LESSON 4.1 – Understanding thermal equilibrium

The difference between Temperature And Heat

<table>
<thead>
<tr>
<th>Temperature, T/θ</th>
<th>Heat, Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the degree of hotness of a body</td>
<td>Is a form of energy</td>
</tr>
<tr>
<td>Is a base quantity</td>
<td>Is a derived quantity</td>
</tr>
<tr>
<td>Depends upon the kinetic energy of the molecules</td>
<td>Depend upon temperature, mass and type of material (specific heat capacity or specific latent heat) (Q = mcθ or Q = ml)</td>
</tr>
<tr>
<td>The S.I. unit is K or °C</td>
<td>The S.I. unit is Joule(J)</td>
</tr>
<tr>
<td>Measured by thermometer</td>
<td>Measured by Joulemeter</td>
</tr>
</tbody>
</table>

Kelvin Scale (K)

The temperature of a substance in Kelvin, also known as absolute temperature.

\[ θ °C = (θ + 273) K \]

Example 1

Convert 120° C to its equivalent temperature in Kelvin.

Solution

Thermal Contact

Two substances are said to be in thermal contact, when heat flows from one substance to another it is in contact with. Heat flows according to temperature differences i.e. from substance hot to cold substance.

The principle of thermal equilibrium

Two bodies in thermal contact are said to be in thermal equilibrium when they reach the same temperature and the net rate of heat transfer between the two bodies is zero.

How a liquid in glass thermometer works?

When a thermometer is in thermal contact with a substance (for example hot water), heat flows from the hot water to the thermometer (mercury). When thermal equilibrium is reached, the net rate of heat transfer between the two substances is zero. The temperature of the thermometer is the same as the temperature of the hot water. Hence by showing its own temperature, the thermometer also reads the temperature of the hot water.
LESSON 4.1 - Understanding Thermal Principle

**Basic principle to construct a thermometer.**

Two important principles to construct a thermometer are.

1. **Specific thermometric property** i.e. a physical quantity which varies with temperature.
   - The table shows four different types of thermometers:

<table>
<thead>
<tr>
<th>Thermometer</th>
<th>Thermometric property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury thermometer</td>
<td>Volume of mercury varies with temperature</td>
</tr>
<tr>
<td>Resistance thermometer</td>
<td>Electrical resistance of a wire varies with temperature</td>
</tr>
<tr>
<td>Thermocouple thermometer</td>
<td>Electromotive force (e.m.f) varies with temperature</td>
</tr>
<tr>
<td>Gas thermometer</td>
<td>Gas pressure varies with temperature</td>
</tr>
</tbody>
</table>

2. **Calibration of thermometer** i.e the process of marking-up a scale on a thermometer.

   To produce a scale for a thermometer, two fixed points of thermometer must first be selected.
   a) Lower fixed point (0°C) – is the melting temperature of pure ice at standard atmospheric pressure.
   b) Upper fixed point (100°C) – is the temperature of steam at standard atmospheric pressure.

**Calibration of a Mercury-in-glass Thermometer on the Celsius Scale**

Freeze some pure water.
Crush the ice into small and fill a funnel with them.
When the ice begins to melt, inset the bulb of a thermometer so that it is covered with ice.
When the mercury stops shrinking, mark the stem of the thermometer at the mercury level, as 0°C.
Now arrange the thermometer inside a flask so that its bulb is just above the surface of boiling water.
When the mercury stops expanding, mark its level on the thermometer stem, as 100°C.
Divide the distance between the marks 0°C and 100°C into 100 equal parts, marked as a scale along the stem.

**The formula is used to calibrate a thermometer**

\[
\theta = \frac{(X - X_0) + (X_{100} - X_0)}{X_{100} - X_0} \times 100^\circ C
\]

\[\theta = \text{temperature of a substance} \]
\[\theta_0 = \text{ice point} \]
\[\theta_{100} = \text{steam point} \]
\[X_0 = \text{the length of the mercury column at ice point} \]
\[X_{100} = \text{the length of the mercury column at steam point} \]
\[X = \text{the length of the mercury column when the thermometer is placed in a substance} \]
Example 2

The lengths of the mercury column in a thermometer at the ice point and the steam point are 12 cm and 20 cm respectively. When the thermometer is placed in a liquid, the length of the mercury column is 15 cm. What is the temperature of the liquid?

Solution

Example 3

The lengths of the mercury thread in a thermometer are 4.0 cm and 24.0 cm respectively at 0°C and 100°C. What is the length of the thread when the thermometer is placed in a substance at 65°C.

