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An investigation into the relationship between heat loss and surface area to volume ratio

Preliminary work

To investigate this relationship what I did for my preliminary work is to collect six varying volumes of water in the same boiling tube:

4cm3, 6cm3, 8cm3, 10cm3, 12cm3 and 14cm3.

The apparatus was set up as sown below.

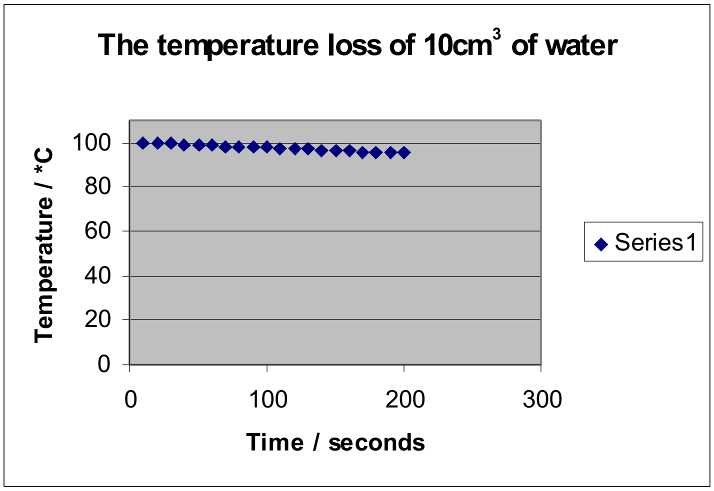
After doing this I will then heat the boiling tube to 100°c and then start the timer, noting at every 10 second interval what the temperature is, continuing for 200 seconds altogether. There will be a thermometer in the boiling tube telling us what the temperature of the water is and also one outside on the desk away from heat sources telling us, roughly, what the room temperature is.

The problem which I encountered was that at this temperature the water will be boiling and ‘spitting’ hence also causing a safety hazard. We could put anti bump granules or put some salt in it, but the salt will change the properties of the tap water, which we do not want. However, with careful heating, the water did not get out of control.

I noticed several mistakes with preliminary work. Firstly I noticed that even if you are careful it is still very difficult to prevent the water from boiling violently. Unfortunately the only measures which can be taken are to point the test tube away from your self and any other people, to boil very carefully, wear an apron and also a pair of goggles.
Secondly I realised that the thermometer was placed free to move and that because of localised heat spots it was unable to measure the temperature properly. What I mean

by this is that some areas of the water used to be hotter than others and if the thermometer came upon that area and moved on the temperature reading would vary. Therefore I decided to clamp the thermometer into place, thus ensuring that it doesn't roll through heat spots.

The third thing which I noticed was the most crucial. I gathered many results and averaged them, then checked them again but the results weren't what I expected. I plotted the results onto a graph.



As you can see the results aren't very decisive. My explanation was that the container in which the water was held wasn't large enough. I also plotted more results onto the graph, the lines were almost identical. The reason I put forward for this is that the next volume of water was too close to that of the first. Therefore I deduced that if I wanted to have accurate and reliable results I would have to change to a much larger container i.e. a beaker and change the volume of water I used considerably.

Planning

After taking into consideration what happened in my preliminary work I decided to fill:

A 300cm^3 beaker with 300cm^3 of water.

A 125cm^3 beaker with 125cm^2 of water.

And a 40cm^3 beaker with 40cm^3 of water.

I chose these certain volumes for two reasons. Firstly that they are far apart and so will not be similar with each other and have different gradients.

I will have a thermometer clamped into position half way into the beaker. I will do this because, as I learned from my preliminary work, there are localised heat spots. So if the thermometer is clamped into a secure position these localised heat spots will not make the temperature shown on the thermometer oscillate, as the thermometer will not roll in and out of these hot spots.

I will heat to 100°C then time for 200 seconds while recording the temperature at every tenth second interval. The safety for the heating procedure is simple. I will be using a beaker so, unlike in my preliminary work, the water doesn't have the potential

to shoot out of the end. But we must still wear safety goggles and an apron to ensure our eyes remain out of harms way.
I will repeat each experiment 3 times, then average these results and so plot them onto a graph. This will make the data more reliable and the chance of an anomalous result occurring will be significantly reduced.
The apparatus will be set up as shown below.

