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Course Code: PHY 111 **Course Title:** General Physics I

Lecture Notes B1 – Temperature and Types of Thermometer

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Introduction

This topic introduces a fundamental quantity called temperature. It is important in the study of heat energy or thermodynamics. Temperature is different from heat. Heat is a form of energy as a result of temperature difference while temperature is a measure of the average kinetic energy of the particles in a substance. Hereafter, the concept of temperature shall be discussed using thermal equilibrium and the zeroth law of thermodynamic. Thereafter, temperature measurement using various temperature scales and the types of thermometer would be explained.

Objectives

At the end of this class, you should be able to:

i. explain the concept of temperature
ii. define temperature in terms thermal equilibrium
iii. state the zeroth law of thermodynamics
iv. solve simple problems on conversion of temperatures on diverse temperature scales.
v. Describe the principle of operation of different types of thermometer

Concept of Temperature

Temperature is a fundamental quantity in the study of heat (thermal energy) or thermodynamics. The concept of temperature differs from heat. Heat is a form of energy. Temperature is a measure of the average kinetic energy of the particles in a substance. It is a sensation or degree of hotness and coldness of a body. Temperature of a body that determines the direction of flow of heat from one body to another. Heat measurement is usually referred to as Calorimetry. Temperature measurement in physics is referred to as thermometry.

Thermal Equilibrium

Consider two bodies having different temperature, say one is hot and the other cold. The temperature of the hot body is higher (because it possesses more heat energy) than the colder body. The temperature of a body that determines the direction of flow of heat from that body to another. Therefore, if the two bodies are placed in thermal contact with each other, heat energy flows from the hot body to the cold body until the temperatures of the two bodies are the equal. At this instance, the two bodies are said to be in thermal equilibrium with each other. So, a thermal equilibrium exists between two bodies when they are in thermal contact with each other and there is no net flow of heat between them. Hence, thermal equilibrium is the state in which two bodies in physical contact with each other have identical temperatures

The Zeroth Law of Thermodynamics

It states that if two thermodynamics bodies A and B are separately in thermal equilibrium with a third body C, then the bodies A and B are in thermal equilibrium with each other.

The Zeroth law of thermodynamics is as explained below.

Consider bodies A, B and C enclosed in an adiabatic wall, to ensure that no heat energy is lost to or gained from the surrounding (as shown below). If bodies A and B separated from each other by an adiabatic wall. Each of the aforementioned body is in contact with a third body **C** separated through a diathermic wall. Bodies A and B will attain a thermal equilibrium with body **C.**

An **adiabatic** wall is one that heat cannot pass through. It is made from a thermal insulator such as glass, wool, asbestos, cork etc.

A **diathermal or diabatic wall** is one that heat can pass through. It is made from a thermal conductor such as Copper, Silver, Steel etc.

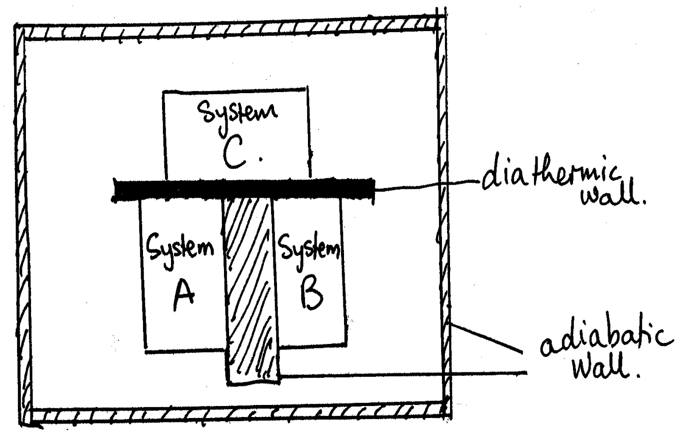


Fig. 1: Bodies A and B are in Thermal Equilibrium with body C.

Therefore, in terms thermal equilibrium, the temperature of a system is defined as that property that determines whether two or more systems are in thermal equilibrium with each other or not.

