• PROGRAM OF "PHYSICS"

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PHYSICS 2
(FLUID MECHANICS AND THERMAL PHYSICS)

02 credits (30 periods)

Chapter 1 Fluid Mechanics

Chapter 2 Heat, Temperature and the Zeroth Law of Thermodynamics

Chapter 3 Heat, Work and the First Law of Thermodynamics

Chapter 4 The Kinetic Theory of Gases

Chapter 5 Entropy and the Second Law of Thermodynamics

CHAPTER 2
Temperature and the Zeroth Law of Thermodynamics

Temperature and the Zeroth Law of Thermodynamics

Thermal Expansion (of Solids and Liquids)

Heat and the Absorption of Heat by Solids and Liquids

1. Temperature and the Zeroth Law of Thermodynamics

1.1 Notions

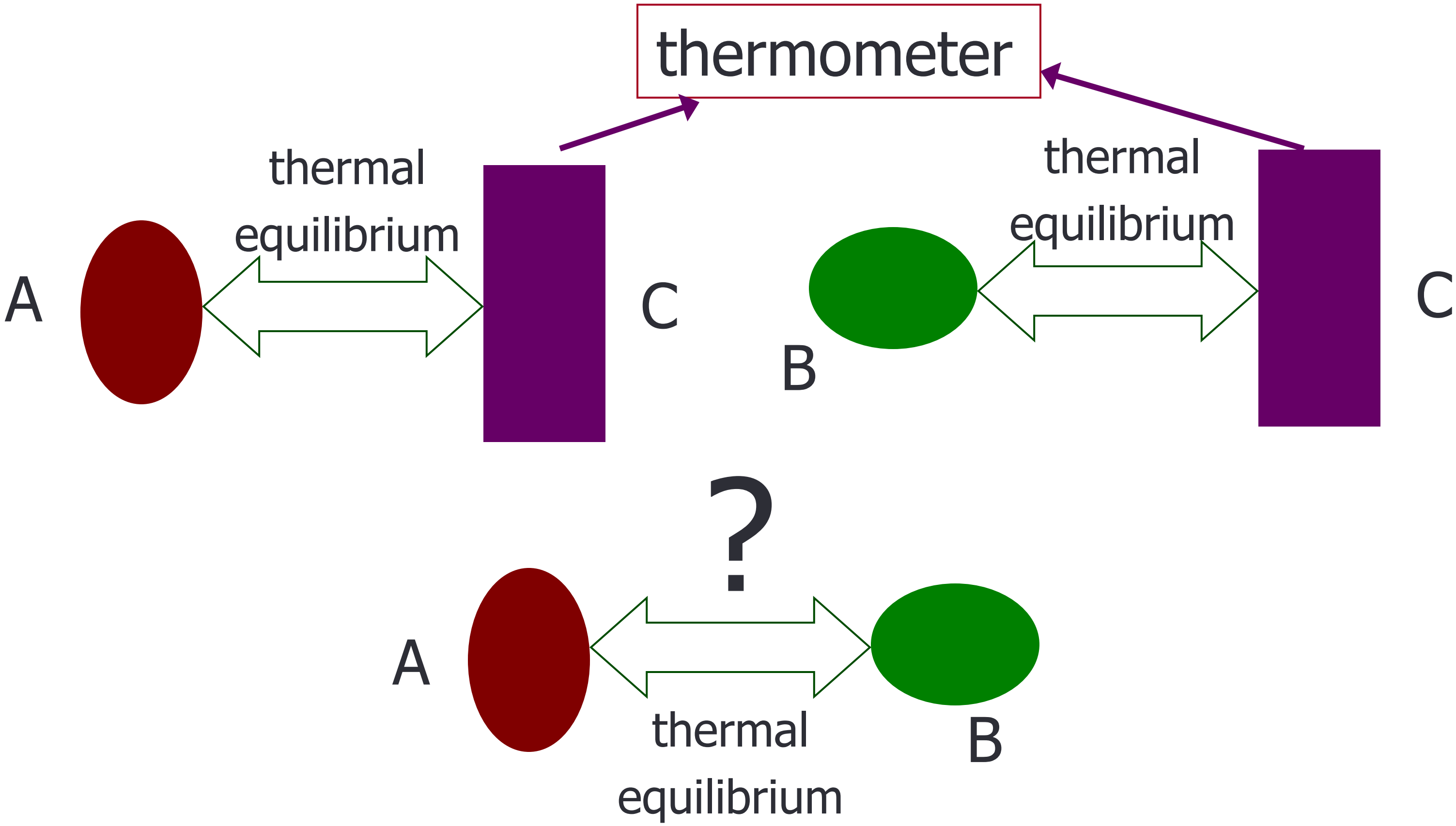
What is HEAT ?

- Heat is the transfer of energy from one object to another object as a result of a difference in temperature between the two.
- Two objects are in thermal contact with each other if energy can be exchanged between them
- Thermal equilibrium is a situation in which two objects in thermal contact with each other cease to exchange energy by the process of heat.

$\longrightarrow$ These two objects have the same temperature

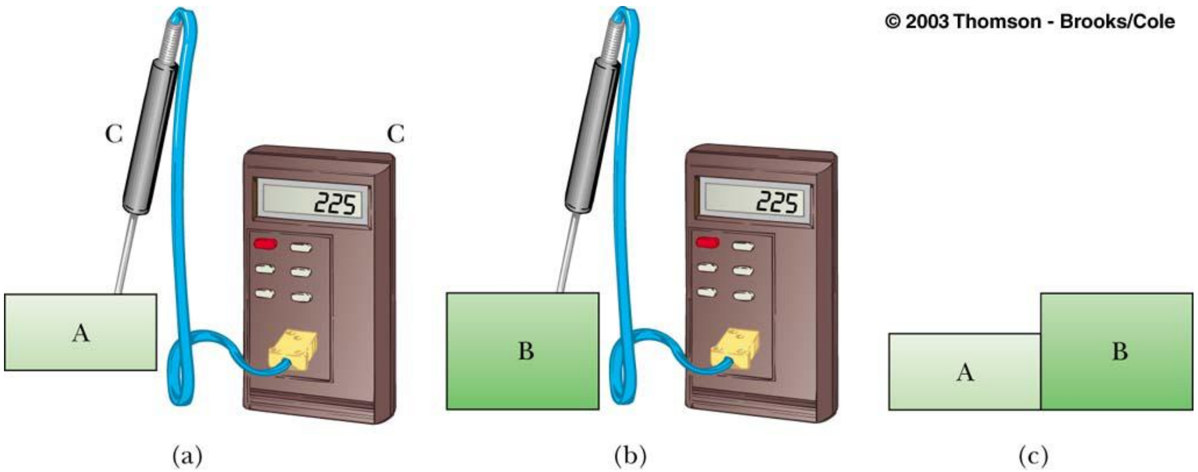
→ **Heat is the energy transferred between a system and its environment because of a <u>temperature difference</u> that exists between them.**

→ **Units: 1 cal = 4.1868 J**



1.2 The zeroth law of thermodynamics (the law of equilibrium) :

" If objects A and B are separately in thermal equilibrium with a third object C, then objects A and B are in thermal equilibrium with each other "



If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

Thermometers :

Devices that are used to define and measure temperatures

Principle : Some physical property of a system changes as the system's temperature changes

Physical properties that change with temperature :

(1) the volume of a liquid,
(2) the length of a solid,
(3) the pressure of a gas at constant volume,
(4) the volume of a gas at constant pressure,
(**5)** the electric resistance of a conductor, and
(6) the color of an object.

