**Chapter 15: Quantity of Heat and Heat Transfer**

***Please remember to photocopy 4 pages onto one sheet by going A3→A4 and using back to back on the photocopier***

**Questions to make you think**

1. A candle needs oxygen to burn, which is why, if we want to resuscitate a dying fire, we blow on it.   
   So why does blowing on a candle put it out?
2. If you lick a frozen pipe why will your tongue stick to the pipe?
3. When cooking potatoes on a gas cooker you put the gas supply onto ‘max’ to get the water boiling as quickly as possible.

The water is now boiling.

If you turn the gas down will it take longer for the potatoes to cook or will it not make any difference?

This all assumes that there is no cover on the saucepan. Why would a cover change things?

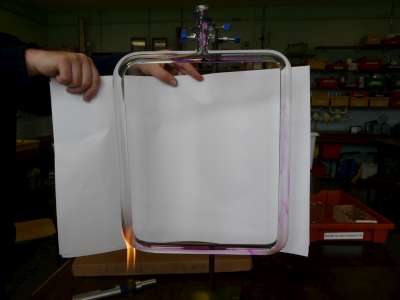
1. Everybody knows heat rises. *Why* does heat rise?
2. Why is water a very good substance for fire extinguishers (apart from the fact that it’s cheap)?
3. The foil and the cotton towel in the diagram are both at the same temperature – so why does the foil *feel* colder?
4. How is it possible to walk across hot coals and not get hurt?   
   Hint: it’s not about preparing your mind in advance
5. Your oven at home is at 200 0C. Why is okay to put your hand in the oven but you only get burnt if you touch the metal parts.
6. Why might a glass crack when you pour boiling water into it?
7. Why is colder at the top of a mountain even though you are closer to the sun?
8. In *Current Anthropology*, Dr Louis Liebenberg describes how Xi San hunters in the Kalahari chase antelope. They wait until the hottest part of the day with temperatures often exceeding 40 degrees. Why would they do this, and how might this have been a crucial factor in the evolution of humans?

**Student Notes**

**Heat is a form of** **energy** (which can cause a rise in temperature when added or a fall in temperature when withdrawn).

**Heat Transfer\***

Three methods of Heat Transfer: 1. Convection 2. Radiation 3. Conduction

**1. Convection** is the transfer of heat through a fluid by means of circulating currents of fluid caused by the heat.

Because hot water expands, it is less dense than cooler water and so rises.

This principle is used in domestic hot water and heating systems.

**2. Radiation** is the transfer of heat energy from one place to another in the form of electromagnetic waves.

This radiation lies in the ***infrared*** region of the electromagnetic spectrum.

**3. Conduction** is the movement of heat energy through a substance by the passing on of molecular vibration from molecule to molecule, without any overall movement of the substance.

You are expected to be able to demonstrate how to compare rates of conduction through different solids (Junior Cert)

**U-Value\***

The U-value of a house is a measure of the rate of heat loss to the surroundings.

U-Values are used in domestic situations to give an indication of how well a substance (roof, walls, tiles, etc) allows heat to flow (conduct) through it.

U-Values are a measure of the *conductivity* of a substance, i.e. a structure that is a good insulator has a low U-Value.

**What is meant by the *U*-value of a material?** [2014 OL][2010 OL]  
Definition: U-value is a measure of the heat flow through 1 m2 of material each second when a temperature difference of one degree exists between the two sides

[2014]

**The *U*-value of the material in a double-glazed window in a house is 2.8 W m–2 K–1.   
The window has an area of 3.0 m2.**

**How much energy is lost through the window in one hour if the temperature inside the house is 20 °C and the outside temperature is 11 °C?**

**Solution**

*The clue is in the unit.* The U-value is 2.8 W m–2 K–1. That means 2.8 Joules are lost every second per square meter for every one degree of a temperature difference.

We are interested in the heat lost through 3 m2, over a period of one hour if the temperature difference is 9°.

So total heat lost = 2.8 × 60 × 60 × 3 × 9 = 272160 J

**Specific Heat Capacity**

Get two identical polystyrene cups (we’re going to assume that they are poor absorbers so don’t absorb heat). Pour one kg of *ethyl* *alcohol* into the first container and one kg of *water* into the second container.   
Keep heating until they have both increased by one degree Celsius (this would also be one Kelvin).  
 Will it require the same amount of energy to heat equal amounts of both substances by one degree?  
Nope. The alcohol required 2400 Joules while the water required 4200 Joules.

We refer to these numbers as the *specific heat capacity* of the substance.

**The Specific Heat Capacity\*** of a substance is the heat energy needed to change *one kilogram* of the substance by *one Kelvin*.

The **symbol** for Specific Heat Capacity is **c.**Its unit isthe **Joule *per kilogram* per Kelvin (J kg-1 K-1).**

**Q = mc****Δθ**

Change in heat energy = (mass)(specific heat capacity)(change in temperature)

△θ (representing *change in temperature*) is pronounced “delta theta”\*

**The Heat Capacity** of a substance is the heat energy needed to change the substance by one Kelvin.

The **symbol** for heat capacity is C (capital c, as opposed to small c which is the symbol for specific heat capacity**).**Its unit isthe **Joule per Kelvin (J K-1).**

**Q = c****Δθ**

Change in heat energy = (heat capacity)(change in temperature)

**Storage Heaters**

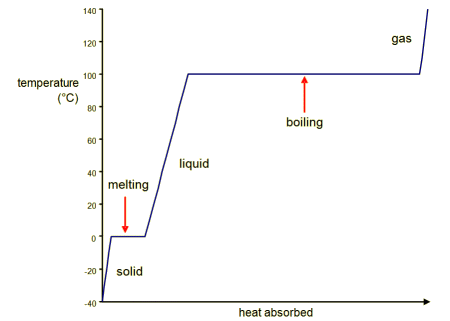
* In an electric storage heater, bricks with a high specific heat capacity are heated overnight by passing an electric current through a heating coil in the bricks. The bricks are surrounded by insulation.
* The bricks are heated by night when electricity is cheaper.
* The system is closed in but has a cover which can be opened to release the heat when needed.
* During the day the bricks slowly give out their heat, thus heating the room.
* Because the bricks have a high specific heat capacity they can absorb a lot of heat without increasing very much in temperature, therefore only slowly losing much back to the environment.

**Latent Heat**

1. A dog pants to help him cool - how does this work?
2. A flamingo pees down his leg to help him cool – how does this work?  
   Would it work for you? Try it and see. How could you tell if it was working?
3. How come you often feel colder when you come out of the water (after going for a swim) even though the air is warmer than the water?
4. Why is a steam burn more dangerous than a burn from boiling water, even when both are at the same temperature (1000 C)?

