UNIT G484	Module 3	4.3.2	Temperature

- ***Candidates should be able to*** :

  - ***Explain*** *that thermal energy is transferred from a region of **higher temperature** to a region of **lower temperature**.*

  - ***Explain*** *that regions of **equal** temperature are in **thermal equilibrium**.*

  - ***Describe*** *how there is an **absolute scale of temperature** that does not depend on the property of any particular substance (i.e. the **thermodynamic scale** and the concept of **absolute zero**).*

  - ***Convert*** *temperatures measured in **Kelvin to degrees Celcius** (or vice versa) :*

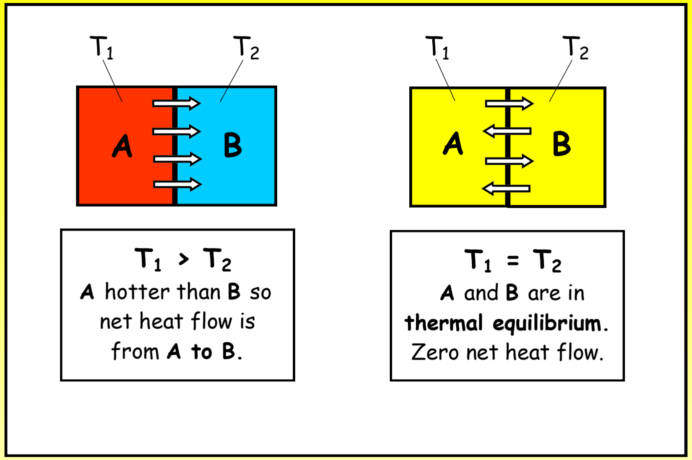
    $$T\ (K) = \theta\ (^{\circ}C) + 273.15$$

  - *State that **absolute zero** is the temperature at which a substance has **minimum internal energy**.*

DEFINING TEMPERATURE IN TERMS OF THERMAL EQUILIBRIUM

TEMPERATURE *is a term which we commonly use to describe how **hot** or **cold** an object is. It is sometimes defined as the **degree of hotness (or coldness)** of a system. However, using the physiological sensation of hotness is rather non-scientific, since how hot an object feels when touched depends not only on the person's sense of touch, but also on the material of the object. For example, what you describe as hot might only feel warm to me and the metal parts of a school desk feel much cooler than the wooden lid and yet they are at the same temperature.*

*The best way to define temperature is to use the idea of **thermal energy flow resulting from a temperature difference** in much the same way as liquid or gas flow is caused by a pressure difference.*

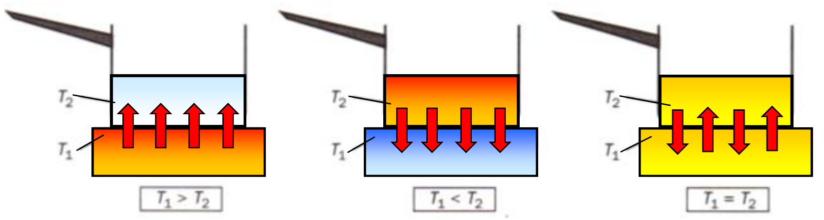


*If two objects **A** and **B**, initially at different temperatures T_1 and T_2 are placed in thermal contact, **there is a net flow of heat (thermal energy) from the object at the higher temperature to that at the lower temperature.***

*In this way object **B gains** heat energy while object **A loses** it and this continues until the **temperatures equalise.***

*There is then no further net transfer of heat and the two objects are said to be in **THERMAL EQUILIBRIUM.***

The diagram shown below illustrates the idea of heat flow and thermal equilibrium between two objects in contact.



(a) Pan gains heat and becomes hotter.

(b) Pan loses heat and becomes colder.

(c) Pan and plate are at the same constant temperature. Thermal equilibrium.

*In **(a)** a pan containing water is placed on a **very hot** metal plate. **Heat flows from the plate to the pan,** which becomes hotter, so the **temperature (T_1) of the plate must be greater than that of the pan (T_2).***

*In **(b)** the pan containing the hot water has been placed on a very cold metal plate. The **temperature (T_1) of the plate is very much less than that of the pan (T_2), so heat flows from the pan to the plate and the pan gets cooler.***

*After some time **the rate of heat flow from the pan to the plate becomes Equal to the rate of heat flow from the plate to the pan.***
*The **temperatures of the pan and plate are then the same** and the two objects are said to be in **THERMAL EQUILIBRIUM**.*

*Our discussion so far leads to the following definition of **TEMPERATURE** :*

TEMPERATURE is that property which determines whether or not one object is in thermal equilibrium with another.

