GENERAL PHYSICS I

Course Code: PHY 101

Session: 2019/2020

OLADEJO O. F. (Ph.D)
Department of Physics
Faculty of Basic and Applied Sciences

Contents: Temperature, Thermometers and Temperature scales, Thermal Expansion of Solids and Liquids, Macroscopic description of an ideal Gas, Heat and Internal Energy, Specific heat, Calorimetry, Latent heat and Phase change.

Week 1:

- Temperature
- Thermometers and Temperature scales
- Thermal Expansion of Solids and Liquids

Week 2:

- Macroscopic description of an ideal Gas
- Heat and Internal Energy
- Specific heat
- Calorimetry
- Latent heat and Phase change.

Temperature

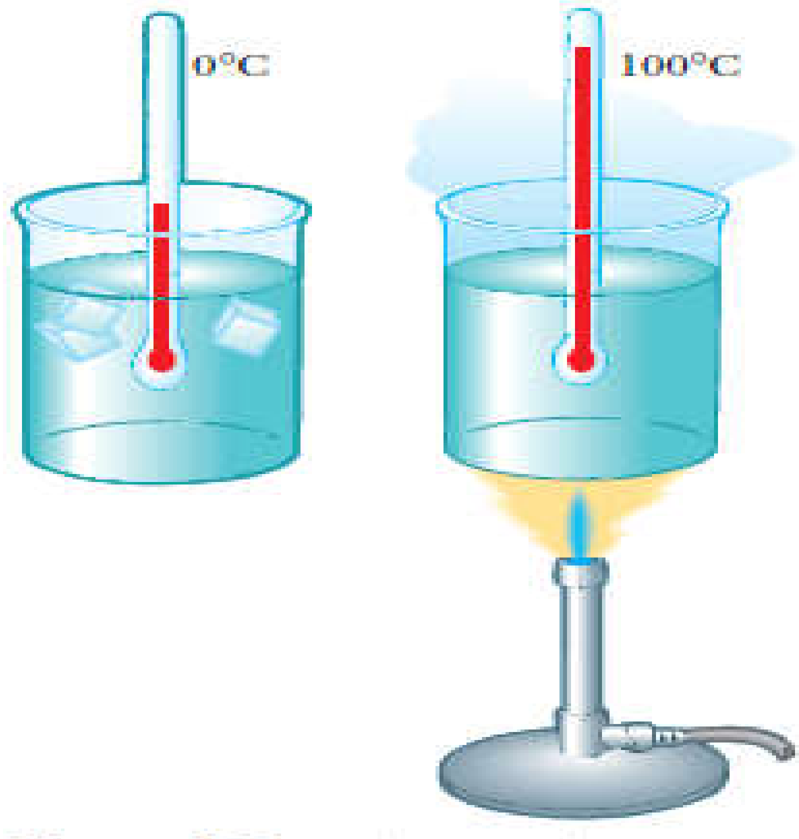
- Temperature is commonly associated with how hot or cold an object feels when we touch it.
- While our senses provide us with qualitative indications of temperature, they are unreliable and often misleading
- Understanding the concept of temperature requires understanding *thermal contact* and *thermal equilibrium*.
- Two objects are in **thermal contact** if energy can be exchanged between them.
- Two objects are in **thermal equilibrium** if they are in thermal contact and there is no net exchange of energy.

- The exchange of energy between two objects because of differences in their temperatures is called **heat**
- **Thermometer** is a device calibrated to measure the temperature of an object.
- **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.