Solution

Mercury Thermometer

The specific thermometric property used in this thermometer is the changes of the volumes of mercury with the temperature i.e when the temperature increases, the volume of the mercury increases.

The sensitivity of the thermometer can be increased by
1. using a thinner-walled glass bulb
2. reducing the diameter of the capillary tube

Mercury is used in the thermometer because
1. has a higher boiling point
2. does not stick to the glass
3. is opaque and therefore it is easier to read.
4. expands and contracts uniformly
TUTORIAL 4.1

1. Which of the following is true?
   A. The unit of heat is °C
   B. Heat is a form of energy
   C. Heat flows from a cold substance to a hot substance.

2. Heat and temperature are
   A. forms of energy
   B. scalar quantities
   C. measured in the S.I.units
   D. measured by the same instrument.

3. 0°C is equivalent to
   A. -273 K
   B. -173 K
   C. 100 K
   D. 273 K
   E. 373 K

4. An earth-monitoring satellite falls into the earth’s atmosphere at a high velocity and reaches at the sea surface with a high temperature. After a while the temperature of the satellite is same as the temperature of the sea water. This is caused by
   A. The heat released by the satellite
   B. The heat absorbed by the sea water
   C. The satellite is cooled by the sea water
   D. The satellite and the sea water are in thermal equilibrium

5. The diagram shows a metal sphere P at 80°C is immersed in a cooler liquid Q.

   ![](image)

   Thermal equilibrium is reached when
   A. temperature of P = temperature of Q
   B. mass of Q displaced = mass of P
   C. volume of Q = volume of P
   D. specific heat capacity of P = specific heat capacity of Q

6. The diagram shows two copper blocks, L and M, touching each other. The initial temperatures of L and M are 50°C and 30°C respectively.

   ![](image)

   Which statement is correct when L and M are at thermal equilibrium?
   A. Temperature of L is higher than M
   B. The quantity of heat in L is the same as in M
   C. Rate of change in temperature of L is bigger than that of M
   D. Net rate of heat flow between L and M is zero

7. The diagram shows object A and object B are of temperatures T₁ and T₂. The heat flows from A to B until the thermal equilibrium is reached at a temperature T.

   ![](image)

   Which relationship between T₁, T₂ and T is true?
   A. T₁ > T₂ > T
   B. T₂ > T₁ > T
   C. T₁ > T > T₂
   D. T₂ > T > T₁

8. Which principle is used in a Mercury thermometer?
   A. Principle of conservation of temperature
   B. Principle of conservation of energy
   C. Principle of thermal equilibrium
   D. Principle of the forces in equilibrium
9. The physical quantity which varies with temperature is called as
A. Latent heat of fusion
B. Latent heat of vapourization
C. Specific heat capacity
D. Specific thermometric property

10. Which of the following is true?

<table>
<thead>
<tr>
<th>Thermometer</th>
<th>Thermometric Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Mercury thermometer</td>
<td>Volume mercury varies with temperature</td>
</tr>
<tr>
<td>B Thermocouple thermometer</td>
<td>Potential difference varies with temperature</td>
</tr>
<tr>
<td>C Gas thermometer</td>
<td>Gas density varies with temperature</td>
</tr>
<tr>
<td>D Resistance thermometer</td>
<td>Electromotive force varies with temperature</td>
</tr>
</tbody>
</table>

11. Regarding to the fixed points in the Celsius scale of a mercury thermometer, which of the following is true?

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Lower fixed point</th>
<th>Upper fixed point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>the freezing point of mercury</td>
<td>the boiling point of mercury</td>
</tr>
<tr>
<td>B</td>
<td>the boiling point of mercury</td>
<td>the freezing point of mercury</td>
</tr>
<tr>
<td>C</td>
<td>the freezing point of water</td>
<td>the boiling point of water</td>
</tr>
<tr>
<td>D</td>
<td>the boiling point of water</td>
<td>the freezing point of water</td>
</tr>
</tbody>
</table>

12. The lengths of the mercury column in a thermometer at the ice point and the steam point are 5 cm and 25 cm respectively. When the thermometer is placed in a liquid, the length of the mercury column is 12 cm. What is the temperature of the liquid?

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 30 °C</td>
<td>35 °C</td>
</tr>
<tr>
<td>C 55 °C</td>
<td>70 °C</td>
</tr>
<tr>
<td>E 85 °C</td>
<td></td>
</tr>
</tbody>
</table>

13. The lengths of the mercury thread in a thermometer are 8 cm and 20 cm respectively at 0°C and 100°C. What is the length of the thread when the thermometer is placed in a substance at -25°C?

