THERMAL PHYSICS p1

Thermometry

What is Temperature?

- Temperature
  - Is something hot or cold?
  - Relative measure

Temperature is a **measure of the average kinetic energy** of the particles making up the substance being examined.

Temperature must not be confused with heat.

Heat is the amount of **vibrational energy contained in a particular mass**.

Temperature and Its Measurement

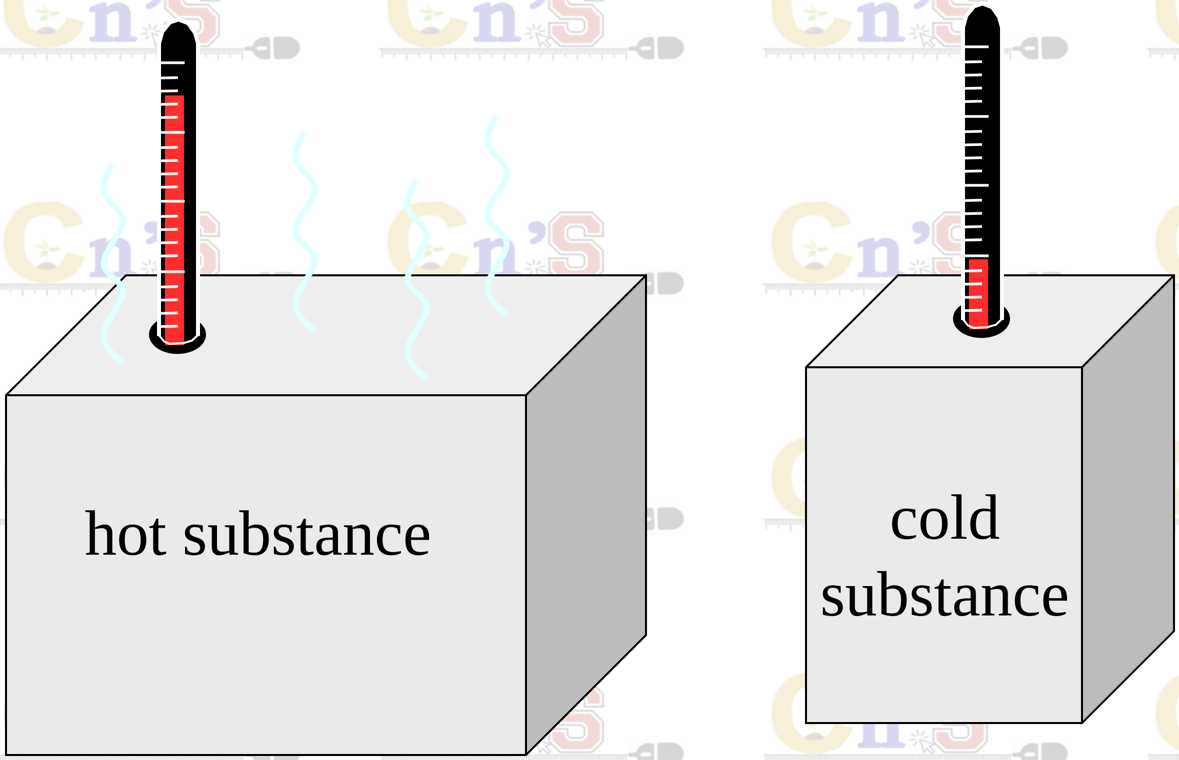
- How do we measure temperature?
- Thermometer: Device with a physical property that changes with temperature and can be easily measured quantitatively.
- If two objects are in contact with one another long enough, the two objects have the same temperature *(thermal equilibrium).*
- **Two or more objects in thermal equilibrium have the same temperature.**

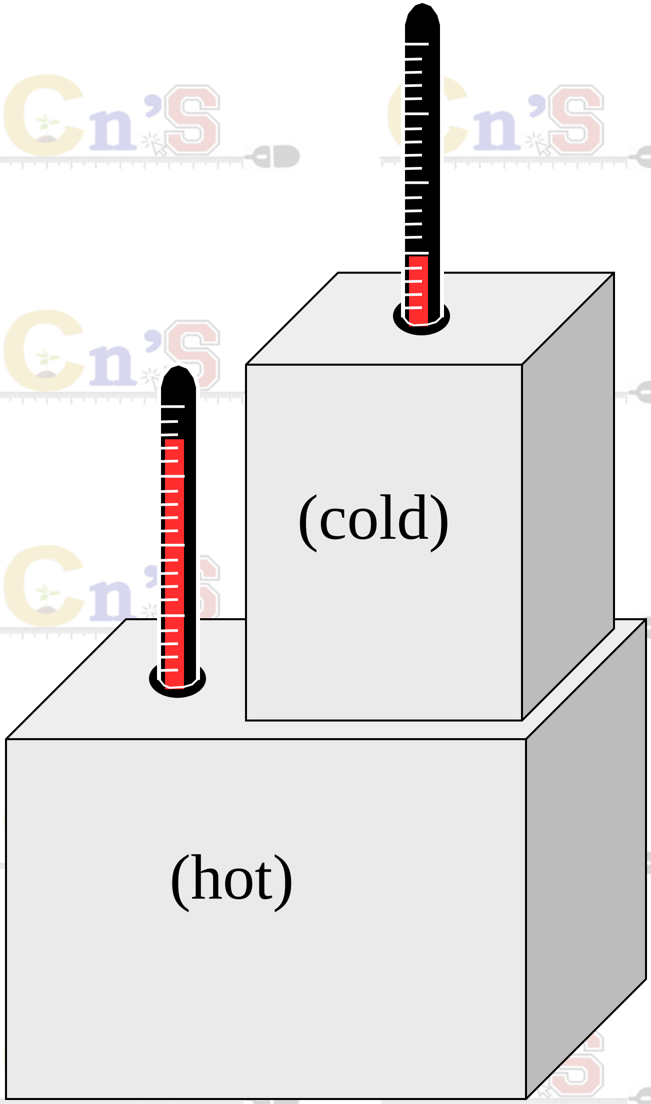
  Zeroth law of thermodynamics.