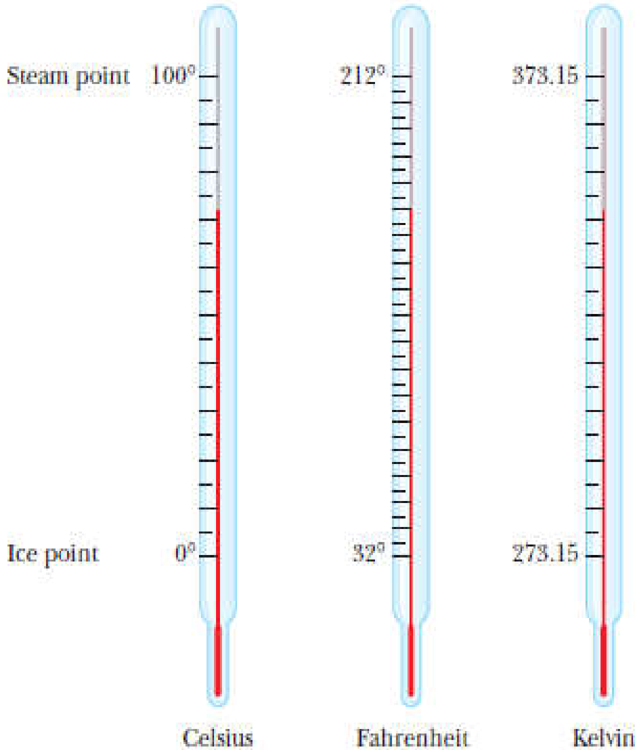
Thermometers and Temperature scales

- When a thermometer is in thermal contact with a system, energy is exchanged until the thermometer and the system are in thermal equilibrium with each other.
- For accurate readings, the thermometer must be much smaller than the system, so that the energy the thermometer gains or loses doesn’t significantly alter the energy content of the system.
- Some physical property that changes with temperature and can be calibrated to make the temperature measurable are:

- the volume of a liquid
- the length of a solid
- the pressure of a gas held at constant volume
- the volume of a gas held at constant pressure
- the electric resistance of a conductor, and
- the color of a very hot object.



Schematic diagram of a mercury thermometer. Because of thermal expansion, the level of the mercury rises as the temperature of the mercury changes from 0^oC (the ice point) to 100^oC (the steam point).

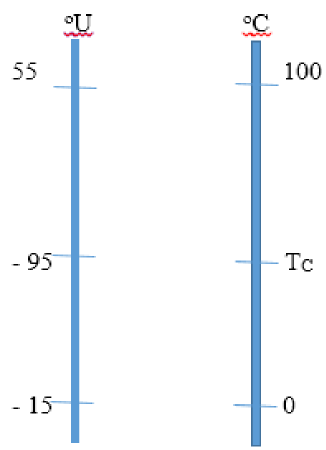


A comparison of the Celsius, Fahrenheit, and Kelvin temperature scales.

To convert one temperature scale to another use the relation:

$$\frac{Boiling.pt - freezing.pt}{reference.pt - freezing.pt} = cons\tan t$$

- Example 1: A student in Uniosun describe a temperature scale called U on which the boiling point of water is 55.0 °U and the freezing point is – 15 °U. To what temperature on the Celsius scale would a temperature of T = –95.0 °U correspond?



$$\frac{55 - -15}{-95 - -15} = \frac{100 - 0}{T_C - 0}$$

$$T_C = \frac{-8000}{70} = -114.3\,^{o}C$$

- Example 2: Suppose on a linear temperature scale A, water boils at – 55.0 ºA and freezes at – 160 ºA. What is a temperature of 350 K on the A scale?

$$\frac{-55--160}{T_A--160}=\frac{373-273}{340-273}$$

$$T_A=-90^o A$$

- Example 3: At what temperature is the Fahrenheit scale reading equal to that of Celsius scale?

$$\frac{212 - 32}{T - 32} = \frac{100}{T}$$

$$180\ T = 100\ T - 3200$$

$$T = -40$$

Thermal Expansion of Solids and Liquids

- Physical properties (e. g. length, area and volume) of some substances change with their temperature change. This phenomenon, known as **thermal expansion,** plays an important role in numerous applications.
- For the change in linear dimension, the new length can be calculated using

$$L = L_o + \alpha L_o \Delta T$$

- where L is the new length, L_o is the initial length, α is the proportionality constant called average coefficient of linear expansion for a given material and ΔT is the change in temperature.