Common thermometer : a mass of liquid — mercury or alcohol — that expands into a glass capillary tube when heated

$\rightarrow$ the physical property is the change in volume of a liquid.

1.3 Temperature Scales

Thermometers can be calibrated by placing them in thermal contact with an environment that remains at constant temperature

- Environment could be mixture of ice and water in thermal equilibrium
- Also commonly used is water and steam in thermal equilibrium

a. Celsius Scale

- Temperature of an **ice-water** mixture is defined as **0º C**
  - This is the ***freezing point*** of water
- Temperature of a **water-steam** mixture is defined as **100º C**
  - This is the ***boiling point*** of water
- Distance between these points is divided into **100 segments**

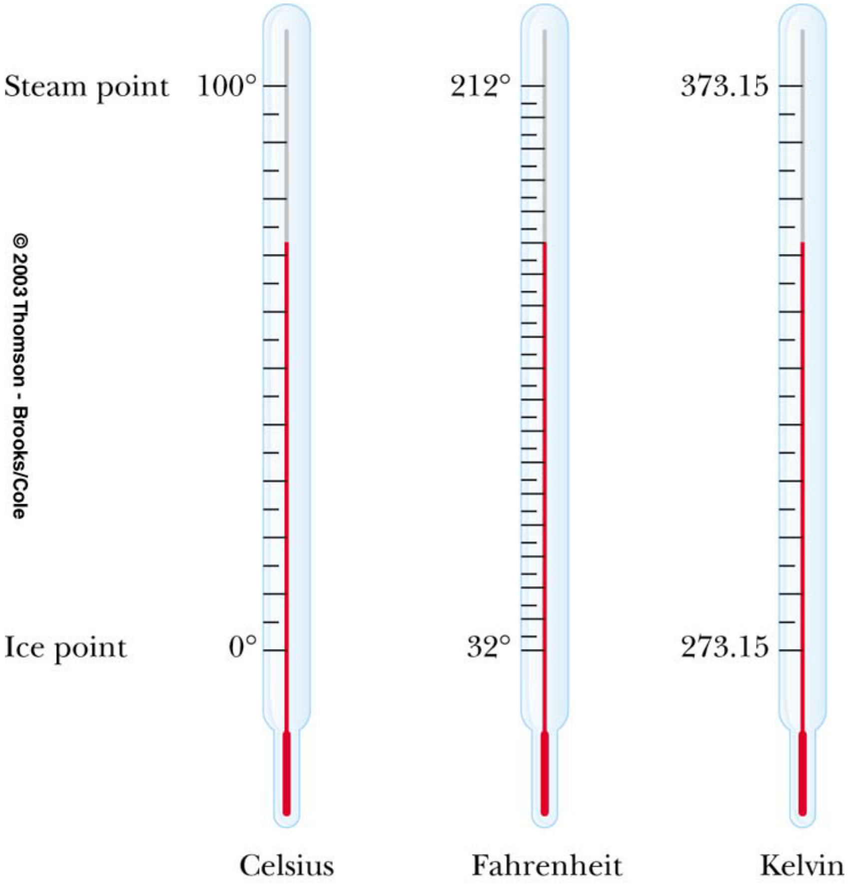
b. Kelvin Scale

- When the pressure of a gas goes to zero, its temperature is –273.15º C
- This temperature is called ***absolute zero***
- This is the **zero point of the Kelvin scale** : –273.15º C = 0 K
- To convert: **TC = TK – 273.15**

c. Fahrenheit Scales

- Most common scale used in the US
- Temperature of the **freezing point is 32º**
- Temperature of the **boiling point is 212º**
- **180 divisions** between the points

Comparing Temperature Scales



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$$T_C = T_K - 273.15$$

$$T_F = \frac{9}{5} T_C + 32$$

$$\Delta T_F = \frac{9}{5} \Delta T_C$$

TEST 1

What is the physical significance of the factor 9/5 in equation $T_F = \frac{9}{5} T_C + 32$

SOLUTION

$$100T_C - 0T_C = 232T_F - 32T_F \;;\; 100T_C = 180T_F$$

$$1T_C = \frac{180}{100} T_F = \frac{9}{5} T_F \;;\; 1T_C = \frac{9}{5} T_F$$

$$\Delta T_F \rightarrow \frac{\Delta T_F \times 1T_C}{9/5T_F} = \Delta T_C \;;\; \frac{5}{9} \Delta T_F = \Delta T_C$$

$$\Delta T_F = T_F - 32 \;;\; \Delta T_C = T_C - 0$$

$$\frac{5}{9}(T_F - 32) = T_C - 0 \;;\; T_F = \frac{9}{5} T_C + 32$$

PROBLEM 1

A healthy person has an oral temperature of 98.6 F. What would this reading be on the Celcius scale?

SOLUTION

$$\frac{9}{5}T_F \rightarrow T_C$$

$$\Delta T_F = T_F - 32 = 98.6F - 32F = 66.6F$$

$$66.6F \quad \rightarrow \quad \frac{66.6F \times 1C}{9/5F} = 37.0C = \Delta T_C$$

$$37.0T_C = T_C - 0$$

$$T_C = 37.0C$$

PROBLEM 2

A time and temperature sign on a bank indicates the outdoor temperature is -20.0C. Find the corresponding temperature on the Fahrenheit scale.

SOLUTION

$$1T_C \rightarrow \frac{9}{5}T_F$$

$$-20.0C \rightarrow \frac{-20.0C \times 9/5F}{1C} = -36.0F = \Delta T_F$$

$$-36.0F = T_F - 32F$$

$$T_F = -4.0F$$

PROBLEM 3

On a day when the temperature reaches 50°F, what is the temperature in degrees Celsius and in kelvins?

SOLUTION

$$T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(50 - 32) = \boxed{10°\mathrm{C}}$$

$$T = T_C + 273.15 = 10°\mathrm{C} + 273.15 = \boxed{283\ \mathrm{K}}$$

PROBLEM 4

A pan of water is heated from 25°C to 80°C. What is the change in its temperature on the Kelvin scale and on the Fahrenheit scale?