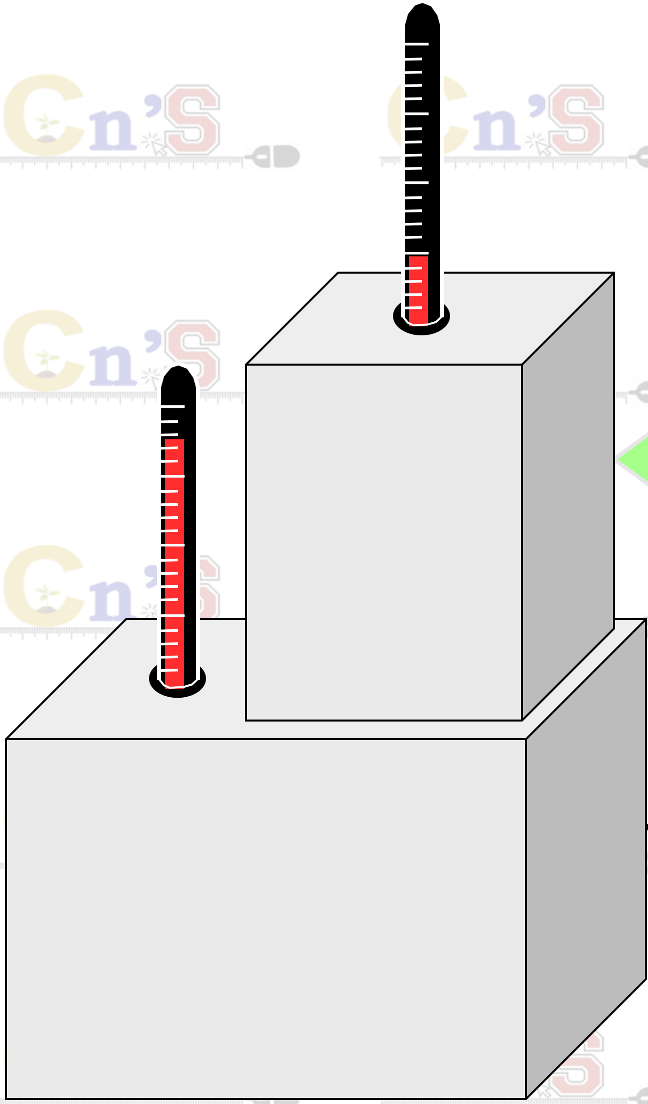
Zeroth Law of Thermodynamics

If A is in thermal equilibrium with B and B is in thermal equilibrium with C, A is in thermal equilibrium with C.

- allows definition of temperature
- objects at thermal equilibrium have same T
- Heat moves from high T to low T objects

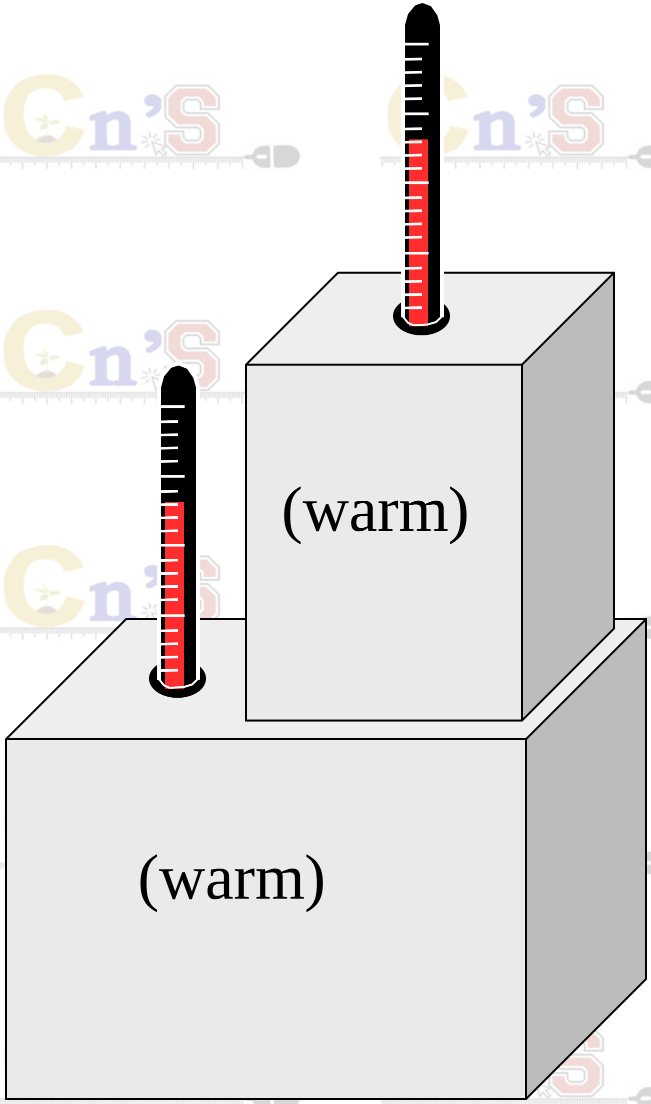

hot substance
cold
substance


(cold)
(hot)



What's going to happen to the temperature of the small block?