Properties of a Thermometric Substance

The property of a thermometric substance changes with temperature. So, to measure temperature, it is necessary to select a physical property or parameter of a chosen substance which varies uniformly with temperature. A parameter or property is a variable which is assigned a constant value during a discussion or event. Some of the examples of these properties or parameters are:

(i) the volume of a liquid;
(ii) the volume of a gas at constant pressure;
(iii) the pressure of a gas at constant volume;
(iv) the electrical resistance of a conductor;
(v) the emf change of a thermocouple when there is a temperature difference between the junctions of a thermoelectric thermometer.

Reference Temperatures

Reference temperatures are temperatures at fixed points. Fixed points are useful as reference temperatures. Changes in the properties or parameters from the fixed points are assigned numbers called degrees on a calibrated scale. The two types of fixed points are:

i. The Lower fixed point (Ice point): is the temperature of melting point of pure ice or freezing point of pure water at standard atmospheric pressure. This temperature is marked 0^oC.
ii. The Upper fixed point (Steam point): is the temperature of steam rising from pure water boiling under standard atmospheric pressure. In other words, it is the temperature of one standard atmosphere. This temperature is 100^oC.

This is the difference between the upper fixed point and the Lower fixed point is called the fundamental interval.

The Temperature Scales

The types of temperature scales are:

i. The Celsius scales.
ii. The Fahrenheit scale.
iii. The absolute scale of temperature

Celsius Scale

The ice point is 0^oC and the steam point is at 100^oC. Each part represents 1^oC.
Let X represents the property of the thermometric substance, which serves as temperature indicator.
Let X_o = Ice/ lower fixed point
Let X_{100} = Steam point/upper fixed point
Fundamental interval = $X_{100} – X_o$.

If X_t is the value of at temperature t_c

$$t_c = \frac{X_t - X_0}{X_{100} - X_0} \times 100\ ℃ \qquad (1)$$

Example 1

The lengths of the mercury column of a mercury thermometer are 1.02 cm and 12.76 cm respectively at the standard fixed points. What is the temperature of body, which produces 5.0 cm of this mercury column?

$$t_c = \frac{5 - 1.02}{12.76 - 1.02} \times 100\ ℃ \quad = \quad 33.9℃$$

Fahrenheit Scale

The ice point is 32°F while the steam point if 212°F. The fundamental interval is 180 divisions. Each division represents 10°F.

$$t_F - 32 = \frac{X_t - X_{32}}{X_{212} - X_{32}} \times 180 \text{ °F} \qquad (2)$$

$$t_F = \left[\frac{X_t - X_{32}}{X_{212} - X_{32}} \times 180 + 32\right] \text{ °F}$$

On Fahrenheit scale, $X_{212} = X_{100}\ and\ X_{32} = X_0$

$t_F = \left[\frac{X_t - X_0}{X_{100} - X_0} \times 180 + 32\right]$ °F $\quad = \left[\frac{t_c}{100} \times 180 + 32\right]$ °F

Therefore, t_F and t_c area related by the expression

$$t_F = \left[\frac{9}{5}\text{°C} + 32\right]\text{°F or} \qquad t_C = \frac{5}{9}[t_F - 32]\text{°C} \qquad (3)$$

Example 2

Covert 20°C to Fahrenheit scale.

Solution

$t_F = \left[\frac{9}{5}\text{°C} + 32\right]\text{°F} \quad = \quad \left[\frac{9}{5}(20) + 32\right]\text{°F} \quad = \quad 68\text{ °F}$

Absolute Scale of Temperature (or Thermodynamic Scale)

The thermodynamic scale is the standard temperature scale used in scientific measurements. The symbol on this scale is T and it is measure in Kelvin after Lord Kelvin.

Triple point of water is the reference point on the thermodynamic scale where saturated water vapour, pure water and melting ice are in equilibrium to each other. The temperature of the triple point of water has been found to be 273.16K. The ice point is 273.15K. Pressure accounts for the slight difference in the two cases.

According to Charles law, Pressure (P) varies with temperature T. When the graph is extrapolated, it meets the temperature axis at -273.15°C. Lord Kelvin called this value of temperature absolut**e zero** (0 K). It is to be noted that the value of pressure at this temperature reduce to zero.

