difference, the time of contact and the thermal conductivity of the materials.

Hot baths, hot packs, electric heating pads and occasionally hot paraffin applied to the skin heat the body by conduction. Conductive heating is used in treating conditions such as arthritis, neuritis, sprains and strains , contusions, sinusitis and back pain.

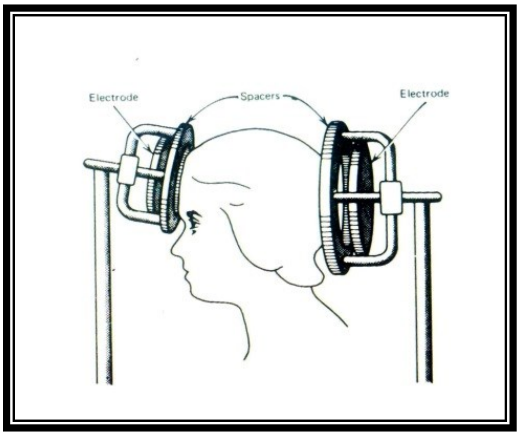
Radiant (IR) heat is also used for surface heating of the body. This is the same from the heat we feel from the sun or from an open flame. The IR wavelengths are between 800 and 40000nm. The waves penetrate the skin about 3mm. Radioactive heating is generally used for the same conditions as conductive heating, but it is considered to be more effective because the heat penetrates deeper.

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

In ***short-wave diathermy*** two methods are used to get the electromagnetic energy into the body: -

1. The capacitance method.
2. The inductance method.

In both methods the body part to be heated becomes a part of a resonant electrical circuit. A simple resonant circuit consists of a capacitor and an inductor. Electrical energy from a power supply flows back and forth between the capacitor and the inductor, thus providing an alternating electric field.
In the capacitance method of short-wave diathermy, the tissue to be heated is placed between two capacitor plates that have an oscillating electric field across them (see figure 5). The changing electric field forces the ions in the tissue to move back and forth; they thus acquire kinetic energy, part of which is dissipated when the ions collide with molecules in the tissue. The heat produced when the energy is dissipated depends approximately on the square of the current times a constant determine by the tissue properties. This type of energy loss is called joule (resistive) heating.



Figure(5):Location of capacitor plates for short wave diathermy

The second method of transferring short wave energy into the body is *magnetic induction*. In induction diathermy, either a coil is placed around the body region to be treated or a "pancake" coil is placed near the part of the body (see figure 6). The alternating current in the coil results in an alternating magnetic field in the tissues. Consequently alternating (eddy) currents are induced, producing joule heating in the body region being treated. Short-wave diathermy is used in the treatment of bursitis, arthritis, traumatic injuries, strains, and sprains.

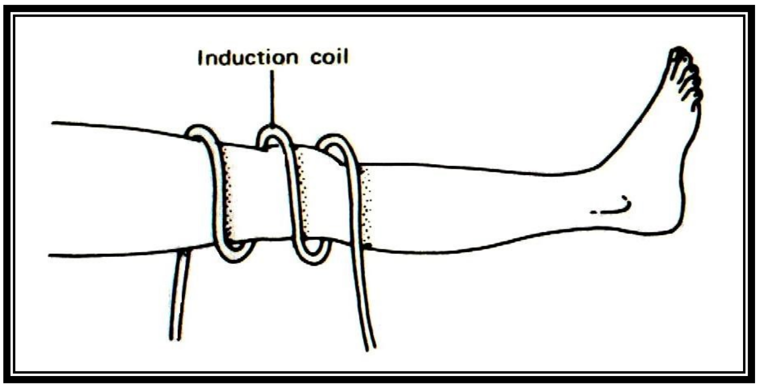


Figure (6):Location of induction coil around knee for short wave diathermy.