SOLUTION

$$\Delta T = \Delta T_C = 80°C - 25°C = 55°C = \boxed{55\ K}$$

$$\Delta T_F = \tfrac{9}{5}\Delta T_C = \tfrac{9}{5}(55°C) = \boxed{99°F}$$

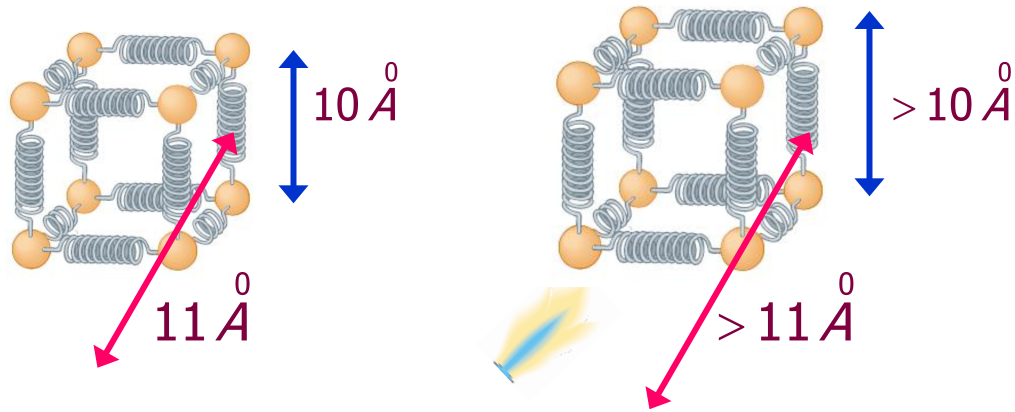
2. Thermal expansion of solids

2.1 Notions

Thermal expansion is a consequence of the change in the average separation between the constituent atoms in an object

Joints are used to separate sections of roadways on bridges

$\rightarrow$ Thermal expansion



As the temperature of the solid increases, the atoms oscillate with greater amplitudes $\rightarrow$ the average separation between them increases $\rightarrow$ the object expands.

2.2 Average coefficient of linear expansion

L_i : initial length along some direction at some temperature T_i
ΔL : amount of the increase in length
ΔT : change in temperature

The average coefficient of linear expansion is defined :

$$\boxed{\alpha \equiv \frac{\Delta L / L_i}{\Delta T}} \quad \Leftrightarrow \quad \boxed{\Delta L \equiv L_f - L_i = \alpha L_i \Delta T}$$

→ "The change in length of an object is proportional to the change in temperature"

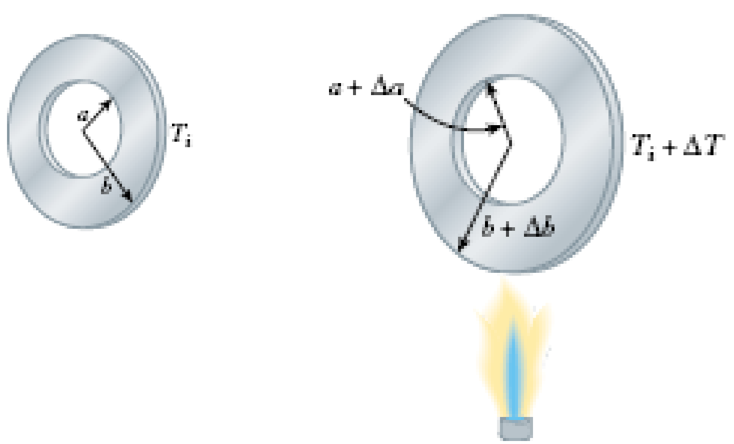
2.3 Average coefficient of volume expansion

V_i : initial volume at some temperature
T_i ΔV : amount of the increase in volume
ΔT : change in temperature

The average coefficient of volume expansion is defined :

$$\boxed{\beta \equiv \frac{\Delta V / V_i}{\Delta T}} \quad \Leftrightarrow \quad \boxed{\Delta V \equiv V_f - V_i = \beta V_i \Delta T}$$

Relationship between α and β **?**



Relationship between α and β

Consider a box of dimensions *l*, *w*, and *h*.
Its volume at some temperature T_i is $V_i = lwh$
If the temperature changes to $T_i + \Delta T$,
its volume changes to $V_i + \Delta V$, where each dimension changes according to : $\Delta L \equiv L_i - L_f = \alpha L_i \Delta T$

$$\longrightarrow V_i + \Delta V = (l + \Delta l)(w + \Delta w)(h + \Delta h)$$

$$= (l + \alpha l \Delta T)(w + \alpha w \Delta T)(h + \alpha h \Delta T) = lwh(1 + \alpha \Delta T)^3$$

$$= V_i\left[1 + 3\alpha\Delta T + 3(\alpha\Delta T)^2 + (\alpha\Delta T)^3\right]$$

Because for typical values of $T < 100°\mathrm{C}$, $\alpha\Delta T << 1$:

$$(\alpha\Delta T)^2 \approx 0\,;(\alpha\Delta T)^3 \approx 0 \longrightarrow V_i + \Delta V = V_i\left[1 + 3\alpha\Delta T\right];$$

$$\longrightarrow \frac{\Delta V}{V_i} = 3\alpha\Delta T$$

Compare with : $\boxed{\beta \equiv \frac{\Delta V / V_i}{\Delta T}}$ $\Rightarrow$ $\boxed{\beta = 3\alpha}$

TEST

The change in area A_i of a rectangular plate when the temperature change an amount of ΔT is

A. $\Delta A = \alpha A_i \Delta T$

B. $\Delta A = 2\alpha A_i \Delta T$

C. $\Delta A = 3\alpha A_i \Delta T$

TABLE 19.2 Average Expansion Coefficients for Some Materials Near Room Temperature

Material	Average Linear Expansion Coefficient (α) $(°C)^{-1}$	Material	Average Volume Expansion Coefficient (β) $(°C)^{-1}$
Aluminum	24×10^{-6}	Alcohol, ethyl	1.12×10^{-4}
Brass and bronze	19×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Acetone	1.5×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerin	4.85×10^{-4}
Glass (Pyrex)	3.2×10^{-6}	Mercury	1.82×10^{-4}
Lead	29×10^{-6}	Turpentine	9.0×10^{-4}
Steel	11×10^{-6}	Gasoline	9.6×10^{-4}
Invar (Ni–Fe alloy)	0.9×10^{-6}	Air at 0°C	3.67×10^{-3}
Concrete	12×10^{-6}	Helium	3.665×10^{-3}

→ **Principle of a thermostats: *bimetallic strip***

PROBLEM 5 A steel railroad track has a length of 30.000 m when the temperature is 0.0°C.

