Medical Physics

The First Stage

Second Term –Fourth Lecture

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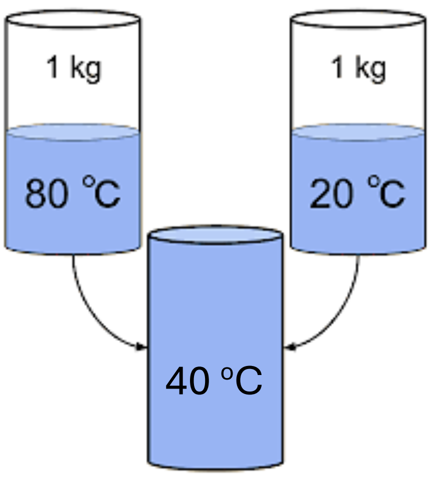
Temperature and Zeroth Low of Thermodynamic

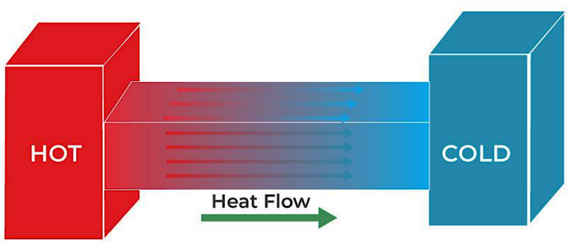
We often associate the concept of temperature with how hot or cold an object feels when we touch it. In this way, our senses provide us with a qualitative indication of temperature. Our senses, however, are unreliable and often mislead us.

For example, if you stand in bare feet with one foot on carpet and the other on an adjacent tile floor, the tile feels colder than the carpet even though both are at the same temperature. The two objects feel different because tile transfers energy by heat at a higher rate than carpet does. Your skin "measures" the rate of energy transfer by heat rather than the actual temperature. What we need is a reliable and reproducible method for measuring the relative hotness or coldness of objects rather than the rate of energy transfer. Scientists have developed a variety of thermometers for making such quantitative measurements.

If you have two objects at different initial temperatures eventually reach some intermediate temperature when placed in contact with each other.

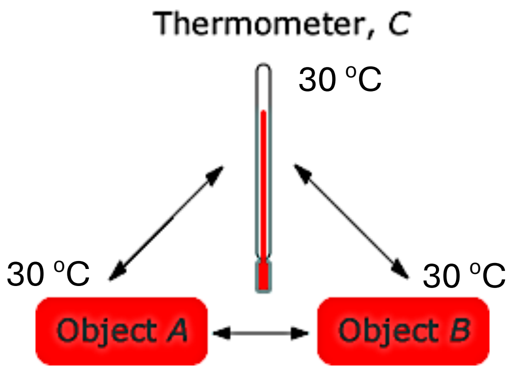
For example, when hot water and cold water are mixed in a container, energy is transferred from the hot water to the cold water and the final temperature of the mixture is somewhere between the initial hot and cold temperatures.





Imagine that two objects are placed in an insulated container such that they interact with each other but not with the environment. If the objects are at different temperatures, energy is transferred between them, even if they are initially not in physical contact with each other.

For purposes of this discussion, let's assume two objects are in thermal contact with each other if energy can be exchanged between them by these processes due to a temperature difference. Thermal equilibrium is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact.

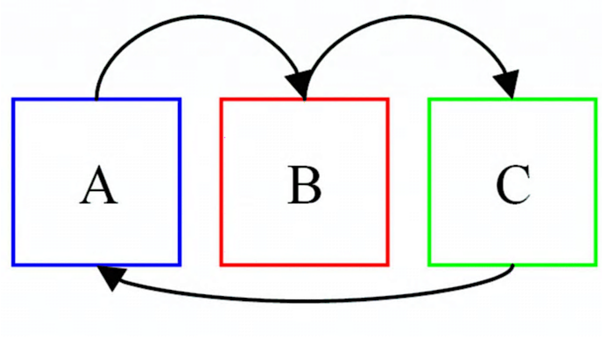


Let's consider two objects A and B, which are not in thermal contact, and a third object C, which is our thermometer. We wish to determine whether A and B are in thermal equilibrium with each other. The thermometer (object C) is first placed in thermal contact with object A until thermal equilibrium is reached as shown in last Figure.

