BRITISH PHYSICS OLYMPIAD 2011 – 12

BPhO EXPERIMENTAL PROJECT

TEACHERS' GUIDELINES

The project this year is to investigate heat capacity and in particular the specific heat capacity of two materials which in most aspects have quite different characteristics.

The purpose is to improve your students understanding of the 'experimental method', with the emphasis being placed not so much on the expectation of great accuracy of the final results, but rather on the grasp of the method with its limitations and uncertainties, its advantages and disadvantages.

Students are required to produce a report giving a description of their work, equipment, method, diagrams, theory (simple formulae that they have used in their calculations only), results (graphically or in tabular form) and a conclusion. Reports should attempt to show that they understand some aspects of their approach; what indeed are its good points and what are the difficulties they have encountered in producing a result which may or may not be very accurate. On reading the report, one should see a discussion of their results in the conclusion, indicating what confidence they have in them. A short write-up is better than a long one, but an analysis of their results through their personal evaluation of their experiments and the range of variation of final results is important.

The project can be carried out either individually or in pairs. Teachers are encouraged to discuss the ideas, particularly about the equations and the principles of both specific heat capacity and heat capacity, comment on results, generally guiding the pupils rather than allowing them to become confused. The experimental work has a social aspect that can lead to the development and sharing of ideas, enjoyment in achieving results for a challenging piece of work, and satisfaction in completing the task. It is not an exam. A degree of critical evaluation of the experiment should be written by the student in their conclusion and they should be responsible for this themselves.

There are two categories of entry: category **A** is for students in years 12 and 13 preparing for A or AS level examinations, Highers in Scotland, or IB whilst category **G** is for GCSE, year 11 students, or equivalent age students. The teacher should submit the best project report in each category from the school in both hardcopy and by email - C.Isenberg@kent.ac.uk. These should be sent to:

Dr C. Isenberg
BPhO Experimental Competition
Electronics Laboratory
University of Kent
Canterbury, Kent CT2 7NT

by Monday 19th December 2011. The best reports will be made available on the BPhO website (permission will be requested of students and teachers) and the students concerned will be invited to a prize presentation. All students who carried out the experiment and produced a project report will receive a certificate.

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KEEPING COOL

INTRODUCTION

When you use your computer, you may notice that the cooling fan will start up, sometimes after a few minutes, in order to cool down the microprocessor chip (cpu). The need to conduct and convect heat away from the cpu chip is vital as it severely curtails its lifetime when it runs just a few degrees too hot. If it is hot enough to lose significant heat energy by radiation then it is too late! Some computer addicts will overclock the cpu on their computer to make it run faster and they have to add extra cooling, as the chip will then run even hotter. Cooling of the microprocessor is aided by "gluing" it to a heat sink – a small sheet of metal which will conduct heat away. However, it is also important that this metal can absorb as much heat energy as possible without its temperature rising too much. This property is known as **heat capacity**, and there are many situations where the ability to absorb heat energy is very important.

This project concerns the measurement of the **heat capacity** of (a) a 2p coin and (b) a house brick. It is true that you would not cool your cpu down by gluing it to a 2p coin, nor a house brick for that matter, but it gives us a standard metal for comparison and the value we obtain is similar to the metal that is used for the heat sink. The piece of brick is by contrast a quite different material and you could not imagine that it would be much use for cooling your cpu. So it will be interesting to measure its value and then consider what other factors might be important for cooling the cpu.

DEFINITIONS

The **heat capacity** of an object is the heat required to raise its temperature by 1 ^{o}C.
The **<u>specific</u> heat capacity** of a material is the heat required to raise the temperature of **1 kg** of the material by 1 ^{o}C.
e.g. for water, it needs almost 4,200 J to heat 1 kg by 1 ^{o}C
In this project both of these quantities are constants for all the materials used.

EQUIPMENT

- Several 2p coins (N.B. If you use several 2p coins, make sure that they are made of the same alloy – i.e. some are magnetic and some are not!)
- A small piece of a house brick (ask your teacher for this – see Safety Section). You would also want to know the approximate mass of the whole brick it comes from.
- Balance
- Two thermometers
- Copper or pyrex or expanded polystyrene calorimeter (see below)
- Source of hot water or cold water and means of heating or cooling small coins or brick.
- Clingfilm
- Thread or tongs to handle hot objects

EXPERIMENTS

(a) Using a copper or pyrex or expanded polystyrene calorimeter (this is just the name for a container when it is used in a heat experiment; a pyrex calorimeter is a beaker and a polystyrene calorimeter is a polystyrene cup), some 2p coins and water perform an experiment to measure the heat capacity of a 2p coin, C_{2p}.
Calculate the specific heat capacity of the metal of the coin.

(b) Using the containers (calorimeters) as in (a) and replacing the coins by a suitable sized fragment of a house brick, determine the heat capacity of the fragment and hence the heat capacity of a whole brick, C_b.
Calculate the specific heat capacity of the material of the brick.

- In both experiments take precautions to minimize the heat loss.
- Initially assume there is no heat loss.
- Subsequently make an estimate/measurement of the heat loss in each case and correct your values of C_{2p} and C_b.
- All measurements should contain an uncertainty estimate which should appear in your table of results.