(a) What is its length when the temperature is 40.0°C?

SOLUTION

(a) The increase in length

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

$$= \left[11 \times 10^{-6} ({}^{o}C^{-1})\right](30000\ m)(40.0\ {}^{o}C)$$

$$= 0.013\ m$$

The length of the track at 40.0°C :

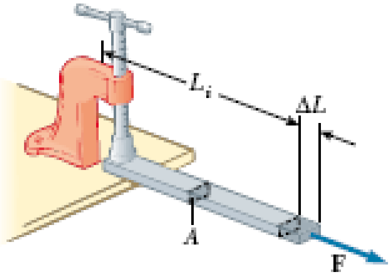
$$L_f = L_i + 0.013\ m = 30.013\ m$$

PROBLEM 5 A steel railroad track has a length of 30.000 m when the temperature is 0.0°C.

(a) What is its length when the temperature is 40.0°C?

(b) Suppose that the ends of the rail are rigidly clamped at 0.0°C so that expansion is prevented. What is the thermal stress set up in the rail if its temperature is raised to 40.0°C? Knowing that the Young's modulus for steel : 20 × 1010 N/m².

SOLUTION **(b)** **Young's modulus**: measures the resistance of a solid to a change in its length :



$$Y = \frac{F/A}{\Delta L / L_i} \longrightarrow \textbf{stress}$$

Thermal stress : $F/A = Y\dfrac{\Delta L}{L_i}$

$$\frac{F}{A} = (20\times 10^{10}\ N/m)\times\frac{0.013\ m}{30.000\ m} = 8.7\times 10^{7}\ N/m^{2}$$

PROBLEM 6 A glass flask with volume 200 cm^3 is filled to the brim with mercury at 20°C. How much mercury overflows when the temperature of the system is raised to 100°C? The coefficient of linear expansion of the glass is $0.40 \times 10^{-5}\ K^{-1}$.

SOLUTION

TABLE 19.2 Average Expansion Coefficients for Some Materials Near Room Temperature

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$1.2 \times 10^{-5}\ K^{-1}$

$100°C - 20°C)$

$100°C - 20°C)$

$$\Delta V_{mercury} - \Delta V_{glass} = 2.9\ cm^3 - 0.19\ cm^3 = 2.7\ cm^3$$

PROBLEM 7 A metal rod is 40.125 cm long at 20.0°C and 40.148 cm long at 45.0°C. Calculate the average coefficient of linear expansion of the rod for this temperature range.

SOLUTION

$$\Delta L = \alpha L_0 \Delta T \text{ implies } \alpha = \frac{\Delta L}{L_0 \Delta T} = \frac{0.023 \text{ cm}}{(40.125 \text{ cm})(25.0 \text{ C}^\circ)} = 2.3 \times 10^{-5} \ (\text{C}^\circ)^{-1}.$$

PROBLEM 8 A glass flask whose volume is 1000.00 cm^3 at 0.0°C is completely filled with mercury at this temperature. When flask and mercury are warmed to 55.O°C, 8.95 cm^3 of mercury overflow. If the coefficient of volume expansion of mercury is 18.0 x 10^{-5} K^{-1}, compute the coefficient of volume expansion of the glass.

SOLUTION

$$\Delta V_{\mathrm{Hg}} = V_0 \beta_{\mathrm{Hg}} \Delta T = (1000.00\ \mathrm{cm}^3)(18 \times 10^{-5}\ (\mathrm{C}^\circ)^{-1})(55.0\ \mathrm{C}^\circ) = 9.9\ \mathrm{cm}^3.$$

$$\Delta V_{\mathrm{glass}} = \Delta V_{\mathrm{Hg}} - 8.95\ \mathrm{cm}^3 = 0.95\ \mathrm{cm}^3.\quad \beta_{\mathrm{glass}} = \frac{\Delta V_{\mathrm{glass}}}{V_0 \Delta T} = \frac{0.95\ \mathrm{cm}^3}{(1000.00\ \mathrm{cm}^3)(55.0\ \mathrm{C}^\circ)} = 1.7 \times 10^{-5}\ (\mathrm{C}^\circ)^{-1}.$$

3. Heat and the Absorption of Heat by Solids and Liquids

3.1 The specific heat

- **The heat capacity** C of a particular sample of a substance is defined as the **amount of energy** needed to raise the temperature of that sample **by 1°C**.

If heat Q produces a change T in the temperature of a substance :

$$\boxed{Q = C\Delta T}$$

J/^{0}C

- The **specific heat** c of a substance is the heat capacity **per unit mass**

If energy Q transferred by heat to mass m of a substance changes the temperature of the sample by ΔT, then the **specific heat of the substance** :

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

J/kg.^{0}C

$$\Leftrightarrow \quad \boxed{Q = mc\Delta T}$$

N.B.: if c varies with temperature over the interval (T_i , T_f) :

