NOTES

Thermodynamics

Thermodynamics
= the study of heat transformations into other forms of energy

Thermal Energy
= the sum of average kinetic energy per particle multiplied by the number of particles

Temperature
= average kinetic energy of all particles
This kinetic energy can be **rotational, vibrational or translational.**

= the measure of the ability of a physical system to transfer heat to another physical system

Heat = Q
= transfer of energy from objects with higher temperature to objects with lower temperature

Specific Heat = C
= the amount of energy needed to increase the temperature of 1kg by 1temperature unit

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Heat Transfer can occur through:

- Conduction solids
- Convection gases, liquids
- Radiation
  → no matter required

1. Consider two samples of different gases. One sample consists of helium atoms and the other sample consists of diatomic oxygen molecules. If the samples are at the same temperature, will the particles within the sample have the same average speed?

→ same T ⇒ same KE

$T_{He} = T_{O_2}$

$\frac{1}{2} m_{He} v_H^2 = \frac{1}{2} m_{O_2} v_{O_2}^2$

$m_{He} <<< m_{O_2}$ ⇒ to maintain the equality $v_{He} >>> v_{O_2}$ to make up for $m_{He} << m_{O_2}$

∴ He has higher average speed.

2. The particles in a sample of table salt (sodium chloride) are not free to move about. They are locked in place in a structure known as a crystal lattice. Can the particles of sodium chloride possess kinetic energy?

Yes, KE from vibrating is present.

3. Explain why high quality thermos bottles have a vacuum lining as a major component of their insulating ability.

→ Only radiation is possible through vacuum ⇒ convection and conduction are impossible → only 1 way out of 3 ways to lose heat

Heat Transfer

$$Q = mC\Delta T = mC(T_{final} - T_{initial})$$

Conservation of Energy: In a closed isolated system consisting of object A and object B, the total thermal energy is equal to the thermal energy of A + the thermal energy of B. The total energy of such a system remains always constant. $E_A + E_B = constant$

In a closed isolated system the change in thermal energy is equal to the heat transfer

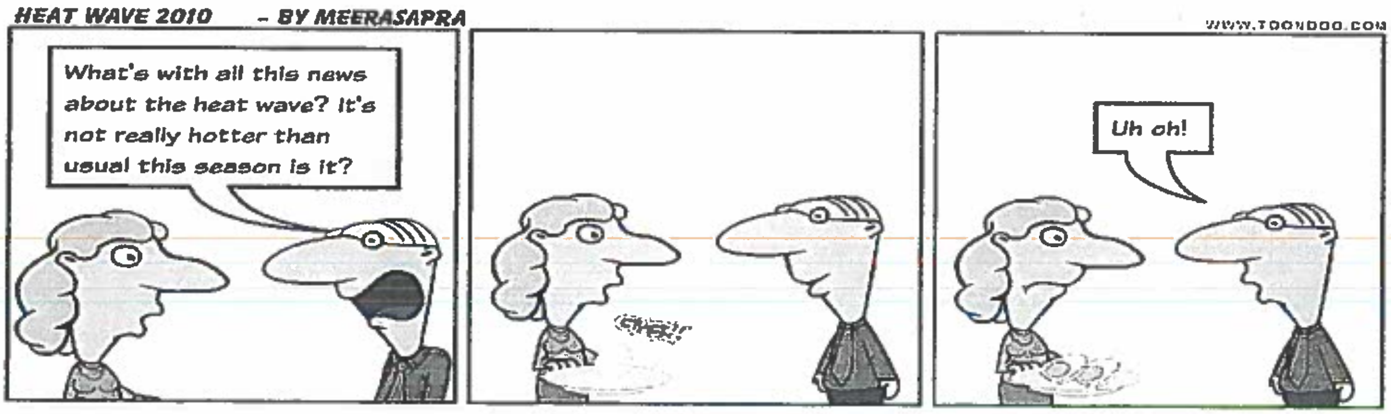
specific heat capacity [J/kg · °C] [J/kg · K]

