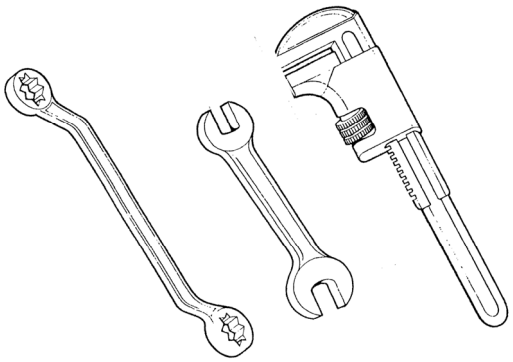
Trade of Plumbing

Module 3: Domestic Heating/MMA Welding

Unit 3: Domestic Heating System Installation

Phase 2



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Document Release History

Date	Version	Comments
June 2006	V.1.0	
17/02/14	2.0	SOLAS transfer

Module 3 – Domestic Heating/MMA Welding

Unit 3 – Domestic Heating System Installation

Duration – 35 Hours

Learning Outcome:

By the end of this unit each apprentice will be able to:

- State the various types of boilers and heating controls.
- Calculate thermal expansion in plumbing materials.
- Calculate specific heat capacities of liquids and solids.
- Calculate the kilowatt rating of boilers.
- Install a basic domestic heating system project using copper, pex, P.B. pipe.
- Calculate the cost of installation of a domestic heating system.

Key Learning Points:

Rk	**Types of boilers.**
Rk	**Domestic heating controls, heating zones, basic electricity.**
Rk	**Flues.**
Sc M	**Thermal expansion, linear coefficients of expansion, expansion loops.**
Rk	**Thermal insulation.**
Sc M	**Specific heat.**
Rk M	**Radiator and boiler sizing.**
Sk	**Interpretation of drawings.**
Sk	**Installation of heating system project – fitting boiler, cylinder, radiators, feed and expansion tank, pipework and fittings etc.**
Sk H	**Use of hand tools, power tools, gas torches.**
P	**Good working practice.**
P	**Initiative.**
P	**Planning.**
P	**Teamwork.**
P	**Communication.**

Sk M	**Pricing and estimating.**

Training Resources:

- Classroom facilities.
- Information sheets.
- Workshop facilities.
- Sample heating controls.

Exercise

- Two apprentices to install a basic domestic heating system project from schematic Drawing No. 2.3.3 in the curriculum document.

Key Learning Points Code

M = Maths D= Drawing RK = Related Knowledge Sc = Science

P = Personal Skills Sk = Skill H = Hazards

Thermal Expansion

It is a well known fact that when a substance or material is heated it gets larger or expands; and when it cools it gets smaller or contracts. In other words, material "moves" as its temperature varies, and this is called thermal expansion.

Why do materials expand when heated and contract on cooling?

Imagine the space taken up by a group of people standing fairly still. Now, if all these people started to 'rock-n-roll', they would jostle and push one another about, and in doing so they would take up more space.

The separate molecules which go to make up a material are always on the move, vibrating to and fro at a rate depending upon the amount of heat energy they possess. When cold, their heat energy is small and they keep fairly still and close to one another, taking up as little space as possible.

When the material is heated, its molecules gain energy and start to "dance" with increasing vigour and so, of course, they take up more space. The result is an increase in the size of the material; that is, the material expands on being heated.

When the material cools down it loses heat energy, the molecules slow down, and a reduction in size or contraction results.

Coefficient of Thermal Expansion

The amount any material will expand when it is heated depends upon the material itself; whether it is in a solid, liquid or gaseous state; and upon its heat content.

The amount that solids will expand for each °C of temperature rise is easily measured and is fairly constant. To whatever extent a solid expands or contracts for 1° change in temperature, it will expand or contract ten times as much for 10° change in temperature.

Liquids and gases do not behave quite so conveniently, and water in particular behaves in a most unexpected manner.

For the present, consider the effect of thermal movement on solid materials such as pipes, boilers and sheet metal roof coverings. This thermal movement affects the material in all its dimensions. The length, width and thickness all increase as the temperature of the material increases. However, since most of the materials the plumber deals with, e.g. pipes and bays of sheet metal on roofs, are so much longer than they are wide or thick, it will only be necessary to examine the more readily seen effects of heat on the length of the material.

