THERMAL PROPERTIES OF MATTER

NEWTON'S LAW OF COOLING

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It is a frequently observed phenomenon that objects at temperatures higher than that of their surroundings tend to lose heat. Sir Isaac Newton was the pioneer in conducting a systematic scientific inquiry into this phenomenon.

Based on his experimental observations, Newton formulated a principle known as Newton's Law of Cooling. According to this law:

The rate at which a body loses heat is directly proportional to the temperature difference $(T - T_0)$ between the body and its surroundings.

Mathematically, this relationship is expressed as:

$$-\frac{dT}{dt} \propto (T - T_0)$$

Here, $\frac{dT}{dt}$ represents the rate of change of temperature with respect to time, and $(T - T_0)$ is the temperature difference between the body and the surroundings. The negative sign indicates that the temperature of the body is decreasing over time.

The rate at which heat is lost is not only influenced by the temperature difference but also by the characteristics of the radiating surface. Typically, experiments are conducted in a still air environment, and Newton's Law of Cooling is applicable within a specific temperature range, usually around 30°C. However, it's worth noting that when the air surrounding the object is in constant motion, the law remains valid even for larger temperature differences. The dynamics of continuous air movement play a role in heat dissipation, allowing the law to extend its applicability to scenarios with greater temperature differentials.

Verification of Newton's law of Cooling

The validation of Newton's Law of Cooling is conducted through an indirect method, where the assumption of its correctness is followed by experimental verification. The law is expressed as:

$$-\frac{dQ}{dt} \propto (T - T_0)$$

Or

$$-\frac{dQ}{dt} = K(T - T_0) \qquad \text{...... (i)}$$

In this equation, K is a positive constant of proportionality, and its specific value relies on the radiating surface's area and nature. Considering $dQ = mc\,dT$, we can rewrite equation (i) as:

$-mc\frac{dT}{dt} = K(T - T_0)$ ..... (ii)

Now, combining equations (i) and (ii), we obtain:

$\frac{dT}{T-T_0} = -\frac{K}{mc}dt = -kdt$ ...... (iii)

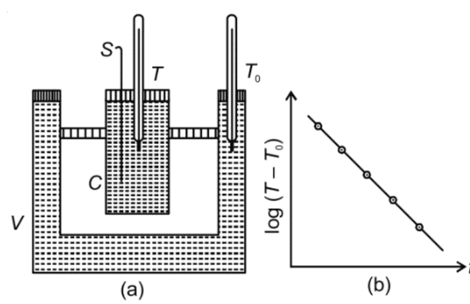
Here, k is defined as K/mc, representing a constant. Integrating both sides of equation (iii) results in:

$\ln(T - T_0) = -kt + C$ ..... (iv)

Where C is the constant of integration. Equation (iv) depicts a straight line, indicating that for Newton's law of cooling to hold true, the graph between $\ln(T - T_0)$ and t should be linear. This approach establishes the relationship between the law's theoretical formulation and its experimental confirmation.

Experimental Setup

The apparatus employed for the experiment is illustrated in the figure. It comprises a copper calorimeter (C), externally coated in black (to ensure uniform radiating surface characteristics), and equipped with a cork that houses a half-degree thermometer (T) and a stirrer (S). The calorimeter is filled with water heated to approximately 30°C to 40°C above the room temperature. This calorimeter is then suspended within a double-walled vessel (V). The space between the walls of this vessel is filled with water at room temperature, establishing a constant temperature enclosure. To measure the temperature of the enclosure, an additional half-degree thermometer (T_0) is utilized.



Temperature Monitoring Process: The water inside the calorimeter is gently stirred, and its temperature (T) is systematically recorded. Initially, readings are taken every half minute, followed by intervals of one minute, and in the later stages, measurements are made every two minutes. This process is iterated until the temperature of the water in the calorimeter is approximately 5°C above the mean temperature (To) of the enclosure. Subsequently, the differences (T - To) are computed for various time intervals (t). A graph is then constructed, depicting the relationship between ln(T-T0) and time (t). Remarkably, the graph assumes a linear form, as depicted in Figure (b) above, thereby substantiating the validity of Newton's law of cooling.

Example.

A physical entity undergoes a cooling process, decreasing from an initial temperature of 60°C to 40°C within a span of 7 minutes. To ascertain its temperature following an additional 7-minute interval, considering the surroundings to be at a temperature of 10°C.

Solution.

In the initial scenario, denoted as the first case, where $T_1 = 60°C, T_2 = 40°C, T_0 = 10°C$, and $t = 7$ minutes, we utilize the logarithmic form ln $T_1 - \frac{T_0}{T_2} - T_0 = Kt$ to derive the expression:

$ln \ \frac{60 - 10}{40 - 10} = 7K$

Simplifying, we obtain ln $\frac{5}{3} = 7K$ (equation 1).

Now, considering the second case where T represents the temperature after the subsequent 7 minutes ($T_1 = 40°C, T_2 = T, T_0 = 10°C, t = 7 \ minutes$), we employ the same logarithmic expression:

$In \ \frac{40-10}{T-10} = 7K$ (equation 2).

By comparing equations (1) and (2), we deduce that ln $\frac{5}{3} =$ ln $\frac{30}{T-10}$, leading to the solution T = 28°C.