On the Celsius temperature scale,

$$-273.15\text{°C} = 0$$

$$0\text{°C} = 273.15K$$

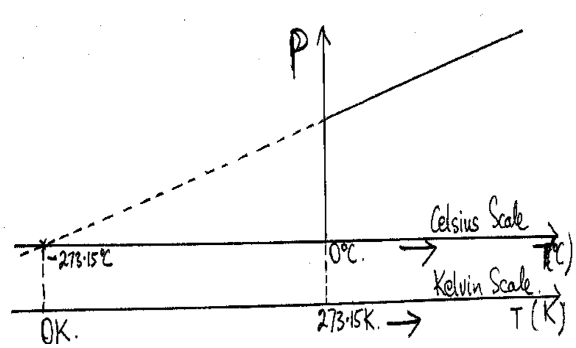


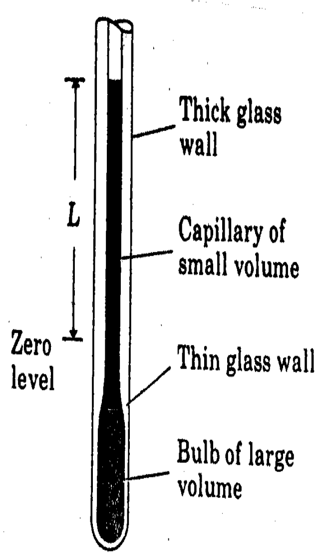
Fig. 2

Types of Thermometers

Thermometers may be classified according to the thermometric properties used in constructing such thermometers. For example, we have:

i. **Liquid-in-Glass Thermometers**: uses the expansion of the liquid in the glass tube. As the liquid volume increases with temperature rise, the length of the liquid along the tube varies with temperature.
ii. **Constant Volume-Gas Thermometer**: makes use of a given mass of gas whose pressure varies with temperature at constant volume.
iii. **Constant Pressure-Gas Thermometer**: makes use of a given mass of gas whose volume varies with temperature at constant pressure.
iv. **Resistance Thermometer**: uses of the variation of resistance of a given conductor such as platinum with temperature.
v. **Thermo-electric Thermometer**: makes use of the variation of electromotive force (emf) developed between the pair of junctions of two dissimilar metals with temperature.

Liquid-in-Glass Thermometers



The liquid-in-glass thermometer makes use of either mercury alcohol. The laboratory thermometer, clinical thermometer and the Maximum and Minimum (six's) thermometer are the commonly used mercury-in-glass thermometers. However, the alcohol-in-glass thermometers are used in temperate countries because alcohol has a much lower melting point than mercury.

The expansion or increase in length (L) of the mercury-in-glass thermometer is used as a property as the temperature increases. Using the Celsius scale therefore, the temperature t is defined as:

$$t_c = \frac{L_t - L_0}{L_{100} - L_0} \times 100\ ^\circ\text{C} \qquad (4)$$

where, L_t = length of the mercury column at t°C; L_0 = length of the mercury at 0°C

L_{100} = length of the mercury at $100°C$

Table 1 Properties of Mercury and Alcohol as Thermometric Liquids

	Mercury	**Alcohol**
1	Mercury cannot measure a much lower temperature as alcohol.	Alcohol may be used for much lower temperature than mercury's.
2	It could be used to measure temperatures well above 500°C even as high as 800°C	It is not suitable for temperatures above 50°C or 60°C.
3	Mercury does not wet glass.	Alcohol wets glass.
4	Mercury expands less than alcohol for a given rise in temperature.	Alcohol expands more than mercury for a given rise in temperature.
5	Mercury is opaque. Silvery in colour it is therefore easily seen.	Alcohol is transparent. It has to be coloured before it can be seen.
6	A good conductor of heat	A poor conductor of heat.
7	It has low specific heat capacity.	Has high specific heat capacity.

- **The Clinical Thermometers**

The clinical thermometer is usually used in the hospital clinics. It is specifically designed for measuring the temperature of the human body. It has features such as stem, constriction and bulb containing mercury. The stem of the clinical thermometer is calibrated from 35°C to 45°C. The constriction on the stem is near the bulb. Its essence is to prevent the mercury from entering the bulb. Thus the measurement can be read at ease. The broken thread of the mercury can be returned back to the bulb by jerking the thermometer.