**Latent Heat Curve:\***

Look at the following graph of *temperature* versus *heat absorbed* for water:



|  |  |
| --- | --- |
| Stage1 | As heat is absorbed we note that the temperature rises from -40 0C to 0 0C |
| State 2 | At the melting point the energy taken in is used to change the state of the substance from solid to liquid rather than causing an increase in temperature. Hence the term *latent* (meaning *hidden*) heat. |
| Stage 3 | Once all the substance has changed state the temperature begins to rise again. This continues up until the water has reached 100 0C. |
| State 4 | At the boiling point of water the energy taken in is used to change the state of the substance from liquid to gas rather than causing an increase in temperature. |
| Stage 5 | Once all the substance has changed to a gas the temperature begins to rise again. |

**The Specific Latent of Fusion (lf)** of a substance is the amount of heat energy need to change 1 kg of the substance from a solid to a liquid without a change in temperature.

**The Specific Latent of Vaporisation (lv)** of a substance is the amount of heat energy needed to change 1 kg of the substance from a liquid to a gas without a change in temperature.

**The unit of Specific Latent Heat is the Joule per kilogram (J kg-1).**

Note that there is no reference to Kelvin in this unit.   
This is because there is no temperature change.

**Formula for latent leat**

**Q = ml**

Heat needed to change state = *mass* × *specific latent heat*

Tick the box activity:

|  |  |  |
| --- | --- | --- |
|  | **Substance is taking heat in** | **Substance is giving heat out** |
| **Boiling** |  |  |
| **Freezing** |  |  |
| **Condensing** |  |  |
| **Evaporating** |  |  |
| **Melting** |  |  |

**The Heat Pump** is a device that extracts available heat from one area and transfers it to another to either heat or cool an interior space.

Examples:

1. Refrigerator

2. Perspiration

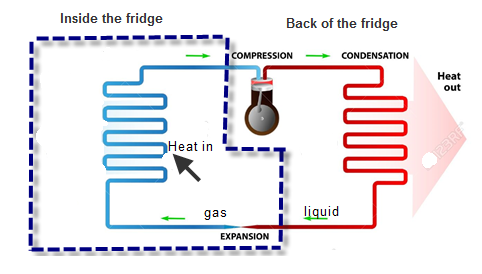
**How a heat pump works (a fridge contains a heat pump)**

The section on the left (in blue) is inside the fridge; the section on the right (in red) is at the back of the fridge

A special liquid is pumped around the pipe as shown.

In order to help to figure out how it works, note the following.

* *Inside* the blue section the liquid expands quickly, and in going from a liquid to a gas it takes in energy from around the pipe. This pipe is inside the fridge so the air in that section cools down.
* *Outside* the blue section a pump is used to compress the gas which causes it to go back into a liquid state, and in the process it gives heat energy back out to the surroundings.
* Note that this liquid needs to have a high specific latent heat of vaporisation and low boiling point – can you say why?



**Perspiration and Latent heat**  
The reason we perspire is to cool down – everybody knows that, but how does it work?

It’s not obvious, but we act as a very large reservoir of heat, and when a drop of water forms on our skin it absorbs some of this heat energy from the skin and evaporates (turns to a gas).

But because water has quite a high latent heat value, one drop of sweat absorbs a lot of heat before evaporating.

The implications for this could not be greater. It explains why humans are one of the few mammals which don’t have fur – can you think why it was important?

It also explains why we feel so cold when we get out of a swimming pool – but why do not feel as cold when we’re in the pool (where the temperature of the water is lower than the temperature of the surrounding air)?

Contrary to common wisdom, getting caught in a shower of rain will not lead to you catching a cold. After all, a cold is caused by a virus, so this should have nothing to do with rainfall.   
But if there was to be a link, could latent heat have a role to play, and if so, what would it be?

**Leaving Cert Mandatory Experiments:**

Measurement of specific heat capacity of water

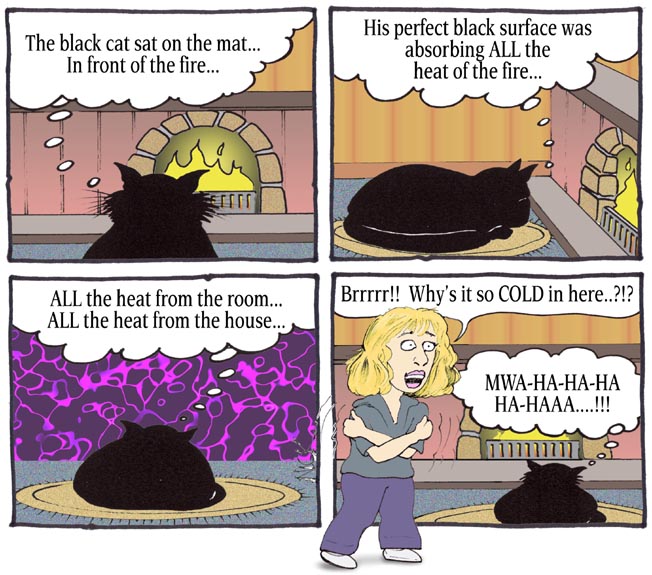
Measurement of the specific latent heat of fusion of ice

Measurement of the specific latent heat of vaporisation of water

THAT’S ALL FOLKS!!

**Leaving Cert Physics Syllabus**

|  |  |  |  |
| --- | --- | --- | --- |
| **Content** | **Depth of Treatment** | **Activities** | **STS** |
|  |  |  |  |
| 1. Concept of heat | Heat as a form of energy that causes a rise in temperature when added or a fall in temperature when withdrawn |  |  |
| QUANTITY OF HEAT |  |  |  |
| 1. Heat capacity, specific heat capacity | Definitions and units | Appropriate calculations | Storage heaters |
| 2. Latent heat, specific latent heat | Definitions and units | Appropriate calculations | Heat pump, e.g. refrigerator, perspiration. |
| HEAT TRANSFER |  |  |  |
| 1. Conduction | Qualitative comparison of rates of conduction through solids | Simple experiments | U-value; use in domestic situations |
| 2. Convection |  | Simple experiments | Domestic hot-water and heating systems |
| 3. Radiation | Radiation from the sun | Simple experiments | Everyday examples.  Solar heating |

**MEASUREMENT OF THE SPECIFIC HEAT CAPACITY OF WATER**

**APPARATUS**

Power supply, joulemeter, heating coil, calorimeter, thermometer, electronic balance.