- If the linear dimensions of an object change due to changes in its temperature, then the surface area and volume of the object also change. The new area can be calculated from

$$A = A_o + \beta A_o \Delta T$$

where $\beta = 2\alpha$ is the average coefficient of area expansion while the new volume can be calculated from

$$V = V_o + \gamma V_o \Delta T$$

where $\gamma = 3\alpha$ in the average coefficient of volume expansion.

- Example 4: An oil trucker loaded 33000 L of diesel fuel and travel with it to a location where the temperature difference is – 23 °C to deliver his entire load. How many liters did he deliver? The coefficient of volume expansion for diesel fuel is $9.50\ x\ 10^{-4}$.

$$V = V_o + \gamma V_o \Delta T$$

$$V = 33000L + (9.50x10^{-4}\ /^o\ C)(33000L)(-23^o C)$$

$$= 32279L$$

- Example 5: A circular metal ring at 30.0 ^oC has a hole with a radius of 2.0 cm. What minimum temperature must it have so that it can be slipped onto a steel metal rod having a cross-sectional area of 12.6 cm^2. Average coefficient of linear expansion, α, for the metal is 17 *x* 10^{-6} ^oC.

$$A_o = \pi r^2 = \frac{22}{7} x(2.0)^2 = 12.57\,cm^2$$

$$A = 12.6cm^2, \beta = 2\alpha = 34 \times 10^{-6o} C$$

$$\Delta A = \beta A_o \Delta T;$$

$$\Delta T = \frac{\Delta A}{\beta A_o} = \frac{A - A_o}{\beta A_o} = 70.2^o C$$

$$T = \Delta T + T_o = 100.2^o C$$

- Example 6: An aluminum-alloy rod has a length of 10.000 cm at 20.000°C and a length of 10.015 cm at the boiling point of water. What is the length of the rod at the freezing point of water?

First, determine the average coefficient of linear expansion of the alloy

$$\Delta L = \alpha L_o \Delta T$$

$$\alpha = \frac{\Delta L}{L_o \Delta T} = 1.875 \times 10^{-5} (^o C)^{-1}$$

At the freezing point of water the length of the rod will be

$$L = L_o + \alpha L_o \Delta T$$

$$L = 10.000\,cm + 1.875 \times 10^{-5} (^o C)^{-1} \times 10.000\,cm \times -20^o C$$

$$L = 9.996\,cm$$

Week 2:MACROSCOPIC DESCRIPTION OF AN IDEAL GAS

- The quantities volume V, pressure P and Temperature T are related for a sample of gas of mass m by equation of state. In general, the equation of state is very complicated but if the gas is maintained at a very low pressure (or low density) the equation of state become quite simple.
- The number of mole *n* of a substance is related to its mass *m* through the expression

$$n = \frac{m}{M}$$

- where *M* is the molar mass of the substance express in *g/mol*.

- For an ideal gas, equation of state is

$$PV = nRT$$

R (=8.31 J/mol.K) is the universal gas constant.

Example 7

- An ideal gas occupies a volume of 200 cm^3 at 293 K and a pressure of 1.5 x 10^2 Pa. Find the number of moles of gas in the container. And the new temperature if the volume of the container is doubled while the pressure falls to 1.0 x 10^2 Pa.

$$n = \frac{PV}{RT} = \frac{(1.5\times10^2 Pa)(2\times10^{-4} m^3)}{(8.31 J/mol.K)(293K)} = 1.23\times10^{-5} mol$$

For the new temperature;

$$nR = \frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

$$\Rightarrow T_f = \frac{P_f V_f}{P_i V_i} T_i = \frac{(1.0\times10^2\, Pa)(4\times10^{-4}\, m^3)(293K)}{\left(1.5\times10^2\, Pa)(2\times10^{-4}\, m^3\right)}$$

$$= 391K$$

- Example 8:A mole of oxygen gas is at a pressure of 1.01 x 10^5 Pa and a temperature of 27.0°C. (a) If the gas is heated at constant volume until the pressure doubles, what is the final temperature? (b) If the gas is heated until both the pressure and the volume are doubled, what is the final temperature?