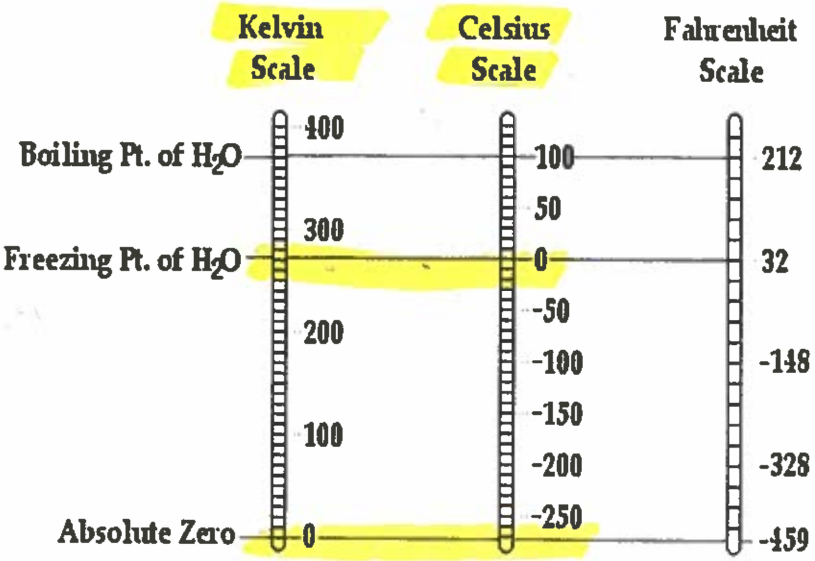
$$\Delta E = Q = mC\Delta T$$

mass [kg]

Change in temperature [°C] OR [K]

Specific Heat of Common Substances			
Material	Specific Heat [J/kg·K]	Material	Specific Heat [J/kg·K]
Aluminum	897	Lead	130
Brass	376	Methanol	2450
Carbon	710	Silver	235
Copper	385	Steam	2020
Glass	840	Water *	4180
Ice	2060	Zinc	388
Iron	450		





$0\ ^\circ C = 273\ K$

$-273^\circ C = 0\ K$

$$T_C + 273 = T_K$$

Example1: How much heat needs to be transferred in order to increase temperature of a 5.0-kg brass object from 257 K to 317 K?

$m = 5.0\ kg$

$T_i = 257\ k$

$T_f = 317\ k$

brass → $c = 376\ J/kg\cdot k$

Assume a closed isolated system

$Q = mC\Delta T$

$= (5.0)(376)(317-257)$

$= 112\ 800\ J$

$\therefore 1.1\times10^5\ J$ of heat needs to be transferred.

Example 2: What quantity of heat is required to raise the temperature of 450 grams of water from 15°C to 85°C? The specific heat capacity of water is 4.18 J/g·°C?

$T_i = 15^\circ C$

$T_f = 85^\circ C$

$C = 4.18\ J/g\cdot{}^\circ C$

$\rightarrow 4180\ J/kg\cdot{}^\circ C$

$m = 450\ g$

$\rightarrow 0.450\ kg$

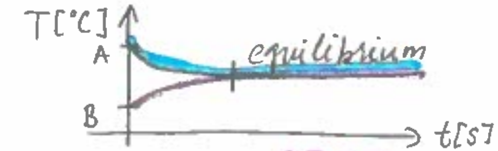
$Q = mC\Delta T$

$= (0.450)(4180)(85-15)$

$= 131\ 670\ J$

$\therefore 1.3\times10^5\ J$ of heat is required.

Thermal Equilibrium



Example 3: A 12.9-kg sample of an unknown metal at 26.5°C is placed in a Styrofoam container containing 50.0 kg of water at 88.6°C. The water cools down and the metal warms up until thermal equilibrium is achieved at 87.1°C. Assuming all the heat lost by the water is gained by the metal and that the container is perfectly insulated, determine the specific heat capacity of the unknown metal. The specific heat capacity of water is 4180 J/kg·°C

G: $m_w = 50.00\,kg$

$T_{iw} = 88.6°C$

$T_{fw} = T_{fm} = 87.1°C$

$T_{im} = 26.5°C$

$m_m = 12.9\,kg$

R: $C_m = J/kg \cdot °C$

A: $\Delta E_m = -\Delta E_w$

S: $E_w = mc\Delta T$

$= (50.0)(4180)(87.1 - 88.6)$

$= -313500\,J$

$E_m = +313500\,J$

$Q = mc\Delta T$

$313500 = (12.9)(c)(87.1 - 26.5)$

$c = *$

$* \; C = \frac{313500}{(12.9)(87.1-26.5)}$

$= 401.028\ldots \; J/kg \cdot °C$

$\therefore \; C \doteq 4.0 \times 10^2 \; J/kg \cdot °C$

$400 \doteq 388$

⇒ the unknown metal is zinc (not 100% pure,

Example 4: How big was a sample of ice if changing its temperature from -6 °C to – 3 °C required 3.1x10^4 J of energy?

$T_i = -6°C$

$T_f = -3°C$

$Q = 3.1 \times 10^4\,J$

ice → $c = 2060\,J/kg \cdot °C$

• assume closed isolated.

R: $m = ?\,[kg]$

A: $Q = mc\Delta T$

$m = \frac{Q}{c\Delta T}$

$m = \frac{3.1 \times 10^4}{(2060)(-3-(-6))}$

$m = 5.01618\ldots\,kg$

∴ The sample is 5.0 kg.

