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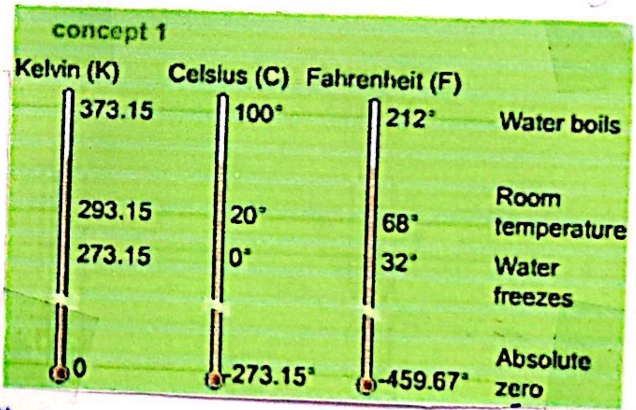
Temperature and Heat

Temperature is a measure of how hot or cold something is; specifically, a measure of the average kinetic energy of the particles in an object, which is a type of energy associated with motion.

- Therometers: measure temperature based on physical properties.
- In the "old" days, body temperature was measured with a glass thermometer filled with mercury, a material that expands significantly with temperature and whose expansion is proportional to the change in temperature.
- Today, a wide variety of physical properties are used to determine temperature. Some medical clinics use thermometers that measure temperature with plastic sheets containing a chemical that changes color with temperature. Battery-powered digtial thermometers rely on the fact that resistor's resistance chang with temperature.

Temperature scales



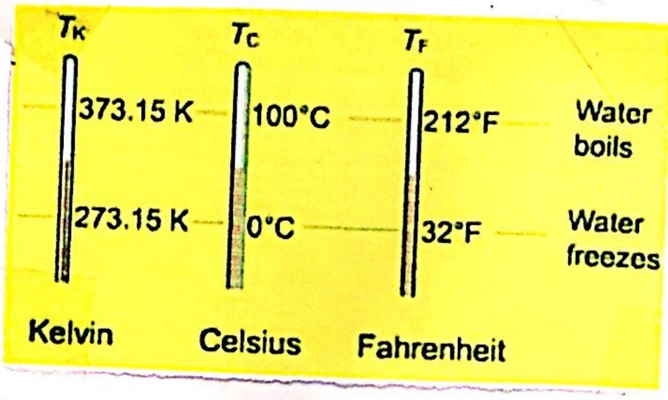
In the United States, the Fahrenheit system is the most common measurement system for temperature. The units in this system are called degrees. In most of the rest of the world, however, temperatures are measured in degrees Celsius. Physicistes use the Celsius scale or, quite often, another scale called the Kelvin scale. All three scales are shown on right.

- Temperature scales

Kelvin, Celsius, and Fahrenheit

water freezes at 0 °C

Absolute zero is 0 K



Temperature Scale conversions.

$T_K = T_C + 273.15$

$T_C = (5/9)(T_F - 32)$

where

T_K = Kelvin temperature

T_C = Celsius temperature

T_F = Fahrenheit temperature

Example: convert 98.6 °F to celsius and kelvin

Solution

$T_C = (5/9)(T_F - 32)$

$T_C = (5/9)(98.6 - 32) \Rightarrow T_C = 37.0\ °C$

$T_K = T_C + 273.15$

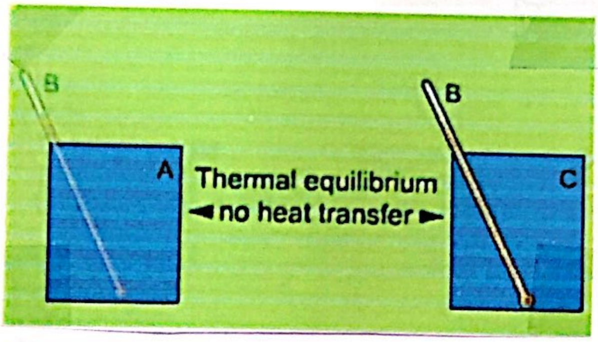
$T_K = 37.0 + 273.15 \Rightarrow T_K = 310.15\ K$

Heat: Thermal energy transferred between objects because of a difference in their temperatures.