$$\frac{nR}{V} = \frac{P_i}{T_i} = \frac{P_f}{T_f}$$

$$\Rightarrow T_f = \frac{P_f T_i}{P_i} = \frac{2 \times (1.01 \times 10^5 \, Pa)(27 + 273K)}{1.01 \times 10^5 \, Pa}$$

$$= 600K$$

$$nR = \frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

$$\Rightarrow T_f = \frac{P_f V_f}{P_i V_i} T_i = \frac{2 \times (1.01 \times 10^5 \, Pa) \times 2V_i \times (27 + 273K)}{(1.01 \times 10^5 \, Pa) \times V_i}$$

$$= 1200K$$

- **Tutorial questions (Due for submission on/ before 72 hours from the time posted):**

➢ Thermal equilibrium is a situation in which two objects in thermal contact (A) would exchange energy. (B) transfer energy to one another (C) convert heat energy to another form of energy. (D) obey first law of thermodynamics. (E) would not exchange energy by heat or electromagnetic radiation.

➢ Suppose you empty a tray of ice cubes into a bowl partly full of water and cover the bowl. After an hour, the content of the bowl come to thermal equilibrium, with more liquid water and less ice than you started stated with. Which of the following is true? (A) The temperature of the liquid water will be higher than the temperature of the remaining ice. (B) The temperature of the liquid water will be lesser than the temperature of the remaining ice (C) The comparative temperatures of the liquid water and ice depend on the amounts present. (D) The temperature of the remaining ice will be greater than that of the liquid water. (E) None of the above

- A UNIOSUN student puts $1.0 \, x \, 10^{-2}$ kg of water in a 2.00 L pressure cooker and heats it to 470 ^{o} C. What is the pressure inside the container? Universal gas constant (R) = 8.31 J/mol.K.
- The temperature on Celsius and Fahrenheit scales will have the same value at T equal to _
- At what temperature on the Fahrenheit scale will the temperature on the Celsius scale be exactly half the value of that of the Fahrenheit scale?
- A scientist in Uniosun describe a temperature scale called U on which the boiling point of water is 75.0 ^{o}U and the freezing point is – 15 ^{o}U. To what temperature on the Fahrenheit scale would a temperature of T = –95.0 ^{o}U correspond?

HEAT AND INTERNAL ENERGY

- Internal energy is all the energy of a system that is associated with its microscopic components — atoms and molecules, while heat is the transfer of energy between a system and its environment due to a temperature difference between them.
- The SI unit of heat being a form energy is Joule (J)
- **SPECIFIC HEAT**
- Specific heat ***c*** is the energy per unit mass required to change the temperature of a substance by 1 ^{o}C.

$$c = \frac{Q}{m\,\Delta\,T}$$

- where Q is the heat energy required to change the temperature of a body, m is the mass of the body and ΔT is the temperature change.
- The SI unit of specific heat is J/kg. ^{o}C.

Latent heat and Phase Change

The energy Q required to change the phase of a given pure substance can be determined using $$\boldsymbol{Q = \pm mL}$$

Where L called the **latent heat** of the substance and it depends on the nature of the phase change as well as on the substance.

The unit of latent heat is the joule per kilogram (J/kg). The positive sign in the above equation is chosen when energy is absorbed by a substance, as when ice is melting. The negative sign is chosen when energy is removed from a substance, as when steam condenses to water

The **latent heat of fusion** $(\boldsymbol{L_f})$ is used when a phase change occurs during melting or freezing, while the **latent heat of vaporization** $(\boldsymbol{L_v})$ is used when a phase change occurs during boiling or condensing.

Example 9: An aluminum rod of mass 300 g is 20.0 cm long at 20°C. If 10 kJ of energy is added to the rod by heat, what is the change in length of the rod?