**PROCEDURE**

**This experiment is built around the following equation:**

**Energy supplied via the heating coil = energy absorbed by calorimeter + energy absorbed by the water**

**Energy supplied = (mcΔθ)cal + (mcΔθ)water**

So in order to find the specific heat capacity of water (cwater) we just need to find a value for everything else in the equation above and then use some straightforward algebra to get what we’re looking for.

Note that ccal (the specific heat capacity of the metal which the calorimeter is made from) will be supplied.

1. Find the mass of the water by first measuring the mass of the empty calorimeter, then the mass of the calorimeter with water in it, and subtracting one form the other.
2. Set up the apparatus as shown in the diagram (with a power supply connected to the joulemeter).
3. Record the initial temperature of the water (we assume this to be the same temperature as the calorimeter).
4. Switch on the power supply
5. Allow the temperature of the water to rise by approximately 10 degrees.
6. Switch off the power supply.
7. Note the reading on the joulemeter (this corresponds to the total energy supplied).
8. Note the final temperature of the water (which also corresponds to the final temperature of the calorimeter).
9. Calculate the specific heat capacity of water (cwater) using the equation above.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**RESULTS**

Mass of calorimeter:

Mass of calorimeter + water:

Mass of water:

Initial temperature of water (and calorimeter):

Final temperature of water (and calorimeter):  
Joulemeter reading:

Change in temperature Δθ:

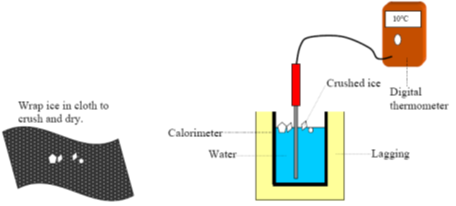
**PRECAUTIONS**

1. Ensure that the calorimeter is well insulated to avoid loss of heat energy.
2. Stir the water throughout the experiment to ensure that the thermometer reading reflects the heat supplied.
3. Use a sensitive thermometer graduated to 0.1 or 0.2 degrees. An error of 1 deg. in 10 is a large percentage error.
4. Ensure that the heating element is covered with water to avoid any loss of heat energy.

**NOTE**

What you are not told in the text-book is that all these ‘Heat’ experiments are notoriously inaccurate due to heat loss. Personally I think anything within 33% of the correct value is great. But then I never was much good at Physics.

**MEASUREMENT OF THE SPECIFIC LATENT HEAT OF FUSION OF ICE**

**APPARATUS**: Ice, water, calorimeter, lagging, beakers, kitchen paper, thermometer and electronic balance.

**This experiment is built around the following equation:**

Heat lost by calorimeter + heat lost by water = Heat gained by ice turning to water + heat gained by melted ice

**(m*c*Δθ)cal + (m*c*Δθ)water = (m*l*)ice + (m*c*Δθ)melted ice**

So in order to find a value for the latent heat of fusion of ice (*l*ice) we just need to find a value for everything else in the equation above and then use some straightforward algebra to get what we’re looking for.

Note that values for ccal and cwater will be supplied.

**PROCEDURE**

1. Find the mass of the calorimeter.
2. Half fill the calorimeter with water.
3. Find the combined mass of the calorimeter and water. The mass of the water can be calculated by subtraction.
4. Record the initial temperature (θinitial) of the calorimeter plus water.
5. Feck in some crushed, dried ice. Keep feckin’ it in until the temperature of the water has fallen by about 10 °C.
6. Find the combined mass of the calorimeter plus water plus crushed ice. The mass of the ice can be calculated by subtraction.
7. Take a note of the lowest temperature reached (θfinal)
8. Use the equation above to calculate a value for the latent heat of fusion of ice.

**RESULTS**

Mass of calorimeter:

Mass of calorimeter plus water:

Room temperature:

Temperature of ice:

Initial temperature of water (θinitial):

Final temperature of water (θfinal):

Mass of calorimeter plus water plus ice:

**CALCULATIONS**

The rise in temperature of the ice (θΔmelted ice) = θfinal – 0 °C . . . . . . . . . . .

The fall in temperature of the calorimeter (Δθcal) = is θinitial  – θfinal . . . . . . . . . . . .

The fall in temperature of the water (Δθwater) = is θinitial  – θfinal . . . . . . . . . . . .

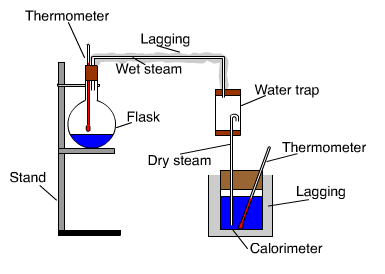
Mass of water:

Mass of ice:

**PRECAUTIONS**

1. Ensure that the ice is dried (dab it with tissue paper) before adding to the calorimeter.
2. Use a well insulated calorimeter to avoid loss or gain of heat to the surroundings.
3. Stir well and record the lowest temperature when all of the ice has melted.

**MEASUREMENT OF THE SPECIFIC LATENT HEAT OF VAPORISATION OF WATER**

**APPARATUS**

Calorimeter, beaker, conical flask, steam trap, retort stand, heat source, thermometer, electronic balance.

**DIAGRAM**

**This experiment is built around the following equation:**

Energy lost by steam condensing to water + energy lost by condensed steam cooling down = energy gained by calorimeter + energy gained by the water

**(m*l*)steam + (m*c*Δθ)condensed\_steam = (m*c*Δθ)cal + (m*c*Δθ)water**

So in order to find a value for the latent heat of vapouristaion of water (*l*steam) we just need to find a value for everything else in the equation above and then use some straightforward algebra to get what we’re looking for.

Note that values for ccal and cwater will be supplied.

**PROCEDURE**

1. Find the mass of the calorimeter.
2. Half fill the calorimeter with water.
3. Find the massof the water plus calorimeter and by subtraction find the mass of the water.
4. Record the temperature of the calorimeter plus water θinitial
5. Boil the water in the flask until steam issues freely from the delivery tube.
6. Allow dry steam to pass into the water in the calorimeter until the temperature has risen by about 20 °C, then remove the steam delivery tube from the water.
7. Record the final temperature θfinal of the calorimeter plus water plus condensed steam.
8. Find the mass of the calorimeter plus water plus condensed steam and by subtraction find the mass of the condensed steam.

**RESULTS**

Mass of the calorimeter........................... =

Mass of calorimeter plus cold water .................................. =

Initial temperature of water..................... =

Temperature of the steam........................ =

Final temperature of water ...................... =

Final mass of steam calorimeter plus water plus steam ............................... =

**CALCULATIONS**

Mass of cold water .................................. =

Mass of steam .................................. =

Δθcondensed\_steam = . . . . . . . .