TEMPERATURE SCALES

- *The temperature of an object depends on its **nature**, its **mass** and **the amount of thermal (heat) energy which has been supplied to it or extracted from it.***

- *Temperature is measured with a **THERMOMETER** calibrated on a suitable **TEMPERATURE SCALE**.*

- *All thermometers measure temperature by measuring a particular **THERMOMETRIC PROPERTY** of a substance whose value changes with temperature (e.g. a mercury-in-glass thermometer uses the variation in the length of a mercury column contained in a capillary tube, whereas a thermistor uses the change in electrical resistance of a semiconductor with temperature).*

- *A temperature scale is defined in terms two **FIXED POINTS** which are standard degrees of hotness which can be accurately reproduced. The interval between the two fixed points, called the **FUNDAMENTAL INTERVAL**, then defines temperature on the scale.*

THE CELCIUS SCALE

On this scale :

- *The **unit** of measurement is the :*

DEGREE CELCIUS (°C)

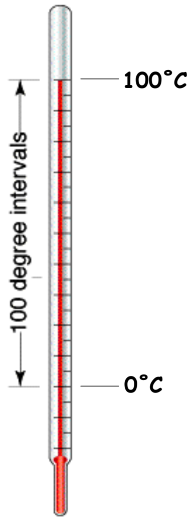
*and the **symbol** used for temperature is :*

θ *(greek letter 'Theta')*

- *The **two fixed points** are :*

The STEAM POINT (100°C) which is the temperature at which steam and pure boiling water are in equilibrium at standard atmospheric pressure *.

The ICE POINT (0°C) which is the temperature at which pure ice can exist in equilibrium with water at standard atmospheric pressure *.



CELCIUS SCALE

* Standard atmospheric pressure (STP) = 1.013 x 10^5 Pa (N m^{-2}).

SOME COMMON THERMOMETERS

When deciding which type of thermometer is most suitable for a specific temperature measurement, many factors, such as accuracy, sensitivity, range, speed of response, size etc. need to be considered.

*The table below shows some commonly used thermometers with their **thermometric property, range, advantages and disadvantages.***

Thermometer	Range	Thermometric property	Advantages	Disadvantages
Liquid-in-glass	-20 to +350°C for mercury. -100 to +50°C for ethanol.	Length of mercury or ethanol column in a capillary tube.	Simple, direct reading, cheap, compact.	Limited range, fragile, slow response, large heat capacity.
Constant-volume gas	-250 to +1500°C	Pressure of fixed mass of gas at constant volume.	Extremely accurate, very wide range, very sensitive.	Bulky, not direct reading, slow response.
Platinum resistance	-200 to +1200°C	Electrical resistance of a platinum coil.	Very accurate, very wide range, very sensitive.	Bulky and inconvenient to use, slow response.
Thermistor	-50 to +300°C	Electrical resistance of a semiconductor.	Very sensitive, cheap, robust, excellent response.	Not as accurate as other resistance types, non-linear.
Thermocouple	Up to +1700°C	Electrical p.d. between two different metals in contact.	Accurate, wide range, compact and robust, good for small objects, very good response.	Sensitive electrical equipment has to be used because p.d. is small.

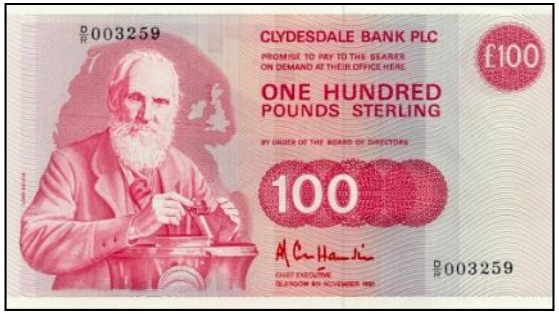
COMPARISON OF TEMPERATURE SCALES

Each of the thermometers we have considered defines its own unique temperature scale according to the thermometric property it is based on.

*Except at the fixed points where, by definition, they agree, thermometers using different thermometric properties may give different temperature readings when placed in the same environment. This is because **different thermometric properties vary differently with temperature.***

*For example, if the top of the mercury thread in a liquid-in-glass thermometer is exactly **half-way between the fixed points**, the reading indicated is **50°C** (i.e. exactly half the interval between 0°C and 100°C). However, the pressure reading on a constant-volume gas thermometer for the same temperature of **50°C** may **not be exactly half-way between the two fixed point pressures.** So the **temperature reading from the gas thermometer would differ slightly from the one obtained from the liquid-in-glass thermometer.***

*Both thermometers are correct according to their own scale, but the disagreement, though slight, means that a temperature reading is only justifiable in terms of the thermometer being used. In order to avoid such inconvenience, a temperature scale is needed which is **independent of any thermometric property.***



WILLIAM THOMSON (LORD KELVIN) - 1824 - 1907 who determined **ABSOLUTE ZERO** and the **KELVIN SCALE OF TEMPERATURE** is Commemorated on the back of this Scottish £100 note.