What's going to happen to the temperature of the large block?



Heat is a form of energy that flows from one object to another

Thermometers

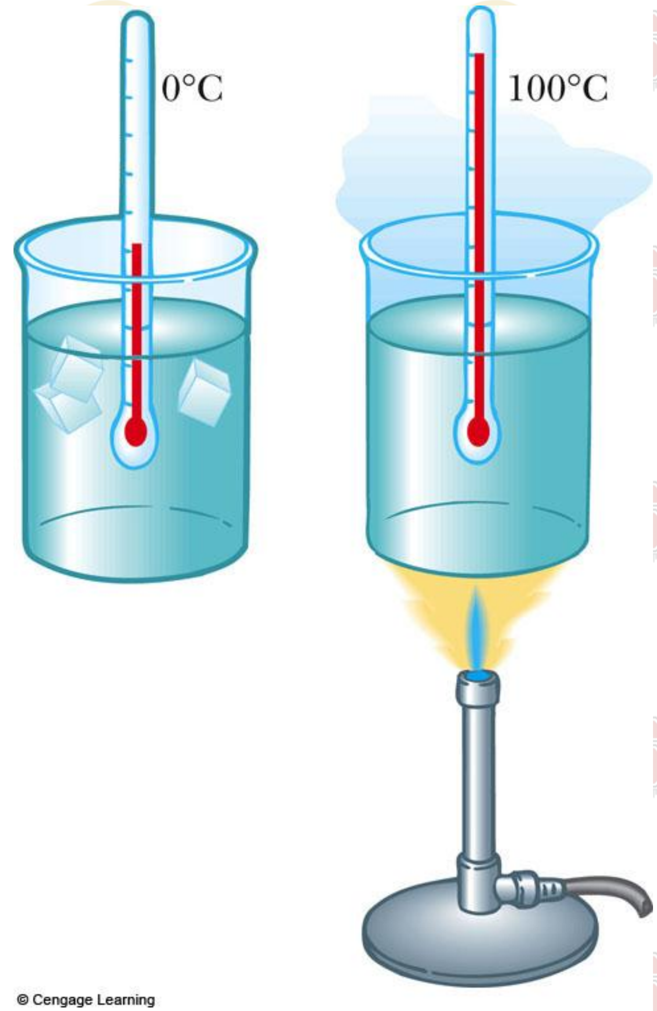
- Used to measure the temperature of an object or a system
- Make use of physical properties that change with temperature
- Many physical properties can be used
  - Volume of a liquid
  - Length of a solid
  - Pressure of a gas held at constant volume
  - Volume of a gas held at constant pressure
  - Electric resistance of a conductor
  - Color of a very hot object

- The essentials of thermometric properties.

- The property should be a single valued function
- And a continuous function.
- The ideal is if it varies linearly with temperature.

Thermometers (Mercury)

- A mercury thermometer is an example of a common thermometer
- The level of the mercury rises due to thermal expansion
- Temperature can be defined by the height of the mercury column

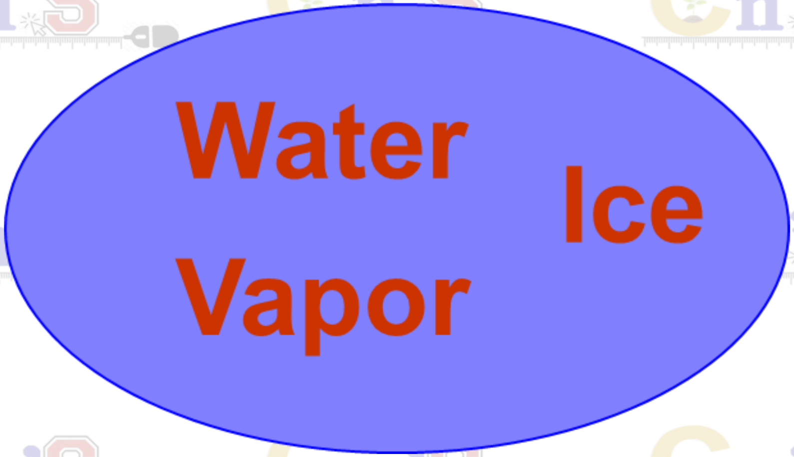


Fixed Points

- The Ice Point is the temperature at which pure ice can exists in equilibrium with water at standard atmospheric pressure.

- The Steam Point is the temperature at which pure water can exists in equilibrium with its water vapour at standard atmospheric pressure.

The Triple Point of water is the temperature at which pure ice, pure water & pure water vapour can exists together in equilibrium. There is only one pressure it occurs.



- Equation for temperature based on two fixed points

$$\theta = \frac{x_\theta - x_L}{x_H - x_L}(\theta_H - \theta_L) + \theta_L$$

- The SI unit of temperature is the kelvin, K.

