2021 Sec 4 Physics Chapter 20

Thermal Physics - ANSWERS

Example 20.1
(a) Volume of mercury
(b) Intensity of infra-red radiation
(c) Resistance of a thermistor

Example 20.2
- Electromotive force (or e.m.f.) generated

- It requires a junction which has to be kept at a steady temperature. This may be difficult to maintain.

Example 20.3
- During collisions with the walls of the container, the gas molecules experience a change in velocity. This means that the container exerts a force on the molecules.
- By Newton's Third Law, the molecules also exert a force on the walls of the container. The force per unit area exerted on the walls due to the collision of gas molecules is the pressure of the gas.

Modes of transfer of thermal energy	**Conduction**	**Convection**	**Radiation**
Mechanism – how does it work? **Medium?** • Solid • Liquid • Gas	Thermal energy is transmitted through a medium from one particle to another through vibrations about fixed positions (mainly in a solid) Presence of free electrons in metals help to transfer thermal energy faster	Thermal energy is transmitted from one place to another by the movement of heated particles of a gas or liquid due to density changes	Heat source transmits electromagnetic waves. (in the form of infra-red radiation) Does not require any medium
Factors which affect the **rate** of thermal energy transfer	Distance between particles (much better in solids than liquids/gases)	Position of heat source and whether convection currents can be set up [warm fluid rises, colder fluid sinks]	Colour, surface texture, surface area, temperature [dark/dull surface is good radiator or emitter of radiation]
Applications • Natural occurrence • Design of appliances (Also refer textbook examples)	Good conductors are used in cooking; Poor conductors are used to insulate buildings	Sea breeze and land breeze	Houses in hot countries and factory roofs are painted in white, light-coloured paint/ aluminium paint so as not to absorb too much heat

Example 20.4

- Carbon dioxide gas (in atmosphere) has similar absorption and transmission properties as glass (in a greenhouse).
- It absorbs the solar radiation and also traps the long wavelength radiation emitted from the Earth's surface.
- Overtime, the temperature on the Earth's surface increases, contributing to global warming.

Example 20.5

- $Q = m\,c\,\Delta\theta$

  $c = Q / (m\,\Delta\theta) = 12\,000\text{ J} / ((1.00\text{ kg})(45 - 31)\text{K})$ - *substitute with units!*

  $= 12000 / 14 = 857.14 \approx 860\text{ J kg}^{-1}\text{ K}^{-1}$ (2 s.f.) or $860\text{ J kg}^{-1}\text{ (°C)}^{-1}$

20.4.2

Solid *(example: aluminium)*	Liquid *(example: ethanol)*
Precautions	
The holes should not be too large so that there is better contact between the heater and thermometer with the aluminium block	Stir the ethanol to allow better distribution of heat within the ethanol.
Sources of Error and Possible Improvements to the Set-up	
There is loss of thermal energy to the surroundings. The aluminum block can be lagged. Lag the aluminium block so that there is less heat lost to the environment. (Heat loss may cause c measured to be lower than actual value.)	There is loss of thermal energy to the surroundings. Reduce heat loss by lagging the container (Heat loss may cause c measured to be lower than actual value.) Beaker can be covered to minimize evaporation of ethanol

Example 20.6

- $Q = m\,L_v$

  $L_v = Q / m = 45\,000\text{ J} / (20/1000)\text{ kg} = 2.25 \times 10^6\text{ J kg}^{-1}$

  Or $= 45\,000\text{ J} / 20\text{ g} = 2250\text{ J g}^{-1}$

Experimental determination of specific latent heat (of)	
fusion *(example: water and ice)*	vaporisation *(example: water and water vapour)*
Sources of Error	
• Some water may evaporate from the beaker in both set-ups; • Some thermal energy supplied by the heater may go into increasing the temperature of the surrounding air / water trapped among ice and not be fully absorbed by the ice.	• Some water may be lost due to evaporation; • It may be difficult to determine the point at which the scale is balanced.
Possible Improvements to the Experiment	
Use a control to estimate the rate of loss of water mass due to evaporation.	Use a control to estimate the rate of loss of water mass due to evaporation.

Example 20.7
Let θ be the final temperature (assume it is above 0 °C)

Energy lost by water (to fall from 30 to θ)	= energy gained by ice (to 0 °C) + energy gained by ice for melting + energy gained by water (from ice) rise from 0 to θ

Convert all masses to "kg".

$$m_2 c_2 (30 - \theta) = m_1 c (0 - (-20)) + m_1 L_f + m_1 c_2 (\theta - 0)$$

$$(0.20\ \text{kg})(4200\ \text{J (kg °C)}^{-1})(30\ \text{°C} - \theta) = (0.01\ \text{kg})(2050\ \text{J (kg °C)}^{-1})(20\text{°C}) + (0.01\ \text{kg})(3.34 \times 10^5\ \text{J kg}^{-1}) + (0.01\ \text{kg})(4200\ \text{J (kg °C)}^{-1})\ \theta$$

$$840(30 - \theta) = 410 + 3340 + 42\ \theta$$

$$\theta\ (42 + 840) = 25200 - 410 - 3340$$

$$\theta = 24.32 \approx 24\ \text{°C}$$

20.44 Evaporation

	Boiling	Evaporation
• Similarities	Both involve a change of state from liquid to gas.	
• Differences	• Occurs at boiling point (constant temperature); • Occurs throughout the liquid; • Bubbles can be seen	• Occurs at any temperature; • Occurs at the surface of the liquid; • No bubbles can be seen.