From that moment on, the thermometer's reading remains constant and we record this reading. The thermometer is then removed from object A and placed in thermal contact with object B as shown in last Figure. The reading is again recorded after thermal equilibrium is reached. If the two readings are the same, we can conclude that object A and object B are in thermal equilibrium with each other. If they are placed in contact with each other, there is no exchange of energy between them.

We can summarize these results in a statement known as the zeroth law of thermodynamics (the law of equilibrium):

If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

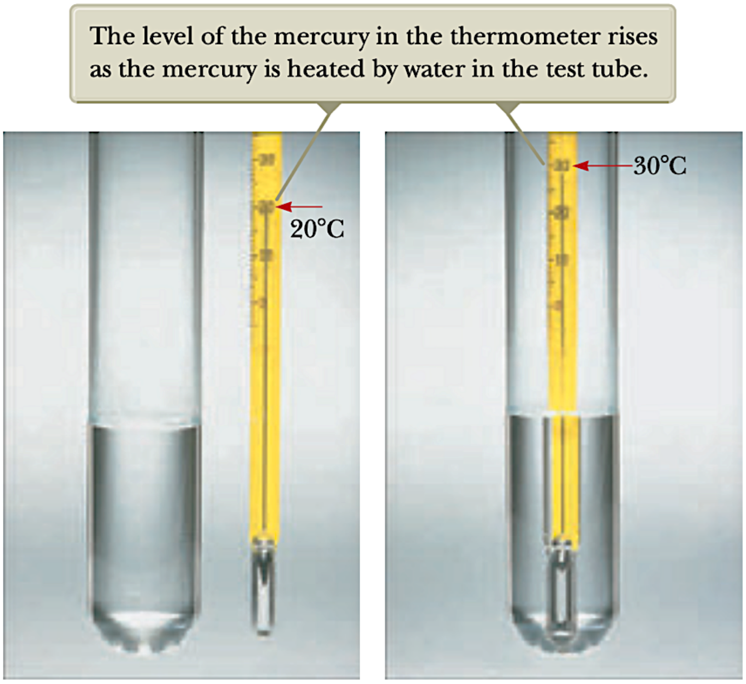


Application on *Zeroth Law* of thermodynamics

1- Thermometers and the Celsius Temperature Scale

Thermometers are devices used to measure the temperature of a system. All thermometers are based on the principle that some physical property of a system changes as the system's temperature changes. Some physical properties that change with temperature are (1) the volume of a liquid, (2) the dimensions of a solid, (3) the pressure of a gas at constant volume, (4) the volume of a gas at constant pressure, (5) the electric resistance of a conductor, and (6) the color of an object.

A common thermometer in everyday use consists of a mass of liquid—usually *mercury or alcohol*—that expands into a glass capillary tube when heated (see next figure).



In this case, the physical property that changes is the volume of a liquid. Any temperature change in the range of the thermometer can be defined as being proportional to the change in length of the liquid column. The thermometer can be calibrated by placing it in thermal contact with a natural system that remains at constant temperature. One such system is a mixture of water and ice in thermal equilibrium at atmospheric pressure.

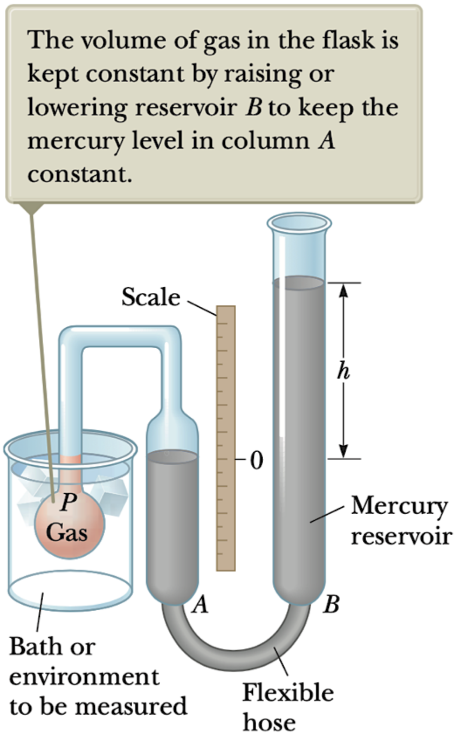
On the Celsius temperature scale, this mixture is defined to have a temperature of *zero degrees Celsius "Freezing point"*, which is written as 0°C; this temperature is *called the ice point of water*.