I will have to work out the surface area and volume in order to find the surface area to volume ratio.
Below is a diagram of a beaker and therefore I will prove why the formula works.

Surface area $= (2 \times \pi \times r \times d) + (2 \times \pi \times r^2)$
Volume $= \pi \times r^2 \times d$

The Variables and Constants

My constant will be temperature I take it to, i.e. 100°C.
The first variable is the volume of the water; this is easily controlled by simply measuring out how much water is being used.
The localised heat spots are variables as well. To ensure a fair reduction of these heat spots I simply stirred the beaker with the thermometer while I heated. This dispersed the heat spots and so there should be less during cooling as the molecules which are responsible for the 'spots' (the ones with the most energy) will be separated from each other. During cooling these localised heat spots will be controlled be keeping the thermometer in one place. Thus ensuring no accidental contact with the spots which were spread throughout the beaker.
The temperature of the surrounding air is another variable. I will control this by performing the experiment in one day. This is difficult but must be done. The reason for this is that no day has quite the same temperature and so will affect the cooling rate of the water. Basically this happens because if for example the day is cooler the particles will have less energy than a day which is warmer. Because of this it means that once the water is left to cool the surrounding air particles will absorb the heat of the water readily, 'sucking' it away. This would mean that the water molecules slow down faster and so loose their heat / energy faster. Therefore performing the experiment on the same day will ensure that the molecules / particles in the surrounding air will not affect the temperature.
Excessive boiling is another variable. What I mean by this is simply that you will lose a relatively considerable amount of water if you boil the water for a long period of time, note only this but during cooling some evaporation will also occur. This happens because as the molecules in the water get enough energy they will be able to escape into the surrounding atmosphere. Because of this, your depth and volume, would change and so throw off your surface area calculation and volume calculation. The answer to this is simply heat the water to just below 100°C allow it to cool then measure the depth of the water in the beaker.
The last variable is the thickness of the glass in the different sized beakers. Basically the beakers are different sizes and so have different thicknesses of glass. This matters because it will also affect the rate of cooling. This is controlled simply by using the same beaker and putting different, measured, quantities of water in.

Hypothesis

I hypothesise that large animals have a smaller surface area to volume ratio therefore the beaker with the greatest volume will loose heat the slowest. And that the small animals have a large surface area to volume ratio; this represents the beakers with the smallest volume of water and so the beaker with the smallest volume of water will loose heat the fastest. On the graph the initial rate will be quite quick but then steady out. I.e. it will be curved.

I also predict that if you halve the surface area to volume ratio you will halve the initial rate of heat loss also if you halve the volume twice from the initial volume by however much the temperature dropped during the first halved sample it will drop the same again. i.e. if you have $500cm^3$ to $250cm^3$ and let's say that the temperature dropped by 8°C I predict that if you halve that $250cm^3$ to $125cm^3$ the temperature will drop by 8°C again.
As shown in the above diagram I hypothesise that if you halve the volume of the water you will also halve the initial rate of heat loss.

