Physics: 11. Heat

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

**Syllabus**

**OP22** Recall that heat is a form of energy and that it can be converted into other forms of energy

**OP23** Investigate and describe the expansion of solids, liquids and gases when heated, and contraction when cooled

**OP24** Demonstrate the expansion of water on freezing

**OP25** Measure the temperature of various solids and liquids at, above and below room temperature; determine the melting point of ice and the boiling point of water

**OP26** Investigate the effect of pressure on the boiling point of water

**OP27** Explain the difference between heat and temperature

**OP28** Carry out experiments that involve changes of state from
  i. solid to liquid and liquid to solid
  ii. liquid to gas and gas to liquid

**OP29** Plot a cooling curve and explain the shape of the curve in terms of latent heat

**OP30** Appreciate that all hot bodies radiate heat

**OP31** Carry out simple experiments to show the transfer of heat energy by conduction, convection and radiation; investigate conduction and convection in water

**OP32** Identify good and bad conductors of heat and compare insulating ability of different materials.

**Student Notes**

Temperature is a measure of the hotness or coldness of an object

Heat is a form of energy and it can be converted into other forms of energy

To show that heat is a form of energy you must be able to show that it can do work (because energy is the ability to do work).
Work is done when an object is being moved.
So we need to show that heat can move something.

**Demonstration**
Alcohol in a thermometer expands and moves up the glass when heat is applied.
Solids, liquids and gases expand when heated, and contract when cooled

Solids expand when heated and contract when cooled
Demonstration
1. Heat the brass ball.
2. Note that the ball fits through the ring when the ball is cold but not when hot.

Liquids expand when heated and contract when cooled
Demonstration
1. Connect a glass tube to the top of a beaker of water (use dye to make the water more visible). I use a Bunsen burner instead of a hair-dryer).
2. Note that the water rises up the tube as it gets heated and drops back down as it cools.

Gases expand when heated and contract when cooled
Demonstration
1. Gently heat the flask of air (much better to use a hair dryer in case the flask breaks).
2. Note that bubbles come out of the tube when the flask is heated and as it cools water from the trough rises back up the tube because of the partial vacuum which has formed.

The anomaly (strangeness) of water
Water is an exception to almost all other substances in that when it drops below 4°C the water actually expands when cooling rather than contracting.
The explanation for this is a little complicated (it has to do with the arrangement of water molecules, but you don’t need to know it for exam purposes).
Demonstration
1. Fill a glass bottle with water and place it in a plastic bag in a freezer.
2. When you take it out the following day the bottle will be broken because the water has expanded on freezing.
   (The purpose of the bag was to ensure that all the pieces of glass get taken out).
This is why water pipes sometimes burst in winter causing flooding in a home.

The effect of pressure on the boiling point of water
Demonstration
Reduced pressure decreases the boiling point of water
1. Suck up water which is at about 80°C into a syringe so that the syringe is about one-quarter full.
2. Cover the open end (watch out- it’s hot!) and pull back the handle to create a partial vacuum.
3. Result: The water begins to boil!
4. Explanation: the air acts like a blanket which presses down on the water and makes it difficult for the water molecules to leave (‘jump out of’) the liquid and become part of the air.
5. Higher pressure therefore results in a higher boiling point (the molecules need to have more energy/move more rapidly to make the transition).
Changes of state, the cooling curve and latent heat

1. Heat a boiling tube of wax to a high temperature and as it cools note the temperature.
2. Plot a graph of temperature against time.
3. Note that the temperature decreased at a steady rate until (in this case) it reached 43 °C. This is when the wax began to change state from a liquid to a solid.
4. It remains at this temperature until all the wax has solidified (in this case it took 4 minutes) and after that it began to drop in temperature again as the solid wax cooled down.

**Explanation**
As the wax changes state from a liquid to a solid it gives out heat without cooling down. This heat is called latent heat because latent means ‘hidden’ and in this case it is not obvious where the heat is coming from.

**Latent heat** is the heat taken in or given out when a substance is changing state (without changing temperature)
Heat Transfer: Conduction, Convection and Radiation

Heat can be transferred in three different ways - conduction, convection and radiation.

