Temperature & Zeroth law of Thermodynamics

(Thermodynamics)

e-content for B.Sc Physics (Honours)
B.Sc Part-I

Paper-II

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Temperature

1. Energy

a. <u>Definition of energy</u>

Energy is a fundamental physical concept. It is the capacity for performing work. The transference of energy by a process involving the motion of the point of application of a force, as when there is movement against a resisting force or when a body is given acceleration; it is measured by the product of the force and the displacement of its point of application in the line of action.

That definition of work is adequate as a definition of mechanical work, but that definition of the word energy is nearly useless. Of course, that's what dictionaries do, define words in terms of other words in endless circles—they are about usages more than meanings. A fundamental concept cannot be defined in terms of other concepts; that is what *fundamental* means.

b. <u>Conservation of energy</u>

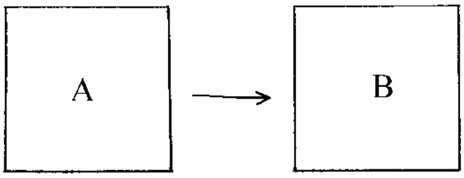
We can list the forms that energy might take. In effect, we are saying that if such and such happens in or to a system, then the energy of the system changes. There is potential energy, which is related to the positions of parts of the system. There is kinetic energy, which is related to the movements of parts of the system. There is rest energy, which is related to the amount of matter in the system. There is electromagnetic energy, chemical energy, and nuclear energy, and more.

We find that for an *isolated* system, the total amount of energy in the system does not change. Within the system, energy may change from one form to another, but the total energy of all forms is a conserved quantity. Now, if a system is <u>not</u> isolated from the rest of the universe, energy may be transferred into or out of the system, so the total energy of such a system may rise or fall.

2. Thermal Equilibrium

a. <u>Temperature</u>

Consider two objects, each consisting of a very large number of atoms and/or molecules. Here, very large means at least several multiples of Avogadro's Number of particles. We call such an object a *macroscopic* object. Consider that these two objects (they may be two blocks of aluminum, for instance, though they need not be the same material—they might be aluminum and wood, or anything) are isolated from the rest of the universe, but are in *contact* with each other.



We observe that energy flows <u>spontaneously</u> from one block (A) to the other (B). We say that block A has a higher *temperature* than block B. In fact, we say that the energy flow occurs <u>because</u> the blocks have different temperatures. We further observe that after the lapse of some time, called the *relaxation time*, the flow of energy from A to B ceases, after which there is zero net transfer of energy between the blocks. At this point the two blocks are in *thermal equilibrium* with each other, and we would say that they have the same temperature.

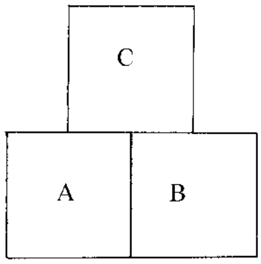
b. <u>Heat</u>

The word *heat* refers to energy that is transferred, or energy that flows, spontaneously by virtue of a difference in temperature. We often say heat flows into a system or out of a system, as for instance heat flowed from block A to block B above. It is <u>incorrect</u> to say that heat resides in a system, or that a system contains a certain amount of heat.

There are three mechanisms of energy transfer: conduction, convection, and radiation. Two objects, or two systems, are said to be in *contact* if energy can flow from one to the other. The most obvious example is two aluminum blocks sitting side by side, literally touching. However, another example is the Sun and the Earth, exchanging energy by radiation. The Sun has the higher temperature, so there is a net flow of energy from the Sun to the Earth. The Sun and the Earth are in contact.

c**. <u>Zeroth "Law" of Thermodynamics</u>**

Two systems in thermal equilibrium with each other have the same temperature. Clearly, if we consider three systems, A, B, & C, if A & B are in thermal equilibrium, and A & C are in thermal equilibrium, then B & C are also in thermal equilibrium, and all three have the same temperature.



3. Thermometers

a. Temperature scales

What matter are temperature differences. We can feel that one object is hotter than another, but we would like to have a quantitative measure of temperature. A number of temperature scales have been devised, based on the temperature difference between two easily recognized conditions, such as the freezing and boiling of water. Beyond that, the definition of a degree of temperature is more or less arbitrary. The Fahrenheit scale has 180 degrees between the freezing and boiling points, while the Celsius scale has 100. Naturally, we find 100 more convenient than 180. On the other hand, it turns out that the freezing and boiling points of water are affected by other variables, particularly air pressure. Perhaps some form of absolute scale would be more useful. Such a scale is the Kelvin scale, called also the *absolute temperature scale*. The temperature at which the pressure of a dilute gas at fixed volume would go to zero is called the *absolute zero* temperature. Kelvin temperatures are measured up from that lowest limit. The unit of absolute temperature is the *kelvin* (K), equal in size to a degree Celsius. It turns out that $0\ K = -273.15\ ^{o}C$.

b. Devices

Devices to measure temperature take advantage of a thermal property of matter—material substances expand or contract with changes in temperature. The electrical conductivity of numerous materials changes with temperature. In each case, the thermometer must itself be brought into thermal equilibrium with the system, so that the system and the thermometer are at the same temperature. We read a number from the thermometer scale, and impute that value to the temperature of the system. There are bulb thermometers, and bi-metallic strip thermometers, and gas thermometers, and thermometers that detect the radiation emitted by a surface. All these must be calibrated, and all have limitations on their accuracies and reliabilities and consistencies.