To calculate the physical amount a material will expand or contract, reference will be made to the "LINEAR COEFFICIENTS OF THERMAL EXPANSION". The word "linear" means lengthwise and "coefficient" means fraction, so the term really describes that fraction by which a given or unit length of material will expand when its temperature is increased by 1°, or will contract when its temperature decreases by 1°.

If a piece of material 1m long expands by 1mm when its temperature is raised by 1°C, it can be said to have expanded by one thousandth of its length. This number written as a decimal would read 0.001 and relates to the expansion of that material per degree Celsius temperature rise. This fraction is referred to as the "coefficient of linear expansion".

To calculate the increase in length of a given piece of material due to thermal expansion, three pieces of information must be known.

(i) The original length of the material;

(ii) The increase in temperature by which it is raised;

(iii) The coefficient of expansion for that material.

The coefficient of thermal expansion rates of use to the plumber are given in the following table:

Table 1. Coefficients of Thermal Expansion

MATERIAL	APPROXIMATE COEFFICIENT PER °C
Copper	0.000016
Mild Steel	0.000011
Plastic	0.00018
Lead	0.000029
Aluminium	0.000026

The calculation used to find the amount material expands in length (linear expansion) is expressed as:

Length (in mm) X temperature change X Coefficient

Example 1

Find the amount a 9m long plastic pipe will expand due to a temperature rise of 24°C.

= 9,000 X 24 X 0.00018

= 38.9mm

This emphasises the need to allow for expansion when using plastic pipes.

Thermal Insulation

Thermal insulation may be described as the application of special materials to pipes and storage vessels to prevent excessive loss of heat energy and damage from frost. Insulation material entraps small pockets of air, since still air is a bad conductor of heat.

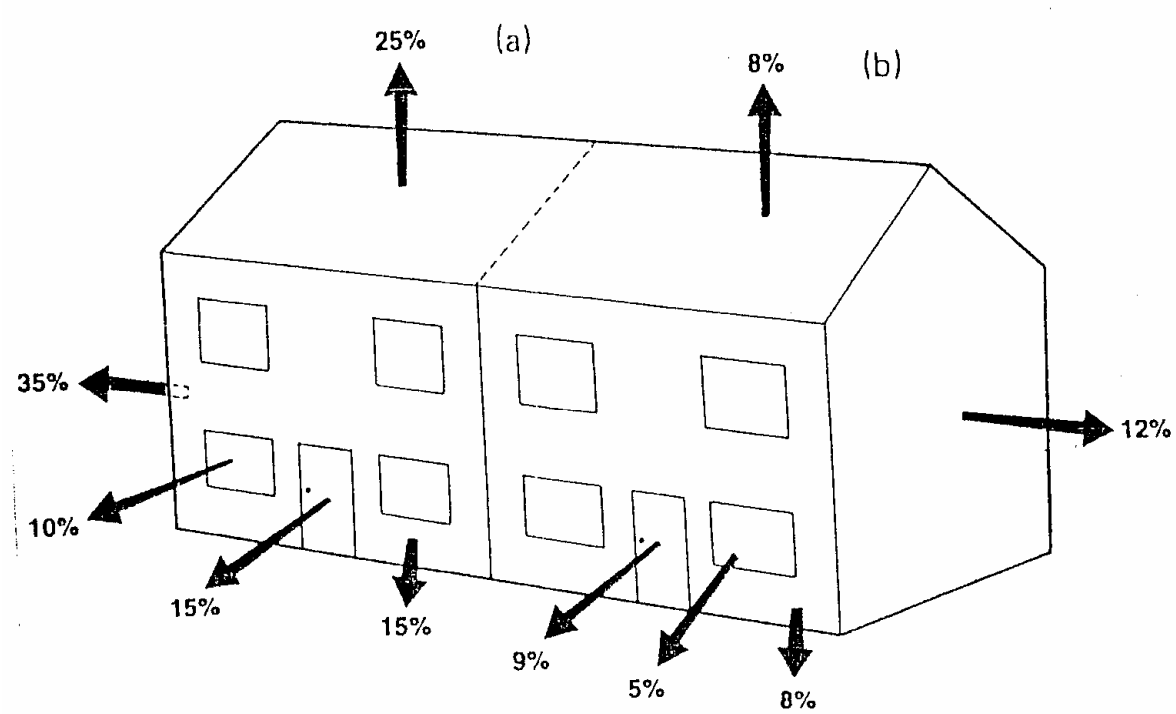
Apart from trapping pocks of air a good insulation material should not be flammable and if used externally or in damp conditions, sufficient precautions should be taken to ensure that the material is kept draught-proof and impervious to moisture.