Conduction is the method by which heat travels from particle to particle through a solid.

Convection is the transfer of heat through a liquid or gas when the particles move and carry the heat with them.

Radiation is the transfer of heat from a hot object without the need for a medium.

All objects radiate heat, but not all substances conduct or convect heat.

<table>
<thead>
<tr>
<th></th>
<th>Conduction</th>
<th>Convection</th>
<th>Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Liquids</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Gases</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Conduction

To compare the ability of different metals to conduct heat
1. Use the apparatus shown which consists of a piece of timber with four different strips of metal.
2. Place some candle wax at the end of each metal and stand a match in the wax at the end.
3. Light the Bunsen (or candle) under the middle and note the order in which the matches fall. The match which falls first was standing in the best conductor.

To show that water is a poor conductor of heat
1. Half fill a boiling tube with water and use piece of metal gauze to hold down the ice.
2. Holding the boiling tube at an angle with a tongs, heat it at the top using the Bunsen burner for a short period of time.
   Result: the water at the top boils which the ice at the bottom stays frozen.

Convection

To demonstrate convection currents in water
1. Use the apparatus shown and drop in some copper sulphate or potassium permanganate to act as a dye.
2. Place the Bunsen under one of the corners and note the movement of the water around the apparatus.

To demonstrate convection currents in air
Cut tissue paper into narrow strips; tie the strips together at one end using the piece of thread and hang them from a retort stand as shown over a hot-plate.
Result: the tissue paper will begin to move as a result of the convection current generated by the hot-plate.
Radiation
Dark materials are better radiators of heat than shiny materials.

Demonstration
1. Take two identical metal containers and paint one with one black and the other silver.
2. Fill both with hot water.
3. Using a thermometer and stop-watch note which container cools the quickest.
4. The dark container cooled more quickly because it is a better radiator of heat.

Conductors and Insulators

A conductor is a substance which allows heat to flow through it easily

An insulator is a substance which does not allow heat to flow through it easily

To compare the insulating ability of different materials

Demonstration
1. Take two identical containers and wrap one in cotton wool.
2. Fill both with hot water.
3. Note which container cools more quickly than the other.
4. The container which cooled more slowly had better insulating material.

Note: There are no maths problems in this chapter.
Exam Questions

1. [2006]
   Define temperature and give a unit used to express temperature

2. [2008][2010]
   Give two differences between heat and temperature.

3. [2007][2010 OL][2007 OL]
   The diagram shows a piece of equipment that can be used to investigate the effect of heat on a metal.
   The ball will pass through the ring when it is cold.
   When the ball is heated it will no longer pass through the ring.
   Answer the following questions about this investigation.
   (i) Explain why the ball does not pass through the ring when it is heated.
   (ii) How would you get the ball to fit through again?
   (iii) What does this investigation tell us about the effect of heat on metals?

4. [2009 OL]
   Describe, with the help of a labelled diagram, how you could carry out an experiment to show that metals expand when heated.
   Use the following headings: Labelled diagram, Equipment, Procedure, Result.

5. [2011 OL]
   Electric cables made from copper sag or droop in summer as shown in the diagram.
   What property of metals does this demonstrate?

6. [2008 OL]
   The diagram shows a round-bottomed flask full of coloured water.
   (i) What would you expect to notice if the flask is heated gently?
   (ii) Give a reason why this should happen.
   (iii) Why is coloured water used during this investigation?

7. [2010 OL][2007 OL]
   In an investigation to see the effect heating had on gases, a student heated a round-bottomed flask containing air using a hairdryer as shown in the diagram.
   (i) What would you expect the student to have seen when the flask was heated?
   (ii) What conclusion can you draw from this investigation?

8. [2010]
   The apparatus shown in the diagram was used to investigate the expansion and contraction of a gas.
   (i) What is observed when the flask is heated?
   (ii) Explain your observation when the flask is heated?
   (iii) What is observed when the flask is allowed to cool?
   (iv) Explain what you observe as the flask cools.