Δθcal = . . . . . . . . . . . . .

Δθwater = . . . . . . . . . .

**PRECAUTIONS:**

1. Ensure that only steam (not water) enters the water in the calorimeter. Use a "steam trap" (it actually traps water) if available
2. Use a tilted insulated tube as an alternative delivery pipe for dry steam. This does away with the need to use a steam trap.
3. Use a well-insulated calorimeter to avoid loss or gain of heat to the surroundings

**Extra Credit**

\***Specific Heat Capacity**

It doesn’t matter if the object is being heated from 20 C to 30 C, or from 920 C to 930 C; each is an increase of 10 C and therefore the same amount of heat energy is required in both cases.

Basically, if a substance has a high s.h.c. a lot of heat is required to change its temperature.

If a certain amount of heat is needed to raise the temperature of an object by 10 C (1 K), this same amount of heat will be given out if the object cools by 10 C.

Remember that a *temperature difference* of 1 K is the same as a temperature difference of 10 C.

**What is a Calorie?**

One calorie (small c) is the amount of heat needed to raise the temperature of 1 gram of water by one degree Celsius.

This is quite a small amount, so we also usually use the kilo-calorie (sometimes called Calorie with big C) which is the amount of heat needed to raise the temperature of *1,000 g* of water by one degree.

The energy associated with food is measured in Calories, as opposed to calories.

We know that the amount of energy required to raise the temperature of 1 kg of water by one degree is 4180 Joules (the specific heat capacity of water), therefore one Calorie corresponds to 4180 Joules.

To make things even more unnecessarily complicated, food labelling often uses kilojoules, so one Calorie equals 4.18 kiloJoules.

**\*△θ: pronounced “delta theta”**

The symbol △ is used in many contexts to symbolise “change”. In fact the expression dy/dx is shorthand for

△y/△ x ; ‘a change in y divided by a change in x’. This corresponds to the slope of a line where y is on the vertical axis. The formula y2 – y1 / x2 –x1 is merely a more cumbersome way writing this same thing. Of course it’s easy to calculate the slope when you just have a straight line. But what about if instead of a line you have a curve, and you want to find the slope of the curve (at a specific point)?

This is where the genius of Newton came in. He invented ‘Differentiation’ and its associated rules to enable us to calculate this. Differentiation, together with its sister ‘Integration’ come together to form an area of mathematics called ‘Calculus’.

At approximately the same time as Newton was coming up with this, another mathematician called Leibtniz was discovering it independently, but with different notation. When Newton found out about this he accused Leibtniz of stealing his ideas and threw the mother of all sulks. To make things worse, it was Leibtniz’ who used the notation △y/△ x. Newton’s was considered to be too cumbersome. You might still come across it in places. He used f’(x) and f’’(x) to signify first order and second order differentiation.

**\*Graph of Temperature versus Time for water: Latent Heat Curve**

Explanation

If you've got a block of ice at –50 C and heat it up, you will notice that while it's melting the melted water will not rise above 00 C until all the ice has melted. The heat which is being added is not causing a rise in temperature – hence the term ‘latent heat’ (‘hidden heat’).

Only when all the ice has turned to water does the temperature begin to rise again.

Similarly when the water reaches boiling point at 1000 C, the water which turns to water vapour first will not rise above 1000 C until it's all water vapour.

Nobody has ever asked me *why* this should be the case, which is a small cause for concern, but just goes to show that we really are teaching students not to think for themselves.

Anyway, to make sense of the curve, I think it must mean that ice absorbs heats better than water, which would explain why all the ice turns to water before the water heats up, and similarly at the water/steam point.

Now this merely begs the follow up question; *why* does ice absorb heat more quickly than water?

This in turn brings us back to our definitions of heat capacity.

Why does one substance have a different specific heat capacity than another?

I guess it must mean that the forces between the water molecules in the ice stage are less than the forces between them in the water stage.

But isn't it interesting that we as physics teachers give the impression that what you read in the book is all there is to it, whereas in actual fact these questions only serve to open the door on a whole new and deeper level of understanding.

It's no wonder that students are walking away from physics in the classroom.

Or maybe it’s just me.

Oh by the way, all (and I mean all) textbooks which give this diagram conveniently omit to mention that it is next to impossible to achieve this in practice.. It assumes all energy goes into the water; that there is no loss of energy by conduction, convection or radiation; that water evaporates only when it is boiling, and that pressure is kept constant.

**How to get water from petrol**

This technique is used by soldiers in the desert.

Suspend a small metal pail over a larger bucket. Pour petrol into the small pail. As the petrol evaporates it cools down the pail. Water vapour from the air now condenses on the outside of the pail and drips into the larger bucket.

**How to keep water cool**

Use a leather container and hang it from a branch. The water will very slowly seep through and when it reaches the outside it evaporates, cooling the container (of course this is only useful if you have plenty of water available to keep topping up the system).

**\*Refrigerator**

Did you know that if you leave a fridge open it will not cool down a room?

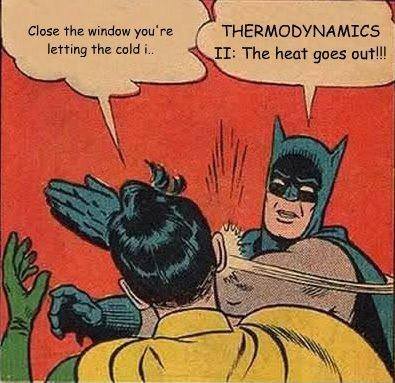
This is because all the heat it removes merely gets transferred to the back of the fridge where it gets pushed out into the room.

**\*Heat Transfer**

**Conduction**

You get up for a pee in the middle of the night.

On your way to the bathroom you pass over different floors composed of (i) ceramic tiles, (ii) timber and (iii) woollen carpet. Now all three floors are at the same temperature (room temperature), so why do they *seem* to be at different temperatures?



**\*U-Value**

So why the letter ‘U’?

Apparently it’s short for the term ‘Unit Heat Loss Rate’.

It seems to have the opposite meaning to ‘tog value’ for fibres in that the greater the U-value the poorer an insulator it is.

**Exam questions**

Specific heat capacity of copper = 390 J kg–1 K–1; Specific heat capacity of water = 4200 J kg–1 K–1

s.h.c. of aluminium = 910 J kg-1 K-1; Specific latent heat of fusion of ice is 3.3 × 105 J kg-1

1. [2003][2008 OL][2010 OL]

What is heat?

1. [2003 OL][2004 OL][2005 OL][2006 OL][2007 OL][2008 OL][2009]

Name two methods by which heat can be transferred.

1. [2004 OL]

What is meant by conduction?