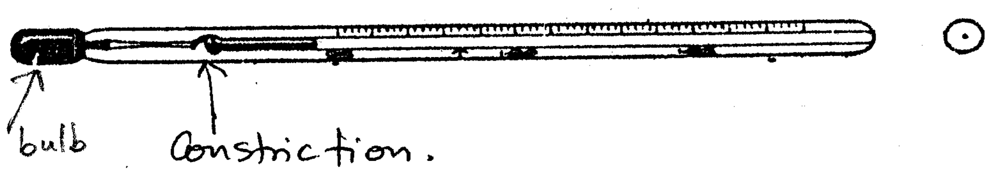


Fig. 4 Clinical Thermometer

- The laboratory thermometers are longer than the clinical thermometers and they have no constrictions in them. Besides, they are usually longer with longer range of temperatures from -10°C to about 150°C.

- **The Maximum and Minimum (Six's) Thermometers**

The Minimum and Maximum thermometer is used to record the minimum and maximum temperatures of the day. The knowledge of such temperatures over a period of time may be useful in predicting the weather.

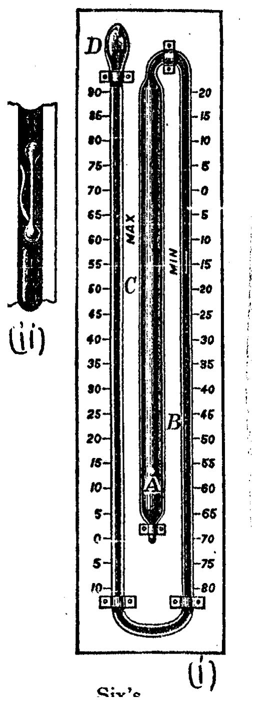


Fig. 5: Maximum and Minimum (Six's) Thermometer

The thermometer consists of long bulb A (that contains either alcohol or mercury), a thread of mercury BC and bulb D (which is partly filled with alcohol or mercury). Above the surface of the mercury thread at B and C are light steel indices. When the liquid in A expands, the mercury thread in BC is pushed round sending the index at C upwards and leaving the index B in position. When the alcohol in A contracts, the mercury thread BC is drawn back leaving the C index to record the maximum temperature reached. The index B similarly records the minimum temperature reached. A magnet is used to reset each index by drawing them down to the surface of the mercury thread.

Constant Volume Gas Thermometers

Consider a fixed mass of gas kept at constant volume in a container capable of measuring the pressure P. So, if P_0 andP_{100} are the pressures at ice and steam points respectively and P_t is the pressure at an unknown temperature t°C. Then

$$t_c = \frac{P_t - P_0}{P_{100} - P_0} \times 100\ ^\circ\text{C} \qquad (5)$$

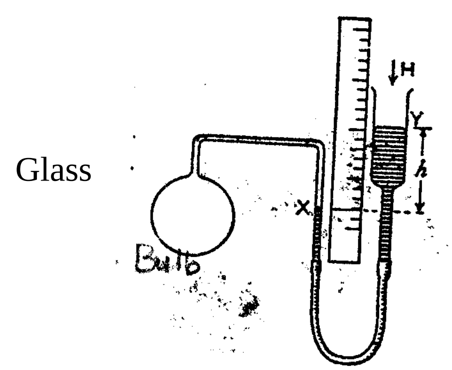


Fig. 6 Constant Volume Gas Thermometer

It consists of a glass bulb of about $100cm^3$ in volume containing dry air. This bulb is connected to a fine glass capillary tube and a rubber pressure tube, which in turn is connected to a moveable reservoir of mercury.

There is mark X on the capillary tube. This is the constant volume mark. The total pressure on the air is (H + h) where H is the atmosphere pressure and h is the height of the mercury above the mark X.

If $P_0 = H + h_o$

$P_{100} = H + h_{100}$

$P_t = H + h_t$

Then

$$t_c = \frac{P_t - P_0}{P_{100} - P_0} \times 100\ °C$$

$$t_c = \frac{h_t - h_0}{h_{100} - h_0} \times 100\ °C \qquad (6)$$

Similarly, for a Constant Pressure gas thermometer

$$t_c = \frac{V_t - V_0}{V_{100} - V_0} \times 100\ °C \qquad (7)$$

Resistance Thermometers

Resistance thermometer makes use of the variation of resistance of a given conductor such as platinum with temperature. On the platinum resistance scale of temperature, equal changes in resistance denote equal changes in temperature.