9. [2006]
   Describe an experiment to show the expansion of water when it freezes.
   You may include a labelled diagram if you wish.
10. [2009]
The boiling point of water can be determined using the apparatus shown in the diagram.
(i) Why are boiling (anti-bumping) chips added to the water?
(ii) At what temperature does water boil, at standard (normal) atmospheric pressure?
(iii) What effect does the raising of pressure have on the boiling point of water?
(iv) What effect does the lowering of pressure have on the boiling point of water?

Conduction, Convection and Radiation

11. [2011 OL][2007 OL]
Heat is transferred in different ways.
In each case use a word from the list on the right to correctly complete each sentence below.
(i) Heat travels through solids by ________________.
(ii) Heat travels through liquids and gases by ________________.
(iii) Heat travels from the Sun to the Earth by ________________.

12. [2006 OL]
Heat may be transferred from hot to cold places by the three methods listed on the right.
Choose the method of heat transfer that occurs in each of the following.
(i) The boiling of water in a kettle. ________________
(ii) The heating of the Earth by the Sun. ________________

13. [2006]
Name the mode of heat transfer from the hot liquid, through the spoon, to the hand.

14. [2009]
Copper, aluminium and iron rods are set-up as shown in the diagram. A metal ball is attached by wax to the end of each rod. Hot water is poured into the beaker. The ball falls from the copper rod first. What conclusion can be drawn from this observation?

15. [2011 OL]
A student set up the investigation shown in the diagram.
The apparatus consisted of a metal box that was filled with boiling water.
A piece of candle wax was placed on the top end of each rod.
The piece of wax on top of the copper rod melted first and the piece of wax on top of the glass rod melted last.
Answer the following questions about this investigation.
(i) What does the result of this investigation tell us about copper, iron and glass?
(ii) Why was it important to use rods of the same length and thickness and that they dipped into the boiling water to the same depth?
16. [2011]
The experiment shown in the photograph was set up by a student.
(i) What changes take place to the water in the beakers A and B as time passes?
(ii) Explain why these changes occur.
(iii) What instrument would be used, in this experiment, to monitor the changes?
(iv) Name a material to replace copper in this experiment that will not allow these changes to occur.

17. [2007]
(i) What does the experiment shown in the diagram tell us about the transfer of heat energy in water?
(ii) If you wanted to warm all of the water why would the bottom of the test tube be the best place to heat with the Bunsen flame?

18. [2006]
Heat moves in liquids by convection. Give one difference between convection and conduction.

19. [2009]
The photograph shows a solar panel being installed. Water passing through the panel is heated by the sun.
(i) How does heat from the sun travel, through the vacuum of space, to the earth?
(ii) Give one advantage or one disadvantage of fitting solar panels to your home?

**Insulation**

20. [2009 OL]
The diagram shows two metal cans equal in size and filled with the same amount of water at 100 °C. Can A is wrapped in cotton wool and can B has no wrapping.
(i) After 15 minutes, which can, A or B, would you expect to have the higher temperature?
(ii) Give a reason for your answer.
21. [2006]

The graph is a cooling curve. The substance used in this experiment was naphthalene. Naphthalene has a melting point of 80 °C. The rate of heat loss was constant throughout the experiment.

(i) What is happening to the naphthalene on the horizontal section of the graph?

(ii) What is the heat loss on the horizontal section of the curve called?

22. [2010]

A substance that is a solid at room temperature was heated above its melting point and then allowed to cool at a steady rate. The temperature was taken at regular intervals. The data is in the graph. Why is there no drop in temperature between B and C?

23. [2008]

A pupil heated some lauric acid, which is a solid at room temperature, until it turned into a liquid. The lauric acid was then allowed to cool at a uniform rate. The temperature of the lauric acid was taken every minute. The data from this experiment is given in the table.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>75</th>
<th>64</th>
<th>54</th>
<th>43</th>
<th>43</th>
<th>43</th>
<th>43</th>
<th>43</th>
<th>32</th>
<th>22</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (minutes)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

(i) Draw a graph, using this data, of temperature against time (x-axis) in the grid provided below.

(ii) Explain the shape of the graph that you obtain.

(iii) Use the graph to estimate the melting point of lauric acid.
Exam Solutions

1. Temperature is a measure of the hotness of an object.
   The unit of temperature is degrees Celsius (°C).

2. Heat is a form of energy (and temperature isn’t).
   Temperature is a measure of the hotness of an object (and heat isn’t).