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 4 cm</td>
<td></td>
</tr>
<tr>
<td>B 5 cm</td>
<td></td>
</tr>
<tr>
<td>C 10 cm</td>
<td></td>
</tr>
<tr>
<td>D 12 cm</td>
<td></td>
</tr>
<tr>
<td>E 16 cm</td>
<td></td>
</tr>
</tbody>
</table>

14. A thermometer which is not calibrated is marked 200 small divisions between ice point and steam point. When the thermometer is inserted into a liquid, the level of the mercury at mark 120. What is the temperature of the liquid?

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Lower fixed point</th>
<th>Upper fixed point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 253 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 313 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 333 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 353 K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E 373 K</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15. A resistance thermometer has a resistance of 100 Ω at the steam limit and 75 Ω at the ice limit. When the thermometer is inserted in a substance, the resistance is 40 Ω. What is the temperature of the substance?

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Lower fixed point</th>
<th>Upper fixed point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A -240 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B -80 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 80 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 240 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E 300 °C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16. Which liquid A, B, C or D, can be used to make a liquid-in-glass thermometer to measure temperatures from -50°C to 50°C?

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Lower fixed point</th>
<th>Upper fixed point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A -115 °C</td>
<td></td>
<td>78</td>
</tr>
<tr>
<td>B -39 °C</td>
<td></td>
<td>357</td>
</tr>
<tr>
<td>C 0 °C</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>D 17 °C</td>
<td></td>
<td>118</td>
</tr>
</tbody>
</table>

17. The diagram shows a thermometer.
Which modification will increase the sensitivity of the thermometer?

A. Using a longer capillary tube
B. Using a bulb with a thicker wall
C. Using a glass stem with a thicker wall
D. Using a narrower bore of capillary tube

18 Mercury is used in the thermometer because it

A. sticks to the glass
B. has a lower boiling point
C. expands and contracts uniformly
D. is transparent and therefore it is easier to read.

19 The figure shows a mercury thermometer.

(a) Name component
- P...............................................................
- Q..............................................................

(b) What principle is used in a Mercury thermometer?

..................................................................

(c) State the thermometric property used when making of the thermometer?

..................................................................

(d) The lengths of the mercury thread in the thermometer are 12 cm and 20 cm respectively at 0°C and 100°C. What is
(i) the length of the thread when the thermometer is placed in a substance at 20°C.

(ii) the temperature when the thermometer is placed in the substance caused the length of the mercury thread is 7 cm.

<table>
<thead>
<tr>
<th>Thermometer</th>
<th>Liquid used</th>
<th>Glass-walled bulb</th>
<th>Diameter of capillary tube</th>
<th>Glass-bore stem and cross-section</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>mercury</td>
<td>thin</td>
<td>big</td>
<td>thick and curved</td>
</tr>
<tr>
<td>Q</td>
<td>mercury</td>
<td>thick</td>
<td>small</td>
<td>thin and plane</td>
</tr>
<tr>
<td>R</td>
<td>mercury</td>
<td>thin</td>
<td>small</td>
<td>thin and curved</td>
</tr>
<tr>
<td>S</td>
<td>alcohol</td>
<td>thick</td>
<td>big</td>
<td>thick and plane</td>
</tr>
<tr>
<td>T</td>
<td>alcohol</td>
<td>thin</td>
<td>small</td>
<td>thick and curved</td>
</tr>
<tr>
<td>U</td>
<td>alcohol</td>
<td>thick</td>
<td>small</td>
<td>thin and plane</td>
</tr>
</tbody>
</table>

Additional information:
- Freezing point of mercury = -39°C  Boiling point of mercury = 360°C
- Freezing point of alcohol = -112°C  Boiling point of alcohol = 78°C

20 You are representing the country in carrying out a research project on the weather at the North Pole. The surrounding temperature is between -40°C to -8°C. One item of the equipment to be taken for your research is a thermometer.

(a) State the principle used in a liquid–glass thermometer.

(b) State how a liquid-glass thermometer can be used to measure the body temperature of a sick person. Explain heat transfer that takes place at each stage of measurement.

(c) The table shows the characteristics of six types of thermometers P, Q, R, S, T and U.

Based on the table above;
LESSON 4.1 - Understanding Thermal Principle

(i) Explain the suitable characteristics of the thermometer so that can be used to measure temperatures at the North Pole.

(ii) Decide which thermometer is most suitable to be taken for your research and give reasons.

(b) A thermometer which is not calibrated has a mercury column of length 8.0 cm when the temperature is 0°C and 20.0 cm when the temperature is 100°C. The mercury column is 5.0 cm when put in liquid X.

(i) Determine the temperature of liquid X in Kelvin.

(ii) State a thermometric property used when making of a thermometer.