**Module 5**

**THERMAL PHYSICS**

# Checklist: Mindmaps and Examinable material

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Physical quantity | Symbol | SI Unit | **check 1** | **check 2** | **check 3** |
| energy |  | joule J |  |  |  |
| kinetic energy | *K, KE* | joule J |  |  |  |
| potential energy | *U, PE* | joule J |  |  |  |
| internal energy | *U , E*int | joule J |  |  |  |
| heat | *Q* | joule J |  |  |  |
| work | *W* | joule J |  |  |  |
| pressure | *P* | pascal Pa |  |  |  |
| temperature | *T* | kelvin K |  |  |  |
| mass | *m* | kilogram kg |  |  |  |
| thermal conductivity | *k* | W.m-1.K-1 |  |  |  |
| emissivity | ε |  |  |  |  |
| absorptivity | α |  |  |  |  |
| specific heat (capacity) | c | J.kg-1.K-1 |  |  |  |
| latent heat coefficient | L | J.kg-1 |  |  |  |
| Stefan-Boltzmann constant | σ | 5.667×10-8 W.m-2.K-4 |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| **Concepts and ideas** | **check 1** | **check 2** | **check 3** |
| Heat and temperature |  |  |  |
| Absolute zero temperature |  |  |  |
| Thermometer |  |  |  |
| Electromagnetic spectrum: radio, microwaves, IR, visible, UV, X rays, gamma rays |  |  |  |
| Speed of light, frequency, wavelength |  |  |  |
| Methods of heat transfer: radiation, conduction, convection |  |  |  |
| Blackbody, Wien’s Displacement Law |  |  |  |
| Specific heat capacity |  |  |  |
| Change of phase (state: solid, liquid, gas) |  |  |  |
| Latent heat |  |  |  |

**Equations**

***You should construct equation templates for the equations listed blow***

power ****

temperature T (K) = T (°C) + 273

specific heat 

latent heat 

conduction 

convection 

radiation (emission) 

radiation (absorption) 

at any wavelength 

net radiation *P*net = *P*rad - *P*abs

##### THERMAL PHYSICS

Matter may exist in the solid, liquid or gaseous states. Although on the microscopic level all matter is made up of atoms or molecules, everyday experience tells us that the three states have very different properties. Solids are composed of atoms held together by attractive or cohesive forces. If the cohesive forces are strong, the atoms are tightly bound to one another and the matter is in the solid state. If the cohesive forces are weak and the atoms have considerable movement with respect to each other, the matter is in the liquid or gaseous state. So the further apart the atoms are from each other, the smaller the cohesive forces. Temperature greatly affects the average position of the particles (atoms or molecules) with respect to each other and so determines whether they are going to be solid, liquid or gas.

If water is cooled in the fridge it turns to ice because the kinetic energy of the water molecules becomes less than the cohesive bond energy and so water turns to a solid (ice). If on the other hand we "heat up" the water, which means we make the kinetic energy much greater than the cohesive energy, then water turns to gas (water vapour).

Many solid properties depend on temperature and inter-atomic bonds, for example, diamond conducts heat four times faster than copper at room temperature. If you can make a defrosting board out of a giant slab of diamond, then your frozen chicken will defrost four times faster (in theory)! Liquid nitrogen boils at a temperature of -196 ºC. If a fresh rose is dunked into the liquid nitrogen and then removed, it can be smashed so that it will shatter like glass. That is, it's mechanical properties are temperature dependent.

###### Temperature and Heat

In everyday language we use the terms heat and temperature loosely as if they had the same meaning. In physics they have different meanings. Consider the following example: take a beaker half filled with water and place some ice in it. Put a thermometer in the water and wait till the temperature of the water becomes stable so that the temperature of the water and the ice are the same. Now place the beaker over a Bunsen burner and start heating it. You'll notice that the temperature of the water stays the same as long as there is ice left. We all agree that the flame is ***heating*** the water but the thermometer says that the ***temperature*** does not change. Once all the ice melts, the temperature of the water starts to rise. From this we can see that we'll need to closely examine our ideas about the meanings of heat and temperature.

Matter can be regarded as being made up of particles called atoms. These particles always possess some random movement, hence, each particle will have a certain amount of kinetic energy. The kinetic energy can be of three different forms: translation, rotation and vibration.