CONSTANTS

SPECIFIC HEAT CAPACITIES	
Copper	385 J kg^{-1} ^{o}C^{-1}
Pyrex	840 J kg^{-1} ^{o}C^{-1}
Water	4179 J kg^{-1} ^{o}C^{-1}
Polystyrene	very small

SAFETY

- Discuss your method with your teacher who will be able to advise on safety precautions.
- Do not sit down with a beaker of hot water on the bench in front of you in case you knock it over.
- You should avoid using steam or heating the metal in a flame.
- Do not hammer pieces of brick off a large brick to break it up. Your teacher should be able to supply some pieces (goggles should be worn for this as pieces of brick may fly off when it is broken)
- Your write-up should contain specific references to safety, so you must be aware of this as you carry out your experiments.

PROCEDURE

- You should discuss your ideas with your teacher. They are not there to give you instructions, but they can help you along the way if you get stuck, or act as a sounding board if you want to see whether or not your approach seems reasonable.
- You will most likely use a "method of mixtures" in which you mix a cold material with warm water or vice versa. You can then measure the final temperature of the mixture and, knowing the masses involved and the specific heats, calculate the heat capacity of the original item. For a well insulated system, the change in heat energy will be zero when hot and cold materials are mixed together. Thus,

  Heat energy lost by the hot sample = Heat energy gained by the cold water

  Using $\Delta Q = mc\Delta\theta$, where ΔQ is the change in heat energy, m is the mass of material, c is the specific heat capacity of the material and $\Delta\theta$ is the change in temperature of the material,

$$m_{hot}\, c_{hot}\, (\theta_{hot} - \theta_{final}) = m_{cold}\, c_{cold}\, (\theta_{final} - \theta_{cold})$$

where m_{hot} (m_{cold}) is the mass of the hot sample (cold water), c_{hot} (c_{cold}) the specific heat of the hot sample (cold water), θ_{hot} (θ_{cold}) is the temperature of the hot sample (cold water), and θ_{final} is the final temperature of the mixture.

Rearranging, we obtain $$c_{hot\ sample} = \frac{m_{cold}\ c_{cold}\ (\theta_{final} - \theta_{cold})}{m_{hot}\ (\theta_{hot} - \theta_{final})}$$

(You can choose hot water and a cold sample instead; which is better do you think?)
To include the calorimeter as well, since that has to be heated along with the cold water, just replace $m_{cold}c_{cold}$ with $m_{cold}\ c_{cold} + m_{calorimeter}\ c_{calorimeter}$

- What is the ratio of coins to water or brick to water? This can be varied. How does the temperature drop whilst you are sitting watching it reach the final temperature? Can you correct for that heat loss in a simple way, perhaps by seeing how quickly the mixture drops in temperature?
- You will probably need to wrap the brick in cling-film as it can absorb water.
- You should try more than one method; if we are to be convinced by your results, we need to see that doing the experiment differently still gives the same values. It probably won't so you need to comment on that and try and work out why it doesn't.
- There are other methods besides the method of mixtures and you may want to try one of these instead.

WRITE -UP

The key element here, which you may find the hardest, is to evaluate your results. Are they reliable, or do you think that it would be best not to place too much reliance on them? What variation is there? What evidence is there to show that the results may be good or bad? What is good about your experiment, what is less good about your technique, and what could be done to improve the result if you ever did the experiment again?

- You should give a brief description of the experiment and the apparatus using appropriate diagrams.
- You should also briefly comment on how your method will give a good result, or perhaps why it will not give a good result. Does it minimise the heat loss or ensure accuracy of your final result by having a much more accurate thermometer? Will having a really good thermometer overcome a poor method? The comments are so that you can justify your experiment and also so that you can indicate that you have understood many of the difficulties and shortcomings of your experiment or method.
- Measurements should be repeated so that you can take averages and also so that you can comment on the variation. If a reading varies when it is retaken, then you can get some idea of the uncertainty on the reading.

- Estimate the uncertainties on your readings and write these down in the table.
- You should have a ruled table of results with units, and any graphs with titles and labelled axes (you do not have to have a graph).
- Estimate the uncertainty on your final result. Write down an appropriate number of significant figures. Use the correct units.

CONCLUSION

- Comment on whether in fact you can distinguish the metal of the coin from the material of a brick by this method. For this comparison, you will need to calculate the **specific** heat capacity of the metal of the coin and the material of the brick.
- Make a conclusion which briefly summarises your results and compares them. Does brick have any of the right properties to cool your cpu? It obviously does not have enough of them to be used.
- Evaluate your experiment and results. Write down the good and bad points and how you would convince a reader that your results are reliable or unreliable. Be honest!
- It is important that you learn about doing experiments from this project. With hindsight, could you have made any improvements to your method, or obtained better results by using an entirely different approach? Stand back and examine what you have done and comment critically on it.

FINALLY

Your experiment is not about getting the best numerical result. It is about carrying out an experiment that you can understand and that you can convince the reader that you understand so that he or she is made aware of its shortcomings and its good points as well.