Justification

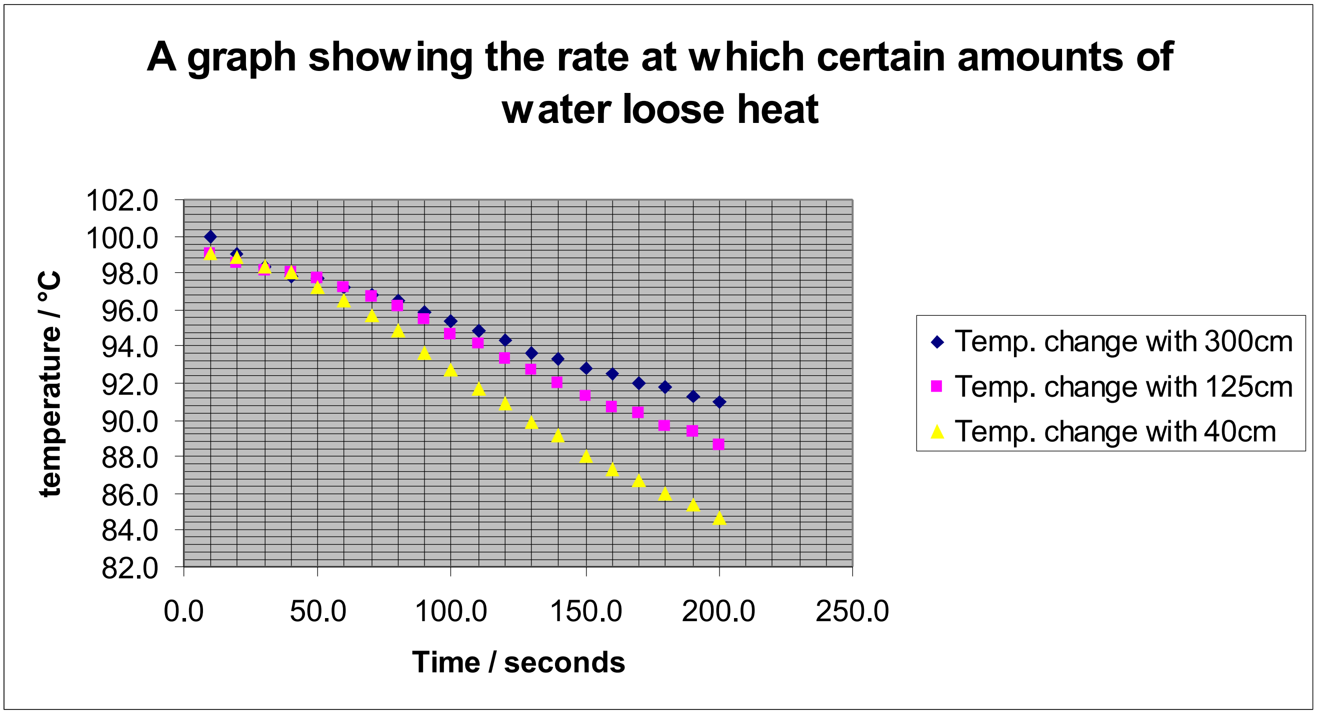
I made my prediction by keeping in mind the fact that heat loss and heat gain are the same as diffusion across a semi permeable membrane. Using this fact I know that a large surface area to volume ratio will allow diffusion at a much faster rate than that of a smaller surface area to volume ratio. For example alveoli in our lungs have a considerably large surface area to volume ratio and we know that alveoli are tremendously efficient at allowing diffusion to occur at a fast rate. Relating this to the experiment, I can say that a mouse would loose heat quicker than an elephant.
I hypothesised that if you halved the volume you would also halve the rate; I believe this because if you halve the volume you have roughly halved the molecules of that volume there for the remaining volumes will loose their heat to the surroundings and the outer atoms, in the water, will gain the heat and so the heat will be lost to the surroundings directly.