The ***internal energy*** (thermal energy) of a system is defined as the total sum of all the kinetic and potential energies associated with the random, disordered motion plus potential energies of all the particles of the system. It is not a form of energy, but a way of describing the fact that the energy in atoms is both stored as kinetic and potential energy.

***Temperature*** defines the relative 'hotness' or 'coldness' of an object. If two objects that are at different temperatures are placed in contact with each other, then energy will spontaneously flow from the hot object to the colder one. This will result in two objects reaching the same temperature. Two objects, at the same temperature are said to be in ***thermal equilibrium***. Thus, we can define the temperature of an object as that property that determines the direction of heat flow between it and its surroundings.

***Zeroth law of thermodynamics***: If object A and object B are in thermal equilibrium with object C, then they are in thermal equilibrium with each other.

On the atomic level, temperature refers to the average translational kinetic energies of the particles that make up the object.

***Heat*** is the amount of energy transferred to or from a system due to a temperature difference.

**HOT (*T*H) heat *Q* cold (*T*C)**

When heat energy is absorbed by a substance, it does not necessarily mean that there will be an increase in temperature. If there is no increase in the translational kinetic energies of the particles, the temperature will remain the same. For example, water boils at a temperature of 100 oC. The energy being absorbed by the water goes into weakening the bonds so that water changes from a liquid to a gas.

For objects at the same temperature can contain different amounts of internal energy. For example, a splash of hot oil may sting, but a saucepan of hot oil at the same temperature can cause series burns if tipped onto you. This is because the larger number of particles in the saucepan of oil will possess a greater amount of internal energy even though the average translational kinetic energy of the particles in the saucepan and the splash are the same.

In all process, energy is conserved. For thermodynamic processes this conservation of energy is known as the ***first law of thermodynamics***. Energy conservation limits what is possible. Something can’t happen where the total energy is more after the event than before.

Energy spreads out – flow of energy from a hot object to the cooler surroundings. This process is described by the ***second law of thermodynamics***. The concept of ***entropy*** is related to “how spread out is the energy”. In all processes, the overall ***entropy never decreases***, it usually increases so that the universe becomes more disordered. In spontaneous events, differences in temperature between objects leads to a distribution of energy giving rise to an equilibrium situation, that is, a situation which has maximum entropy and is the situation that is most probable. Because there are more ways of spreading the energy around over many objects than localising it in a few, the energy goes from the hot object to the cold object.

###### Absolute Temperature scale

There is a physical lower temperature limit of matter. Nothing can be cooled below

- 273.15 ºC. So for convenience, scientists have devised the absolute temperature scale which starts with -273.15 ºC and called it 0 K (**not** degrees kelvin!). So the relationship between celsius and kelvin is:

*T*K = *T*C + 273.15 (1)

where *T*K is the temperature in kelvin, and *T*C is the temperature in celsius.

  Water freezes at 0 ºC or  *T*K = 0 + 273.15 = 273.15 K (pressure 1 atm)

Water boils at 100 ºC or  *T*K = 100 + 273.15 = 373.15 K (pressure 1 atm)

Normal room temperature is at 20 ºC or *T*K = 20 + 273.15 = 293.15 K

 To measure temperature we have to measure another macroscopic quantity that is directly influenced by temperature. There are many ways to do this. ***Thermometers*** use physical properties ranging from electrical resistance to radioactivity. But the oldest of all is the mercury thermometer. All materials change their physical dimensions when heated or cooled. The change in length is a direct measure of temperature.

Body Temperature

37 oC is the temperature at which most tissues and organs of the human body function best, i.e., the enzyme catalysed reactions of metabolism occur most effectively. The temperatures of peripheral tissues of the body, e.g., the skin, muscles and subcutaneous tissues are generally cooler and fluctuate more than the relatively well maintained core temperature.

The metabolic rates are very dependent on the body's temperature. If the body’s core temperature changes by 1%, there is a corresponding change of about 10% in the metabolic rate. If a person has a temperature of 40 oC (3 oC above normal) the metabolic rate is about 30% greater than normal. If the body temperature drops below normal, the metabolic rate drops. This is called ***hypothermia***. In various surgical procedures, general hypothermia is used to lower the body temperature to decrease the metabolic rate and hence decrease the need for oxygen. In heart operations the body temperature is maintained between 26 oC and 32 oC.

