Thermal Properties of Matter (Part I)

Specific Heat Capacity
Melting and Boiling
Thermal Expansion of Solids, Liquids and Gases

5/29/2009
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Internal Energy of a Body

The internal energy (U) of a body refers to the sum of kinetic energies (due to the motion of the atoms, molecules) and potential energies (due to the intermolecular interactions between atoms).

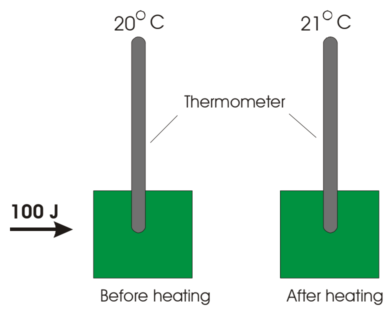
$$U = \sum K.E + P.E$$

A rise in temperature will lead to an increase in the kinetic energy of the atoms/molecules and they will move with greater velocity. The inter-molecular separation will increase as well, so the potential energy. Thus the internal energy will also increase.

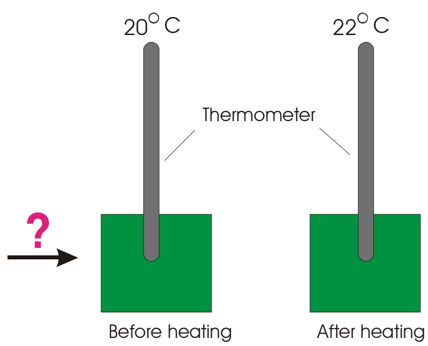
Heat Capacity

Consider the following examples:

A metal 'A' which has a mass of 1 kg is at room temperature, 20 ^{o}C. It is supplied with, say 100 J of energy so that its temperature is raised to 21 ^{o}C. In other words, 100 J of energy is needed to increase its temperature by 1 ^{o}C.



Task 1: If now the same metal 'A' which is again at 20 ^{o}C is considered, how much heat will be needed to raise its temperature to 22 ^{o}C?



Now, the temperature is raised by 2 ^{o}C; it is logical that you will need to supply **twice** as much energy as compared to the first case. Therefore 200 J of energy is required.

So, 100 J of heat is needed to raise the temperature of metal 'A' by 1 ^oC; therefore we say that ***metal 'A' has a heat capacity of 100 J for every one degree of temperature rise***. In other words, metal 'A' has the ability to absorb 100 J of energy to change its temperature by 1^oC.

Definition:

The heat capacity of a body is the amount of heat required to raise its temperature by 1 ^oC (or 1 K).

$$\text{Heat Capacity, } C = \frac{\text{Energy (J)}}{\text{Rise in Temperature (K)}}$$

$$C = \frac{E}{\theta}$$

The unit of heat capacity is: JK^{-1} (or $J\,^oC^{-1}$).

Example 1:

216 J of energy is required to raise the temperature of aluminum from 15^o to 35^oC. Calculate the heat capacity of aluminum.

Answer:

Energy, E = 216 J

Initial temperature, Θ_i = 15 ^oC;

Final temperature, Θ_f = 35 ^oC;

Rise in temperature (temperature change), Θ = 35 – 15 = 20 ^oC.

Using the formula:

$$\text{Heat Capacity, } C = \frac{\text{Energy (J)}}{\text{Rise in Temperature (K)}}$$

$$C = \frac{E}{\theta} = \frac{216}{20} = 10.8\ JK^{-1}$$

[Your answer could also be given as $J\,^oC^{-1}$.]

Task 2:

If the temperature was given in Kelvin, would there be a difference in above answer? Justify your reasoning.