A good insulation material should have a "low thermal conductivity". This means that it must resist the passage of heat through it.

Porosity is another property that insulation should have. The value of still air as a thermal insulator has already been mentioned. If you could wrap a layer of really still air around a pipe you would do a good job of insulation. This is impossible, of course, but a similar effect can be created by using good insulation material. Most of the modern insulating materials are sponge-like or fibrous in structure, containing millions of tiny air cells which trap air and hold it still.

Good insulation materials should be resistant to vermin and fungal attack. Materials such as glass fibre, mineral wood, foamed plastics and polystyrene are excellent choices and are used extensively throughout the building industry giving excellent results.

In industrial installations thermal insulation is usually fitted by specialist contractors. However, in domestic work this task is often carried out by the plumber. Careful attention should be given to this job and coverage must be complete and uniform if it is to be fully effective. Gaps between sections and skimped thickness must always be avoided.



Heat loss. House (a) before insulation, (b) afterwards

Figure 1. Thermal Insulation

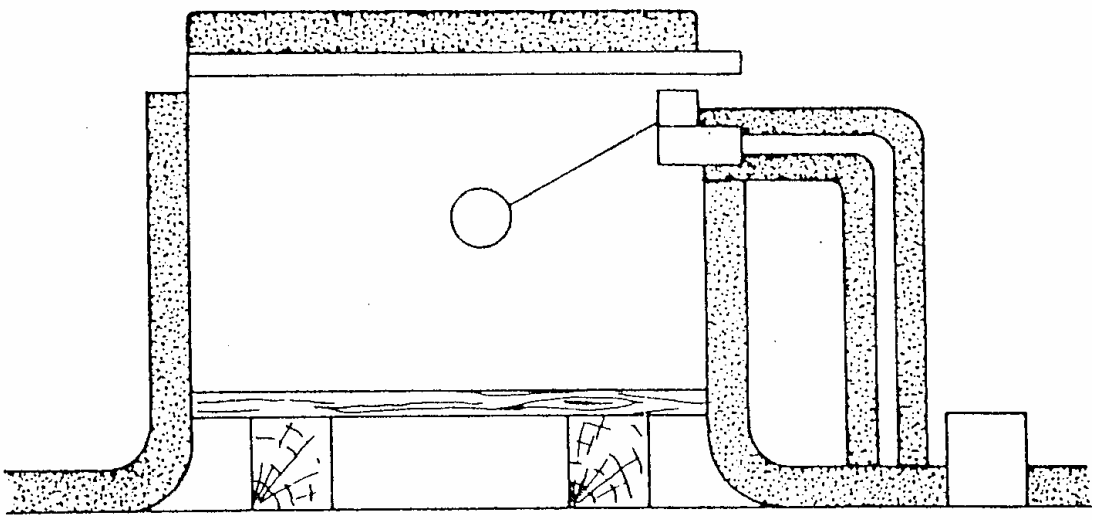
Materials and their Applications

- **Glass Fibre**
  Used in loose fill form to insulate wall cavities and attic spaces. Also available in blanket or roll form.
- **Foam Rubber**
  Available in two metre lengths and used to insulate pipes.
- **Polystyrene**
  Available in sheet form and often used to insulate storage cisterns in roof spaces.

Purpose made insulating jackets in many sizes are also made for hot water storage cylinders. They are made in a wide variety of materials, such as fibre glass, mineral wool, and sheep's wool treated against vermin and in covers ranging from brown calico to washable plastics. The fuel savings effected with one of these jackets can be quite considerable and it is a fact that in most cases the cost of insulation pays for itself in a year or two, an investment well worth making.

Properties of Insulating Materials

1. Low Thermal Conductivity.
2. Incombustible.
3. Moisture Resistant.
4. Porosity.
5. Resistant to Vermin.
6. Resistant to Fungal Attack.
7. Weight.
8. Ease of Application.
9. A Good Surface Finish.