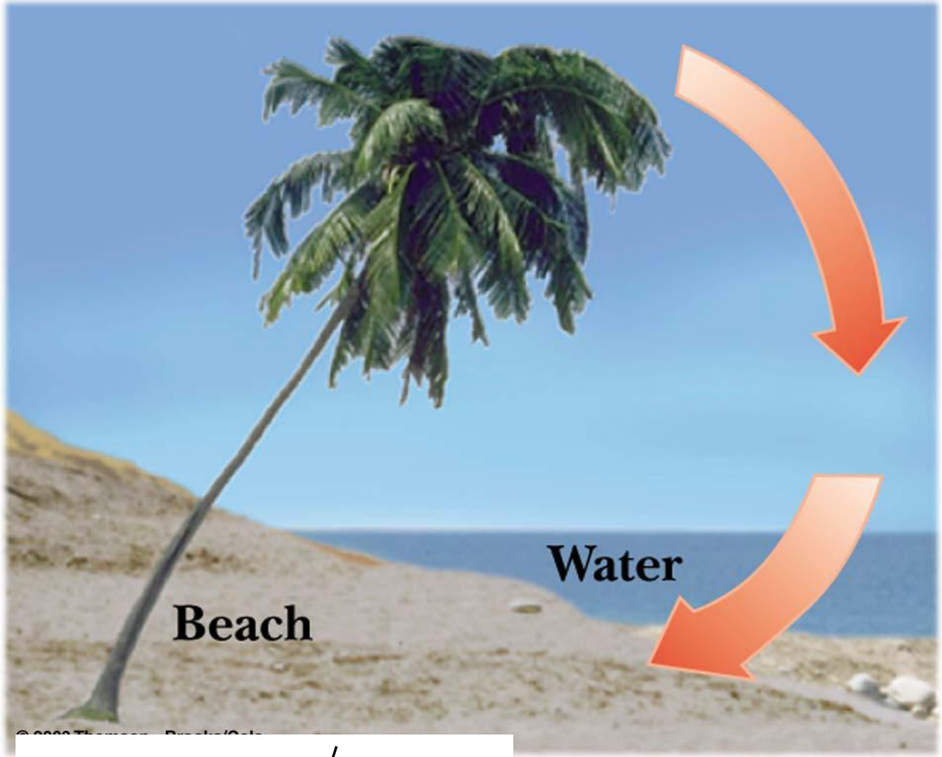
$$Q = m\int_{T_i}^{T_f} c\,dT$$

Some Specific Heats and Molar Specific Heats at Room Temperature

Substance	Specific Heat cal/(g·K)	Specific Heat J/(kg·K)	Molar Specific Heat J/(mol·K)
Elemental Solids			
Lead	0.0305	128	26.5
Tungsten	0.0321	134	24.8
Silver	0.0564	236	25.5
Copper	0.0923	386	24.5
Aluminum	0.215	900	24.4
Other Solids			
Brass	0.092	380	
Granite	0.19	790	
Glass	0.20	840	
Ice (−10°C)	0.530	2220	
Liquids			
Mercury	0.033	140	
Ethyl alcohol	0.58	2430	
Seawater	0.93	3900	
Water	1.00	4180	

Consequences of Different Specific Heats

- Water has a high specific heat compared to land
- On a hot day, the air above the land warms faster
- The warmer air flows upward and cooler air moves toward the beach



What happens at night?

$$c_{Si} = 700\ J/kg^{\circ}C$$

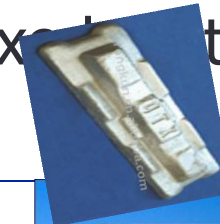
$$c_{H_2O} = 4186\ J/kg^{\circ}C$$

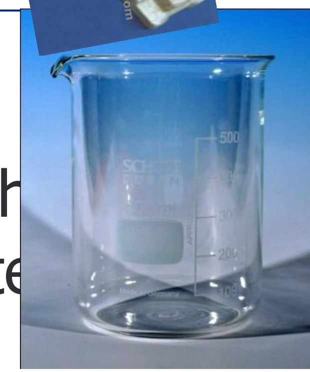
What happens at night?

1. same
2. opposite
3. nothing
4. none of the above

PROBLEM 9 A 0.050 0-kg ingot of metal is heated to 200.0°C and then dropped into a beaker containing 0.400 kg of water initially at 20.0°C.

(a) If the final equilibrium temperature of the mix tem is 22.4°C, find the specific heat of the metal.





SOLUTION

(a) Conservation of energy : The energy leaving th part of the system by heat is equal to that ente cold part of the system

$$Q_{cold} = -Q_{hot}$$

The energy transfer for the water : $m_w c_w (T_f - T_w) \quad (>0)$

The energy transfer for the sample of unknown specific heat :

$$m_x c_x (T_f - T_x) \quad (<0)$$

$$\longrightarrow m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)$$

PROBLEM 9 A 0.050 0-kg ingot of metal is heated to 200.0°C and then dropped into a beaker containing 0.400 kg of water initially at 20.0°C.

(a) If the final equilibrium temperature of the mixed system is 22.4°C, find the specific heat of the metal.

SOLUTION

$$m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)$$

$$(0.400\ kg)(4\ 186\ J/kg.^0C)(22.4\,^0C\ -\ 20.0\,^0C)$$

$$= -(0.050\ 0\ kg)(c_x)(22.4\,^0C\ \ 200.0\,^0C)$$

$$c_x = 453\ J/kg.^0C$$

PROBLEM 9 A 0.050 0-kg ingot of metal is heated to 200.0°C and then dropped into a beaker containing 0.400 kg of water initially at 20.0°C.

(b) What is the amount of energy transferred to the water as the ingot is cooled?

SOLUTION

(b) $Q = m_w c_w (T_f - T_w)$

$$= (0.400\ kg)(4\ 186\ J/kg.^0C)(22.4\,^0C\ -\ 20.0\,^0C)$$

$$= 4020\ \text{J}$$

PROBLEM 10 A bullet of mass of 2.00 g is fired with the speed of 200 m/s into the pine wall. Assume that all the internal energy generated by the impact remains with the bullet. What is the temperature change of the bullet?

SOLUTION

The kinetic energy of the bullet :

$$\frac{1}{2}mv^2 = \frac{1}{2}(2.00\times10^{3}\ kg)(200\ m/s)^2 = \ 40.0\ J$$

$$\Delta T = \frac{Q}{mc} = \frac{40.0\ J}{(2.00\times10^{-3}\ kg)(234\ J/kg.^{0}C)}$$

$$\Delta T = 85.5\ {}^{0}C$$

PROBLEM 11 During a bout with the flu an 80-kg man ran a fever of 39.0^{O}C instead of the normal body temperature of $37.O^{O}$C. Assuming that the human body is mostly water, how much heat is required to raise his temperature by that amount?

SOLUTION

$$Q = mc\,\Delta T = (80\,\text{kg})(4190\,\text{J/kg}\cdot\text{K})(2.0\,\text{K}) = 6.7 \times 10^{5}\,\text{J}$$

3.2 Molar specific heats

- Sometimes it's more convenient to describe a quantity of substance in terms of **the number of moles** n rather than **the mass** m of material.

Total mass: $m = nM$

n : the number of moles n of a substance

M : molar mass - g/mol

$$Q = mc\Delta T = nMc\Delta T$$

We put: $\boxed{C = Mc}$ $\Rightarrow$ $\boxed{Q = nC\Delta T}$

C : **molar specific heat** (specific heat of one mole)

Be careful!

C: **heat capacity**

C : **molar specific heat**

C **: molar specific heat** (specific heat of one mole)

$$\boxed{C = Mc} \qquad \boxed{Q = nC\Delta T}$$

Example: The molar heat capacity of water is

$$C = Mc = (0.018 kg / mol) \times (4190 J / kg.K)$$
$$= 75.4 J / mol.K$$

- **Constant volume:** $\boxed{Q = nC_V \Delta T}$

  C_V : the molar specific heat at constant volume

- **Constant pressure:**

$$\boxed{Q = nC_P \Delta T}$$

  C_P : the molar specific heat at constant pressure

C: **molar specific heat** (specific heat of one mole)

$$\boxed{C = Mc} \qquad \boxed{Q = nC\Delta T}$$

Substance	Specific Heat, c (J/kg·K)	Molar Mass, M (kg/mol)	Molar Heat Capacity, C (J/mol·K)
Aluminum	910	0.0270	24.6
Beryllium	1970	0.00901	17.7
Copper	390	0.0635	24.8
Ethanol	2428	0.0461	111.9
Ethylene glycol	2386	0.0620	148.0
Ice (near 0°C)	2100	0.0180	37.8
Iron	470	0.0559	26.3
Lead	130	0.207	26.9
Marble ($CaCO_3$)	879	0.100	87.9
Mercury	138	0.201	27.7
Salt (NaCl)	879	0.0585	51.4
Silver	234	0.108	25.3
Water (liquid)	4190	0.0180	75.4