1. [2010 OL]

Explain how heat is transferred in a solid.

1. [2004 OL][2010 OL]

Describe an experiment to show how different solids conduct heat at different rates.

1. [2004 OL]

Why are the pipes in the solar panel usually made from copper?

1. [2010 OL]

Explain the term ‘U-value’.

1. [2002 OL]

What is the effect of increasing the U-value of a structure?

1. [2004 OL][2010 OL]

The U-value of a house is a measure of the rate of heat loss to the surroundings.

Give two ways in which the U-value of a house can be reduced.

1. [2006 OL]

In an electric storage heater, bricks with a high specific heat capacity are heated overnight by passing an electric current through a heating coil in the bricks. The bricks are surrounded by insulation.

Why is insulation used to surround the bricks?

1. [2006 OL]

Name a material that could be used as insulation in a storage heater.

1. [2006 OL]

What is convection?

1. [2006 OL]

Describe an experiment to demonstrate convection in a liquid.

1. [2002 OL]

Why is the heating element of an electric kettle near the bottom?

1. [2006 OL]

Explain how the storage heater heats the air in a room.

1. [2004 OL]

Why does warm water rise to the top of the solar panel?

1. [2008]

An electric toaster heats bread by convection and radiation.

What is the difference between convection and radiation as a means of heat transfer?

1. [2004]

Why are the pipes in the solar panel usually painted black?

1. [2006][2004] [2002 OL][2008 OL]

Define specific heat capacity.

1. [2004]

Define specific latent heat.

1. [2004]

Storage heaters have a large heat capacity. Explain why.

1. [2007]

Why does the temperature of an athlete reduce when she perspires?

1. [2010]

Explain why snow is slow to melt as the day-time temperatures rises above 0 °C.

1. [2006 OL]
2. The total mass of the bricks in a storage heater is 80 kg and their specific heat capacity is 1500 J kg–1 K–1.

During a ten-hour period the temperature of the bricks rose from 15 oC to 300 oC.

Calculate the energy gained by the bricks.

1. Calculate the power of the heating coil.
2. [2009]

How much energy is required to raise the temperature of 500 litres of water from 20 0C to 50 0C?

(specific heat capacity of water = 4200 J kg–1 K–1; density of water = 1000 kg m–3; 1 litre = 10–3 m3)

1. [2002 OL]
2. An electric kettle contains 1.5 kg of water. The specific heat capacity of water is 4180 J kg-1 K-1.

Calculate the amount of energy required to raise the temperature of the water from 15 0C to 100 0C.

1. The kettle takes 4 minutes to heat the water from 15 0C to 100 0C. Calculate the power of the kettle.

(Assume all the energy supplied is used to heat the water).

1. [2006]
2. 400 g of water at a temperature of 15 oC is placed in an electric kettle. The power rating of the kettle is 3.0 kW. Calculate the energy required to raise the temperature of the water to 100 oC.
3. Calculate the energy supplied by the kettle per second.
4. Calculate the least amount of time it would take to heat the water to 100 oC.
5. In reality, the time taken to heat the water will be greater. Explain why.
6. [2008 OL]

A saucepan containing 500 g of water at a temperature of 20 °C is left on a 2 kW ring of an electric cooker until it reaches a temperature of 100 °C.

1. Calculate the rise in temperature of the water.
2. Calculate the energy required to heat the water to 100 °C.
3. Calculate the amount of energy the ring supplies every second.
4. Calculate the time it will take to heat the water to 100 °C.
5. [2004]
6. 500 g of water at a temperature of 15 0C is placed in a freezer.

The freezer has a power rating of 100 W and is 80% efficient.

Calculate the energy required to convert the water into ice at a temperature of –20 oC.

1. How much energy is removed every second from the air in the freezer?
2. How long will it take the water to reach a temperature of –20 oC?
3. Allowing a liquid to evaporate in a closed pipe inside the freezer cools the air in the freezer. The vapour is then pumped through the pipe to the outside of the freezer, where it condenses again.

Explain how this process cools the air in the freezer.

1. The freezer causes the room temperature to rise. Explain why.

The specific heat capacity of ice is 2100 J kg-1 K-1

1. [2009]

Read the following passage and answer the accompanying questions.

The sun is a major source of ‘green’ energy. In Ireland solar heating systems and geothermal systems are used to get energy from the sun.

There are two main types of solar heating systems, flat-plate collectors and vacuum-tube collectors.

A flat-plate collector is usually an aluminium box with a glass cover on top and a blackened plate on the bottom. A copper pipe is laid on the bottom of the box, like a hose on the ground; water is passed through the pipe and transfers the absorbed heat to the domestic hot water system.

In a vacuum-tube collector, each tube consists of an evacuated double-walled silvered glass tube in which there is a hollow copper pipe containing a liquid. The liquid inside the copper pipe is vaporised and expands into the heat tip. There the vapour liquefies and the latent heat released is transferred, using a heat exchanger, to the domestic hot water system. The condensed liquid returns to the copper pipe and the cycle is repeated.

In a geothermal heating system a heat pump is used to extract solar energy stored in the ground and transfer it to the domestic hot water system.

* 1. Why is the bottom of a flat-plate collector blackened?
  2. The liquid in a vacuum-tube solar collector has a large specific latent heat of vaporisation. Explain why.
  3. How is the sun’s energy trapped in a vacuum-tube solar collector?
  4. Describe, in terms of heat transfer, the operation of a heat pump.
  5. Give an advantage of a geothermal heating system over a solar heating system.

1. [2010 OL]****

The diagram shows a solar heating system.

1. How is the sun’s energy transferred to the solar collector?
2. Why is the solar collector normally painted black?
3. How is the heat transferred from the solar panel to the hot water tank?
4. The heating coil for the hot water tank are placed at the bottom, explain why.
5. Give an advantage and a disadvantage of a solar heating system.

**Mandatory Experiments**

**Specific Heat Capacity**

1. [2004 OL][2010 OL]

In a report of an experiment to measure the specific heat capacity of a substance (e.g. water *or* a metal), a student wrote the following.

“I assembled the apparatus needed for the experiment.

During the experiment I took a number of measurements of mass and temperature.

I used these measurements to calculate the specific heat capacity of the substance.”