- The interval of one kelvin is 1/273.15 of T point of water as measured on the thermodynamic scale of temperature. OR
- *One degree Kelvin is: 1 / 273.16 of the difference between absolute zero and the triple point of water.*
- Triple point of water is 273.16K

- Absolute zero is 0K

- Ice point is 273.15K & Steam point is 373.15K

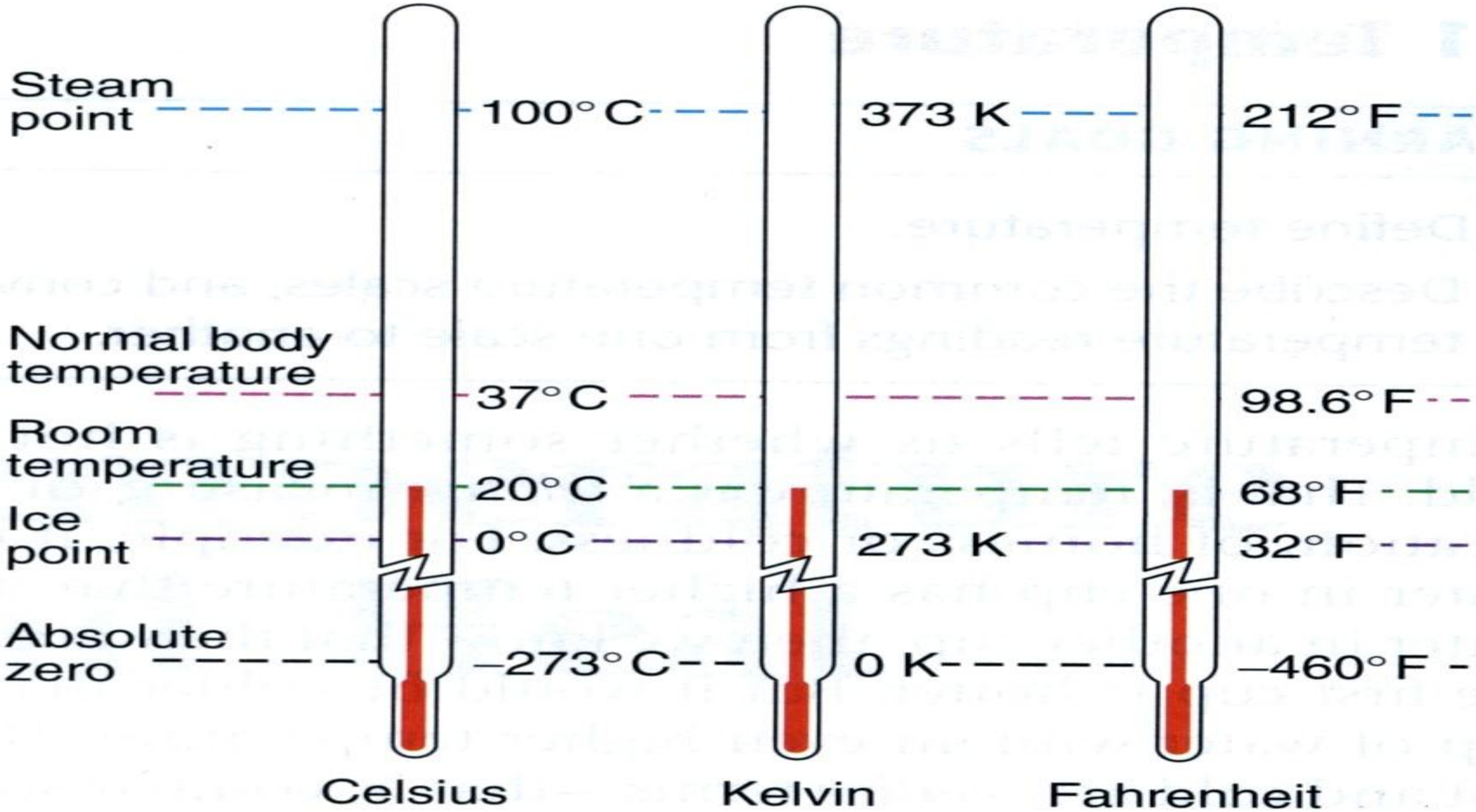


FIGURE 5.2 Temperature Scales

The common temperature scales are the Fahrenheit and Celsius scales. They have 180- and 100-degree intervals, respectively, between their ice and steam points. A third scale, the Kelvin (absolute) scale, is used primarily in scientific work and takes zero as the lower limit of temperature—absolute zero (0 K). The unit or interval on the absolute Kelvin scale is the kelvin (K).

Temperature scales

- The Celsius scale had the **melting point of ice** as its **lower** fixed point and the **boiling point of water** as the **upper** fixed point, both measured at standard atmospheric pressure.
  - Ice point 0°
  - Steam point 100°
  - One degree Celsius is 1 / 273.16 (approximately 0.00366) of the difference between absolute zero and the triple point of water.
  - This is the same definition as for a degree Kelvin. So a temperature change of 1K equates to a change of 1oC.

- Fahrenheit Scale
  - Ice point 32°
  - Steam point 212°

- Equation for absolute temperature based on triple point of pure water.

$$T = \frac{X_T}{X_{tr}} \times 273.16$$

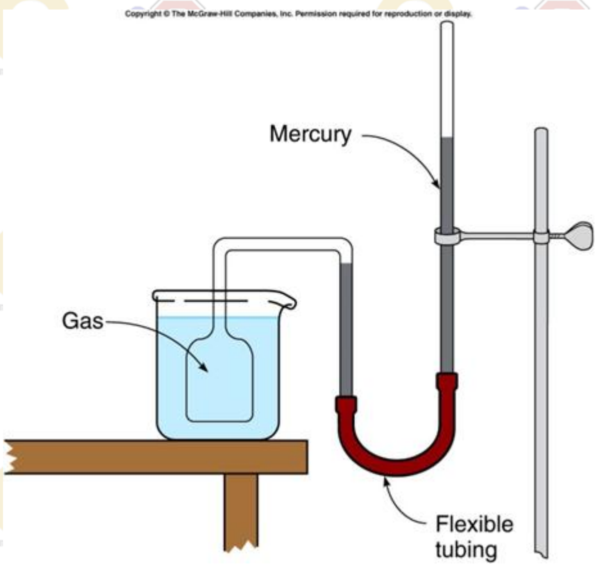
- Relationship between Celsius and absolute temperature