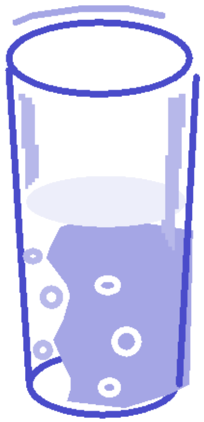
3. 4 Phase change and heats of transformation

a. Phase change

States of matter: Phase Transitions

ICE **WATER** **STEAM**

Add heat



Add heat

These are three states of matter (plasma is another one)

Substance	Melting Point (°C)	Boiling Point (°C)
Helium	− 269.65	− 268.93
Nitrogen	− 209.97	− 195.81
Oxygen	− 218.79	− 182.97
Ethyl alcohol	− 114	78
Water	0.00	100.00
Sulfur	119	444.60
Lead	327.3	1 750
Aluminum	660	2 450
Silver	960.80	2 193
Gold	1 063.00	2 660
Copper	1 083	1 187

- A *phase change* occurs when the physical characteristics of the substance change from one form to another
- Common phases changes are
  - Solid to liquid – melting
  - Liquid to gas – boiling
- Phases changes involve a change in the internal energy, but *no change in temperature*

b. Heat of transformation (latent heat)

- Different substances respond differently to the addition or removal of energy as they change phase
- The amount of energy transferred during a phase change depends on the amount of substance involved
- If a quantity Q of energy transfer is required to change the phase of a mass m of a substance, 1 the heat of transformation of the substance is defined by :

$J/kg \leftarrow \boxed{L \equiv \dfrac{Q}{m}} \longrightarrow \boxed{Q = mL}$

(because this added or removed energy does not result in a temperature change - "hidden" heat)

- From solid to liquid : Heat of fusion L_F
- From liquid to gas : Heat of vaporization L_V

Some Heats of Transformation

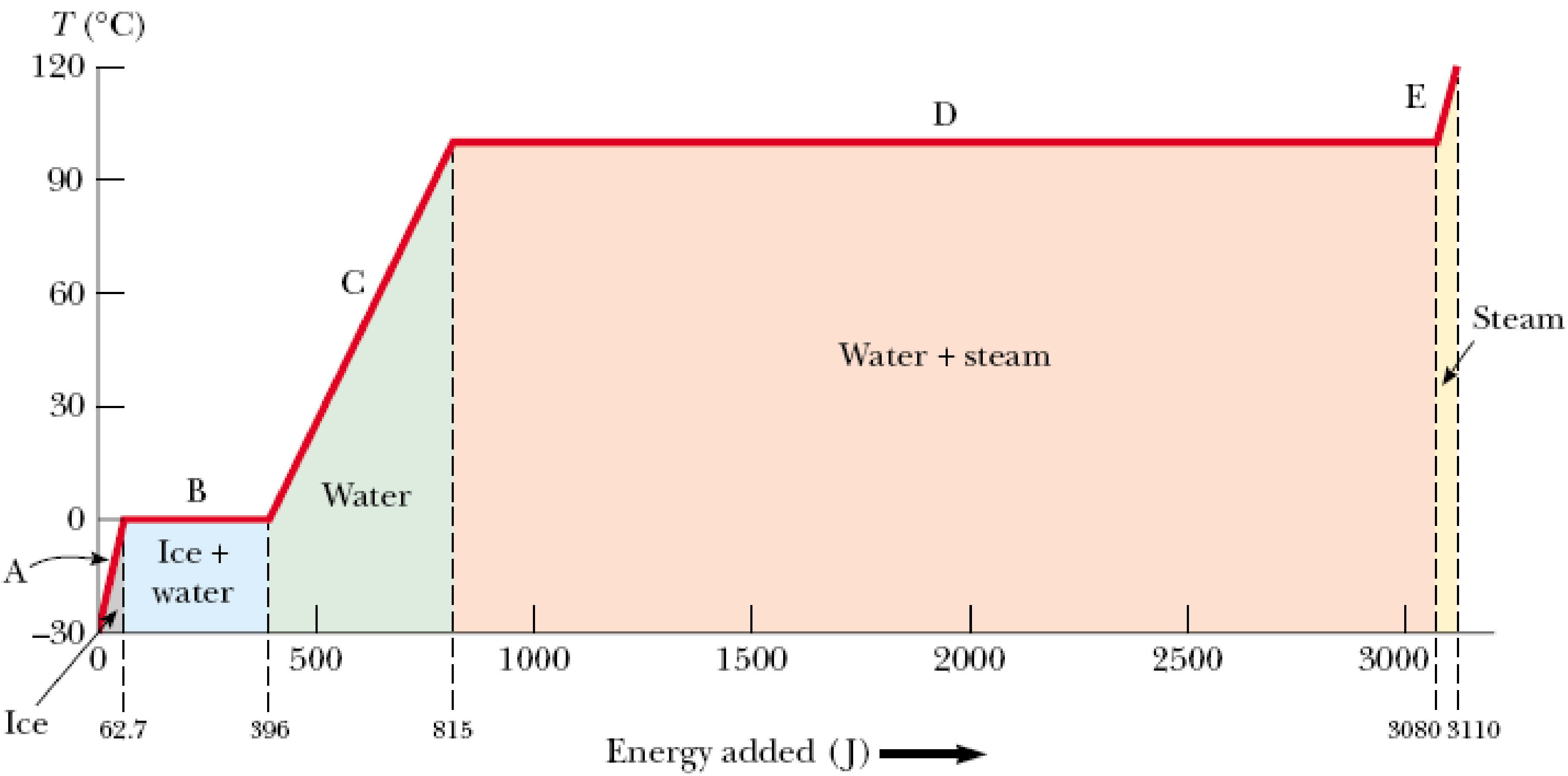
	Melting		Boiling	
Substance	Melting Point (K)	Heat of Fusion L_F (kJ/kg)	Boiling Point (K)	Heat of Vaporization L_V (kJ/kg)
Hydrogen	14.0	58.0	20.3	455
Oxygen	54.8	13.9	90.2	213
Mercury	234	11.4	630	296
Water	273	333	373	2256
Lead	601	23.2	2017	858
Silver	1235	105	2323	2336
Copper	1356	207	2868	4730