Fig. 8 Platinum Resistance

Let R_0 and R_{100} be the resistances of ice and steam respectively and R_t the resistance of the platinum at t_R°C.

$$t_R = \frac{R_t - R_0}{R_{100} - R_0} \times 100\ °C \qquad (8)$$

The platinum resistance thermometer has a high degree of accuracy. It can measure a wide range of temperature. Its main disadvantage is that it takes a long time to take on the temperature of its surroundings. This is where the thermo-electric thermometer is a good substitute.

Exercise

A platinum resistance thermometer has a resistance of $25.50\ \Omega$ at 0°C and $43.80\ \Omega$ at 0°C. Assuming that the resistance changes uniformly with temperature, what is

(a) The temperature when the resistance is 6.50 Ω?
(b) The resistance of the thermometer when the temperature is 35°C?

Thermo-Electric Thermometers
The thermo-electric thermometer is otherwise called thermo-couple. This type of thermometer is constructed by using the Seebeck effect.

Seebeck effect simply states that if two dissimilar metals, such as copper and iron are joined to make a complete circuit, then on heating one end of the junctions, a current flows round the circuit. The galvanometer detects and measures the magnitude of the current that flows in the circuit.

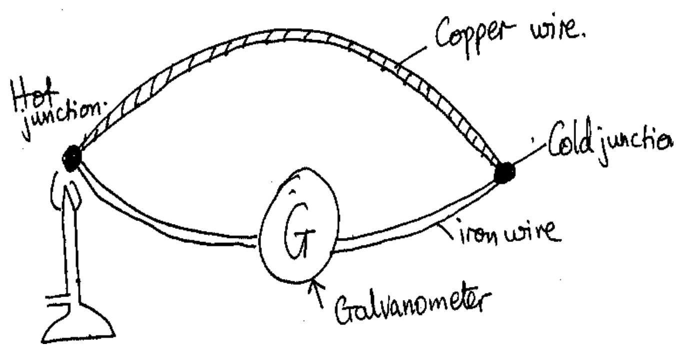


Fig. 9: Thermo-Electric Couple

This type of arrangement is called a thermo-couple. The e.m.f established round the circuits depends on the nature of the metals used to form the couple and also on the temperature difference between the hot and cold junctions. The thermo-electric couple is capable of measuring up to 1500°C.
Let E_0 and E_{100} be the e.m.f of ice and steam respectively and E_t the e.m.f of thermo-electric thermometer at t_E°C. Therefore,

$$t_E = \frac{E_t - E_0}{E_{100} - E_0} \times 100\ ℃ \qquad (9)$$

Temperature Range of Various Thermometers

Type of Thermometer	**Range**
Mercury Thermometer	–20℃ – 333℃
Alcohol Thermometer	–110℃ – 55℃
Gas Thermometer	–200℃ – 1600℃
Resistance Thermometer	–200℃ – 1500℃
Thermo-electric Thermometer	–200℃ – 3000℃
Pyrometer	Up to 3200℃
Bimetallic Thermometer	–50℃ – 550℃

Assessment Questions

1. Differentiate between temperature and heat
2. What do you understand by thermal contact and thermal equilibrium?
3. State the Zeroth law of temperature.
4. Define temperature in terms of thermal equilibrium.
5. Define triple point of water
6. List the types of thermometers that exist and their corresponding thermometric properties used for their construction.
7. What is Seebeck effect?

Assignment

1. The boiling point of substance Y is $-129.35℃$. Obtain the values of this temperature in Kelvin and degree Fahrenheit.
2. At ice and steam point an ungraduated mercury thermometer reads 20.5 cm and 320 cm respectively at standard pressure. What will the scale read when the temperature is 70°C?
3. Find the temperature at which the Fahrenheit and the Celsius scales coincide.
4. The boiling point of sulfur is 444.6°C. Sulfur's melting point is 586.1°F lower than its boiling point.
   a. Determine the melting point of sulfur in degrees Celsius.
   b. Find the melting and boiling points in degrees Fahrenheit.
   c. Find the melting and boiling points in kelvins.
5. State the advantages and disadvantages of the use of alcohol over mercury as thermometric liquids

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