- Energy flow due to temperature difference
- q: represents heat
- units: watt (W)

Zeroth law of thermodynamics.

Zeroth law of thermodynamics: If objects A and B are in thermal equilibrium, and objects B and C are in thermal equilibrium, then A and C will be in equilibrium as well.

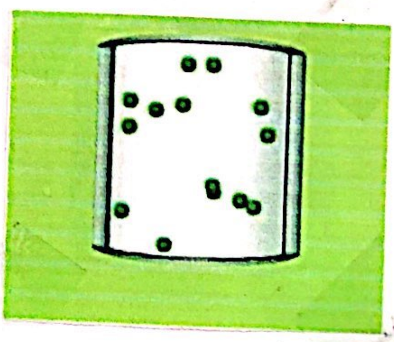


When you place two objects with different temperatures next to each other, the warmer object will cool off and the cooler object will warm up. Heat will flow until the objects reach thermal equilibrium, meaning they have the same temperature.

For example, thermometers rely on heat flowing until they reach thermal equilibrium with substance whose temperature they are measuring. Their practical use also relies on another principle, called the zeroth law of thermodynamics.

Internal energy: The energy associated with the molecules and atoms that make up a system.

- Internal energy: energy of system's atoms, molecules
- In thermodynamics, the properties of the molecules and/or atoms that make up the object or system are now the focus. They also have energy, a form of energy called internal energy. The internal energy includes the rotational, translational and vibrational energy of individual molecules and atoms.

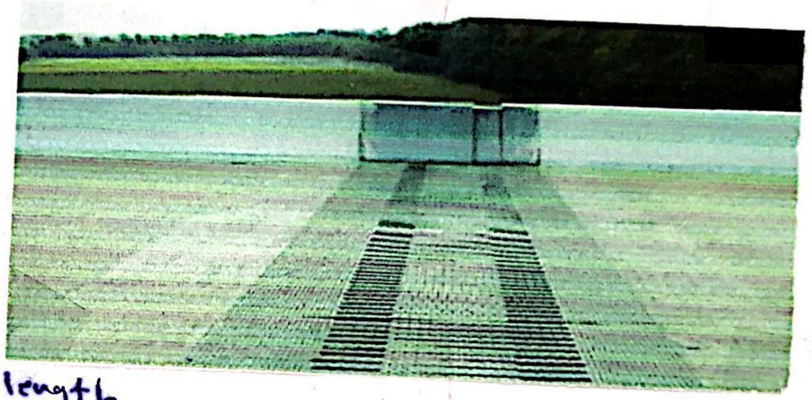


Thermal expansion:

The increase in the length or volume of a material due to a change in its temperature.

- Thermal expansion: Most materials expand with increased temperature.
- Different materials exeand at different rates.
- Good engineering takes expansion into account. For instance, bridges are built with expansion joints like the one shown in this figure

Thermal expansion: linear



Thermal linear expansion: change in the length of a material due to a change in temperature.