Thermogaphy

The temperature varies from point to point on the surface of the skin due to external factors, the internal metabolism and circulatory processes near the skin. Abnormal conditions such as breast cancer lead to an increase in the skin temperature in the region of the cancer of about 1 oC because of increased vascularity and increased metabolic processes associated with a tumor.

A simple method to obtain a surface temperature map of the body is to measure the infrared radiation emitted from the body. The higher the temperature the greater the amount of infrared radiation emitted at higher frequencies. A typical instrument can measure a temperature difference of 0.2 oC and record a thermogram in 2 s. Because infrared radiation is strongly absorbed by tissue, thermography does not directly detect temperatures below the surface of the skin.

Clinical applications of thermography include breast cancer (not reliable when used alone), the diagnosis and management of cerebrovascular disease, deep vein thrombosis, perforating veins, rheumatoid arthritis and burns.

**METHODS OF HEAT TRANSFER**

###### Conduction

If two objects at different temperatures are placed in contact, energy will flow from the higher to the lower temperature object. This is called ***conduction***. This is sometimes not obvious: Like when you shake hands with a person with cold hands. The conclusion that many people make is that cold has travelled from that person to you. It is only energy that is transferred. The coldness that you feel is simply the energy leaving your hand.

Experiment: Put a block of wood and a bowl of water in the fridge. Allow the water to freeze. Then take both of them out and feel them. Which feels "colder"? Most will say the ice. So which has the lowest temperature. If you say the ice, then you are **wrong**! They both have the same temperature. It feels colder because the ice conducts heat faster than wood. What you feel as "colder" simply means there is more energy leaving your hand every second than when touching the wood. So our concept of hot or cold does not just depend on temperature but also on how fast energy is transferred between different materials.

Energy is transferred by conduction at different rates in different materials. The quantity of heat transferred per unit time (in other words the rate of heat transfer) is given by

 (2)

where *k* is the thermal conductivity, *A* is the cross-sectional area, d*T* is the temperature difference across the length d*x*. d*T*/d*x* is known as the temperature gradient.

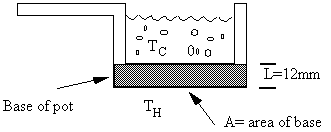
***Example***

An aluminium pot contains water that is kept steadily boiling (100 ºC). The bottom surface of the pot, which is 12 mm thick and1.5×104 mm2 in area, is maintained at a temperature of102 °Cby an electric heating unit. Find the rate at which heat is transferred through the bottom surface. Compare this with a copper based pot. The thermal conductivities for aluminium and copper are

*k*Al = 235 W.m-1.K-1 and *k*Cu = 401 W.m-1.K-1

***Solution***

The following is a schematic diagram of the pot.



The rate of heat conduction across the base is given by equation (2).

For the aluminium base:

*T*H = 102 ºC, *T*C = 100 ºC, d*T* = 2 °C, *L* = d*x* = 12 mm = 0.012 m,

*k* = *k*Al = 235 W.m-1 .K-1, base area = A =1.5×104 mm2**=** 0.015 m2.

Substituting these into the above equation:

dQ/dt = -(235)(0.015)(2)/(0.012) W = 5.9×102 W

For the copper base *k* = *k*Cu = 401 W.m-1.K-1.So the rate of heat conduction across the base is

dQ/dt = -(401)(0.015)(2)/(0.012) W = 1.0 ×103 W

So the copper based pot transfers 1.7 times more energy every second compared with the aluminium pot. Generally copper bottom pots are more expensive. Are their prices 1.7 times those of similar aluminium pots? Or, is this a simplistic way of looking at it?

**Convection**

Convection is the transport of heat by the movement of liquids or gases. People make use of this when they go hot air ballooning. Hot air rises because it expands when heated and therefore becomes less dense. The hot air is then captured by the balloon. The volume of the balloon is chosen so that the buoyancy force on it is larger than the weight of the balloon and the weights attached to it (that includes people). So the balloon rises.

Rising hot air eventually cools, which means now it is more dense and can start falling again. But it can't go straight down since there is rising hot air below it. So it shifts sideways then starts to fall. Air circulating in this way is called a convection current. This is only one special case. The same phenomenon occurs in liquids.