3. (i) Ball expanded / increased in volume
   (ii) Cool the ball / stated cooling method
   (iii) (Metals) expand when heated / contract when cooled

4. Diagram of ball and ring apparatus.
   Ball fits through ring when both are at room temperature.
   Heat the ball over a Bunsen burner for one minute.
   Result: the ball will no longer fit through the ring.

5. Metals expand when heated

6. (i) Water rises up the tube
   (ii) Water (liquid) expands (when heated)
   (iii) Easier to see

7. (i) Bubbles of air coming from the mouth of the flask into water trough
   (ii) Air (gas) expands when heated

8. (i) Bubbles of air come out of the bottom of the glass tube.
   (ii) The air in the flask expanded.
   (iii) The bubbles stop and water rises up the glass tube.
   (iv) Air in flask contracted therefore the air pressure is less than atmospheric pressure.

9. Fill a bottle with water
   Put the bottle in a freezer
   The bottle bursts after a few hours.

10. (i) Chips help to ensure that all the water boils at the same temperature {I know – not on the syllabus so shouldn’t have appeared!}
    (ii) 100° C
    (iii) It raises the boiling point
    (iv) It lowers the boiling point

Conduction, Convection and Radiation

11. (i) Conduction
    (ii) Convection
    (iii) Radiation

12. (i) Convection
    (ii) Radiation

13. Conduction

14. Copper is the best conductor

15. (i) Metals conduct (carry) heat, copper is the best conductor and glass is the worst.
    (ii) So that the experiment would be a fair test / compare like with like

16. (i) The temperature of water in A decreases and temperature of water in B increases.
    (ii) Copper conducts (transfers) heat
    (iii) Thermometer
    (iv) Wood/ plastic/ named plastic e.g. nylon…
17. 
(i) Water is a poor conductor of heat
(ii) Because hot water rises (note that ‘heat rises’ alone gets no marks)
18. Convection: particles of liquid move carrying the heat with them.
   Conduction: heat is transferred from one particle to another without any overall movement of the particles themselves.
19. 
(i) It travels by radiation.
(ii) Advantage: to reduce fuel bills, reduce CO₂ emissions, it is renewable.
   Disadvantage: expensive to set up, less heat is absorbed in winter or on cloudy days.
20. 
(i) Can A will have a higher temperature after 15 minutes.
(ii) Because it is insulated so it loses heat more slowly.

**Latent Heat**

21. 
(i) It is changing from a liquid to a solid
(ii) Latent heat of fusion
22. It is changing state (freezing).
23. 
(i) See graph
(ii) Initially the temperature of the liquid falls until it reaches 43 °C.
   Here it changes state from a liquid to a solid.
   Then the solid cools down.
(iii) 43 °C
Heat Questions
1. Draw a labelled diagram of an apparatus used to demonstrate convection in a liquid.
2. Draw a labelled diagram of the apparatus used to compare the conductivity of different metals. How does it work?
3. Give two uses of a bimetallic strip.
4. Draw a labelled diagram of the apparatus you would use to show that water is a poor conductor of heat.
5. How would you demonstrate that solids expand when heated and contract when cooled? Include a fully labelled diagram.
6. How would you demonstrate that liquids expand when heated and contract when cooled? Include a fully labelled diagram.
7. How would you demonstrate that gas expands when heated and contract when cooled? Include a fully labelled diagram.
8. Why is water not a suitable liquid for use in thermometers?
10. Define convection.
11. A student filled a boiling tube with water and placed an ice-cube at the bottom by keeping metal weight on top of it. The student then heated the top of the boiling tube until the water was boiling at the top.
   (i) What was the student trying to investigate?
   (ii) Why did he put a weight on the cube of ice?
   (iii) Why was it important that the weight was made of metal?
   (iv) What did the student notice?
12. Fill in the table with the words convection, conduction, or radiation where appropriate