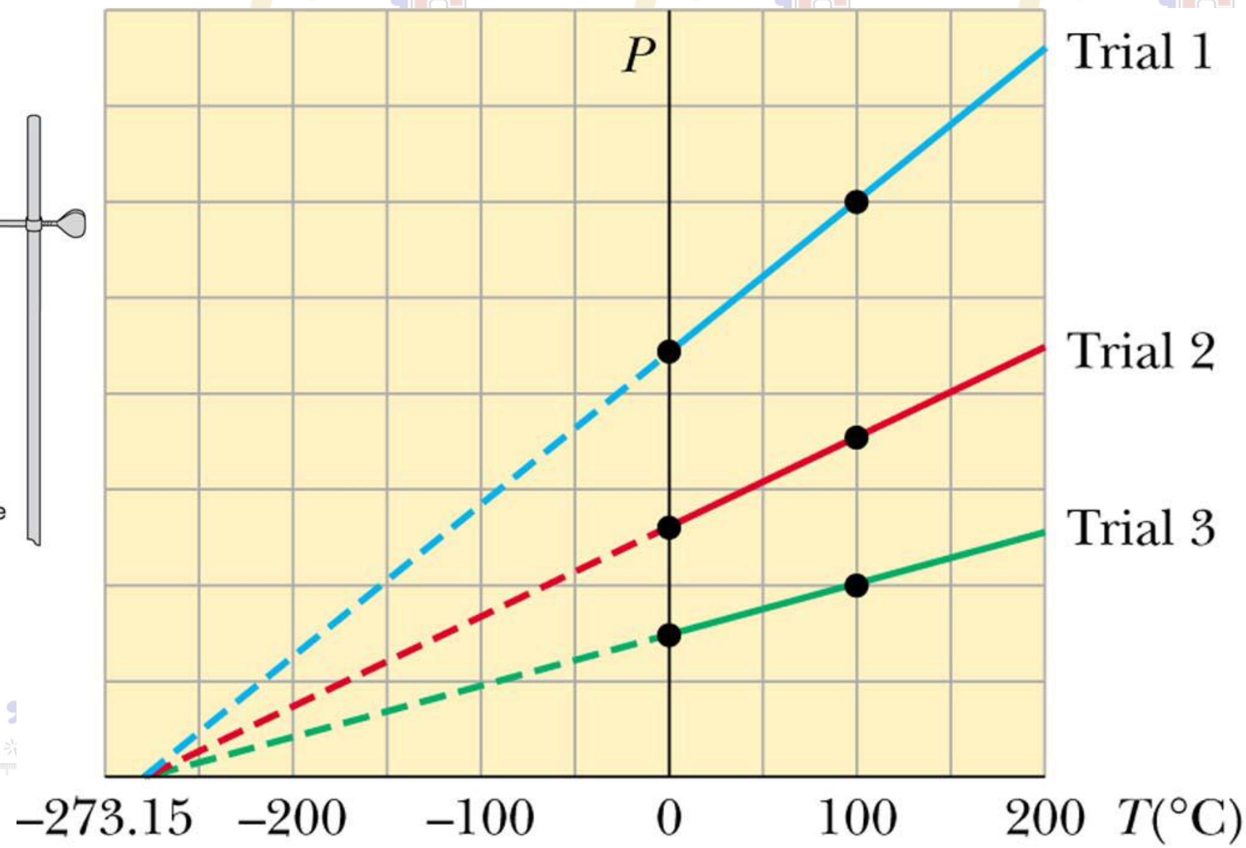
$$T = \theta + 273.15$$

The Kelvin (Absolute) Temperature Scale

- This scale uses the the **triple point of water** as the **upper** fixed point and **absolute zero**(zero molecular motion) as the **lower fixed point**.
- When the pressure of a gas goes to zero, its temperature is –273.15º C
- This temperature is called *absolute zero*
- This is the zero point of the Kelvin scale
  - 0 K = –273.15º C (or rounded to -273)
- To convert: $T_K = T_C + 273$

- If the volume of a gas is kept constant while the temperature is different, the pressure will be different.
- All gases extrapolate to the same temperature at zero pressure
- This temperature is *absolute zero*





Fahrenheit scale

- This scale was introduced by the Russian physicist Fahrenheit.
- The lower fixed point or the ice point is marked 32°F
- The upper fixed point or the steam point is marked 212°F.
- The interval between these 2 points is divided into 180 equal parts.
- Each division is called one degree Fahrenheit and is written as °F.
- A degree on the Fahrenheit scale is 1 180 th part of the interval between the ice point and the steam point.