Example 20.8
- The liquid molecules are in constant random motion and collide with each other continuously.
- When the molecules with higher kinetic energy collide with other molecules when it is near the surface of the liquid, it may gain enough energy to overcome the intermolecular forces of the liquid and leave the liquid body.

Example 20.9
- During evaporation, the fastest-moving molecules leave the liquid. The average kinetic energy of the molecules remaining in the liquid is decreased.
- Since temperature is directly proportional to the average kinetic energy of the molecules in the liquid, temperature falls, and hence cooling occurs.

Example 20.10
D

Discussion

1. The specific heat capacity of water is unusually high. As such, in the day, the water warms up slower than the land, therefore, wind blows from the cold sea towards land, forming sea breeze. In the night, the land cools faster than the water, therefore, wind blows from the land towards the sea, forming land breeze.

2. As gases do not have a fixed volume, the specific heat capacity of gas can be determined either under <u>constant volume</u> conditions or <u>constant pressure</u> conditions. Thus, there are two specific heat capacity values for gas.

3. No. Styrofoam is a poor conductor of heat. Therefore, the temperature measured by the thermometer will not be representative of the temperature reached by the whole piece of Styrofoam. Moreover, the thermal energy supplied by the heater will also not be well distributed through the entire block of Styrofoam. Styrofoam may also melt.

4. (i) temperature. At higher temp, average KE of molecules is higher, so there are more molecules with higher KE.
(ii) surface area. More molecules will be nearer the surface with bigger surface area, thus, more molecules are available for evaporation.
(iii) humidity. Less water vapour in the air provide more empty space for evaporation.
(iv) wind speed: Stronger wind blows away evaporated molecules to provide more empty space for further evaporation.
(v) atmospheric pressure. More evaporation can occur as less energy is needed to do work against atmospheric pressure.

5. <u>Pressure & Boiling Point</u>: When pressure is increased the molecules of that liquid become more and more confined. Thus In order to boil the molecules now require much more energy than they previously required. Similarly when pressure is decreased the molecules become more free and loose so the amount of energy neesed to become a gas is lesser. In effect in the first case with increase in pressure the boiling point also increases; in the second case the pressure decreases so the boiling point also subsequently decreases.

<u>Pressure & Melting Point</u>: Usually the melting point decreases if the pressure decreases, but of course there are exceptions like water.
Lower pressure allows the molecules in a solid to expand the distance between themselves, and to become more active. This is the same as the effect of raising the temperature. If you lower the pressure enough, you can make the molecules so active that they become liquid, without ever adjusting the temperature. You are, in effect, lowering the melting point by lowering the pressure.

<u>Impurities on Melting Point</u>: If impurities are present in water, it will freeze at a temperature less than 0°C, this is due to the factor in the melting point depression equation, but this equation only holds for pure liquids and "impure" liquids, commonly refered to as "solutions". A pure compound is a structure of high molecular symmetry. However, it is a different story for solids, as the impurities affect the crystal structure of a solid and causes the lowering and widening of the interval of temperature in which either of the two (or more) pure solid components would melt. The melting point is not anymore sharp, but a range of values. An impurity is rather assymetrical, or is a poorly organized structure. If the impurites are present with the pure compound, the melting

point will deviate because melting point is also dependent on the high symmetry and organization of molecular structures.

Impurities on Boiling Point: When you add impurities to a solution, for example, salt to water, the water molecules interact with the salt ions. In most cases, energy is taken from the surroundings to dissolve the salt. The salt-water interacted species are now more stable than just the water alone. Now when you try to turn the water into vapor, these interations have to be broken down (the same reason water has a high boiling point than expected due to hydrogen bonding). Breaking down these interactions takes energy, so the boiling point increases because you are now having to separate the water from the salt AND also vaporize it. If the dissolving process releases energy to the surrounding, then the boiling point will be decreased.

Exercises

1. B

2. C

3. induced e.m.f. is proportional to temperature difference between hot and cold junctions $E \propto \Delta\theta$ ➔ $E = k(\theta_h - \theta_c)$

   $4.00 = k(100 - 0) = 100k$ ①

   $-1.50 = k(\theta - 0) = \theta k$ ②

   ② divide by ①, $-1.5/4 = \theta / 100$ ➔ $\theta = 100(-0.375) = -37.5$ °C

4. When the temperature of the container is increased, the moving molecules gain internal energy. Since temperature is directly proportional to the average kinetic energy of the molecules, their average speed and hence their kinetic energy are increased.
   As the molecules are moving faster than before, they will make more collisions per second with the walls. At the same time, each collision now results in a greater force imparted. Hence pressure is increased.