- Measured along one dimension
- Expansion proportional to initial length

linear expansion

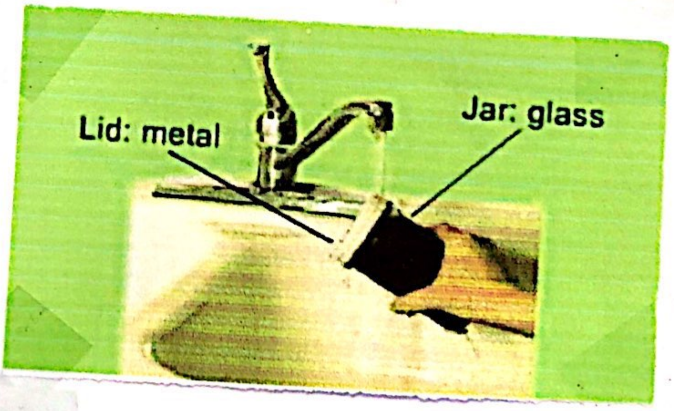
$$\Delta L = L_i \alpha \Delta T$$

where

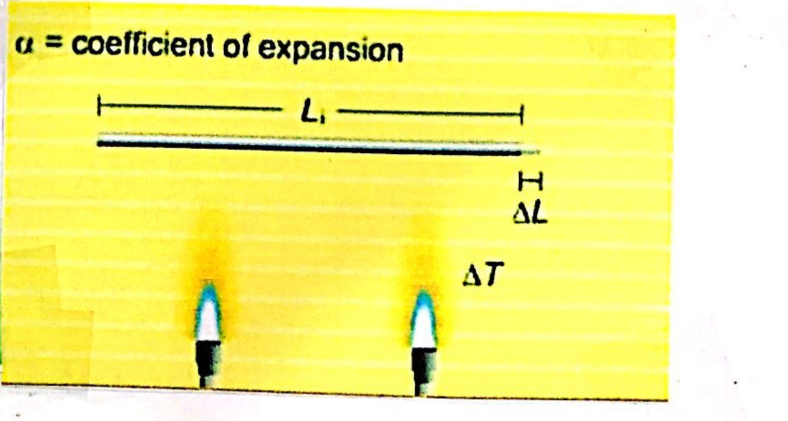
α: coefficient of linear exeansion

L_i: initial length

ΔT: change in temperature

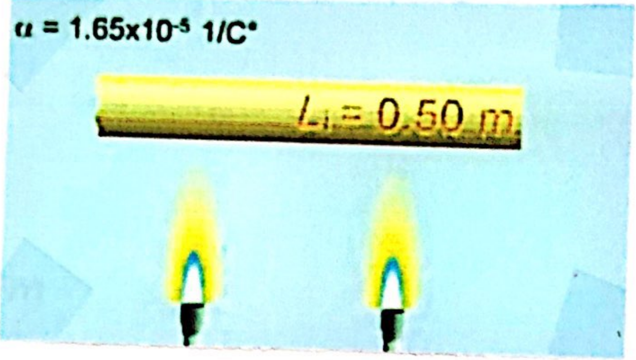


Coefficient of linear expansion (1/C°)	
Carbon steel	1.17×10^{-5}
Iron	1.18×10^{-5}
Copper	1.65×10^{-5}
Silver	1.89×10^{-5}
Aluminum	2.31×10^{-5}
Magnesium	2.48×10^{-5}
Lead	2.89×10^{-5}



Example: The copper rod is heated from 15 °C to 95 °C. What will its increase in length be? Given that: $\alpha = 1.65 \times 10^{-5}$ 1/°C

Solution:



$$\Delta L = L_i \alpha \Delta T$$

$$\Delta T = 95 - 15 = 80\ °C$$

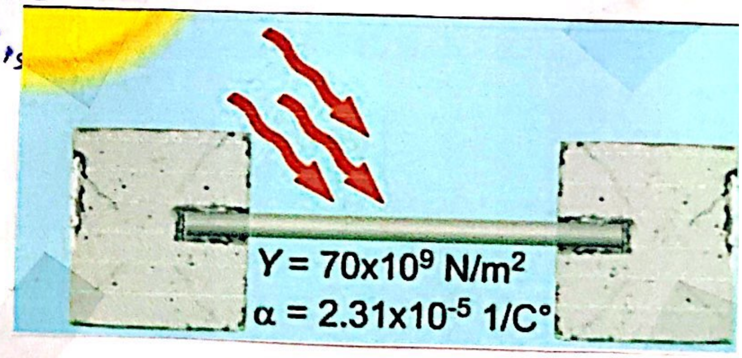
$$\Delta L = 0.5(1.65 \times 10^{-5})(80) = 6.6 \times 10^{-4}$$

Sample Problem: thermal expansion and stress

What stress does the aluminum rod exert when its temperature rises 20K for the below figure?