$$T_F = \tfrac{9}{5}T_C + 32$$ 5.2

$$(\text{or} \quad T_F = 1.8T_C + 32)$$

(Celsius T_C to Fahrenheit T_F)

$$\text{and} \quad T_C = \tfrac{5}{9}(T_F - 32)$$ 5.2a

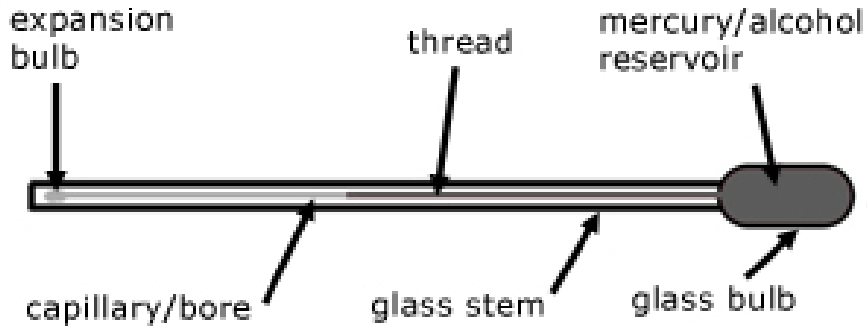
$$\left(\text{or} \quad T_C = \frac{T_F - 32}{1.8}\right)$$

(Fahrenheit T_F to Celsius T_C)

Practice problems:

- 1] Calculate the temperature of the human body (98.6°F) on the centigrade scale.[Ans: 37°C]
- 2] Calculate the temperature which has the same value on the centigrade scale and Fahrenheit scale. [Ans: - 40°C = −40°F]
- 3] Express 100 K in °C [Ans: -173°C]
- 4] Express 127°C in Kelvin. [Ans: 400K]
- 5] Express 100°F:– A] In °C [Ans: 37.8°C] B] In Kelvin [Ans: 310.8K]
- 6] When a thermometer is taken from the melting ice to a warm liquid, the mercury level rises to two-fifths of the distance between the lower and upper fixed points. Find the temperature of the liquid:- A] In °C [Ans: 40°C] B] In Kelvin [Ans: 313K]

Liquid in Glass



The thermometer works by an expanding liquid in a vacuum, moving against a scale.

There are a number of disadvantages to this instrument:

- 1.) The glass itself expands and contracts and leading to under and over reading of temperatures.
- 2.) Parallax errors mean readings are only 0.1oC accurate.
- 3.) The diameter of the bore is not consistent.
- 4.) Their large thermal capacity means that they do not react quickly and they may affect the temperature they are trying to measure.

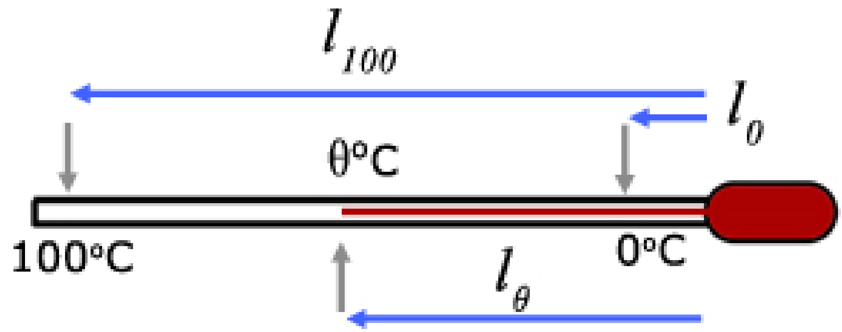
mercury

Alcohol

- opague
- is a metal and therfore a good heat conductor
- does not stick to glass - convex meniscus
- temperature range~ 356ºC ... -39ºC

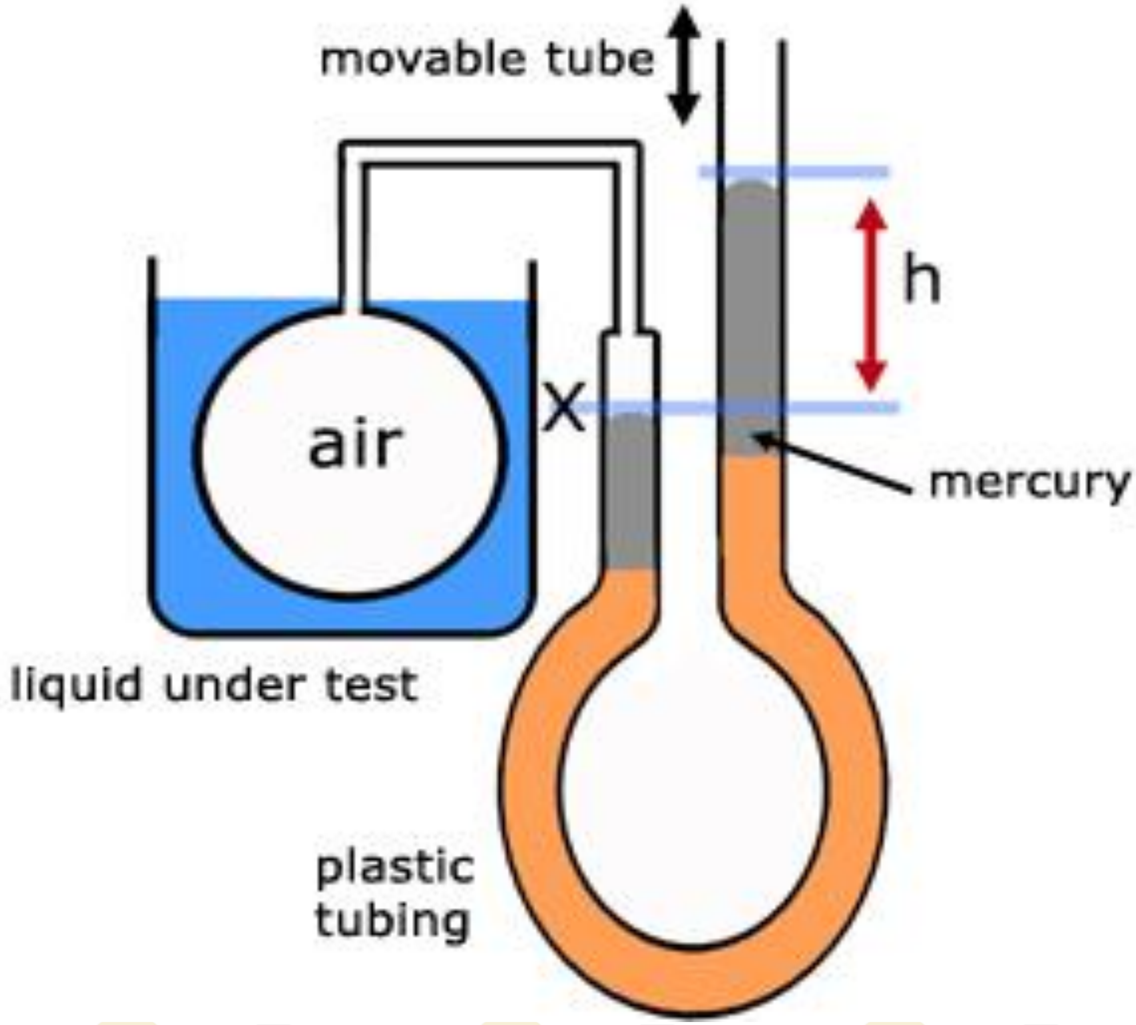
- transparent, must be used with a dye
- heat conduction poor
- sticks to glass - concave meniscus
- temperature range ~ 150ºC ... -114.9 ºC