Insulation of cistern, lid and pipes

Figure 2. Insulation of Cistern, Lid, and Pipes

Thermal Insulating Materials For Pipes, Storage Vessels, etc.

Table 2. Insulating types and application

TYPE	APPLICATION
Loose fill (in 'granular or fibrous form) for example 'mica-fil' and 'fibre-glass'.	Infill to preformed cavities; for example, between hot or cold store vessels and or their prepared casings, round pipes and so on in chases or casings.
Flexible (in strip or blanket form).	'Wrap around' covering for curved surfaces such as pipes, more especially for hot store cylinders, and possibly for rectangular store cisterns and hot water tanks.
RIGID (in preformed ready-to-fit sections).	Made specially for pipes. Also in flat sections for hot water tank and cold store cisterns lagging sets.
PLASTIC (that is workable until set).	For covering awkward or irregular shapes such as uncased boiler surfaces, large cylinders and valves.

James Joule

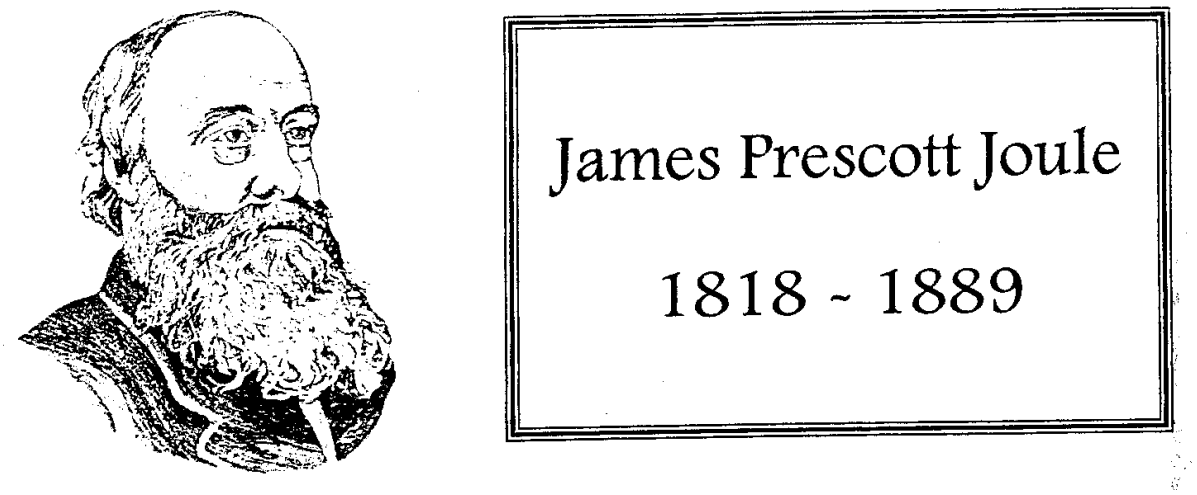


Figure 3. James Prescott Joule

James Prescott Joule's family owned a brewery and, as a young man, he was independently wealthy. He used his money to perform experimental research in several areas. His greatest asset was the ability to think precisely. His work showed his inescapable logic.

All of his research began as an attempt to improve the efficiency of the electric motor so it could replace the steam engine in industrial applications. Joule decided to measure the heat developed by electric currents.

He accurately determined the mechanical equivalent of heat, thus verifying the conservation of energy. But the science community was slow in accepting his results, perhaps because they didn't understand the implications.

Later in life, he worked with William Thomson (Lord Kelvin). Among other things, Joule invented arc welding and the displacement pump. Finally in 1875, his money from conducting experiments ran out. Years of illness followed ending with his death in 1889.

Specific Heat

Specific heat is the amount of heat required to raise 1kg of material 1°C. The specific heat of water is 4.186kJ / kg deg C.

The heat required differs from material to material as indicated by the table below.

Table 3. Specific Heat

MATERIAL	KILOJOULES / KILOGRAM DEG C
Water	4.186
Aluminium	0.887
Cast Iron	0.544
Mild Steel	0.502
Copper	0.385
Lead	0.125

A knowledge of specific heats, and the Heat Energy requirements to raise a given mass of substance through a given rise in temperature is necessary in work on domestic hot water and central heating systems.

One or two examples will show how easy it is to do these calculations.

Example 1

How many kilojoules will be required to raise 75 litres of water from 12°C to 55°C?