<table>
<thead>
<tr>
<th>Object</th>
<th>Method of Heat Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A spoon</td>
<td></td>
</tr>
<tr>
<td>A saucepan of water</td>
<td></td>
</tr>
<tr>
<td>Space</td>
<td></td>
</tr>
</tbody>
</table>
13. Why is the heating element of a kettle placed near the bottom?
14. What is the main way in which heat is transferred when the water in an electric kettle is heated?
15. What is the main way in which heat is transferred when the Sun heats the Earth?
16. What property of oven gloves allow a baker to pick up hot bread?
17. Why do metals expand when heated?
18. What is meant by the term ‘the anomaly of water’?
19. Sublimation occurs when a ________ changes directly to a ________ when heated.
20. What is meant by the term ‘latent heat’?
21. Draw a diagram of a cooling curve for wax and indicate on it all the various states of matter.
22. Why are ice cubes much better at cooling a drink that the equal amount of iced water?
23. Why is a scald from steam much more serious that a burn from boiling water?
24. Why do hurricanes pick up energy when they pass over oceans?
25. Why does a glass beaker often crack when you pour in boiling water?
26. Why is a shiny material both a bad absorber of heat and a bad radiator of heat?
27. Why do hurricanes pick up energy when they pass over oceans?
Higher Order Questions
28. When stepping out of bed on a cold morning, why does it feel colder if your feet touch say, a marble floor rather than a floor with carpet even though both are at the same temperature?
29. Why does water rise when heated?
30. How does perspiration (sweating) help to keep us cool?
31. Many Arabs wear dark clothing in warm weather, even though dark clothes are better at absorbing heat than white clothes. Any idea why?
32. Heat can be transferred by conduction, convection or radiation. A thermos flask tries to keep hot liquids hot by preventing heat loss. Any idea how it minimises each of these three methods of heat transfer?
33. What is the effect of increased pressure on the boiling point of water?
34. Why does increased pressure affect the boiling point of water?
   - Can you think of an application of this (a device which is built on this principle? 
   - Can you think of anyone who might be affected by this?
   - Hurricanes pick up energy while travelling over the ocean.
   - Water evaporates and in doing so picks up heat energy when going from a liquid to a gas.
   - Now later on when it condenses from a gas to a liquid it gives out this heat in the form of molecular energy to nearby molecules which presumably heats them up.
Heat Crossword

Across
2. Gas changing to liquid. (10)
3. Apparatus used to demonstrate that reduced pressure decreases the boiling point of water. (7)
5. You find this in most school thermometers. (7)
6. Visible evidence that gas expands when heated. (7)
7. A glass bottle of water might do this when the temperature drops below 4 degrees. (5)
9. Method by which heat travels from particle to particle through a solid. (10)
12. What type of materials are good absorbers of heat? (4)
13. Transfer of heat from a hot object without the need for a medium. (9)
16. Liquid changing to gas. (7)
17. What type of conductor of heat is water? (4)
18. Energy is defined as the ability to do this. (4)
19. Solid changing to liquid. (7)
20. The heat taken in or given out when a substance is changing state (without changing temperature). (6)
21. What type of materials are poor radiators of heat? (5)
22. Liquid changing to solid. (8)
23. Solids, liquids and gases do this when heated. (6)

Down
1. It is a substance which does not allow heat to flow through it easily. (9)
2. It is a substance which allows heat to flow through it easily. (9)
4. Transfer of heat through a liquid or gas when the particles move and carry the heat with them. (10)
8. Heat is a form of this. (6)
10. It's a form of energy. (4)
11. Solids, liquids and gas do this when cooled. (8)
14. The effect of increased pressure on the boiling point of water. (9)
15. The strangeness of water. (7)
16. used to demonstrate that solids expand when heated. (11)
MCPMICASAOWMGKG
XLOQKLDXYTGYTVM
SIONCFURMSNYAB
MBRODDELIOPRUVU
BGHNUCRNULULOL
AOSANOCBGIFKBO
LQRSRTJWTEJCACOM
NWQFLUAIDIAPKSEQ
WTENRAGXYOINTUU
CONDENSINGNEQOI
CLSLJFDFGIUOMWN
VUFCKHPYUMYLF
UWYOMXXAMWBOADY
ZSOPOTGEYIQDHAP
ESELBBUBPVDMBB

ALCOHOL
BUBBLES
BURST
CONDENSING
CONDUCTION
SYRINGE