Solution:

According to the figure, you see an aluminum rod heated by the Sun and held in place with Concrete blocks. Since the rod increases in temperature, its length also increases. This exerts force on the concrete blocks.



Stress is force per unit area

$$\frac{F}{A} = Y\left(\frac{\Delta L}{L_i}\right) \quad [\text{tensile stress}] \quad —(1)$$

where

Y: Young's modulus for aluminum $[Y = 70 \times 10^9\ N/m^2]$

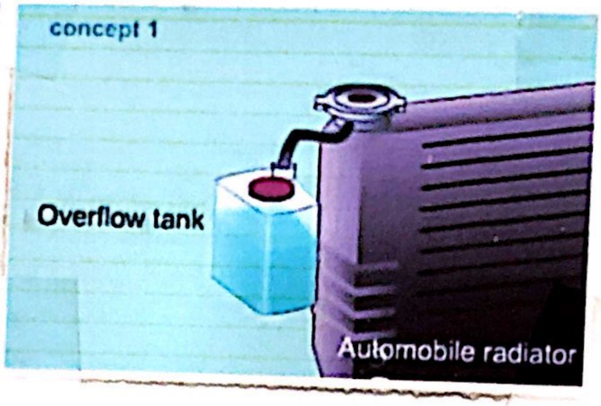
Since $\Delta L = L_i \alpha \Delta T$ sub. into Eq. (1)

$$\frac{F}{A} = Y\left(\frac{L_i \alpha \Delta T}{L_i}\right) \Rightarrow \frac{F}{A} = Y \alpha \Delta T \Rightarrow \frac{F}{A} = 70 \times 10^9 (2.31 \times 10^{-5})(20)$$

$$\Rightarrow \frac{F}{A} = 3.2 \times 10^7\ N/m^2$$

Thermal volume expansion

It is change in volume due to a change in temperature.



- Thermal expansion or contraction also changes the volume of a meterial, and for liquids (and many solids) it is more useful to determine the change in volume rather than expansion along one dimension. The expansion in volume can be significant.

- For example, Automobile cooling systems have tanks that capature excess coolant when the heated fluid expands so much it exceeds the radiator's capacity. A radiator and its overflow tank are shown in the above figure.

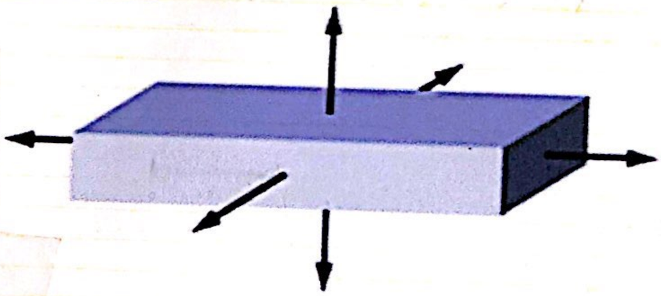
The thermal volume expansion can be calculated by the following equation,

$$\Delta V = V_i B \, \Delta T$$

where

V : volume

V_i : initial volume



For solid

B : coefficient of volume expansion

ΔT : change in temperature

- Coefficient of volume expansion (B) calibrated for K or °C
- B varies by material
- ΔV increase is proportional to V_i.
- $B \simeq 3\alpha$

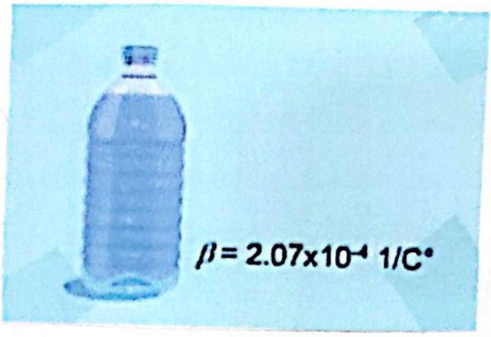
Coefficient of volume expansion (1/C°)