Heat energy required = Mass X Sp Heat X Rise in Temperature

(kJ) = (kg) (kJ/kg) (deg C)

= 75 X 4.186 X 43

Answer = 13,499.85 kJ

James Watt

James Watt was born in Greenock, Scotland on January 19th 1736. His father was the local magistrate who also owned a ship building and house building business.

As a child he was quite delicate and sickly and did not attend school. Instead his mother taught him at home. He also spent many hours in his father's workshop making models – usually of cranes and bridges.

At the age of 17 he decided to become a mathematical instrument maker and left home to take up his studies in his area.

By 1763 he had returned to Scotland where he set himself up as an instrument maker in a university. A year later he married his cousin, who bore him 6 children before her death 9 years later.

In 1764, while repairing a model steam engine, he noticed that it wasted a considerable amount of steam. To improve the engine's efficiency, he invented a condensing chamber where the steam could condense to hot water before being re-heated in the engine and turned back to steam again. Although he took out a patent on his condensing chamber, he did not have the necessary finance to build a full scale engine.

In 1766 he became a land surveyor, and spent the next 8 years marking out routes for canals in Scotland.

In 1775 he went into partnership with Mathew Boulton, who was aware of Watt's patent and was keen to put his invention into production. Their partnership was to last 25 years. A year later Watt married again.

The years that followed were to be the most productive in Watt's life. He built many engines mainly for the copper and tin mining industry. In 1782 Watt designed what many people think was his greatest invention – the double acting piston which pushed as well as pulled in parallel motion. Even today, over two hundred years later, this design is still used in the combustion engine of motor cars. Demands for this new engine came pouring in to Watt & Boulton, mainly from paper or flour mills, distilleries, canals and waterworks.

By 1790 Watt had become a very wealthy man accruing over 76,000 from royalties alone. In 1800 he retired but continued with his inventions. One of these was a sculpturing machine which he use to reproduce original busts and figures for his friends.

During the remaining years of his life Watt received many honours from the science community but refused to take the title of Baronetcy from King George III.

James Watt died on August 1819 at the age of 83. Seldom can the achievement of one man be said to have affected the progress and lives of millions of people for hundreds of years. But such is the contribution of Watt. Indeed, many people believe the industrial revolution might never have happened if not for him.

Power

The SI unit of power is the watt.

1,000 watts = 1 kilowatt (KW)

The joule, which is a measure of heat energy = 1 watt per second.

or J = w/s

Similarly kJ = kW / S

The answer in the previous examples give the amount of heat energy required if the substances involved were to be heated through the stated temperature rise in ONE SECOND.

Clearly this is impractical, because in practice the heating up periods would be much longer.

To express the power required in one hour simply divide the answer by 3,600, which is the number of seconds in one hour, or 7,200 for two hours and so on.

In example one, 13,499 kJ of heat energy was required to heat 75 litres of water from 12°C to 55°C in one second.

If this was to be achieved in 1 hour the formula would be:

$$\frac{13{,}499}{3{,}600} = 3.75 \text{ kW}$$

If it was to be achieved in 3 hours the formulas would be:

$$\frac{13{,}499}{3{,}600 \times 3} = \frac{13{,}499}{10{,}800} = 1.25 \text{ kW}$$

Question 150

How many joules are required to raise 45 litres of water from 10°C to 60°C? Show all working (1966 Examination)

Answer

4.2 kJ (kilojoules) will raise 1 litre water 1 degree C

so kJ = 4.2 X 45 X (60°C - 10°C)

= 9450

then Joules = 9.450,000

Note

1 kJ = 1000 J

Question 151

If the domestic hot water load is 9,450,000 joules, calculate the power in kilowatts to perform this duty in one hour. Show all working

Answer

9,450,000 joules = 9450 kJ

1 kilowatt (kW) = 1 kJ/s

or Power (kW) = $\frac{\text{Energy (kJ)}}{\text{Time (s)}}$

= $\frac{\text{9450 kilojoules}}{\text{3600 seconds in 1 hour}}$

= 2.62 kW

If 55 litres of water is to be heated from 8°C to 70°C, in half an hour what size heater would be required.

