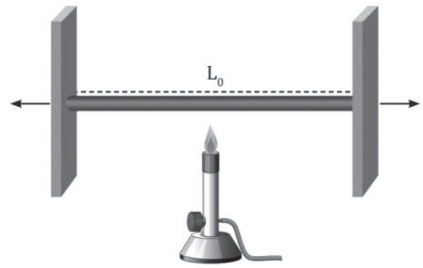
CALORIMETRY

Thermal Expansion in Solids - Thermal Stress/Strain in a rigidly fixed rod

Consider a rod of length L_0 securely positioned between two fixed walls. When this rod is heated, it naturally expands due to thermal expansion. However, because it's confined within the walls, it can't expand freely. As a result, the stress that builds up in the rod due to this restricted expansion is termed thermal stress.



If there are no barriers to limit heat expansion, the increase in length caused by heat expansion is described as follows:

$$\Delta L = \alpha L_0 \Delta T$$

In this case, the strain developed is as follows:

$$\text{Strain} = \frac{\Delta L}{L_0}$$

$$\text{Strain} = \frac{L_0 \alpha \Delta T}{L_0}$$

$$\text{Strain} = \alpha \Delta T$$

Stress developed is as follows:

$$\frac{\text{Stress}}{\text{Strain}} = Y(\text{ Where, } Y = \text{ Young's modulus })$$

$$\text{Stress} = Y \times \text{ Strain}$$

$$\text{Stress} = Y\alpha\Delta T$$

The force developed is as follows:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

$$\text{Force} = \text{Stress} \times \text{Area}$$

$$\text{Force} = Y\alpha\Delta T \times A$$

Heat and Heat Capacity

Heat

Heat is the energy that moves from one object to another when there's a difference in temperature between them.

The amount of heat transferred to an object depends on its mass, the change in temperature, and the type of material it's made of. This relationship is expressed by the formula

$$Q = mc\Delta\theta.$$

Where, c = Specific heat of the material

You can change the temperature of an object by adding heat (which increases the temperature) or removing heat (which decreases the temperature), except during a phase change.

Heat is measured as a scalar quantity. Its units include the joule (in the SI system), the erg, and the calorie (in the CGS system).

Some basic conversions are: $1\text{erg} = 10^{-7}\text{J}, 1\text{cal} = 4.18\ \text{J}$

Heat naturally moves from an object with a higher temperature to an object with a lower temperature until they reach the same temperature.

Heat capacity (C)

It is described as the quantity of heat (Q) needed to increase the temperature of the entire mass (m) of a body by 1° C or 1 K.

The SI unit of heat capacity is JK^{-1}.

$$Q = mc\Delta T$$

$$Q = mc(1^\circ C)$$

Heat capacity (C) = mc

Ex. What is the heat capacity of 40 g of aluminium? (Specific heat = 0.2 cal g–1 °C–1)

Sol. Given,

Mass of aluminium, m = 40 g

Specific heat of aluminium, c = 0.2 cal $g^{-1}c^{-1}$

Now

Heat capacity (C) = m × c

$$C = 40 \times 0.2$$
$$C = 8 cal°C^{-1}$$

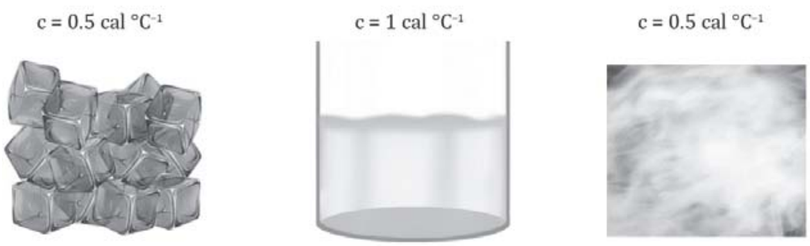
Specific Heat

The specific heat (c) of a substance equals the amount of heat gained or lost by the substance to raise or lower its temperature by 1 degree Celsius for a given mass of the substance.

The SI unit of specific heat is $kg^{-1}K^{-1}$.

We know that,

$$Q = mc\Delta T$$
$$\text{Specific heat (c)} = \frac{Q}{m\Delta T}$$



Ice Water Steam

Latent Heat and Phase Change

Phase Change

- The word "phase" refers to a particular state of matter, like solid, liquid, or gas.
- When matter shifts from one phase to another, it's called a phase change.
- Each substance undergoes phase changes at specific temperatures for a given pressure.
- During a phase change at constant pressure, the temperature stays the same.
- For instance, ice at 0 °C turns into water at 0 °C, and water at 100 °C transforms into steam at 100 °C.

Latent heat (L)

The heat needed to change the phase of a substance per unit mass is called latent heat. The amount of heat required during a phase change of a substance with mass m is expressed as follows:

$$O = mL \text{ (Where. L = Latent heat)}$$
$$L = \frac{Q}{m}$$

The units of latent heat are: cal $^{-1}$, Jg^{-1}, kg^{-1}.

Latent heat is also known as heat of transformation.

Latent heat of fusion

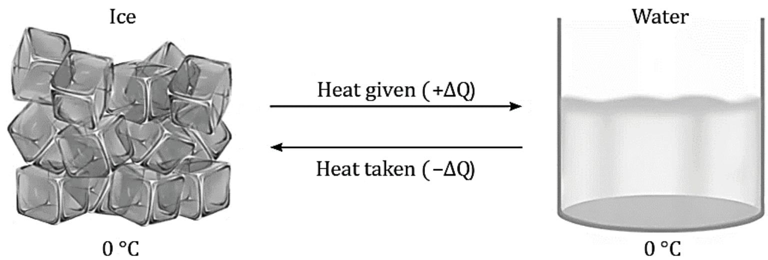
The energy needed to change one unit of a substance at its melting point from solid to liquid is called the latent heat of fusion.