Microwave diathermy is fundamentally different from short-wave diathermy. In short-wave diathermy the tissue to be heated is part of a resonant circuit, while in microwave diathermy the tissue absorbs electromagnetic waves that are incident upon it. The radiation is produced in a special high-frequency tube called a magnetron. The output of the magnetron is fed to an antenna, and the antenna emits the microwaves. A frequency of 2450MHz with a wavelength of about 12cm is usually used (figure 7)

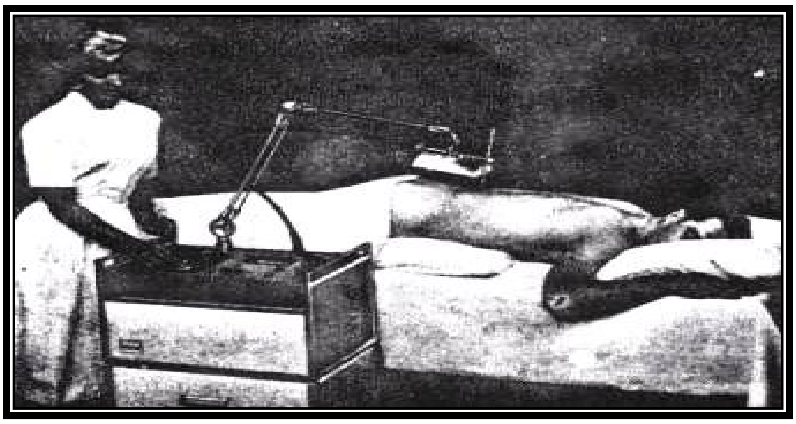


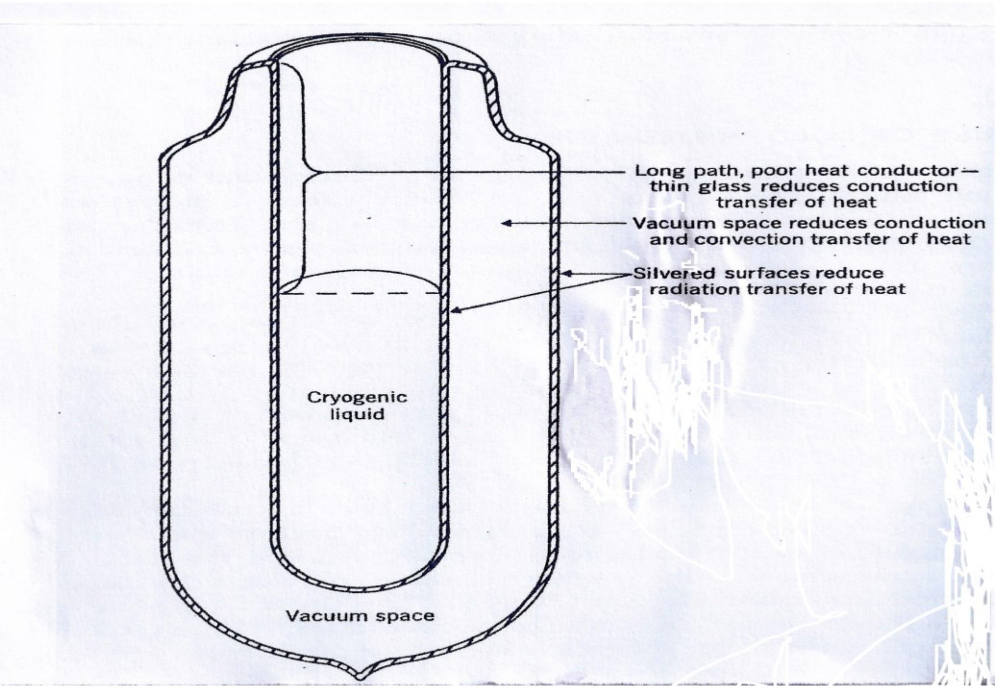
Figure (7): Microwave diathermy being applied to the lower back of a patient.

Ultrasonic waves are also used for deep heating of body tissue. These waves are completely different from the electromagnetic waves. They produce mechanical motion like audible sound waves except the frequency is much higher (usually near 1MHz). In ultrasonic diathermy, power levels of several watts per square centimeter are usually used and the sound source is directly in contact with the body. As the ultrasonic waves move through the body the particles in the tissues move back and forth. The movement is similar to a micro massage and results in heating of the

tissues. Ultrasonic heating has been found useful in relieving the tightness and scarring that often occur in joint disease. It greatly aids joints that have limited motion. It is useful for depositing heat in bones because they absorb ultrasound energy more effectively than dose soft tissue.

