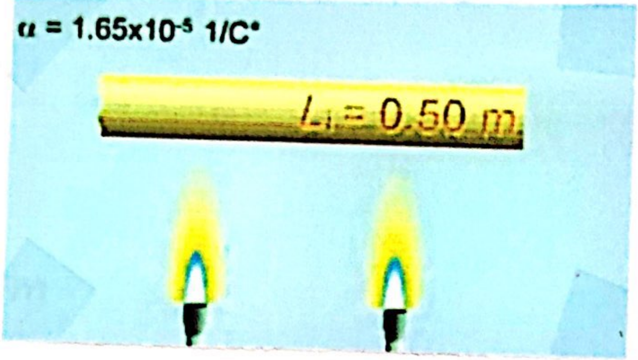
Example: The copper rod is heated from 15 °C to 95 °C. What will its increase in length be? Given that: $\alpha = 1.65 \times 10^{-5}$ 1/°C

Solution:



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

$$\Delta T = 95 - 15 = 80 \text{ °C}$$

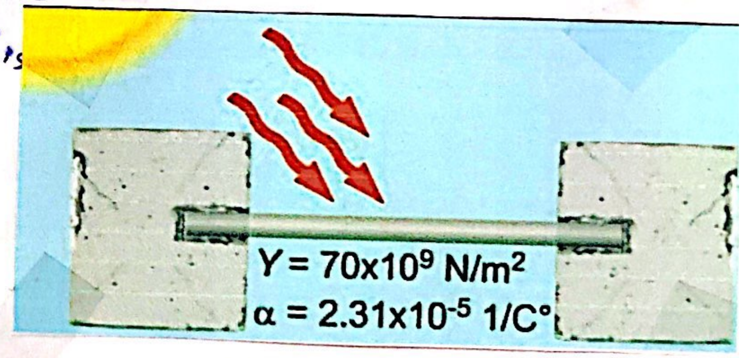
$$\Delta L = 0.5(1.65 \times 10^{-5})(80) = 6.6 \times 10^{-4}$$

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 figures 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 $[Y = 70 \times 10^9 \text{ N/m}^2]$

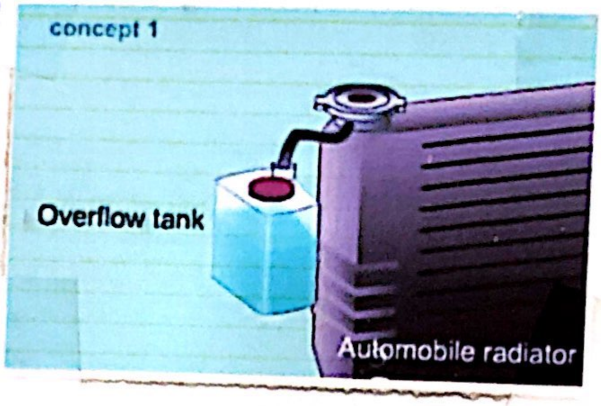
Since $\Delta L = L_i \alpha \Delta T$ sub. into Eq. (1)

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

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

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,

$$\Delta V = V_i \beta \Delta T$$

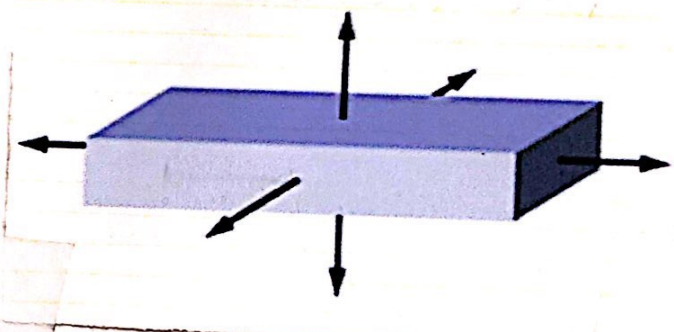
where

V: volume

V_i: initial volume

β: coefficient of volume expansion

ΔT: change in temperature



For solid

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

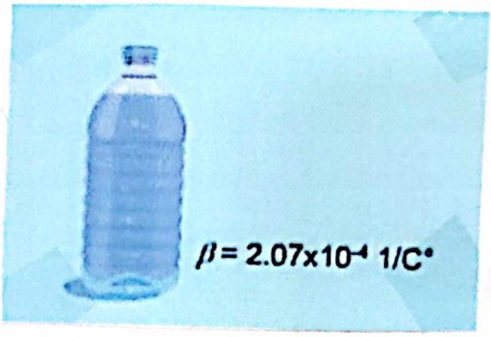
Coefficient of volume expansion (1/C°)

