Heat and Cold in Medicine

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.

In the United States the most common temperature scale is the **Fahrenheit (°F)** scale. Water freezes at 32 °F and boils at 212 °F, and the normal body temperature (rectal) is about 98.6 °F.

Most scientists in the United States use the **Celsius (°C)** scale (formerly called the centigrade scale), which is in common use throughout most of the world. Water freezes at 0° C and boils at 100 °C, and the normal body temperature (rectal) is about 37 °C.

Another important temperature scale used for scientific work is the Kelvin (°k), or absolute, scale, which has the same degree intervals as the celsius scale; °0 K (absolute zero) is -273.15 °C. On the absolute scale water freezes at 273.15 °K and boils at 373.15 °K, and the normal body temperature (rectal) is about 310 °K (Fig. 1). This temperature scale is not used in medicine.

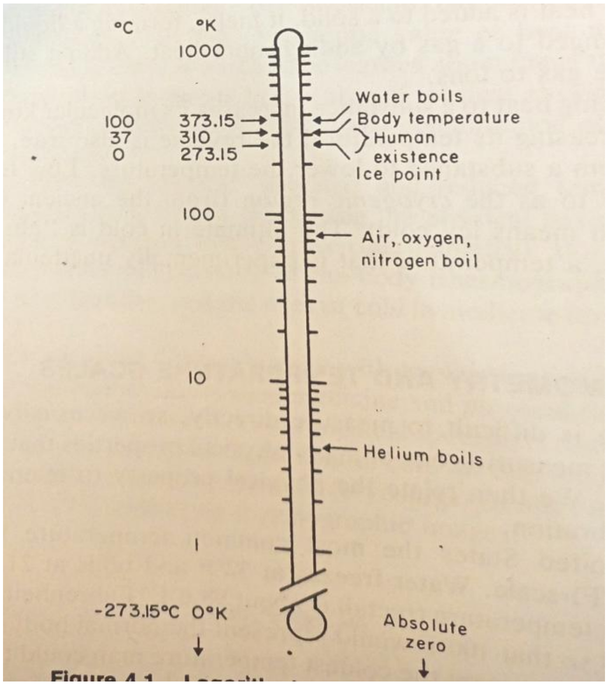

Figure 1

Thermograph

Figure 2 shows a basic thermographic unit used to measure the radiation emitted from a part of the body. Radiation from a small area of a patient (~ 5 mm in diameter) is passed by a mirror arrangement through a mechanical chopper to a detector, which is usually cooled to increase its sensitivity. The chopper changes the continuous radiation to an alternating signal so that it can be more easily amplified. The IR transparent filter removes visible light, and the detector converts the IR (or body heat) radiation to an electrical signal that proportional to the temperature of the surface from which the radiation originated. In order to give a heat picture of the total surface, a mechanical system moves the mirrors so the heat from different body areas can be detected. The position and magnitude of the radiation from each part of the patient are displayed on the cathode ray tube (CRT) of an oscilloscope; the brightness of the image is determined by the temperature, and its position on the screen corresponds to the area of the body being scanned. The CRT displays the different body temperatures as different shades of gray; the hot areas can be shown as either black or white.

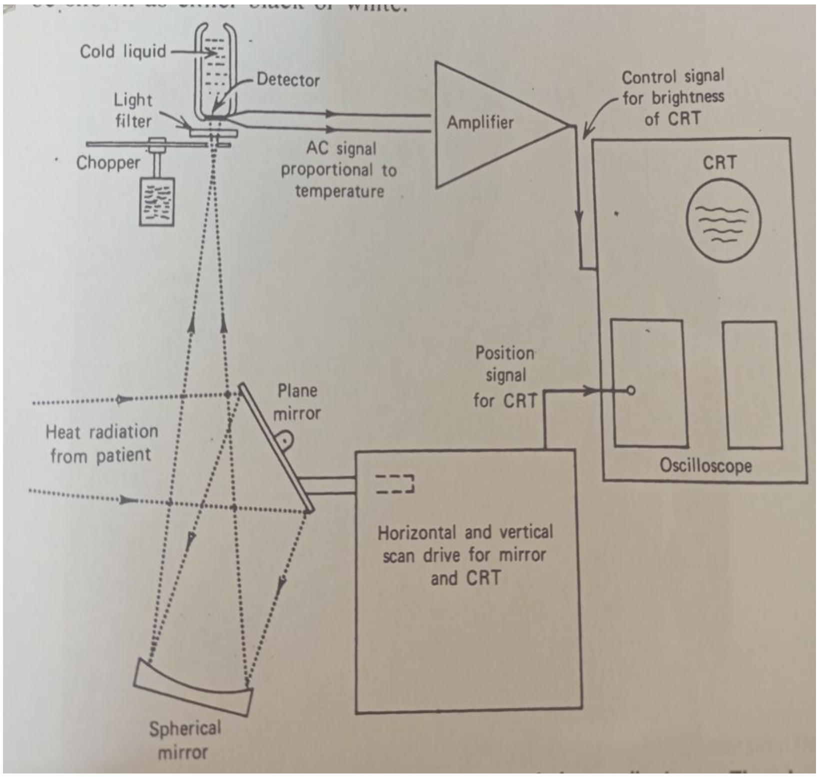

Figure 2

Cold medicine

Cryogenics is the science and technology of producing and using very low temperatures. The study of low-temperature effects in biology and medicine is called cryobiology.