THE THERMODYNAMIC (KELVIN) SCALE

On this scale :

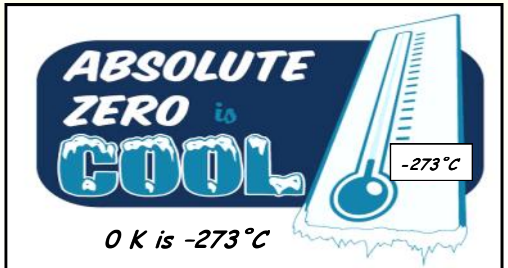
- *The **unit** of measurement is :* **KELVIN (K)**

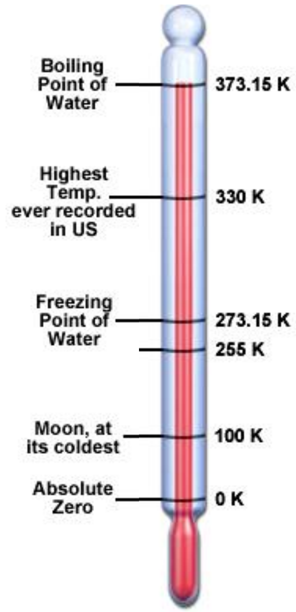
  *And the **symbol** used for temperature is :* **T**

- *The two **fixed points** are :*

TRIPLE POINT OF WATER (273.16 K) which is the temperature at which ice, water and water vapour exist in equilibrium.

ABSOLUTE ZERO (0 K) which is the lowest possible temperature. An object at absolute zero has *minimum internal energy* regardless of the substances it is made of.



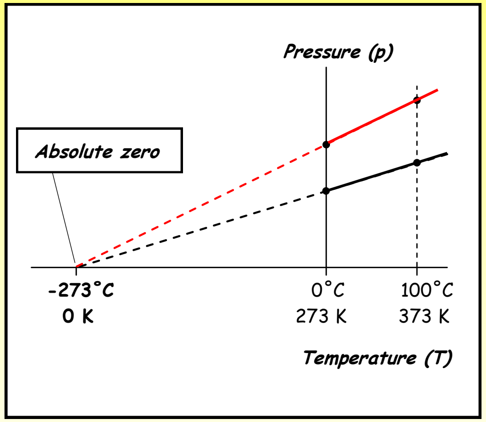


KELVIN SCALE

- *The **THERMODYNAMIC** (or **ABSOLUTE** or **KELVIN**) scale of temperature is a theoretical temperature scale based on the **ABSOLUTE ZERO** of temperature and the efficiency of an ideal heat engine.*

  *It is **absolute** in the sense that, unlike the **CELCIUS** scale which depends on the properties of a substance (water), it depends on the lowest possible temperature **(ABSOLUTE ZERO)**, which is a fundamental feature of nature.*

- *The pressure of a fixed mass of any gas in a sealed container of fixed volume is found to decrease when the temperature is reduced (as shown opposite).*



  *If the pressure is measured at 100°C and 0°C and the line joining these two points on the p/T graph is extended backwards from 0°C, it will cut the temperature axis at **-273°C**. This occurs for **any gas** and for **any mass of gas**.*

- *__ABSOLUTE ZERO__ **(0 K)** is the lowest temperature that **in theory** can be reached. We say **in theory** because although physicists have come very close to achieving it in practice (within 1 μK of 0 K), the quest for absolute zero is still ongoing.*

POINTS TO NOTE

- *A temperature of **1 KELVIN (1 K) is 1/273.16 of the temperature of the triple point of water** as measured on the absolute scale.*

- *To convert between the **CELCIUS** and the **ABSOLUTE** scales we use the following relationships :*

$$\theta/^\circ C = T/K - 273.15$$

$$T/K = \theta/^\circ C + 273.15$$

Using these equations :

  - ***ICE POINT,*** *0°C = 273.15 K.*
  - ***STEAM POINT,*** *100°C = 373.15 K.*
  - ***TRIPLE POINT OF WATER,*** *273.16 K = 0.01°C.*

- *The **KELVIN** is defined so that :*

A temperature change of 1 K is the same as a temperature change of 1°C.

UNIT G484	Module 2	4.3.2	Temperature

- HOMEWORK QUESTIONS

1 (a) **Using diagrams** to illustrate your answer, **explain** what is meant when we say that two objects in contact are in **THERMAL EQUILIBRIUM**.

(b) **Define TEMPERATURE.**

2 (a) What is a **THERMOMETRIC PROPERTY ?**

(b) Give **three** examples of thermometric properties.

(c) **Define** the two **FIXED POINTS** used in the **CELCIUS SCALE** of temperature.

(d) **Explain** why, except at the fixed points, different types of thermometer **may disagree slightly** when measuring the **same temperature**.

3 (a) Define the two **FIXED POINTS** used in the **THERMODYNAMIC (ABSOLUTE) SCALE** of temperature.

(b) Why is the **THERMODYNAMIC SCALE** described as **ABSOLUTE ?**

4 (a) Write down two equations which can be used to convert temperatures between the **CELCIUS** and the **THERMODYNAMIC SCALES**.

(b) Convert each of the following temperatures from the **CELCIUS SCALE** to the **KELVIN SCALE :**

20°C, 37°C, 500°C, -183°C

(c) Convert each of the following temperatures from the **KELVIN SCALE** to the **CELCIUS SCALE :**

20 K, 153 K, 300 K, 1500 K