1. Draw a labelled diagram of the apparatus used.
2. What measurements of mass did the student take during the experiment?
3. What temperature measurements did the student take during the experiment?
4. Give a formula used to calculate the specific heat capacity of the substance.
5. Give one precaution that the student took to get an accurate result.
6. [2007]

The specific heat capacity of water was found by adding hot copper to water in a copper calorimeter.

|  |
| --- |
| mass of calorimeter 55.7 g |
| mass of calorimeter + water 101.2 g |
| mass of copper + calorimeter + water 131.4 g |
| initial temperature of water 16.5 oC |
| temperature of hot copper 99.5 oC |
| final temperature of water 21.0 oC |

*This was not the method most students would have used to carry out the experiment so there was much annoyance when it appeared on the paper. Nevertheless it does differentiate between those students who understand the underlying principles and those who have just learned off a formula.*

The following data was recorded.

1. Describe how the copper was heated and how its temperature was measured.
2. Using the data, calculate the energy lost by the hot copper
3. Using the data, calculate the specific heat capacity of water.
4. Give two precautions that were taken to minimise heat loss to the surroundings.
5. Explain why adding a larger mass of copper would improve the accuracy of the experiment.

**Specific latent heat of fusion of ice**

1. [2009 OL][2013 OL]

A student carried out an experiment to measure the specific latent heat of fusion of ice.

The following is an extract from her report.

“In my experiment, I prepared ice which was at 0 0C and I added it to warm water in a calorimeter. I waited for all the ice to melt before taking more measurements.

I used my measurements to calculate the specific latent heat of fusion of ice.”

1. Draw a labelled diagram of the apparatus used in the experiment.
2. What measurements did the student take in the experiment?
3. How did the student prepare the ice for the experiment?
4. How did the student know the ice was at 0 0C?
5. Why did the student use warm water in the experiment?
6. [2003 OL]

In a report of an experiment to measure the specific latent heat of fusion of ice, a student wrote the following.

“Ice at 0 0C was added to water in a calorimeter.

When the ice had melted measurements were taken.

The specific latent heat of fusion of ice was then calculated.”

1. Draw a labelled diagram of the apparatus used.
2. What measurements did the student take before adding the ice to the water?
3. What did the student do with the ice before adding it to the water?
4. How did the student find the mass of the ice?
5. Give one precaution that the student took to get an accurate result.
6. [2008]

In an experiment to measure the specific latent heat of fusion of ice, warm water was placed in a copper calorimeter. Dried, melting ice was added to the warm water and the following data was recorded.

Mass of calorimeter 60.5 g

Mass of calorimeter + water 118.8 g

Temperature of warm water 30.5 oC

Mass of ice 15.1 g

Temperature of water after adding ice 10.2 oC

1. Explain why warm water was used.
2. Why was dried ice used?
3. Why was melting ice used?
4. Describe how the mass of the ice was found.
5. What should be the approximate room temperature to minimise experimental error?
6. Calculate the energy lost by the calorimeter and the warm water.
7. Calculate the specific latent heat of fusion of ice.

1. [2002]

In an experiment to measure the specific latent heat of fusion of ice, warm water was placed in an aluminium calorimeter. Crushed dried ice was added to the water.

The following results were obtained.

Mass of calorimeter.......................................= 77.2 g

Mass of water.................................................= 92.5 g

Initial temperature of water...........................= 29.4 0C

Temperature of ice ........................................= 0 0C

Mass of ice.....................................................= 19.2 g

Final temperature of water.............................= 13.2 0C

Room temperature was 21 0C.

1. What was the advantage of having the room temperature approximately halfway between the initial temperature of the water and the final temperature of the water?
2. Describe how the mass of the ice was found.
3. Calculate a value for the specific latent heat of fusion of ice
4. The accepted value for the specific latent heat of fusion of ice is 3.3 × 105 J kg-1; suggest two reasons why your answer is not this value.

**Specific latent heat of vaporisation of water**

1. [2005 OL]

In a report of an experiment to measure the specific latent heat of vaporisation of water, a student wrote the following.

“Steam at 100 oC was added to cold water in a calorimeter.

When the steam had condensed, measurements were taken.

The specific latent heat of vaporisation of water was then calculated.”

1. Draw a labelled diagram of the apparatus used.
2. List two measurements that the student took before adding the steam to the water.
3. How did the student find the mass of steam that was added to the water?
4. How did the student make sure that only steam, and not hot water, was added to the calorimeter?
5. Give one precaution that the student took to prevent heat loss from the calorimeter.
6. [2003]

In an experiment to measure the specific latent heat of vaporisation of water, cold water was placed in a copper calorimeter. Steam was passed into the cold water until a suitable rise in temperature was achieved.

The following results were obtained:

Mass of the calorimeter........................... = 73.4 g

Mass of cold water .................................. = 67.5 g

Initial temperature of water..................... = 10 °C

Temperature of the steam........................ = 100 °C

Mass of steam added ............................... = 1.1 g

Final temperature of water ...................... = 19 °C

1. Describe how the mass of the steam was found.
2. Using the data, calculate a value for the specific latent heat of vaporisation of water.
3. Why is the rise in temperature the least accurate value?
4. Give two ways of improving the accuracy of this value.
5. [2010]

In an experiment to measure the specific latent heat of vaporisation of water, a student used a copper calorimeter containing water and a sensitive thermometer. The water was cooled below room temperature before adding dry steam to it. The following measurements were recorded.

Mass of copper calorimeter = 34.6 g

Initial mass of calorimeter and water = 96.4 g

Mass of dry steam added = 1.2 g

Initial temperature of calorimeter and cooled water = 8.2 °C

Final temperature of calorimeter and water = 20.0 °C

1. How was the water cooled below room temperature?
2. How was the steam dried?
3. Describe how the mass of the steam was determined.
4. Why was a sensitive thermometer used?
5. Using the data, calculate the specific latent heat of vaporisation of water.
6. [2005]

In an experiment to measure the specific latent heat of vaporisation of water, cool water was placed in an insulated copper calorimeter. Dry steam was added to the calorimeter. The following data was recorded.

Mass of calorimeter = 50.5 g

Mass of calorimeter + water = 91.2 g

Initial temperature of water = 10 oC

Temperature of steam = 100 oC

Mass of calorimeter + water + steam = 92.3 g

Final temperature of water = 25 oC

1. Calculate a value for the specific latent heat of vaporisation of water.
2. Why was dry steam used?
3. How was the steam dried?
4. A thermometer with a low heat capacity was used to ensure accuracy. Explain why.

**Exam solutions**

Specific heat capacity of copper = 390 J kg–1 K–1; Specific heat capacity of water = 4200 J kg–1 K–1

Specific latent heat of fusion of ice is 3.3 × 105 J kg-1

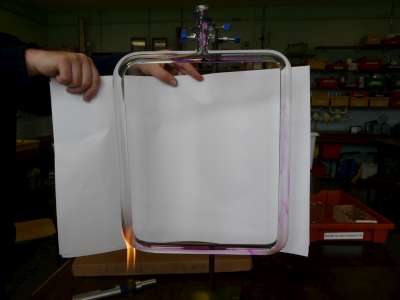
1. Heat is a form of energy
2. Conduction, convection and radiation.
3. Conduction is the movement of heat energy through a substance by the passing on of molecular vibration from molecule to molecule, without any overall movement of the substance.