Obtaining

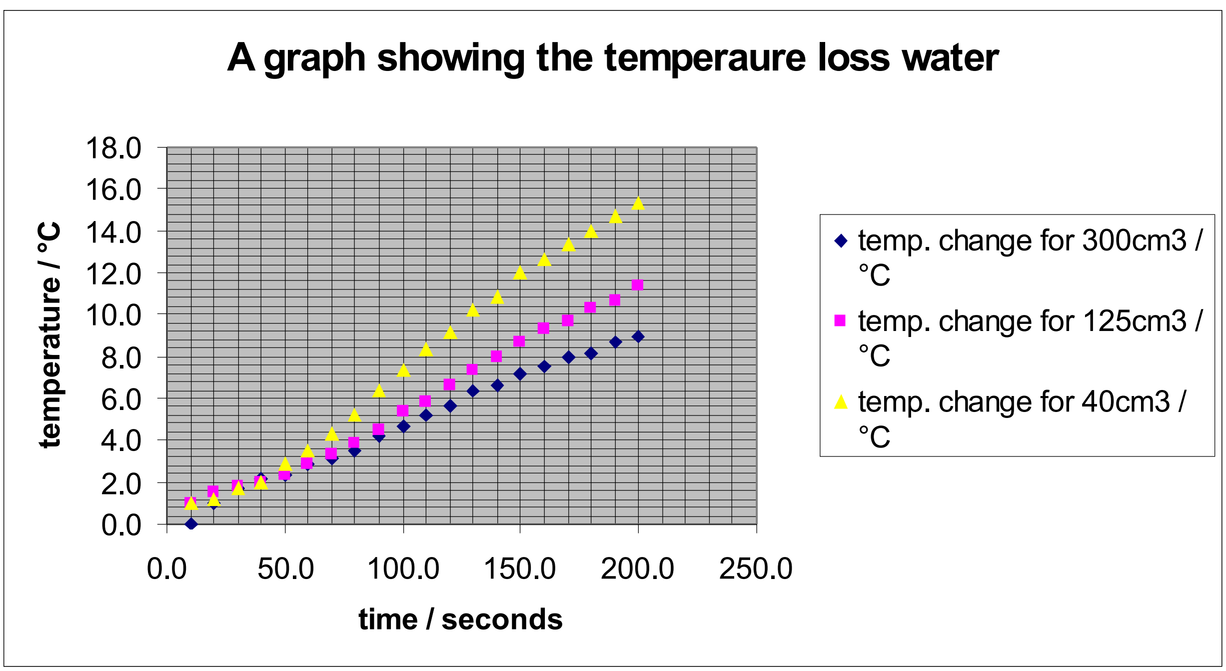
	In a beaker containing 300cm^3			
Time / secs	**Temp. change in exp - 1 / °C**	**Temp. change in exp - 2 / °C**	**Temp. change in exp - 3 / °C**	**Temp. change in average / °C**
10.0	100.0	100.0	100.0	100.0
20.0	99.0	99.0	99.0	99.0
30.0	98.5	98.5	98.0	98.3
40.0	98.0	98.0	97.5	97.8
50.0	98.0	97.5	97.5	97.7
60.0	97.5	97.0	97.0	97.2
70.0	97.0	96.5	97.0	96.8
80.0	97.0	96.0	96.5	96.5
90.0	96.0	95.5	96.0	95.8
100.0	95.5	95.0	95.5	95.3
110.0	95.0	94.5	95.0	94.8
120.0	94.5	94.0	94.5	94.3
130.0	93.0	94.0	94.0	93.7
140.0	93.0	93.5	93.5	93.3
150.0	92.5	93.0	93.0	92.8
160.0	92.0	92.5	93.0	92.5
170.0	92.0	92.0	92.0	92.0
180.0	91.5	92.0	92.0	91.8
190.0	91.0	91.5	91.5	91.3
200.0	91.0	91.0	91.0	91.0
depth of the beakers / cm	7.5	7.5	7.7	7.6
Diameter of the beakers / cm				8.0
Surface area / cm				290.7
Volume / cm				380.3