The rate of energy transferred from a surface (area *A*) by convection can be approximated by the equation

d*Q*/d*t* = *h A* d*T* (3)

where *h* is the convective heat transfer coefficient.

**Radiation**

Energy is transferred by electromagnetic radiation. All of the earth's energy is transferred from the Sun by radiation.

Electromagnetic spectrum

***increasing frequency, energy →***

***decreasing wavelength →***

radio waves→microwaves→infrared→visible→ultraviolet→X rays→ gamma rays

All objects, whether hot or cold emit electromagnetic radiation. The hotter the object, the more energy radiated by the object.

All objects emit and absorb radiation all of the time

Our bodies radiate electromagnetic waves in a part of the spectrum that we can't see called the infrared. However, there are some cameras that can actually see this radiation. The colour and texture of different surfaces determines how well they absorb the radiation.

* “Black” objects absorb more radiation than “white” objects.
* Matt and rough surfaces absorb more than shiny and smooth surfaces.

If you are ever in the snow, take a black and a white piece of cardboard, both the same size. Lay them down on the snow side by side. Over time you will notice that the black cardboard sinks deeper into the snow because it absorbs more heat from the sun and therefore melts more snow underneath it. You will notice this effect if you wear a black jumper and sit in the Sun. You become warm more quickly than if you wore other coloured jumpers.

Curiosity: It is interesting to note that aluminium foil has two different surfaces. One side is shiny and the other is matt. If you want to heat something evenly and quickly then you wrap it up with the matt side on the outside. If you want to keep something cold then the shiny side must be on the outside to lessen the effect of heating by radiation. Do you think that's what the manufacturers intended? Is it really that important, or is it a small effect?

The human skin absorbs all infrared radiation incident upon it. When we are indoors most of the heat loss from our bodies is due to radiation. If the air temperature is about 24 oC the heat lost from the body is approximately 10% by conduction and convection, 67% by radiation and 23% by evaporation. When the air temperature exceeds 30+ °C, then the human body is not able to rid itself of all this excess thermal energy by conduction, convection and radiation.

The power radiated by an object at a temperature *T*obj, with surface area *A* and emissivity ε is

*P*rad = ε σ *A* *T*obj4 (4)

and the power absorbed by an object with surface area A and absorptivity α from the surrounding environment at temperature *T*env is

*P*abs = α σ *A* *T*env4 (5)

and the net power absorbed is

*P*net = *P*rad - *P*abs (6)

For any surface at temperature *T*, α = ε for the same wavelength λ. ε and α vary between 0 and 1. A perfect absorber / emitter is called a ***blackbody*** with ε = α = 1. A shiny surface has low values for ε and α and high values for “black” surfaces. Therefore, a good emitter is a good absorber and a poor absorber is a poor emitter.

Special coatings have been developed for surfaces used in solar collectors. They are good emitter and absorbers at short wavelengths and poor emitters and absorbers at long wavelengths.

The radiation emitted or absorbed is extremely temperature sensitive because it depends on the fourth power of the temperature. If the temperature of an object is doubled, then the rate at which energy radiated from it increases by a factor of sixteen. The surface of the Sun approximates to a blackbody at a temperature of 6000 K. Also the power radiated from a hot object is wavelength (or frequency) dependent. For a blackbody, the maximum power emitted occurs at a wavelength given by the ***Wien’s Displacement Law***

λmax *T* = 2.898x10-3 m.K

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Less than 0.1% of the incident solar energy is captured by the chlorophyll of plant leaves, where it becomes the essential energy supply of the photosynthetic process and, eventually, of the plant and animal kingdom. Photosynthesis fixes carbon in the leaf and stores solar energy in the form of carbohydrate. When the leaf decays, oxygen is consumed and carbon dioxide is liberated. A very small fraction of the organic matter produced is deposited in oxygen deficient environments under conditions that prevent complete decay and loss of energy. This maybe the origin of the fossil fuels: coal, oil shale, petroleum, and natural gas which are rich in energy stored up chemically from the sunshine of the past 600 million years.