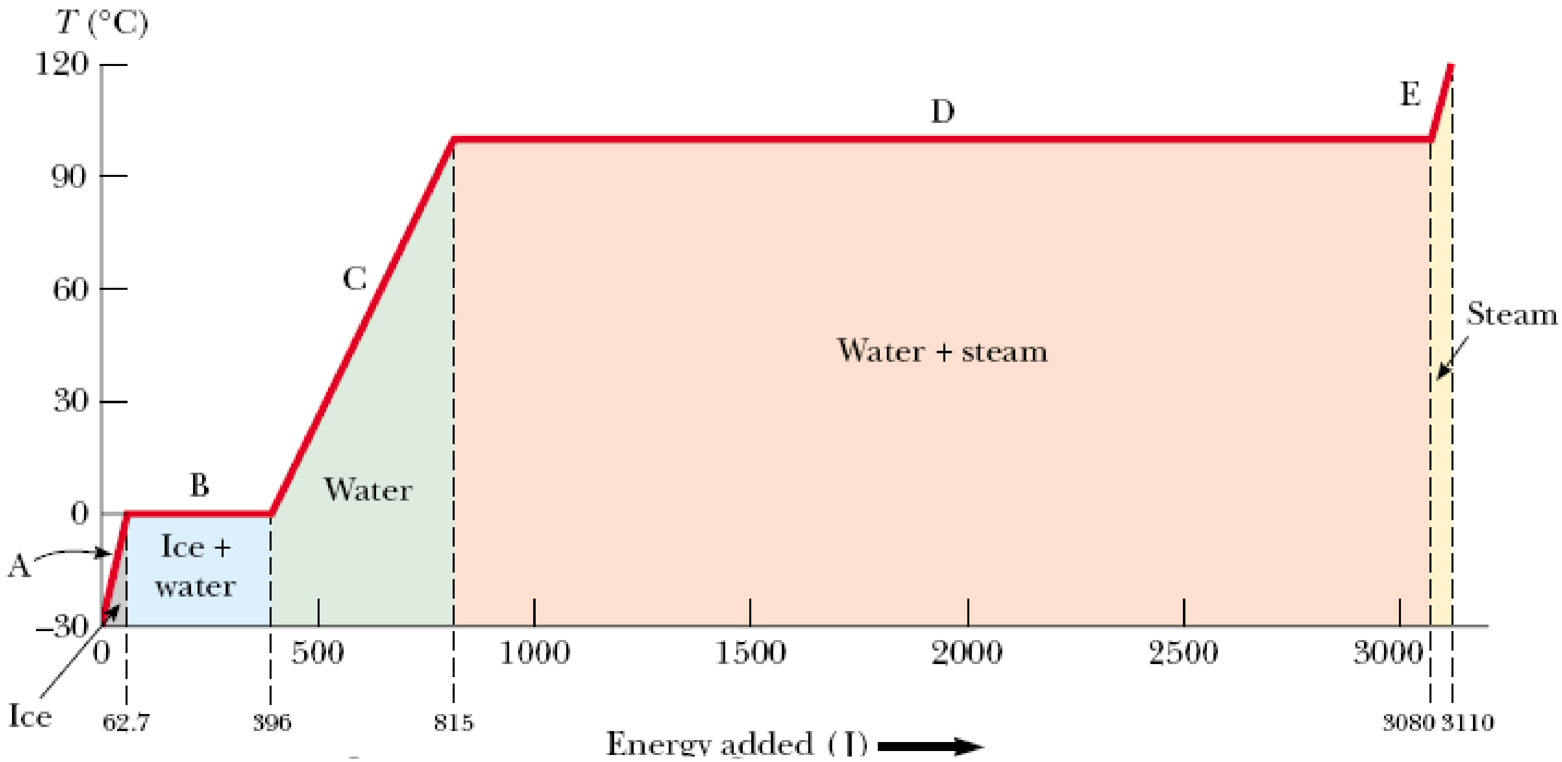
Example : L_F(water) = 3.33×10^5 J/kg

⟶ 3.33×105 J is needed to "fuse" 1kg of ice

→ liquid water

EXAMPLE **Consider the energy required to convert a 1.00-g block of ice at 30.0°C to steam at 120.0°C.**





A : $Q = m_i c_i \Delta T = (1.00 \times 10^{-3}\ \text{kg})(2\,090\ \text{J/kg}\cdot{}^\circ\text{C})(30.0^\circ\text{C}) = 62.7\ \text{J}$

B : $Q = mL_f = (1.00 \times 10^{-3}\ \text{kg})(3.33 \times 10^5\ \text{J/kg}) = 333\ \text{J}$

C : $Q = m_w c_w \Delta T = (1.00 \times 10^{-3}\ \text{kg})(4.19 \times 10^3\ \text{J/kg}\cdot{}^\circ\text{C})(100.0^\circ\text{C}) = 419\ \text{J}$

D : $Q = mL_v = (1.00 \times 10^{-3}\ \text{kg})(2.26 \times 10^6\ \text{J/kg}) = 2.26 \times 10^3\ \text{J}$

E : $Q = m_s c_s \Delta T = (1.00 \times 10^{-3}\ \text{kg})(2.01 \times 10^3\ \text{J/kg}\cdot{}^\circ\text{C})(20.0^\circ\text{C}) = 40.2\ \text{J}$

The total amount of energy : 3.11×10^3 J

PROBLEM 13 What mass of steam initially at 130°C is needed to warm 200 g of water in a 100-g glass container from 20.0°C to 50.0°C ?

Knowing that $c_{Steam} = 2.01 \times 10^3$ J/kg.^{0}C , $L_V = 2.26 \times 10^6$ J/kg

$c_{Water} = 4.19 \times 10^3$ J/kg.^{0}C , $c_{Glass} = 837$ J/kg.^{0}C

Solution The steam loses energy in three stages. In the first stage, the steam is cooled to 100°C. The energy transfer in the process is

$$Q_1 = m_s c_s \Delta T = m_s(2.01 \times 10^3\ \mathrm{J/kg \cdot ^\circ C})(-30.0^\circ\mathrm{C})$$
$$= -m_s(6.03 \times 10^4\ \mathrm{J/kg})$$

In the second stage, the steam is converted to water. To find the energy transfer during this phase change, we use $Q = -mL_v$, where the negative sign indicates that energy is leaving the steam:

$$Q_2 = -m_s(2.26 \times 10^6\ \mathrm{J/kg})$$

In the third stage, the temperature of the water created from the steam is reduced to 50.0°C. This change requires an energy transfer of

$$Q_3 = m_s c_w \Delta T = m_s(4.19 \times 10^3\ \mathrm{J/kg \cdot ^\circ C})(-50.0^\circ\mathrm{C})$$
$$= -m_s(2.09 \times 10^5\ \mathrm{J/kg})$$

PROBLEM 13 What mass of steam initially at 130°C is needed to warm 200 g of water in a 100-g glass container from 20.0°C to 50.0°C ?