Power (kW) = $\frac{\text{Mass X Sp Heat X Temperature}}{\text{Time in seconds}}$

= $\frac{\text{55 X 4.186 X 62}}{\text{1800}}$

= $\frac{14274}{1800}$ = 7.93 kW (8 kW)

= $\frac{14274}{3600}$ = 3.96 (4 kW)

Heat Transfer

Some knowledge of the ways in which heat is transferred is necessary to understand fully the working principles of central heating and hot water systems. There are three methods of heat transfer – conduction, convection and radiation. Each of these will be discussed separately.

Conduction

Conduction is the transfer of heat through or along a solid. If you hold a metal rod and heat up one end with a blowtorch the other end would soon become warm. This is because the heat is being transferred through the metal. Heat travels through all materials but the speed at which it travels varies. The faster the heat travels the better the material is at conduction.

Convection

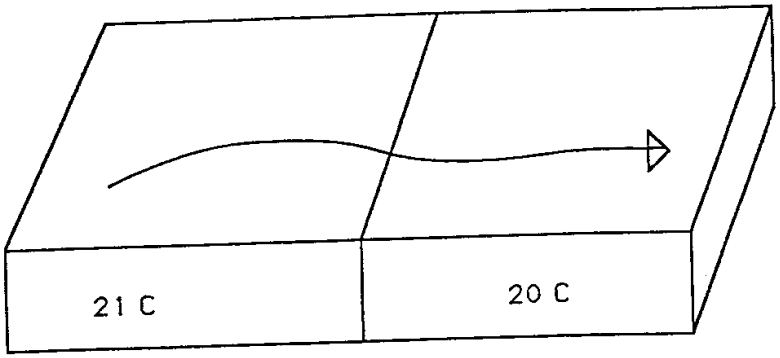
Convection is a form of heat transmission peculiar to liquids and gases. Water and air are typical materials in which it occurs. Very briefly, it may be described as the transmission of heat by the actual movement of particles of liquid or gas. This movement is caused by the change in the particles' weight brought about by a variation in their temperature.

This form of heat transfer explains the movement of heated gases up a fuel pipe or chimney; the movement of water through the circulatory pipework of a hot-water system; and the movement of heated water around the pipework and radiators of a central heating system. It also explains the movement of warmed air around a room.

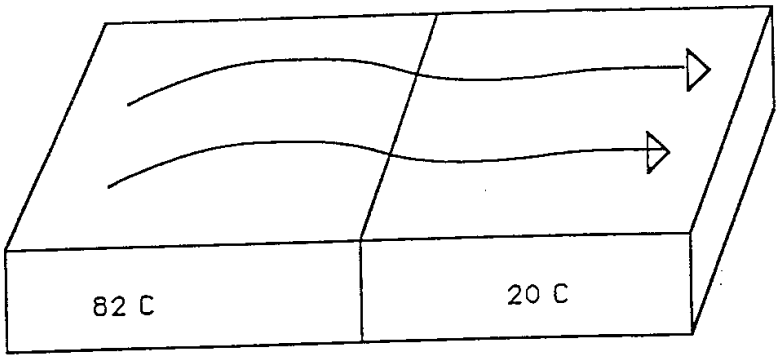
Radiation

Radiation is the transfer of heat energy in the form of straight lines. Radiant heat will pass through the air without appreciably warming it. The heat from the sun is a good example of radiant heat as it travels through millions of miles of space to reach the earth. This heat will also pass through the air without appreciably warming it, but any solid object obstructing the rays will become warmed by them.

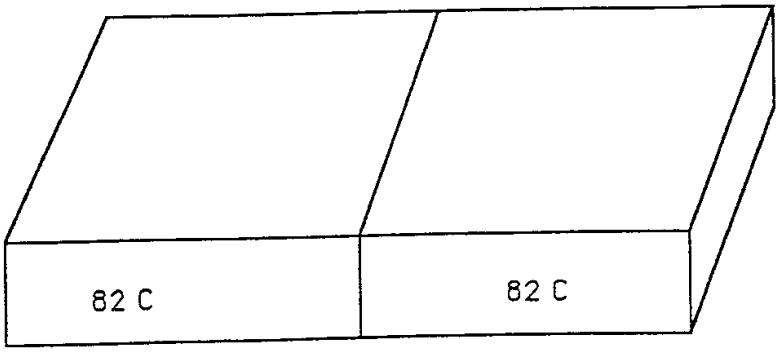
The rate at which a surface absorbs heat depends upon its colour. A blackened surface is an excellent absorber of heat as well as an excellent emitter. Objects that are good absorbers of heat are also good emitters. A surface that is painted silver will not absorb or emit heat readily.