There are at least two reasons for this dependency on the visible part of the spectrum. First, the greatest output of radiation is in this region of the spectrum. Second, visible light photons are of just the right energy to only excite molecules; that is, to raise electrons from one energy level to another and, therefore, to produce biological changes. Radiation of longer wavelength (infrared, radio waves) increases the motion of molecules (their temperature goes up), but does not excite them. Shorter wavelength radiation, such as ultraviolet light and X-rays, both more energetic than visible light, can excite molecules, but they also can ionise molecules in the body and disrupt their normal structure and function.

**Glasshouse effect**

In a greenhouse, the incident radiation from the Sun readily passes through the glass. Inside, the radiation is absorbed by objects as well as the air, but the air cannot escape since it is all enclosed. Consequently, its temperature starts to rises. More radiation coming in means higher air temperature. This can also happen in a car if all the windows are closed. In this case temperatures can reach incredibly high values. People and pets who have been left in cars with the windows closed have died from the high temperatures. So mainly the glass prevents convective losses by stopping the upward flow of warm air.

###### Global Warming

The water vapour and carbon dioxide in the air are good absorbers of infrared radiation. Sunlight passes through the atmosphere and heats up the Earth and the atmosphere. The Earth then emits the radiation out again, but in a different part of the electromagnetic spectrum i.e the infrared. As it turns out, the infrared does not readily pass through certain gases such as carbon dioxide, water vapour, and methane. So these gases absorb the energy from the emitted radiation which in turn warms up the atmosphere to the comfortable temperatures that we experience. This is the Greenhouse effect and it actually is a beneficial phenomenon that helps to support life on Earth. Otherwise the Earth will be as cold and baron as the moon. The problem arises when you put a lot of these greenhouse gases into the atmosphere (too much of a good thing in this case is a bad thing for life forms such as us). The burning of fossil fuels increases the carbon dioxide level. This means that more of the infrared, which is radiated by the earth, will be absorbed by the atmosphere. This could increase the average temperature of the earth and lead to major climatic changes. Some of which may not be in our best interests!

SPECIFIC HEAT

If you light a match and put the flame to a small object such as a needle or a pin then you know that after a few seconds you will not be able to hold the needle because it has become too hot. On the other hand, if you put the flame of the match to a massive object such as a truck (well away from the petrol tank!!), then instinctively you know it will not make one bit of difference to its temperature. Although in both cases the temperature of the flame is the same. So somehow the mass of an object is related to the temperature it will reach in a certain time. The rise in temperature also depends on the substance being heated.

The rise in temperature Δ*T* of an object of mass *m* is given by

Δ*T* = *Q* / *m c* (7)

where *Q* is the energy transferred to or from the object and *c* is the specific heat (specific heat capacity) where the *c* is expressed in units of J .kg-1 .K-1. Eq (7) is only applicable when there is no change is state (phase).

Experiment: We can use this relationship to check out our microwave ovens. Manufacturers claim that microwaves give out a certain amount of power, usually around 700 or 800 W. By placing a litre of water in the microwave and heating it for a certain time, by measuring the temperature of the water before and after heating we can work out whether the manufacturer's claim is true.

Power = (Energy Transferred)/(time interval)

for 1 litre of water the mass is 1 kilogram, specific heat is *c* = 4190 J.kg-1.K-1.

The specific heat of Aluminium is 900 J/kg.K, Copper 386 J/kg.K, Iron (Fe) 447 J/kg.K. This means that less heat is required to heat a copper cooking pan than a steel or aluminium one of equal mass. If you recall that copper is a much better thermal conductor than either aluminium or iron. So it is much more energy efficient to buy an all copper pan. So take note of this the next time you are shopping for cookware.

**Implication of Specific Heat Capacity**

Water has one of the highest specific heat capacities of common substances. Therefore, it takes a lot more energy to raise the temperature of water than most other substances, and a lot more energy is released when the temperature of water falls.

Water can store tremendous of energy because of its high heat capacity. It acts as a source or sink of energy in the oceans and atmosphere. Without the presence of water, temperature variations between day and night would be much greater. This is why the daily temperature fluctuations are much smaller near the coast than inland.

Since water can store large amounts of energy because its high specific heat, it is a good substance to use in a hot water bottle. As the temperature of the water in the bottle drops a lot of energy is given out.

Since the human body has a large specific heat it requires a large amount of energy given out by metabolic processes to cause a rise in body temperature.