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



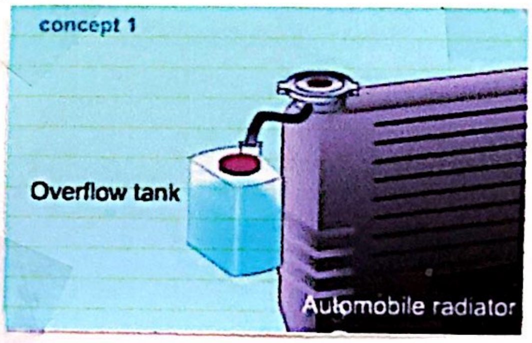
$\Delta V = V_i \, B \, \Delta T$

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

$\Delta V = 0.0083$ 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

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

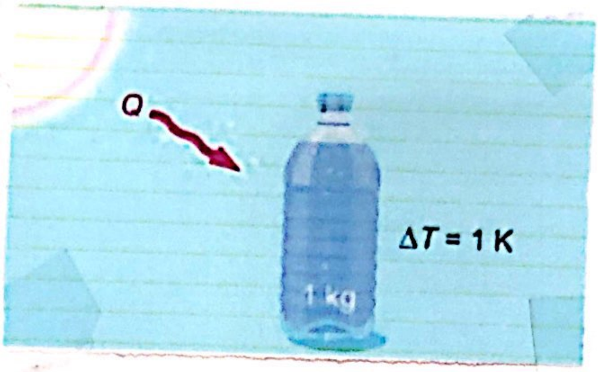
$\Delta V = 0.0176 (2.07 * 10^{-4}) (102 - 18)$

$\Delta V = 0.00031 \; m^3$

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)

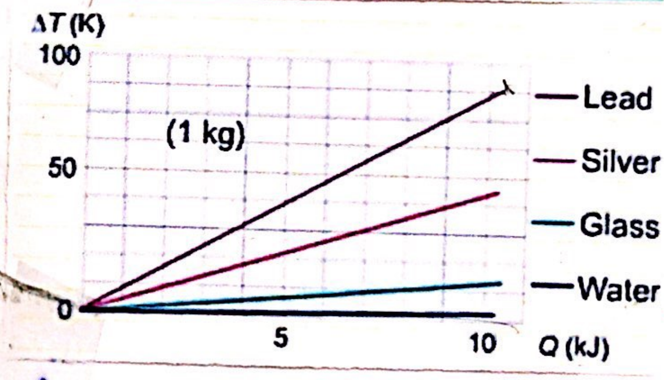
m: mass

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.



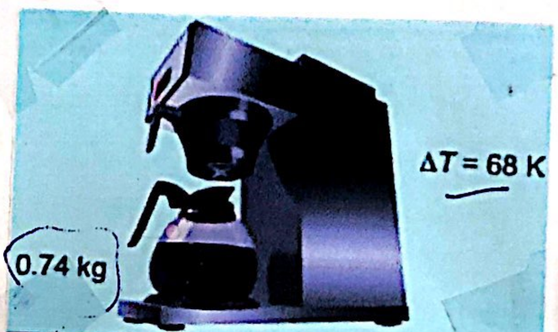
Example: How much heat is required to increase the coffee's temperature 68K?

Solution:

$$Q = mC\,\Delta T$$

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

$$Q = 210000\ J$$



Sample problem: a Calorimeter

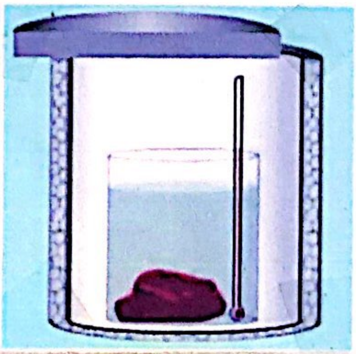
A Calorimeter is used to measure the specific heat of an object. The water bath has an initial temperature of 23.2 °C. An object with a temperature of 67.8 °C is placed in the beaker. After thermal equilibrium is reestablished, the water bath's temperature is 25.6 °C. what is the specific heat of the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



$$Q_w + Q_o = 0$$

$$Q_w = -Q_o$$

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

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

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

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