Small temperature difference -*low rate* of heat flow



greater temperature difference -*Higher rate* of heat flow



No temperature difference - *NO* heat flow

Figure 4. Rates of Heat Flow

Conduction

The transference of heat through or along a solid

Thermal Conductivity of Materials

Copper	**GOOD CONDUCTORS**
Aluminium	
Iron	
Glass	
Brick	
Water	
Wood	
Still Air	**BAD CONDUCTORS**

Convection

The transference of heat through a Liquid or a Gas.

Example

Liquid: The water in a hot water cylinder is heated from the boiler below by convection currents.

Gas: Smoke from a fire is carried up the chimney by convection currents.

Radiation

The transference of heat from its source to another solid object through Air or Space.

Some Examples

From the Sun to You.

From a Fire to You.

Methods of Heat Transfer

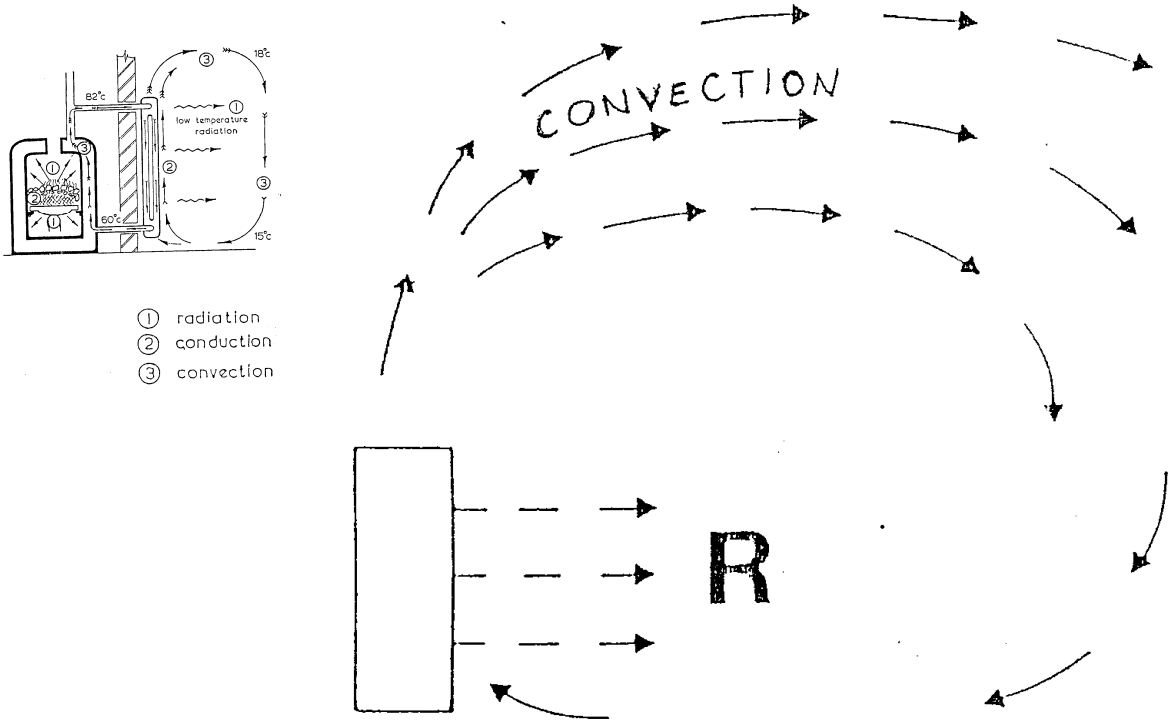


Figure 5. Methods of Heat Transfer

Self Assessment

Specific Heat Questions

Exercise 1

Find the amount of kilojoules to raise the temperature of 150 litres of water from 10°C to 60°C.

Exercise 2

Calculate the quantity of heat in kJ required to raise the temperature of 10 litres of water from 12°C to 50°C.

Exercise 3

Calculate the quantity of heat in kJ given off when 200 litres of water cools from 90°C to 15°C.

Exercise 4

Calculate the quality of heat in Mega Joules required to raise the temperature of 1,500 litres of water from 10°C to 80°C.