Solution:

First determine the new temperature of the rod

$$Q = mc\Delta T = (0.3kg)(900\,J/kg.^{o}C) * \Delta T$$

$$\Delta T = \frac{10000\,J}{270\,J/^{o}C} = 37.0^{o}C$$

$$T_f = (37 + 20)^{o}C = 57^{o}C$$

Then the change in length can be determine from

$$\Delta L = \alpha L_o \Delta T = (24 \times 10^{-6} /^o C)(0.2m)(37.0^0 C) = 1.78 \times 10^{-4} m$$
$$= 1.78 \times 10^{-2} cm$$

- Example 10: A 1.50-kg iron initially at 600°C is dropped into a bucket containing 20.0 kg of water at 25.0°C. What is the final temperature? (Assume the heat capacity of the container is negligible)

$$m_{Fe} c_{Fe} \Delta T + m_w c_w \Delta T = 0$$
$$1.5kg \times 448 J / kg.^o C(600 - T) + 20kg \times 4186 J / kg.^o C(25 - T) = 0$$
$$2{,}496{,}200 = 84392T$$
$$\Rightarrow T = 29.6^o C$$

- Example 11: How much heat is lost in turning 20.0 g of steam at 105 °C to dry ice at – 5 °C? Specific heat of ice = 2090 J/kg.°C, Specific heat of water = 4186 J/kg.°C, Specific heat of steam = 2010 J/kg.°C; L_v and L_f of water are 2.26×10^6 J/kg and 3.33×10^5 J/kg respectively.

➢ Let Q_1 = heat lost in lowering the temperature of steam from 105 °C to 100 °C = $m_s c_s \Delta T$

➢ Let Q_2 = heat lost in turning steam to water at 100 °C = mL_v

➢ Let Q_3 = heat lost in lowering the temperature of water from 100 °C to 0 °C= $m_w c_w \Delta T$

➢ Let Q_4 = heat lost in turning water to ice at 0 °C = mL_f

➢ Let Q_5 = heat lost in lowering the temperature of ice from 0 °C to – 5 °C = $m_i c_i \Delta T$

➢ The total heat lost = $Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$

Note

$$Q_1 = 0.02\,kg \times 2010\ J/kg \times 5^{o}C = 201\,J$$

$$Q_2 = 0.02\,kg \times 2.26 \times 10^{6}\,J/kg = 4.5 \times 10^{4}\,J$$

$$Q_3 = 0.02\,kg \times 4186\ J/kg.^{o}C \times 100\ ^{o}C = 8372\ J$$

$$Q_4 = 0.02\,kg \times 3.33 \times 10^{5}\,J/kg = 6.66 \times 10^{3}\,J$$

$$Q_5 = 0.02\,kg \times 2090\ J/kg \times 5^{o}C = 209\,J$$

$$Q = 6.04 \times 10^{4}\,J$$

- **Tutorial questions (Due for submission on/ before 72 hours from the time posted):**

➢ A steel rod near a blacksmith furnace is 1.00 m long, with a mass of 1.7 kg and cross-sectional area of $1.00 \; x \; 10^{-4}$. If the rod absorbs $4.0 \; x \; 10^{3}$ J. Find the increase in length of the rod.

➢ What mass of steam initially at 130°C is needed to turn 100 g of ice in a 50-g glass container to water at 50.0°C?

➢ The active element of a certain laser is made of glass rod 30.0 cm long and 1.50 cm in diameter. What will be the increase in its volume if the temperature of the rod is increased by 70.0 ^{o}C?

➢ A copper electric wire has essentially no sag between poles 20.0 m apart on a cold day when the temperature is – 5.0 ^{o}C. How much longer is the wire on a hot day when the temperature is 42.0 ^{o}C?

Recommended Text

- Physics for Scientist and Engineers with Modern Physics, Seventh Edition by John W. Jewett, Jr. and Raymond A. Serway
- Schaum's Series Outline, College Physics, Ninth Edition BY Frederick J. Bueche and Eugene Hecht.