Knowing that $c_{Steam} = 2.01 \times 10^3$ J/kg.^{0}C , $L_V = 2.26 \times 10^6$ J/kg

$c_{Water} = 4.19 \times 10^3$ J/kg.^{0}C , $c_{Glass} = 837$ J/kg.^{0}C

Adding the energy transfers in these three stages, we obtain

$$\begin{aligned} Q_{\text{hot}} &= Q_1 + Q_2 + Q_3 \\ &= -m_s(6.03 \times 10^4\ \text{J/kg} + 2.26 \times 10^6\ \text{J/kg} \\ &\quad + 2.09 \times 10^5\ \text{J/kg}) \\ &= -m_s(2.53 \times 10^6\ \text{J/kg}) \end{aligned}$$

Energy received by the water and the glass :

$$\begin{aligned} Q_{\text{cold}} &= (0.200\ \text{kg})(4.19 \times 10^3\ \text{J/kg}\cdot{}^\circ\text{C})(30.0^\circ\text{C}) \\ &\quad + (0.100\ \text{kg})(837\ \text{J/kg}\cdot{}^\circ\text{C})(30.0^\circ\text{C}) \\ &= 2.77 \times 10^4\ \text{J} \end{aligned}$$

Conservation of energy:

$Q_{HOT} = - Q_{COLD}$

$$2.77 \times 10^4\ \text{J} = -[-m_s(2.53 \times 10^6\ \text{J/kg})]$$

$$m_s = \boxed{1.09 \times 10^{-2}\ \text{kg} = 10.9\ \text{g}}$$

PROBLEM 14 A student drinks her morning coffee out of an aluminum cup. The cup has a mass of 0.120 kg and is initially at 20.0ºC when she pours in 0.300 kg of coffee initially at 70.0ºC. What is the final temperature after the coffee and the cup attain thermal equilibrium? (Assume that coffee has the same specific heat as water and that there is no heat exchange with the surroundings.)

SOLUTION

$$Q_{\text{coffee}} = m_{\text{coffee}} c_{\text{water}} \Delta T_{\text{coffee}}$$
$$= (0.300\text{ kg})(4190\text{ J/kg}\cdot\text{K})(T - 70.0°\text{C})$$

The (positive) heat gained by the aluminum cup is

$$Q_{\text{aluminum}} = m_{\text{aluminum}} c_{\text{aluminum}} \Delta T_{\text{aluminum}}$$
$$= (0.120\text{ kg})(910\text{ J/kg}\cdot\text{K})(T - 20.0°\text{C})$$

We equate the sum of these two quantities of heat to zero, obtaining an algebraic equation for T:

$$Q_{\text{coffee}} + Q_{\text{aluminum}} = 0 \qquad \text{or}$$

$$(0.300\text{ kg})(4190\text{ J/kg}\cdot\text{K})(T - 70.0°\text{C})$$
$$+ (0.120\text{ kg})(910\text{ J/kg}\cdot\text{K})(T - 20.0°\text{C}) = 0 \quad T = 66.0°\text{C}.$$

PROBLEM 15 A physics student wants to cool 0.25 kg of Omni Cola (mostly water), initially at 25°C, by adding ice initially at - 20°C. How much ice should she add so that the final temperature will be 0°C with all the ice melted if the heat capacity of the container may be neglected?

SOLUTION

$$Q_{\text{Omni}} = m_{\text{Omni}} c_{\text{water}} \Delta T_{\text{Omni}}$$
$$= (0.25\text{ kg})(4190\text{ J/kg}\cdot\text{K})(0°\text{C} - 25°\text{C})$$
$$= -26{,}000\text{ J}$$

$$Q_1 = m_{\text{ice}} c_{\text{ice}} \Delta T_{\text{ice}}$$
$$= m_{\text{ice}}(2.1 \times 10^3\text{ J/kg}\cdot\text{K})[0°\text{C} - (-20°\text{C})]$$
$$= m_{\text{ice}}(4.2 \times 10^4\text{ J/kg})$$

$$Q_2 = m_{\text{ice}} L_f$$
$$= m_{\text{ice}}(3.34 \times 10^5\text{ J/kg})$$

$$Q_{\text{Omni}} + Q_1 + Q_2 = -26{,}000\text{ J} + m_{\text{ice}}(42{,}000\text{ J/kg}) + m_{\text{ice}}(334{,}000\text{ J/kg}) = 0$$

$$m_{\text{ice}} = 0.069\text{ kg} = 69\text{ g.}$$

PROBLEM 16 (a) How much heat must be absorbed by ice of mass 720 g at - 10^{0}C to take it to liquid state at 15^{0}C?
Knowing that c_{ice} = 2220 J/kg.^{0}C , L_F = 333 kJ/kg
c_{Water} = 4.19 × 10^3 J/kg.^{0}C

Warming the ice:

$$\begin{aligned} Q_1 &= c_{\text{ice}} m (T_f - T_i) \\ &= (2220 \text{ J/kg} \cdot \text{K})(0.720 \text{ kg})[0°\text{C} - (-10°\text{C})] \\ &= 15\,984 \text{ J} \approx 15.98 \text{ kJ}. \end{aligned}$$

Melting the ice:

$$Q_2 = L_F m = (333 \text{ kJ/kg})(0.720 \text{ kg}) \approx 239.8 \text{ kJ}.$$

Warming the liquid:

$$\begin{aligned} Q_3 &= c_{\text{liq}} m (T_f - T_i) \\ &= (4190 \text{ J/kg} \cdot \text{K})(0.720 \text{ kg})(15°\text{C} - 0°\text{C}) \\ &= 45\,252 \text{ J} \approx 45.25 \text{ kJ}. \end{aligned}$$

$$\begin{aligned} Q_{\text{tot}} &= Q_1 + Q_2 + Q_3 \\ &= 15.98 \text{ kJ} + 239.8 \text{ kJ} + 45.25 \text{ kJ} \\ &\approx 300 \text{ kJ}. \end{aligned}$$

PROBLEM 16 (a) How much heat must be absorbed by ice of mass 720 g at - 10^0C to take it to liquid state at 15^0C?
Knowing that c_{ice} = 2220 J/kg.^{0}C , L_F = 333 kJ/kg
c_{Water} = 4.19 × 10^3 J/kg.^{0}C
(b) If we supply the ice with a total energy of only 2I0 kJ (as heat), what then are the final state and temperature of the water?

The remaining heat Q_{rem}: 210 – 15,98 ≈ 194 kJ

The mass m of ice that is melted:`

$$m = \frac{Q_{\text{rem}}}{L_F} = \frac{194 \text{ kJ}}{333 \text{ kJ/kg}} = 0.583 \text{ kg} \approx 580 \text{ g}.$$

580 g water and 140 g ice, at 0°C.