Liquids		Solids	
Mercury	19.6 x 10^{-5}	Glass*	2.14 x 10^{-5}
Water	20.7 x 10^{-5}	Copper*	5.00 x 10^{-5}
Glycerin	50.4 x 10^{-5}	Silver*	5.64 x 10^{-5}
Olive Oil	72.0 x 10^{-5}	Lead*	8.37 x 10^{-5}
Methyl Alcohol	120 x 10^{-5}	Ice (-26°C)	11.3 x 10^{-5}
Acetone	149 x 10^{-5}		

* between 0 -100°C

Example: The temperature of 2.0 L of water increases from 5.0 °C to 25 °C. How much does its volume increase? given that the coefficient of thermal expansion (B) equal to $2.07 * 10^{-4}$ 1/C°

Solution:



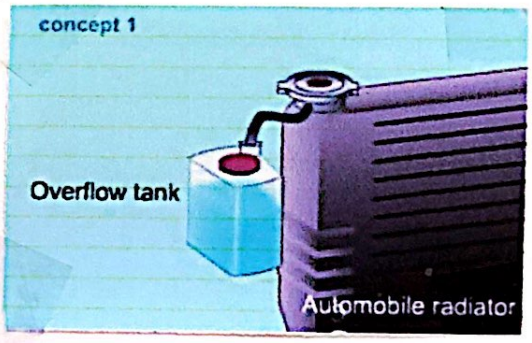
$\Delta V = V_i B \Delta T$

$\Delta V = 2(2.07 * 10^{-4})(25-5)$

$\Delta V = 0.0083$ L

Example: A truck has a radiator that holds 0.0176 m^3 of coolant. The coefficient of volume expansion of the coolant is the same as that of water, $2.07 * 10^{-4}$ 1/°C. The truck starts a trip with a full radiator at 18.0 °C. After 30 minutes, the coolant temperature in the radiator is 102 °C. what volume of coolant has flowed into the radiator's overflow container? (Ignore any expansion of the radiator).

Solution:



$V_i = 0.0176\ m^3$

$B = 2.07 * 10^{-4}$ 1/°C

$T_i = 18$ °C

$T_f = 102$ °C

$\Delta V = ?$

Since

$\Delta V = V_i B \Delta T$

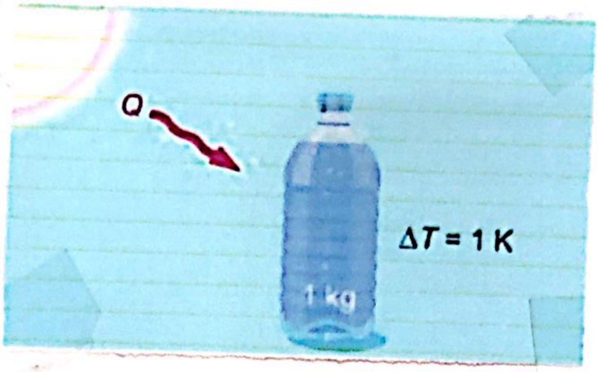
$\Delta V = 0.0176(2.07 * 10^{-4})(102-18)$

$\Delta V = 0.00031\ m^3$

Specific heat

A proportionality constant that relates the amount of heat flow per kilogram to a material's change in temperature.

- A material's specific heat is determined by how much heat is required to increase the temperature of one kilogram of the material by one kelvin.