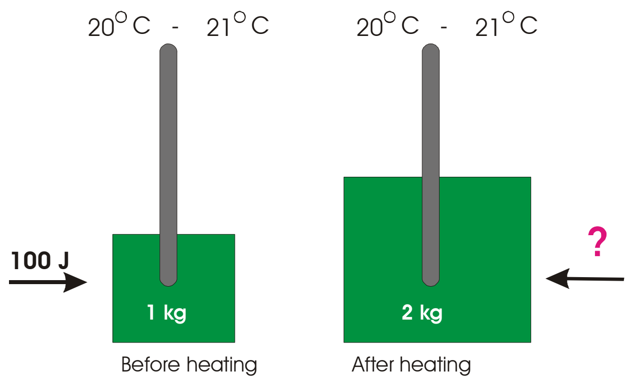
Specific Heat Capacity (shc)

Let's again consider the example of metal 'A'. Consider that the mass of metal 'A' is 1 kg and that 100 J of heat is needed to change its temperature from 20 ^{o}C to 21 ^{o}C.

Task 3: According to you, how much heat will be needed to change the temperature of **2 kg** metal 'A' from 20 ^{o}C to 21 ^{o}C?

Obviously, it should be 200 J of energy. [You might refer to a situation at home when you want to bring to boil ½ a kettleful of water and another time when you want to boil a whole kettleful of water. Will the time be the same? Of course not, the more water you use, the more energy is needed.]

But if you want to determine the amount of heat needed to raise the temperature from 20 ^{o}C to 21 ^{o}C (i.e by 1 ^{o}C) for a mass of 1 kg, then the energy should be 100 J $\left(\frac{200\ (\text{Joules of energy})}{1\ (\text{temp change}) \times 2 (\text{kilogram})} = 100\right)$.



So, if the same metal is used, you should get the same amount of heat for 1 kg (or 1 K) of temperature change. So the shc refers to the amount of heat required to change the temperature of 1 kilogram mass of a body by 1 degree Celsius (or Kelvin). [The term *specific* refers to 1 kg mass or sometimes we say – unit mass]

Definition

The specific heat capacity of a body is defined as the quantity of heat required to change the temperature of unit mass of it by 1K.

$$\text{SHC, } c = \frac{\text{Energy (J)}}{\text{Mass (kg)} \times \text{Temperature change (K)}}$$

$$c = \frac{E}{m \times \theta}$$

$$\text{unit of } c : \ Jkg^{-1}K^{-1}$$

Example 2:

Calculate the specific heat capacity of copper given that 204.75 J of energy raises the temperature of 15 g of copper from 25^oC to 60^oC.

$E = m \times c \times (t_f - t_i)$
$E = 204.75$ J
$m = 15g$
$t_i = 25^oC$
$t_f = 60^oC$

$$c = \frac{E}{m \times \theta}$$

$E = m\,c\,\Theta$

$204.75 = 15 \times c \times (60 - 25)$
$204.75 = 15 \times c \times 35$
$204.75 = 525 \times c$
$c = 204.75 \div 204.75 = 0.39\ J^oC^{-1}\ g^{-1}$

Task 4:

Determine the specific heat capacity of copper in $JKg^{-1}K^{-1}$

Example 3:

The initial temperature of 150g of ethanol is 22^oC. What will be the final temperature of the ethanol if 3240 J is supplied to it?
(Specific heat capacity of ethanol is 2.44 J $^oC^{-1}\ g^{-1}$).

$E = m \times c \times (t_f - t_i)$
$E = 3240$ J
$m = 150g$
$c = 2.44\ J^oC^{-1}g^{-1}$
$t_i = 22^oC$

$3240 = 150 \times 2.44 \times (t_f - 22)$
$3240 = 366\ (t_f - 22)$
$8.85 = t_f - 22$
$t_f = 30.9\ ^oC$

Melting and Solidification

When ice is heated, it changes state from solid into liquid state; this happens at a constant temperature (0 °C). Such a process is known as melting.

Melting is the process by which a substance changes from solid into liquid state at constant temperature.

The **melting point** is that constant temperature at which a solid changes into liquid state.

Task 5: Why the temperature does not change during the change of state?

Liquids also have a characteristic temperature at which they turn into solids, known as freezing point or solidification. In theory, the melting point is same as the freezing point.

During melting, the heat being supplied to the substance at that particular temperature is used to bring about the change of state, and none is available to raise the temperature of that part of the substance until all of it has changed to the liquid state. If heat is still applied, the temperature will begin to rise again.