Example 5: If 3000 J of heat are transferred to a 10kg of silver.

a) Find the change in temperature of the sample

$Q = 3000\,J$

$m = 10\,kg$

silver → $c = 235\,J/kg \cdot °C$

→ closed isolated system

$Q = mc\Delta T$

$\Delta T = \frac{Q}{mc}$

$\Delta T = \frac{3000}{(10)(235)}$

$\Delta T \doteq 1.3\;°C$

$\therefore \; \Delta T = 1.3°C$

b) What is the temperature of the sample after the heat transfer if the sample was orginally 23 °C warm?

$\Delta T = T_f - T_i$

$T_f = T_i + \Delta T$

$T_f = 23°C + 1.3°C$

$T_f = 24.3°C \doteq 24\;°C$

Example 6: 100 g of aluminum with specific heat 897 J/kg °C and temperature 100°C is placed in 400g of water at 25°C. What is the final temperature of the mixture?

[redacted]

Formula:

$$\boxed{m_1C_1(T_{f1}-T_{i1}) + m_2C_2(T_{f2}-T_{i2}) = 0}$$

Where the subscript 1 refers to the first material and subsbript 2 to the other material.

In words, the above equation states that in a close isolated system, the heat transferred (=lost) from the sample with the higher temperature is exactly the amount of heat gained by the sample with lower temperature.

① Al : $m_1 = 100\,g \rightarrow 0.100\,kg$

$C_1 = 897\ J/kg \cdot °C$

$T_{i_1} = 100°C$

② H_2O : $m_2 = 400\,g \rightarrow 0.400\,kg$

$C_2 = 4180\ J/kg \cdot °C$

$T_{i_2} = 25°C$

Final temperature →

⇒ thermal equilibrium

$T_{f1} = T_{f2} = ?\,[°C] = x$

$$m_1C_1(T_{f1}-T_{i1}) + m_2C_2(T_{f2}-T_{i2}) = 0$$

$$(0.100)(897)(x-100) + (0.400)(4180)(x-25) = 0$$

$$89.7x - 8970 + 1672x - 41800 = 0$$

$$-50\,770 + 1761.7x = 0$$

$$\frac{1761.7x}{1761.7} = \frac{50\,770}{1761.7}$$

$$x = 28.8188\ldots$$

∴ The final temperature of the mixture is 29°C.

Practice:

1. Water has an unusually high specific heat capacity. Which one of the following statements logically follows from this fact?

a. Compared to other substances, hot water causes severe burns because it is a good conductor of heat

b. Compared to other substances, water will quickly warm up to high temperatures when heated

[✓ c.] Compared to other substances, it takes a considerable amount of heat for a sample of water to change its temperature by a small amount.

→ this drives lot of coastal weather patterns

2. An 11.98-gram sample of zinc metal is placed in a hot water bath and warmed to 78.4°C. It is then removed and placed into a Styrofoam cup containing 50.0 mL of room temperature water (T=27.0°C; density = 1.00 g/mL). The water warms to a temperature of 28.1°C. Determine the specific heat capacity of the zinc.

① Zn : $m_1 = 11.98\,g \rightarrow 0.01198\,kg$

$T_{i1} = 78.4°C$

② H_2O $m_2 = 50.0\,g = 0.050\,kg$

$T_{i2} = 27.0°C$

$T_{f2} = 28.1°C$

$C = 4180\,J/kg\cdot°C$

$\Delta E_w = -\Delta E_{zinc}$

$$\frac{-m_1 C_1 (T_{f1} - T_{i1})}{-m_1 (T_{f1} - T_{i1})} = \frac{m_2 C_2 (T_{f2} - T_{i2})}{-m_1 (T_{f1} - T_{i1})}$$

$$C_1 = \frac{(0.050)(4180)(28.1 - 27.0)}{-0.01198(28.1 - 78.4)}$$

$$C_1 = \frac{229.9}{+0.602594}$$

$$C_1 \doteq 382\ J/kg\cdot°C$$

∴ the specific heat capacity for this sample of zinc is 382 J/kg·°C.

3. How heavy was a sample of lead if it took 1040 J to change its temperature from 16 °C to 23 °C?

$Q = 1040\,J$

$T_i = 16°C$

$T_f = 23°C$

lead → $c = 130\,J/kg\cdot°C$

→ assume closed, isolated

$m = ?\ [kg]$

$Q = mc\Delta T$

$\rightarrow m = \dfrac{Q}{C\Delta T}$

$$m = \frac{1040}{(130)(23-16)}$$

$$m \doteq 1.1\,kg$$

∴ the sample of lead was 1.1 kg.