How are cryogenic method used in medicine? Low temperatures have been used for long-term preservation of blood, sperm, bone marrow, and tissues.

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 $^{\circ}$C) than at the temperature of solid carbon dioxide (-79 $^{\circ}$C).

Cryosurgery

Cryogenic methods are also used to destroy cells; this application is called cryosurgery. Cryosurgery 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 sensation because low temperatures tend to desensitize the nerves.

Uses of cryosurgery:

1. In the treatment of Parkinson's disease (" shaking palsy "), a disease associated with the basal ganglion of the brain.
2. In the treatment of tumors and warts.
3. In several types of eye surgery.

Thermal conductivity

The thermal conductivity K describes how the temperature varies (ΔT) spatially due to the heat flow between different regions that are separated by a distance Δx. (Conversely, it also describes how much heat flows due to this spatial variation in temperature.) This relation is

$$\frac{1}{A}\frac{\mathrm{d}Q}{\mathrm{d}t} = -K\frac{\mathrm{d}T}{\mathrm{d}x} \sim -K\frac{\Delta T}{\Delta x} \; \ldots\ldots\ldots\ldots\ldots (1)$$

The left-hand side is the amount of heat that flows per unit area A per unit time, and is also called the heat flux. The minus sign indicates that heat flows from hotter regions to colder regions. When there is a well-defined distance $d = \Delta x$ between two regions of different but uniform temperature, say due to the thickness of clothing or an air boundary layer, we can define a heat transfer coefficient per unit area $h = K/d$ and then

$$\frac{1}{A}\frac{\mathrm{d}Q}{\mathrm{d}t} = -h\Delta T \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Heat flow due to other mechanisms, such as due to radiation, can often be expressed in terms of (1) or (2).

One consequence of thermodynamics is that engines that convert chemical energy to heat and use that heat for mechanical work, so-called heat engines, have a limited efficiency to do such useful mechanical work. An ideal heat engine has a maximum efficiency of $\epsilon = 1 - (T_c/T_h)$ when it operates at a temperature T_h and rejects heat to a lower temperature T_c (both expressed in K). Humans operate internally at about T_h= 310K and reject heat to a $T_c \simeq$ 293K ambient, so ϵ would be 5.5% if we were heat engines. This is much less than the ~25% efficiency of humans converting chemical energy into mechanical work. This is not a contradiction because we use the chemical energy directly to do mechanical work and do not produce heat in an intermediate step.

The thermal conductivity of various body tissues is given in Table 1 and that of common materials in Table 2.

Table 1. Thermophysical characteristics of body tissues and organs and other materials.

organ or tissue	thermal conductivity K (W/m-K)	specific heat c_v (MJ/m^3-K)	density (approximate) ρ (kg/m^3)
skin – very warm	2.80	3.77	1,000
skin – normal hand	0.960	3.77	1,000
skin – cold	0.335	3.77	1,000
subcutaneous pure fat	0.190	1.96	850
muscle – living	0.642	3.94	1,050
muscle – excised, fresh	0.545	3.64	1,050
bone – average	1.16	2.39	1,500
bone – compact	2.28	2.70	1,790
bone – trabecular	0.582	2.07	1,250
blood – water at 310 K	0.623	4.19	993
blood – plasma (Hct = 0%) at 310 K	0.599	4.05	1,025
blood – whole (Hct = 40%)	0.549	3.82	1,050
heart – excised, near fresh	0.586	3.94	1,060
liver – excised, near fresh	0.565	3.78	1,050
kidney – excised, near fresh	0.544	4.08	1,050
abdomen core	0.544	3.89	1,050
brain – excised, near fresh	0.528	3.86	1,050
brain – living	0.805	–	–
lung – excised, bovine	0.282	2.24	603
whole body (average)	–	4.12	1,156

Table 2. Thermophysical characteristics of materials.

material	thermal conductivity K (W/m-K)	specific heat c_v (MJ/m^3-K)	density ρ (kg/m^3)
air	0.009246	0.00119	1.18
cotton fabric at 310 K	0.0796	0.0267	160
rubber	0.156	2.41	1,200
ethanol at 310 K	0.163	1.96	789
teflon	0.399	2.20	2,180
concrete	0.934	1.93	2,310
glass, plate	1.09	1.94	2,520
ice at 249 K (−42°C)	2.21	1.76	913
sapphire (normal to c-axis) at 310 K	2–20	2.89	3,970
stainless steel	13.8	3.68	7,910
aluminum	204	2.45	2,710
silver	405	2.59	10,500
diamond, natural	2,000	1.82	3,510