1. Atoms are touching / in contact so the heat/energy gets transferred from one to the other by vibration (without the atoms moving along).
2. Apparatus: See diagram. 4 different metals arranged as shown. Stick an upright match into the pool of wax which is at the other end.

Procedure: Light a candle underneath the middle.

Observation: e.g. wax melts and the matches fall on different rods at different times.

1. It is a good heat conductor.
2. The U-value of a house is a measure of the rate of heat loss to the surroundings.
3. It means that the heat conductivity of the structure is increased.
4. Fibreglass in attic, insulation in cavity wall, double glazing, carpets
5. To prevent heat-loss.
6. Fibre glass / rockwool / cotton wool.
7. Convectionis the transfer of heat through a fluid by means of circulating currents of fluid caused by the heat.
8. Apparatus: See diagram with container, water, dye, heat source labelled.

Procedure: add the dye to the liquid and heat.

Observation: convection current becomes visible.

1. Because hot water rises.
2. The heater heats the air which is beside it. This hot air then rises and is replaced by cold air. This process then gets repeated.
3. The water expands when heated and therefore has a lower density and gets replaced by water which has a higher density (cold water). This is convection.
4. Convection requires a medium, radiation does not.
5. Black is a good absorber of radiation.
6. The specific heat capacity of a substance is the heat energy needed to change one kilogram of the substance by one Kelvin.
7. The Specific Latent of a substance is the amount of heat energy need to change the state of 1 kg of the substance without a change in temperature.
8. They are heated only at night but must release energy slowly during the day.
9. As the water evaporates it takes heat energy from the body.
10. Latent heat of snow/ice (energy needed for change of state) is (very) large
11. Q = mcΔθ ⇒ Q = (80)(1500)(285) = 34 200 000 J = 34.2 MJ
12. P = W/ t ⇒ P = 34 200 000 / (10×60×60) = 950 W
13. Density = mass/volume  mass = (density)(volume)  m = (1000)(500 × 10–3) = 500 kg.

E = mc△θ = (500)(4200)(30) = 6.3 × 107 J

(specific heat capacity of water = 4200 J kg–1 K–1; density of water = 1000 kg m–3; 1 litre = 10–3 m3)

1. Q = mcΔθ  Q = 1.5 × 4180 × 85 = 532 950 J.
2. P=W/t  P = 532 950/240  P = 2221 W.
3. E = m c Δθ

E = (0.40)(4200)(85) = 1.428 × 105 J

1. 3000 J per second = 3000 W
2. Time taken = 1.428 × 105/3000 = 47.6 s
3. Energy will be lost to the surroundings.

A saucepan containing 500 g of water at a temperature of 20 °C is left on a 2 kW ring of an electric cooker until it reaches a temperature of 100 °C.

1. 100 – 20 = 80 °C
2. Q = m cΔθ = 0.5 × 4200 × 80 = 168 000 J
3. 2 kW = 2,000 W = 2,000 J per second.
4. P = W/t t = W/P  t = 168 000/2,000 = 84 secs.
5. Cooling from 15 0C to 0 0C: Q = mcΔθ = (0.5)(4200)(15) = 31500 J

Change of state: Q = ml = (0.5)(3.3 × 105) =165000 J

Cooling ice from 0 oC to -20 oC: Q = (0.5)(2100)(20) =21000 J

Total energy required = Qt = Q1 +Q2 +Q3 =217500 = 2.2 × 105 J

1. 80% efficiency ⇒ 80 W ⇒ 80 J (per second)
2. Power = Q ÷ time

t = (217500 ÷ 80) = 2700 s

1. This change of state requires energy (latent heat) which is taken from inside the freezer and this lowers the temperature .
2. Condensation (vapour to liquid) releases latent heat
3. Dark surfaces are good absorbers of heat/energy/radiation
4. So that a lot of energy gets absorbed (and then released) per kg in the heat exchanger during a change of state.
5. Silvered walls prevent radiation and evacuated walls prevent conduction and convection
6. Energy is taken from one place (making it colder) by allowing the liquid to change state to a gas.

Then in another place the gas condenses to a liquid releasing the heat to another place making it hotter.

1. Geothermal system functions all the time whereas a solar heating system works only during sunshine.
2. Radiation / rays
3. (black surfaces are) better absorbers (of heat/radiation)
4. By the water flowing/pumped (through the collector and the heating coil).
5. Water is heated by convection / hot water rises, etc.
6. Reduces costs, unlimited supply, no pollution, etc.

Needs sun, requires a back-up, costly to install, etc.

**Mandatory Experiments**

1. See diagram.
2. Mass of calorimeter, mass of calorimeter + water,
3. Initial temperature of water, final temperature of water.
4. Energy supplied = (mcΔθ)cal + (mcΔθ)water where Δθ is the change in temperature and ccal is known.
5. Lagging, use sensitive thermometer, ensure that heating coil is completely immersed in the liquid, stir the liquid, large temperature change, etc.
6. It was heated using a hot-plate and temperature was measured using a thermometer.
7. E = m c Δθ

E = (3.02 × 10-2)(390)(78.5) = 924.6 J

1. Heat lost by hot copper = heat gained by calorimeter + water

924.57 = (0.0557)(390)(4.5) + (0.0455)(cw)(4.5)

**** 924.57 = 97.75 + 0.2048 cw

cw = 4.04 ×103 J kg-1 K-1

1. Insulate calorimeter /use lid /transfer copper pieces quickly / use cold water (below room temperature) / polish calorimeter / low heat capacity thermometer
2. A larger mass of copper would result in a larger temperature change and therefore smaller percentage error.
3. See diagram
4. Mass of calorimeter

Mass of calorimeter and warm water

Mass of calorimeter and warm water and ice

Temperature of water before

Temperature of water and melted ice after

1. It was crushed and then dried.
2. By using melting ice.
3. So that the heat lost to the environment when the system is above room temperature is balanced by the heat taken in from the environment when the system is below room temperature.
4. See diagram
5. Mass of calorimeter, mass of water, mass of calorimeter + water, mass of ice, temperature of water
6. The ice was crushed and dried.
7. (mass of calorimeter + water + ice) – (mass of calorimeter + water**)**
8. Insulation, crush, dry, repeat and take average, use lots of ice, transfer ice quickly.
9. To speed up the melting of the ice / in order to melt a larger mass of ice / (concept of) balancing energy losses before and after the experiment.
10. To remove any water/melted ice // melted ice would have already gained latent heat //so that only ice is added // so that no water is added
11. Melting ice is at 0 oC.
12. Final mass of calorimeter + contents minus mass of calorimeter + water.
13. 20 0C / midway between initial and final temperatures (of the water in the calorimeter)
14. {energy lost = } (*mc*Δθ )cal + (*mc*Δθ )warm water