Another commonly used system is a mixture of water and steam in thermal equilibrium at atmospheric pressure; its temperature is defined as 100°C "*boiling temperature*", which is the *steam point of water*.

Once the liquid levels in the thermometer have been established at these two points, the length of the liquid column between the two points is divided into 100 equal segments to create the Celsius scale. Therefore, each segment denotes a change in temperature of one *Celsius degree*.

2- The Constant-Volume Gas Thermometer and the Absolute Temperature Scale

One version of a gas thermometer is the constant-volume apparatus shown in next figure.



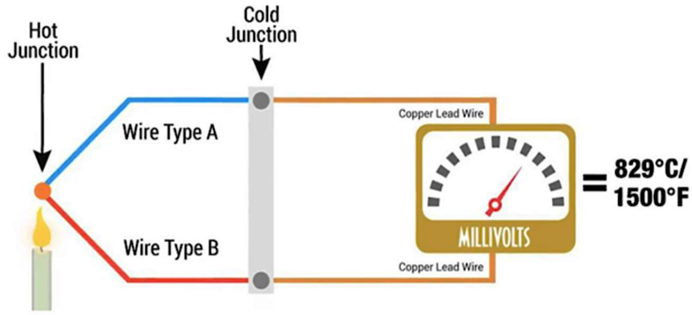
The physical change exploited in this device is *the variation of pressure* of a fixed volume of gas *with temperature*. The flask is immersed in an ice-water bath, and mercury reservoir B is raised or lowered until the top of the mercury in column A is at the zero point on the scale. The height h, the difference between the mercury levels in reservoir B and column A, indicates the pressure in the flask at 0ºC by means of Equation $P = P_0 + \rho g h$.

The flask is then immersed in water at the steam point. Reservoir B is read-justed until the top of the mercury in column A is again at zero on the scale, which ensures that the gas's volume is the same as it was when the flask was in the ice bath (hence the designation "constant-volume"). This adjustment of reservoir B gives a value for the gas pressure at 100ºC.

Note: https://www.youtube.com/watch?v=n0xAQXL905c ; you can use the link to see the device and how it work.

3- Thermocouple

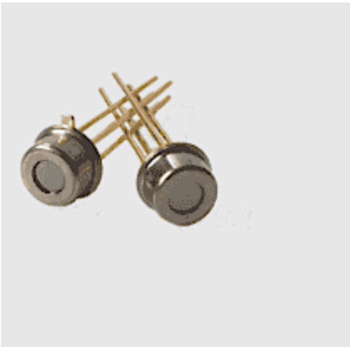
A thermocouple consists of two junctions of two different metals. If the two junctions are at different temperatures, a voltage is produced that depends on the temperature difference.

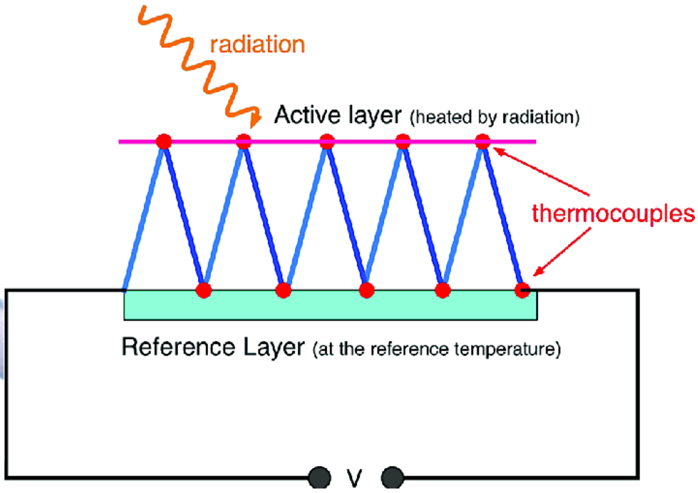


Usually, one of the junctions is kept at a reference temperature such as in an ice-water bath "cold point". The *Copper-Constantin* thermocouple can be used to measure temperatures from (-190 to 300ºC). For a 100ºC temperature difference, the voltage produced is only about 0.004V (4mV). Thermocouples can be made small enough to measure the temperature of individual cells.