Additional information (informative only for you): The periodic table below gives the melting point (in °C) of the elements.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H																	He
	-259.14																	-272
2	Li	Be											B	C	N	O	F	Ne
	180.54	1278											2300	3500	-209.9	-218.4	-219.62	-248.6
3	Na	Mg											Al	Si	P	S	Cl	Ar
	97.8	650											660.37	1410	44.1	112.8	-100.98	-189.3
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
	63.65	839	1539	1660	1890	1857	1245	1535	1495	1453	1083	419.58	29.78	937.4	817	217	-7.2	-157.2
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
	38.89	764	1523	1852	2468	2617	2200	2250	1966	1552	961.93	320.9	156.61	231.9	630	449.5	113.5	-111.9
6	Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
	28.5	725		2150	2996	3410	3180	3045	2410	1772	1064.43	-38.87	303.5	327.5	271.3	254	302	-71
7	Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
	27	700		?	?	?	?	?	?	?	?	?						
			*	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				920	795	935	1010	?	1072	822	1311	1360	1412	1470	1522	1545	824	1656
			**	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
				1050	1750	1600	1132	640	639.5	994	1340	?	?	?	?	?	?	?

Factors affecting melting point (or freezing point)

- *Purity*

  The melting point of a substance is lowered in the presence of impurities. For example, when salt is mixed with water, it will freeze at a temperature lower than 0^oC (its melting point will therefore be lower than 0^oC).

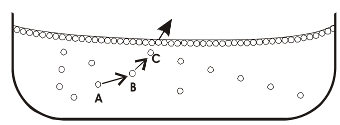
  In cold countries, ice formed on the roads is melted by sprinkling salt or soil. This will lower the freezing point and the ice will therefore melt.

- *Pressure*

  The melting point or freezing point is lowered with increased in pressure.
  When you press hard (exerting pressure) a pin against an ice block, you can see the ice melting at the point of contact and when you remove the pin (relieving the pressure), the melted water will freeze again.
  You can also press hard two ice cubes together; they will stick since at the point of contact between the two ice cubes due to an increase in pressure, they have melted and when they are no more pressed, the ice will freeze again at their normal freezing point.

Evaporation

You should have surely noticed that when you leave your hot cup of tea for sometime on the table, it cools. This is due to a process known as evaporation. The surface water molecules, on gaining enough kinetic energy as a result on collisions from inner water molecules are able to escape.



All the water molecules are in constant random motion. For example, when molecule 'A' collides with molecule 'B', there is a transfer of energy from 'A' to 'B'. when molecule 'B', now having higher kinetic energy, collides with molecule 'C', the latter gains even more kinetic energy. When now molecule 'C' collides with a surface molecule, the latter will have sufficient kinetic energy to escape from the surface leaving the remaining water molecules with less kinetic energy (and therefore less temperature).

Considering the whole liquid, there will be a lot of escape and therefore the remaining water molecules will have less kinetic energy, and eventually less temperature.

Evaporation is the escape of water molecules from the surface of a liquid. Evaporation leads to cooling.

Factors affecting evaporation

- Heat

  When the liquid is heated, more water molecules with have higher kinetic energy, and therefore there will be more escape. So, an increase in the temperature of the liquid brings about an increase in the rate of evaporation.

- Draught (air current)

  While drinking your hot cup of tea/coffee, you usually blow air over it. This helps to cool your tea/coffee. The presence of air current helps in carrying away the just liberated water molecules, leaving more space for liberation of other surface molecules.

- Surface area

  For the same amount of liquid, a larger vessel will contain more surface water molecules than a smaller vessel. So, there will be more escape of water molecules from the surface of a larger vessel and more cooling.

Difference between boiling and evaporation

Boiling	Evaporation
Takes place throughout the whole liquid	Takes place at the surface only
Occurs at a constant temperature	Occurs at any temperature

Evaluation

Do all the MCQ in the topic Heat Capacity and Specific Heat Capacity as well as in the topic Evaporation