The temperature on a liquid in glass thermometers can be calculated by making certain measurements.



$$\theta = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100$$

Constant-Volume Gas Thermometer



- In its original state the glass bulb is full of air and the mercury levels are the same. A mark(X) is made against the glass to record this.
-
- When the bulb is placed in a hot liquid for a temperature reading, the air in the bulb expands, pushing the mercury down on the left and up on the right.
-
- To get the air in the flask back to its original volume, the movable tube is lowered until the mercury is at the level previously marked.

There is now a level difference(head) ***h*** between the two tubes. This is a measure of the pressure of the gas without taking account of atmospheric pressure p_A.

So accounting for atmospheric pressure , the pressure p_θ of the gas at temperature θ is:

$$p_\theta = p_A + h$$

NB all pressures expressed in mm of mercury

It follows that the temperature of the gas, **θ** is given by:

$$\theta = \frac{p_\theta - p_0}{p_{100} - p_0}$$

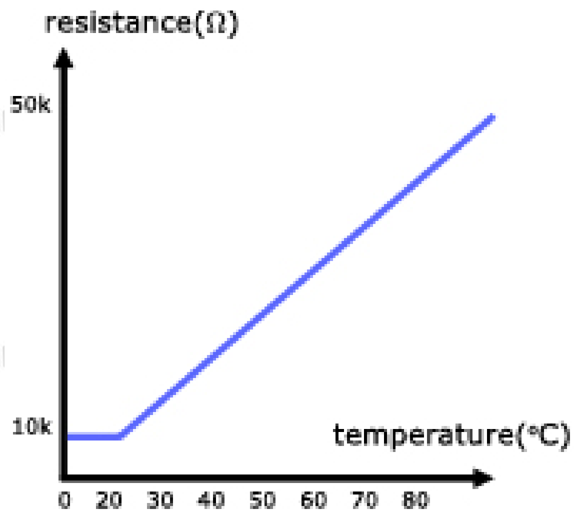
where p_0 and p_{100} are pressures at 0°C & 100°C respectively.

- Temperatures using the constant-volume gas thermometer can be measured to two decimal places.

However there are several sources of error that prevent further accuracy:

- 1. the capillary tube air is not heated
- 2. the volume of the bulb increases with temperature
- 3. air is not an 'ideal gas'

Resistance Thermometer

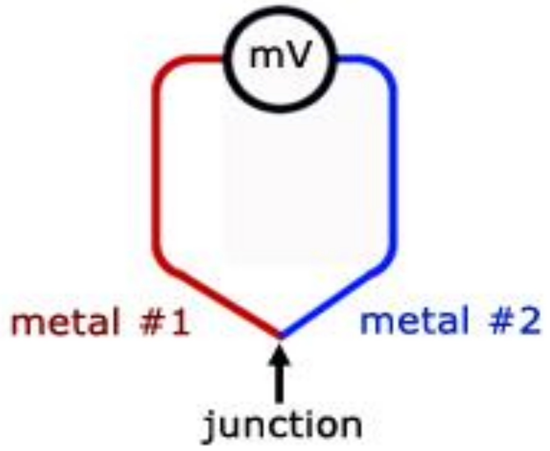


The property of metals that their **resistance is temperature-dependent** makes them ideal as thermometers.

- The metal of choice is platinum as a result of its high melting point(1773^{o}C) and large resistance temperature coefficient*****.
- *α(alpha) a big increase in resistance for a small rise in temp.
- In practice resistance thermometers are either thin films of platinum on a substrate or platinum wire wound around a former.