= (0.0605)(390)(20.3) + (0.0583)(4200)(20.3)

= 5449.6365 / 5449.6 J

1. {Energy gained by ice and by melted ice =}

(*ml*)ice + (*mc*Δθ )melted ice / (0.0151)*l* + (0.0151)(4200)(10.2) / 0.0151 *l* + 646.884

(equate:) 0.0151 *l* + 646.884 = 5449.6365

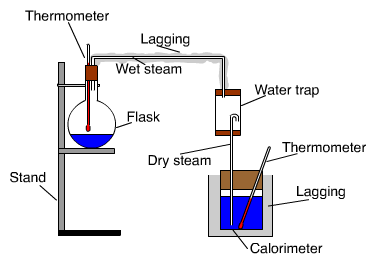
*l* = 3.181 × 105 ≈ 3.2 × 105 J kg–1

2. Heat lost to surroundings when the system is above room temperature would cancel out the heat taken in from the surroundings when the system was below room temperature.
3. Final mass (of calorimeter + water + ice) - initial mass (of calorimeter + water)
4. *mc*Δθ*Al + mc*Δθ*water* = *mlice +mc*Δθ*melted ice*

Fall in temperature = 16.2 oC

Ans = 3.2 × 105 J kg-1

1. Thermometer not sensitive enough, lack of insulation, lack of stirring, heat loss/gain to surroundings, too long for ice to melt, inside of calorimeter tarnished, splashing, heat capacity of thermometer



1. See diagram.
2. Massof calorimeter, mass of water, mass of calorimeter + water, initial temperature of water, initial temperature of steam.
3. Final mass of water + calorimeter minus initial mass of water + calorimeter.
4. Allow steam to flow for some time before inserting it into water, slope delivery tube back to steam generator, use a steam trap.
5. Lagging, insulation, lid, carry out measurements quickly.
6. Final mass of (calorimeter + water + condensed steam) – Initial mass of (calorimeter + water)
7. (ml) steam + (mc∆ϑ) steam = (mc∆ϑ) water + (mc∆ϑ) cal

∆ϑwater = 90C, ∆ϑcal= 90C

∆ϑ) steam = 810C

Answer = 2.2 × 106 J kg-1

1. Read only to one significant figure {the concept of significant figures is not on the syllabus and shouldn’t have got asked. It hasn’t appeared since.]
2. Use a digital thermometer, use more steam, use less water, insulation, cover, stirring, steam trap
3. Ice was added to the water / the water was taken from fridge
4. By using a steam trap (or ensure that the delivery tube is sloped upwards)
5. Final mass of calorimeter plus contents – initial mass of calorimeter and contents
6. For greater accuracy / to reduce (%) error / more significant figures / e.g. to read to 0.1 oC
7. ms = 1.2×10-3 kg

mw = 6.18 × 10-2 kg

Δθs = 80 (K) and

Δθw (= Δθcu) = 11.8 (K)

[heat lost by steam = heat gained by water and calorimeter]

(ml)s + (*mc*Δθ )s = (*mc*Δθ )w + (*mc*Δθ )cu

(1.2×10-3)l + (1.2×10-3)(4180)(80) = (6.18 × 10-2)(4180)(11.8) + (3.46 × 10-2)(11.8)(390)

(1.2×10-3)l + 401.3 = 3048.2 + 159.2

l = 2.34 × 106 J Kg-1

1. mslw + mscwΔθs = mwcwΔθw+ mcccΔθc

Δθs = 75 0C and Δθw (= Δθc) = 15 0C

(0.0011) lw + (0.0011)(4200)(75) = (0.0407)(4200)(15) + (0.0505)(390)(15)

[(0.0011) lw + 346.5 = 2564.1 + 295.425]

lw = 2.28 × 106 J kg-1

1. Calculations assume that only steam is added, not water.
2. Use a steam trap / insulated delivery tube / sloped delivery tube / allow steam to issue freely initially
3. It absorbs little heat from system in calorimeter and calculations assume that no energy is transferred to the thermometer.

**Fun teaching activities**

**Conduction**

A variation on the demonstration in the diagram is to use two similar-looking materials (black blocks – get them from science suppliers); but in this case one is polystyrene and the other is metal.

Place an ice-cube on both and predict what will happen.

Derek Muller has a nice video on YouTube on this (see under the pen-name ‘Veratiasium’) and I think I have one up there also (pretty sure mine was first!).  
Pretty sure his is more professional.

**Convection**

Use empty tea-bags (the pyramid ones) and fold out the paper so that it forms an open cylinder.

Place this up-right on the table and light the top.

As the tea-bag burns down it eventually reaches the point where it is less dense that the surrounding warmer air and rises ‘magically’ upwards to float away.

**Conduction / Convection**

Fill balloon with water, heat it first with a match, then a cigarette lighter. Amazingly the balloon does not burst.

Why?

Even though the plastic material the balloon is made from would not be considered a good conductor, it is very thin (the experiment works best when the balloon is full, causing the skin to be stretched) and heat is quickly transferred through the balloon via conduction, then quickly away from the point of contact due to convection. It is also helped by the relatively large specific heat capacity of water; it can take in a very large amount of heat before it gets very hot.

Eventually however the balloon does develop tiny holes and the water will flow out.

Demo is best done over a basin just in case there is a problem with the balloon.

But over a student’s head is the best fun.

**Radiation**

We have 18-foot ‘Solar Balloons’ which rise very nicely on a sunny day (there must be very little breeze).

The black material absorbs heat and the air inside heats up, expands and because the system is now less dense than the surrounding air, up she goes!

**Radiation**

A thermos flask uses the principles of conduction, convection and radiation to keep the liquid inside from cooling down (or indeed heating up)

Can you figure out the role played by each?

**Latent heat**

Put a dollop of perfume on your hand - what should you notice and why?

Dip a thermometer in (warm) perfume, or wrap an alcohol-soaked rag around a thermometer. What happens?

The *freezerod* is a nice simple piece of apparatus that connects a very cold source (a salt-ice mixture) to water.

The heat moves from the water to the mixture via conduction and after it loses enough heat the water turns to ice. Lovely demonstration.