

## 2.2: The Zeroth Law of Thermodynamics

The mathematical definition that guarantees that thermal equilibrium is an equivalence relation is called the zeroth law of thermodynamics. The zeroth law of thermodynamics states that if two thermodynamic systems are each in thermal equilibrium with a third one, then they are in thermal equilibrium with each other. The law might appear trivial and possibly redundant, but it is a fundamental requirement for the mathematical formulation of thermodynamics, so it needs to be stated. The zeroth law can be summarized by the following simple mathematical relation:

### Definition: Zeroth Law of Thermodynamics

If  $T_A = T_B$ , and  $T_B = T_C$ , then  $T_A = T_C$ .

Notice that when we state the zeroth law, it appears intuitive. However, this is not necessarily the case. Let's, for example, consider a pot of boiling water at  $P = 1$  bar. Its temperature,  $T_{H_2O}$ , is about 373 K. Let's now submerge in this water a coin made of wood and another coin made of metal. After some sufficient time, the wood coin will be in thermal equilibrium with the water, and its temperature  $T_W = T_{H_2O}$ . Similarly, the metal coin will also be in thermal equilibrium with the water, hence  $T_M = T_{H_2O}$ . According to the zeroth law, the temperature of the wood coin and that of the metal coin are precisely the same  $T_W = T_M = 373$  K, even if they are not in direct contact with each other. Now here's the catch: since wood and metal transmit heat in different manners if I take the coins out of the water and put them immediately in your hands, one of them will be very hot, but the other will burn you. If you had to guess the temperature of the two coins without a thermometer, and without knowing that they were immersed in boiling water, would you suppose that they have the same temperature? Probably not.

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