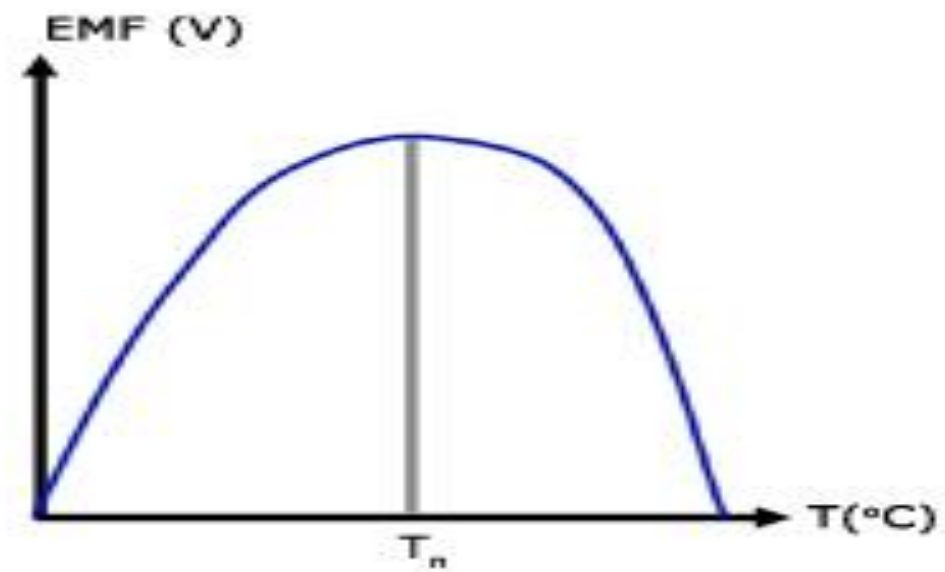
Thermocouple

Thermocouples work on a principle called the **thermoelectric** or **Seebeck Effect**.

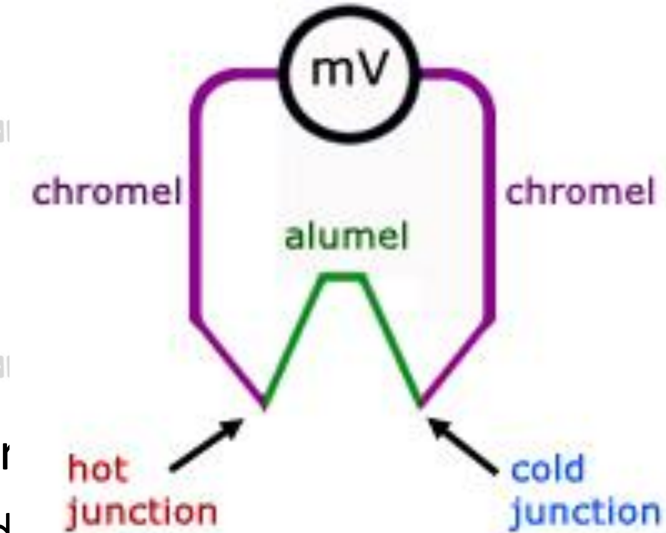


When two different metal wires are twisted together at a junction, an **EMF**(electromotive force) is generated across the loose ends.

The magnitude of this **EMF** relates to the **temperature at the junction**.

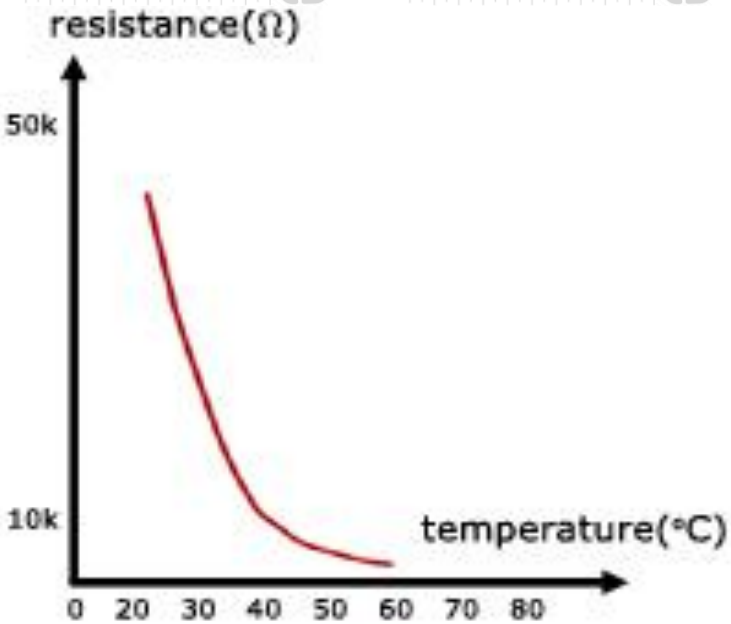


- A more convenient and efficient setup is to have two junctions instead of one, but still have just two metals.



- The reference cold temper
- Typical pairs of metals and
- chromel/alumel ~1100 max.
- Pt/Pt-Rh 1100 - 1700
- Fe/Constantan 95 - 760
- Cu/Constantan 200 - 350

Thermistor



Semiconductors, like metals, have **resistance that is temperature-dependent**. So they too make ideal thermometers.

The difference is, as temperature rises, the resistance of metals <u>increases</u>, but the resistance of semiconductors <u>decreases</u>.

- Semiconductors have **large resistance temperature coefficients**, but they are **negative**.
- This means that there is a **big decrease in resistance for a small rise in temperature**.
- Typical temperature range of thermistors is -70^{o}C ... 300^{o}C .
- The thermal capacities of thermistors are small. So they absorb little heat energy and do not appreciable affect the temperature they are measuring.
- Thermistor resistance is ~1kΩ .