Or

The heat energy released at the melting point when one unit of liquid turns into one unit of solid.

Example:

$L_F = L_{icc} = 80calg^{-1}$

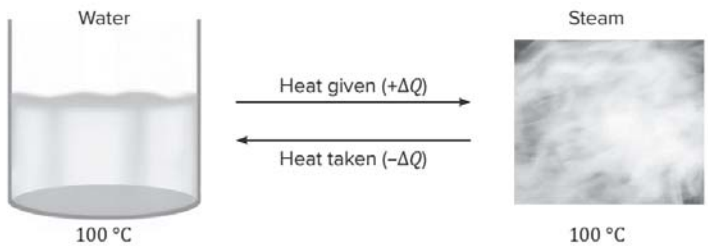


Latent heat of vaporization

The energy needed to change one unit of a substance at its boiling point from liquid to gas is called the latent heat of vaporization.

Or

The heat energy released at the boiling point when one unit of vapor turns into one unit of liquid.



Joule's Law (Heat and Mechanical Work)

When heat changes into mechanical work or vice versa, the ratio of the work done to the heat produced stays the same.

$$\text{i.e., } W \propto Q$$

$$\frac{W}{Q} = J$$

Here, J is known as the mechanical equivalent of heat.

Example:

Let us take a gun and fire a bullet of mass m with speed v towards a metal plate.

The kinetic energy of the bullet is converted into heat energy after striking on the metal plate, which increases the temperature of the bullet.

Let Δθ be the increase in temperature of the bullet.

Kinetic energy = J × Heat energy

$$\frac{1}{2}mv^2 = J(mc\Delta\theta)$$

$$J = \frac{\frac{1}{2}mv^2}{mc\Delta\theta} = \text{ Constant}$$

Where, c = Specific heat of the bullet

Principle of Calorimetry

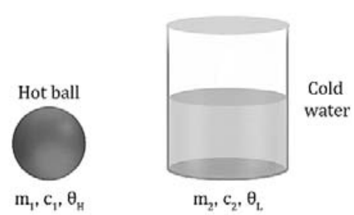
When you combine two substances, one solid and the other liquid, or both liquids, and they're at different temperatures, the heat moves from the warmer one to the cooler one.

Example:

Consider a hot ball of mass m_1, specific heat c_1, and temperature θ_H, which is dropped in some cold water of mass m_2, specific heat c_2, and temperature θ_L..

Let θ_{mix} be the temperature of the mixture at equilibrium.

On mixing the hot and cold bodies, we get the following:



Lower temperature (θ_L) ≤ Temperature of the mixture (θ_{mix}) ≤ Higher temperature (θ_h)
$\theta_L \le \theta_{mix} \le \theta_H$

$$m_1c_1(\theta_H - \theta_{mix}) = m_2c_2(\theta_{mix} - \theta_L)$$

$$\theta_{mix} = \frac{m_1c_1\theta_H + m_2c_2\theta_L}{m_1c_1 + m_2c_2}$$

Ex. When 80 g of water at 30 °C is poured on a large block of ice at 0 °C, what is the mass of ice that melts?

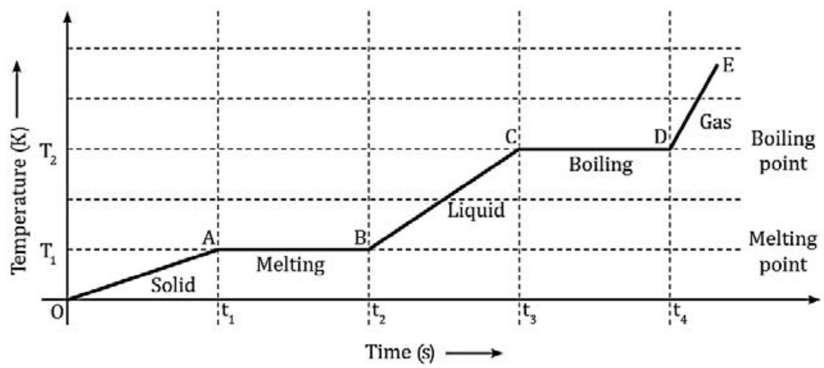
Sol. Let the mass of ice melted be m_i.
Heat gain = Heat loss

$$m_wc_w\Delta T = m_iL_f$$

$$m_i = \frac{80 \times 1 \times 30}{80} = 30\ \text{g}$$

Heating Curve

When you steadily add heat, at a constant rate P, to a solid mass m, and then plot a graph showing temperature changes over time, the resulting graph is called a heating curve.



$$Q = mc_s\Delta T$$

Where, $c_s =$ Specific heat of solid

In region AB, the solid's temperature remains constant over time; only its state, or phase, is transitioning. Therefore,

$$Q = mL_F$$

Where, $L_F =$ Latent heat of fusion

In region BC, the temperature of the liquid is changing with time. So,

$$Q = mc_L\Delta T$$

Where, $c_L =$ Specific heat of liquid

In region CD, the liquid's temperature doesn't change over time; only its state, or phase, is transitioning. Thus,

$$Q = mL_V$$

Where, $L_V =$ Latent heat of vaporization

In region DE, the entire liquid transforms into gas. As the temperature rises here, the gas becomes superheated.