5. Both the stone floor and the carpet are at the same temperature and the feet are warmer than either; hence heat tends to flow from the feet. Stone, being the better thermal conductor, conducts heat away from the feet more rapidly than the floor mat. Consequently, the feet feel cold on the stone but warm on the floor mat.

6. When the water at the bottom near the element is heated, it expands and is less dense, so it will rise. When it rises, the colder water is forced downwards, where it will then be heated and also rise, sending the previously heated water downwards. This convection cycle continues until the water is at the same temperature as the heating element. This provides an efficient and faster way to boil water because it utilizes convection to ensure all water in the kettle is hot.

7. When the air at the bottom is cooled, it will remain at the bottom of the room since it is denser. Hence, the air near the floor will be continuously cooled, while the air above it will be cooled very slowly by losing heat via conduction to the air near the floor. The air in the room will take a long time for the entire room to be cooled and will not be of uniform temperature

8. Energy supplied by heater = Energy gained by ethanol

$$E = mc\Delta\theta$$
$$5000\text{ J} = (0.25\text{ kg})\, c\, (47 - 35)$$
$$c = 1667 \approx 1700\text{ J kg}^{-1}\text{ K}^{-1} \quad (2\text{ s.f.})$$

9. set-up A: energy supplied by heater + surroundings
set-up B: energy from surroundings alone
mass of water due to heater alone = m = 32.5 – 11.8 = 20.7 g

Energy supplied by heater = Energy gained by ice to melt completely

$$E = mL_f$$
$$8000\text{ J} = (20.7\text{ g})\, L_f$$
$$L_f = 386.5 \approx 390\text{ J g}^{-1} \quad (2\text{ s.f.})$$

Note: mass is in g here (no conversion to kg needed)

10. Energy supplied by kettle = Energy gained by ethanol (to become a gas)

$$Pt = mL_v$$
$$(2000\text{ W})(5.0 \times 60\text{ s}) = (0.20\text{ kg})\, L_v$$
$$c = 3.0 \times 10^6\text{ J kg}^{-1}$$

11.

Word equation: energy supplied by heating coil = energy gained by water

Math. equations:

$$Pt = mc\Delta\theta$$
$$VIt = mc\Delta\theta$$
$$(230)(8.6)(5.0 \times 60) = (2.0)\, c\, (100 - 30)$$
$$c = 593400 / 140$$
$$= 4239 \approx 4200\text{ J (kg °C)}^{-1}$$

12. Let θ be the final temperature (when thermal equilibrium is reached)

Assign $c = 4200\text{ J (kg °C)}^{-1}$
$l_f = 3.34 \times 10^5\text{ J kg}^{-1}$

Word equation:

energy lost by lemonade = energy gained by ice to melt (constant temperature)
(temperature falls) + energy gained by water (temperature rises)

Math. equations:

$$Q = m_1 c \Delta\theta = m_2 l_f + m_2 c \Delta\theta$$
$$(0.20)(4200)(30 - \theta) = (0.050)(3.34 \times 10^5) + (0.050)(4200)(\theta - 0)$$
$$(840)(30 - \theta) = 16700 + 210\,\theta$$
$$25200 - 840\,\theta = 16700 + 210\,\theta$$
$$\theta = (25200 - 16700) / (210 + 840) = 8.095$$
$$\theta \approx 8.1\text{ °C}$$

Note: Check that all units on both sides of equation are consistent, else need to do conversion of units.

13. (a) 1. Evaporation occurs at the surface of a liquid. Boiling occurs throughout a liquid.

2. Evaporation can occur at any temperature below the liquid's boiling point & above its melting point. Boiling occurs only at the boiling point.

(b)(i) $Q = mL$ ➔ $m = 0.9583 \approx 0.96$ kg (2 s.f.)

(ii) $Q = m\, c\, \Delta\theta$, $Q = Q_{produced} - Q_{lost}$ ➔ rise = 3.673 ≈ 3.7 °C (2 s.f.)

(iii) Temperature of body after 1 hour = 37 + 3.7 °C = 40.7 °C
This exceeds 40 °C and can cause serious damage to the body.

(iv) $Q = mL$, $Q = Q_{produced} - Q_{lost}$, m in hour
➔ whole race = $m_2 = m \times 3.5 = 1.3125 \approx 1.3$ kg (2 s.f.)

(v) $m_1 = 0.9583$ kg x 3.5
$m_2 = 1.3125$ kg
Level of dehydration = $(m_1 + m_2) / 70$ kg = 0.0667 ≈ 6.67 % > 5 %
The runner will suffer from severe dehydration.