HEATS OF FUSION AND VAPORISATION

From the equation containing the specific heat, it seems that we can keep on transferring heat to an object and raising the temperature indefinitely. In fact, the equation seems to suggest that if we put in an infinite amount of heat we well get an infinite increase in temperature. However, instinctively we know that this is not totally true since at 100 ºC water starts to boil and stays at this temperature until it changes to a gas. So the equation doesn't fully account for changes of state, which are also known as ***phase changes***.

In general, the temperature stays constant during any phase change. That is, from solid to liquid and liquid to gas, although energy (i.e. heat) is still transferred.

There are some definitions we must add at this stage. These are:

Melting point - temperature at which a solid turns to a liquid or vice versa.

Boiling point - temperature at which a liquid turns to a gas (or vapour) or vice versa.

These points can be changed by adding impurities to the water / ice or changing the external pressure.

***Example***

Put a piece of string on an ice cube, which is straight out of the fridge. Sprinkle some salt on the string/ice cube. Wait a few seconds, you will then be able to lift the ice cube by the string. The string seems to have become glued to the cube.

The explanation is this: The salt lowers the freezing temperature of ice. That is, the ice has a good chance of melting if it isn't too cold. So the melted ice soaks into the string. The salt now becomes less concentrated as it diffuses out of the region of the string so the freezing temperature is raised again. Since the rest of the ice cube is still at a temperature below freezing, the water will re-freeze including that which has soaked into the string. So the string will essentially be frozen to the cube.

An almost similar thing happens when you try and lick an ice tray. The tray is say at

-15 ºC so it freezes the moister on your tongue.

How pressure cookers work: These are essentially cooking pots with an air tight lid. As water is heated and turns to vapour, the pressure builds up because the vapour cannot escape. Water usually boils and turns to steam (vapour) at 100 ºC at a pressure of 1 atmosphere (i.e 101 kPa). By increasing the pressure, the water can be heated to higher temperatures before it changes to a vapour. This means that anything being cooked inside the pot will experience higher temperatures and therefore the cooking time will be less. But will it taste as good?

Tea on Mount Everest:The air pressure on top of Mount Everest is about half an atmosphere (i.e 50 kPa). Water will boil (and turn to vapour) at about 70 ºC. Unfortunately this water temperature makes a very poor cup of tea!

Energy is acquired or released when a material changes phase. For example, energy is required to melt ice and vaporise water. However, energy is given out if water vapour condenses or water freezes. The heat acquired or released is called the ***latent heat***. During a phase change there is no change in temperature so we cannot use the equation containing the specific heat to determine the amount of heat transferred. The formal definition of latent heat is the energy given out or absorbed without a change in temperature and is given by

*Q* = *m L* (8)

*Q* is the heat, *m* is the mass, *L* is a constant for a certain material and is called the latent heat of fusion (for melting) or vaporisation (for boiling).

**Latent heat** **of fusion** is the energy required to melt 1 kg of a solid.

*L*f(water) = 3.33×105 J.kg-1.

**Latent heat** **of vaporisation** is the energy required to evaporate 1 kg of a liquid.

*L*v(water) = 2.26×106 J.kg-1.

***Example***

A styrofoam picnic chest has dimensions 0.5 x 0.3 x 0.35 m with walls 0.02 m thick.

1. If the temperature difference across the walls is 35 ºC, at what rate will the heat be conducted out of or into the chest.
2. How many kilograms of ice do you need to put in the chest to keep the beer at 0 ºC for 5 hours?. Assume the beer was initially cooled to 0 ºC.

The thermal conductivity of Styrofoam,*ksty* = 0.010 W.m-1.K-1

Latent heat of fusion of ice,Lf = 333 kJ.kg-1

***Solution***

(1) We are told there is a temperature difference across the walls of the chest. It doesn't matter which side of the chest is at the higher temperature since the rate of heat transfer only depends on the temperature difference.



where *A* is the surface area of the box,d*T* is the temperature difference across the walls, d*x* is the wall thickness.

The box has six sides, we must now calculate the total area

*A* = {(2)(0.5)(0.3) + (2)(0.3)(0.35) + (2)(0.35)(0.5)} m2  = 0.86 m2

d*T* = 35 ºC.

thickness, d*x =* 0.02 m

Substitute these into the rate of heat transfer equation above:

*Q* = {(0.01)(0.86)(35) / 0.02} W = **15.1 W**

So the rate of heat transfer across the walls of the chest is 15.1 W.