	In a beaker containing 125cm^3				In a beaker containing 40cm^3			
Time / secs	Temp. change in exp - 1 / °C	Temp. change in exp - 2 / °C	Temp. change in exp - 3 / °C	Temp. change in average / °C	Temp. change in exp - 1 / °C	Temp. change in exp - 2 / °C	Temp. change in exp - 3 / °C	Temp. change in average / °C
10.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0
20.0	98.5	98.5	98.5	98.5	98.5	99.0	99.0	98.8
30.0	98.0	98.5	98.0	98.2	98.0	98.5	98.5	98.3
40.0	98.0	98.0	98.0	98.0	98.0	98.0	98.0	98.0
50.0	97.5	98.0	97.5	97.7	97.5	97.0	97.0	97.2
60.0	97.0	97.5	97.0	97.2	97.0	96.0	96.5	96.5
70.0	96.5	97.0	96.5	96.7	96.0	95.0	96.0	95.7
80.0	96.0	96.5	96.0	96.2	95.5	93.5	95.5	94.8
90.0	95.5	96.0	95.0	95.5	94.5	92.0	94.5	93.7
100.0	95.0	95.0	94.0	94.7	94.0	91.0	93.0	92.7
110.0	94.5	94.0	94.0	94.2	93.0	90.0	92.0	91.7
120.0	93.5	93.5	93.0	93.3	92.0	89.0	91.5	90.8
130.0	93.0	93.0	92.0	92.7	91.0	88.0	90.5	89.8
140.0	92.0	92.5	91.5	92.0	90.0	87.5	90.0	89.2
150.0	91.0	92.0	91.0	91.3	89.0	86.0	89.0	88.0
160.0	90.5	91.5	90.0	90.7	88.5	85.0	88.5	87.3
170.0	90.0	91.0	90.0	90.3	88.0	84.5	87.5	86.7
180.0	90.0	90.0	89.0	89.7	87.0	84.0	87.0	86.0
190.0	89.5	90.0	88.5	89.3	86.0	83.5	86.5	85.3
200.0	89.0	89.0	88.0	88.7	85.0	83.0	86.0	84.7
depth of the beakers / cm	5.1	5.1	5.0	5.1	3.3	3.2	3.4	3.3
Diameter of the beakers / cm				7.0				4.0
Surface area / cm				188.4				66.6
Volume / cm				195.0				41.5

Analysis



In order to find the gradient of each line I thought it would have been easier to take the values of the points away from 100, because of this the curves will be progressing up the graph. Like shown below.



Now I can work out the rate at which the temperature increases using this simple calculation:

$$\frac{\text{Change in the y axis}}{\text{Change in the x axis}}$$

Along with working out the surface area to volume ratio I will be able to deduce whether or not my hypothesis was correct:

For **$300cm^3$**:

Surface area : volume
= 290.7 : 380.3
= 1 : 0.8

$$\text{Gradient} = \frac{97.7}{50} = 1.954$$

For **$125cm^3$:**

Surface area : volume
= 188.4 : 195.0
= 1 : 1.0

$$\text{Gradient} = \frac{97.7}{50} = 1.954$$

For **$40cm^3$:**

Surface area : volume
= 66.6 : 41.5
= 1 : 1.6

$$\text{Gradient} = \frac{97.2}{50} = 1.944$$

Unfortunately these results do not reflect what I predicted to the extent I hoped. The results which I have processed basically say that no matter what the volume to surface area ratio is the gradient will remain the same. However it is true that the temperature dropped by 3°C from the first one and from the second experiment it dropped 4°C, this proves that since the first experiment was roughly halved from $300cm^3$ to $125cm^3$ and the temperature dropped 3°C then the second experiment was more than halved $125cm^3$ to 40^3 (it should have been 62) the temperature dropped 4°C, this shows that my prediction is true to a certain extent and it also shows that only a significant increase/decrease in volume will make a difference in the temperature results.
It seems that at first the rate of temperature is quite low then increases and then slows down again. I would have expected this to happen straight away. This would probably be due an experimental error; as far as I can explain, I heated the beaker and when I stopped and started timing, although I had taken the Bunsen burner away, the

water was still being heated and then started to cool. This is possible but only for a few seconds not 50 seconds.

Evaluation

Although the experiment proved my prediction correct but only to a certain extent I believe that my results were incorrect and so led me to an incorrect conclusion. My results suggest that the initial rate of heat loss is slow and it speeds up after about 50 seconds. Either my results are incorrect or I haven't got enough of them. What I mean by this is that maybe I should have continued timing the heat loss for another 200 or so seconds. I am suggesting this because I believe that there is a strong possibility that if I based the rate on the whole graph I would have come out with proof that my prediction was in fact true. Therefore this would mean that the curve would appear later on and the results which I have do not represent a curve at all but in actual fact the initial rate.

I could perform further experimentation to follow up this investigation. I could time the rate at which the water heats up. So instead of heating then timing the cooling rate I simply time the heating rate. This would be simpler and o variables such as room temperature, boiling and so on would be eliminated.