4- Thermopile

It can be used to detect the heat radiate by the skin and consisted of a number of thermocouples connected in series. One set of thermocouple junctions (A) is exposed to the radiation and is heated by it, the other set (B) is shielded from the radiation, a highly polished metal cone concentrates the radiation on the exposed junction, and these junctions are coated with lamp-black to enhance the efficiency with which the radiation is absorbed. The meter reading depends on the rate at which heat energy enters the cone and this in its turn depends on the temperature of the skin. Thermopile s are normally calibrated to read skin temperature directly.





5- Thermograph-mapping the body's temperature

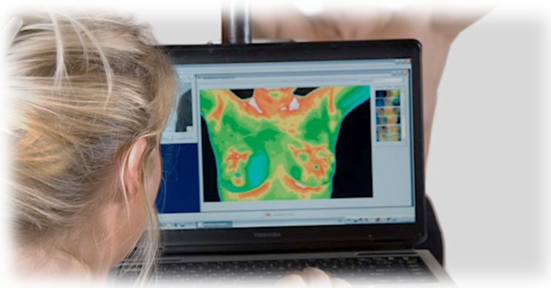
Thermography: Process to measure the body surface temperature, indicate that the surface temperature various from point to another depend on:

1) External physical factors.

2) Circulatory process near the skin-blood flow near the skin is the dominant factor.

Measurement of surface temperature is thought to be useful in diagnoses of some diseases, which may change locally the skin temperature. All objects regardless of their temperature emit heat radiation. The body heat can give (IR) infrared radiation of long waves, which are not visible unlike the red-hot object, which is visible. Thermograph is the process in which the infrared radiation emitted by the body is used to produce a (thermal image) or (temperature map) of the surface of the body. The images are called Thermograms and are normally displayed on a

TV screen. Different temperatures are represented by different colors, in a black and white display by different shades of gray.



Heat radiation power can be measured by: $W = \sigma e T^4$

Were "$\boldsymbol{\sigma}$" is constant= 5.7×10^{-12} W/cm^2 K, "$\boldsymbol{e}$" is emissivity which depends upon the emitter material and "$\boldsymbol{T}$" is the body temperature.

Thermograph uses:

1- A-Cancer detection: Breast cancer could be characterized by an elevated skin temperature in the region of the cancer. The surface temperature above a tumor was typically about 1 °C higher than that above nearby normal tissue, and it was thought that this will be a good procedure for early breast cancer detection.

2- Thermograph used to study the circulation of blood in the head, differences in the blood supply between left and right sides can indicate circulatory problems. In diabetic patients: Thermograph has had considerable success in reducing leg amputation in diabetic. The blood supply in diabetic's leg is usually adequate, but if the tissues break down and an ulcer is formed, the need for blood in the leg may double. The circulation problems of the diabetic then become evident: the ulcer dose not heals and often becomes infected.

3- Dentists recommend the use of medical thermograph in monitoring control in the inflammation process into oral cavity and reaction of the regional lymphatic nodes, maxillary joint disease and other chronic disease of the bones, nerves located in the maxilla facial area.

The Celsius, Fahrenheit, and Kelvin Temperature Scales

In every case, the pressure is zero when the temperature is 2273.15°C. This finding suggests some special role that this particular temperature must play. It is used as the basis for the absolute temperature scale, which sets 2273.15°C as its zero point. This temperature is often referred to as absolute zero. It is indicated as a zero because at a lower temperature, the pressure of the gas would become negative, which is meaningless. The size of one degree on the absolute temperature scale is chosen to be identical to the size of one degree on the Celsius scale. Therefore, the conversion between these temperatures is:

$$T_c = T - 273.15$$

The last equation shows that the Celsius temperature T_C is shifted from the absolute (Kelvin) temperature T by 273.15°. Because the size of one degree is the same on the two scales, a temperature difference of 5°C is equal to a temperature difference of 5 K. The two scales differ only in the choice of the zero point. Therefore, the ice-point temperature on the Kelvin scale, 273.15 K, corresponds to 0°C, and the Kelvin-scale steam point, 373.15 K, is equivalent to 100^0C.

A common temperature scale in everyday use in the United States is the Fahrenheit scale. This scale sets the temperature of the ice point at 32°F and the temperature of the steam point at 212°F. The relationship between the Celsius and Fahrenheit temperature scales is:

$$T_F = \frac{9}{5}T_C + 32^oF$$