- Specific heat of material

$$Q = mC\Delta T$$

where

Q: heat

C: Specific heat (J/kg.K)

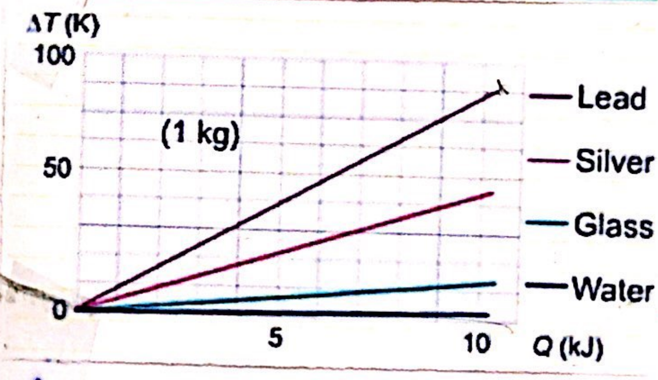
m: mass

ΔT: temperature change in °C or K

	Specific heat (J/kg·K)
Lead	129
Silver	235
Copper	385
Iron	449
Carbon	709
Aluminum	897
Air (27°C)	1007
Ice (0°C)	2110
Water (30°C)	4178

at 10^5 Pa, 25°C

- As you can see from the graph, lead increases in temperature quite readily when heat flows into it, because of its low specific heat. In contrast, water with a high specific heat, can absorb a lot of energy without changing much in temperature.



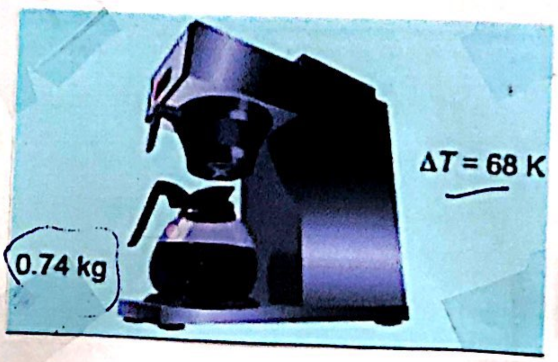
Example: How much heat is required to increase the coffee's temperature 68K?

Solution:

$$Q = mC\Delta T$$

$$Q = (0.74\ kg)(4178\ \frac{J}{kg.K})(68\ K)$$

$$Q = 210000\ J$$



Sample problem: a Calorimeter

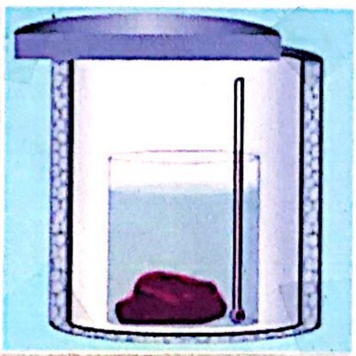
A Calorimeter is used to measure the specific heat of an object. The water bath has an initial temperature of 23.2 °C. An object with a temperature of 67.8 °C is placed in the beaker. After thermal equilibrium is reestablished, the water bath's temperature is 25.6 °C. What is the specific heat of the object?

Solution:

In a calorimeter, a water bath is placed in a well-insulated container. The temperature of the water bath is recorded, and an object of known mass and temperature placed in it. After thermal equilibrium is reestablished, the temperature is measured again. From this informations the specific heat of the object can be calculated.

The use of a calorimeter depends on the conservation of energy. In the calorimeter, heat flow from the object to the water bath (or vice-versa if the object is colder than water). Because the calorimeter is well insulated, negligible heat flows in or out of it. The conservation of energy allows us to say that the heat lost by the object equals the heat gained by the water bath.

- By the conservation of energy, the heat gained by the water bath (beaker + water) equals the heat lost by the object. The sum of the heat transfer is zero.



$$Q_w + Q_o = 0$$

$$Q_w = -Q_o$$

$$m_w C_w \Delta T = -m_o C_o \Delta T$$

$$0.744(4178)(25.6-23.2) = -0.197 C_o (25.6-67.8)$$

$$C_o = \frac{0.744(4178)(25.6-23.2)}{0.197(67.8-25.6)}$$

$$C_o = 897.4 \ J/Kg.K$$