Use of cold in medicine:

Cryogenics is the science and technology producing and using very low temperatures. The study of low temperature effects in biology and medicine is called *cryobiology*. A significant improvement is the insulated container developed by James Dewar in 1892and named after him (figure 8).



Figure(8):

This container is made of glass or thin stainless steel to minimize conductive loss. It has a vacuum space to essentially eliminate convection losses, and the sides are silvered or polished so that radiation striking the surface is reflected rather than absorbed.

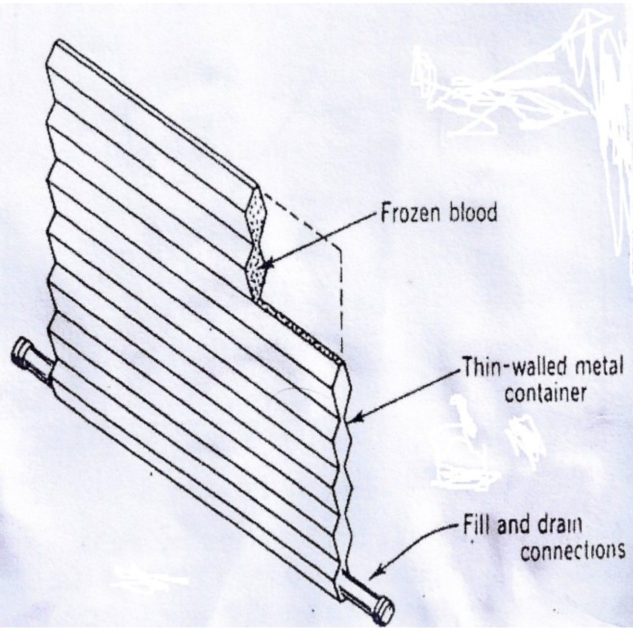
How are cryogenic methods used in medicine? Low temperature have been used for long-term preservation of blood, sperm, bone marrow and tissues. It has been found that for long-term survival, the tissues should be stored at very low temperature. Since the biochemical and physical processes that sustain life are temperature dependent, lowering the temperature reduces the rates of the processes. Preservation is much better at the temperature of liquid nitrogen (-196 ^{0}C) than

at the temperature of solid carbon dioxide (-79 ^{0}C).The conventional non-cryogenic method of blood storage involves mixing whole blood with an anticoagulant and storage it at 4 ^{0}C. About 1% of the red blood cells hemolyze (break) each day, so the blood is not usable after about 21 days.

Blood can be stored for a much time if it is rapidly frozen. Two techniques are used for this: one uses thin walled containers (figure 9),the other is the "blood-sand " method.

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 path.

In the blood-sand method, 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 container, usually at the temperature of liquid nitrogen.



Figure(9):Container for whole blood freezing at cryogenic temperature.

Review questions

1. Consider a fever thermometer that contains 0.1cm^3 of mercury, find the radius of the capillary if a 1 ^{0}C change corresponds to a level change of 0.5cm. Assume the glass does not expand.

(Ans. 0.0033 cm)

2.If the optimum cooling rate for preserving red blood cells is 2000 ^{0}C/min , how long would it take to cool red blood cells from 37 to -196 ^{0}C ?

$$at\,100C^{O} \qquad \nabla V = 1.8\times10^{-2}\,V$$
$$at\,1C^{O} \qquad \nabla V = 1.8\times10^{-4}\,V$$
$$\therefore \nabla V = 1.8\times10^{-4}\times 0.1cm^{3} = 18\times10^{-6}\,cm^{3}$$
$$\because \nabla V = \pi r^{2}h = 3.14\times r^{2}\times 0.5cm$$
$$\therefore r^{2} = 11.464\times10^{-6}\,cm^{2}$$
$$r = 0.00338cm$$

$$Cooling\quad rat = \frac{\Delta T}{\Delta t}\ ,\quad 2000\frac{C^{0}}{\min} = \frac{233C^{0}}{\Delta t} \Rightarrow \Delta t = 0.1165\min. = 7\sec$$