(2) In other words, the question is saying, "what is the least amount of ice that would melt after 5 hours". From part (a) we know that 15.1 J of energy can enter the chest in 1 second. So we must work out how much energy enters in 5 hours. Then calculate how much ice this can melt.

Note that 5 hours = 5 x 3600 seconds = 1.8×104 s.

So total energy in 5 hours = (1.8×104)(15.1) J = 2.718×105 J

The energy *Q*, required to melt ice is given by the latent heat of fusion equation

*Q* = *m L*

where *m* is the mass of the ice that will melt. We can now calculate this mass by rearranging the above equation and substituting

*m* = *Q* / *L* = (2.718×105 / 3.33×105) kg = 0.82 kg

***Example***

How many 20 g ice cubes, whose initial temperature is -10 ºC, must be added to 1.0 L of hot tea, whose initial temperature is 90 ºC, in order that the final temperature of the mixture be 10 ºC? Assume all the ice melts in the final mixture and the specific heat of tea is the same as that of water.

Latent heat of fusion of ice, *Lv* = 333 kJ. kg-1 = 3.33×105 J. kg-1

Specific heat of water, *c*water *= 4190* J. kg-1 K-1

Specific heat of ice, *cice* = 2100 J. kg-1 K-1

Assume that the tea has the same properties as water. Note that 1 litre of water has a mass of 1 kg.

***Solution***

Let *m*ice be the mass of ice required, *m*tea be the mass of tea = mass of water with the same volume = 1kg. Use conservation of energy. The energy required to melt the ice, then heat it to 10 ºC, must come from the tea.

The following are the three stages the ice must go through to reach the final temperature of 10 ºC:

(i) ice heats up from -10 ºC to 0 ºC

(ii) ice melts at 0 ºC

(iii) melted ice heats up from 0 ºC to 10 ºC

(iv) energy for stages (i), (ii), and (iii) must come from tea.

Now conserve energy: i.e

Energy required for (i) + (ii) + (iii) = Energy lost by tea (iv)

The expressions for the different stages are given by

(i) *m*ice *cice*  *T(i)* = *m*ice (2100)(0- (-10) = 2.1×104 *m*ice

(ii) *m*ice *Lv* = 3.33×105  *m*ice

(iii) *m*ice *cwater* *T(iii)* = *m*ice (4190) (10 - 0) = 4.19×104 *m*ice

(iv) *m*tea *cwater* *Ttea*= (1) (4190) (90 - 10) = 3.352×105 J

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Using the conservation of energy equation above we have

(2.1×104 + 3.33×105 + 4.19×104) *m*ice = 3.352×105

Now solving for *m*ice we get *m*ice = 0.847 kg = 847 g of ice are needed. Divide this by the mass of one ice cube (20 g) to find out how many cubes are needed.

847 / 20  43 ice cubes.

Humidity

As water evaporates it adds water to the air. The presence of water vapour in the air is referred to as *humidity*. When air contains a large amount of water vapour (moisture), the humidity is said to be high. When air contains little moisture, the humidity is said to be low or dry. The air can only hold a certain amount of moisture at a particular temperature. The air is said to be saturated when it contains is maximum amount of moisture. Hence, the more humidity the more difficult it is for water to evaporate and add more moisture to the air. The humidity is usually expressed as a percentage. For example, if the air holds half the maximum amount of water vapour that can hold, the relative humidity is said to be 50%. A room can be well heated but without good ventilation and air conditioning it can make the air dry. This causes rapid evaporation from the mucous membranes of the breathing passages, causing irritation and makes infection more likely. The air given to a patient via a respirator is often humidified for the same reason.

Implications of latent heat

The cooling by perspiring, which removes heat from the skin surface by vaporising the perspiration. Thus, on humid days we feel less comfortable because less energy is removed from the body by the processes of perspiration and evaporation.

Evaporative air conditions cool the air by passing it over a moist surface where heat is absorbed from it by water evaporating from the surface.

Scalding by steam produces severe burns due to the large heat of vaporisation of water released when the steam condenses on the skin.

Adopted from a set of lecture notes by Dr Joe Khachan, University of Sydney