Note: 1,000 kilojoules (kJ) = 1 Mega Joule (MJ)

Answers to Exercise 1 to 4 are on the next page.

Exercise 1 – Answer

Heat energy required = Mass X Sp Heat X Rise in Temperature
= 150 X 4.186 X 50
= 31,395 kJ

Exercise 2 – Answer

Heat energy required = Mass X Sp Heat X Rise in Temperature
= 10 X 4.186 X 38
= 1,590 kJ

Exercise 3 – Answer

Heat energy required = Mass X Sp Heat X Rise in Temperature
= 200 X 4.186 X 75
= 62,790 kJ

Exercise 4 – Answer

Heat energy required = Mass X Sp Heat X Rise in Temperature
= 1,500 X 4.186 X 70
= 439,530 kJ
= 439,530 ÷ 1,000 = 439.53 MJ

Specific Heat Questions continued

1. How many kilojoules are required to raise 45 litres of water from 10ºC to 60ºC?
2. Calculate the number of joules required to raise 140 litres of water from 12ºC to 100ºC.
3. Calculate the quantity of heat energy required to raise the temperature of 100 litres of water from 20ºC to 85ºC.
4. If a billet of aluminium 25kg in weight is heated from 9°C to 90°C how many kilojoules of heat energy will be required for this operation? Also show your answer in joules.
5. How many joules are required to raise 1050.5 litres of water from 1°C to 75.75°C?
6. If 560kg of lead is heated through 255°C. How much heat energy would be required?
7. If 1 tonne of copper is heated from 15°C to 555°C, how much heat energy is required? Give your answer in megajoules (MJ).
8. If 1.75 tonnes of water is heated through 45.50C, calculate the heat energy requirements for this operation.
9. A rectangular hot water storage vessel measures 1.25 metres long, 1255mm wide and 555mm high. If it is filled with water, calculate the amount of heat energy required to raise its temperature from 10°C to 87°C.
10. A hot water storage cylinder is 1.25 metres high and 55mm in diameter. How many kilojoules of heat energy are required to raise the water temperature from 13°C to 95°C?

Power Questions

Exercise 1

Calculate the boiler power in kW required to heat 140 litres of water through 55°C in one hour.

Exercise 2

Find the size in kW of an electric water heater capable of heating 45 litres of water from 15°C to 55°C in one hour.

Exercise 3

A gas fired boiler is required to raise 155 litres of water from 12°C to 61°C in three hours. Calculate the size of the boiler.

Answers are on the next page.

Exercise 1 – Answer

$$\frac{\text{Mass X Specific Heat X Temperature Rise}}{\text{Time in seconds}}$$

$$\frac{140 \text{ X } 4.186 \text{ X } 55}{3{,}600}$$

$$= 8.95 \text{ kW}$$

Exercise 2 – Answer

$$\frac{\text{Mass X Specific Heat X temperature Rise}}{\text{Time in seconds}}$$

$$\frac{45 \text{ X } 4.186 \text{ X } 40}{3{,}600}$$

$$= 2.09 \text{ kW}$$

Exercise 3 – Answer

$$\frac{\text{Mass X Specific Heat X Temperature Rise}}{\text{Time in seconds}}$$

$$\frac{155 \text{ X } 4.186 \text{ X } 49}{3{,}600 \text{ X } 3}$$

$$\frac{155 \text{ X } 4.186 \text{ X } 49}{10{,}800}$$

$$= 2.94 \text{ kW}$$

Power Questions continued

1. Calculate the boiler power in kilowatts required to heat 159 litres of water through in one hour.
2. Calculate the power in kW required to raise 45kg of water from 15°C to 70°C in 2 hours.
3. Find the power required to heat 136 litres of water in one hour from 6°C to 60°C.
4. An electric water heater is required to heat 55 litres of water from 9°C to 75°C in 30 minutes.Calculate the size of the heater.
5. A central heating system holds 350 litres of water. If the water in the system is to be heated through 72°C in 35 minutes what size boiler would be required?
6. What size gas boiler would be required to heat 100 litres of water from 6°C to 92°C in 1 hour 15 minutes?
7. A billet of aluminium weighs 45kg. Calculate the power required to heat it through 660°C in 2 hours 20 minutes. Specific heat capacity of aluminium = 0.887.
8. Calculate the power in kW required to heat 140 litres of water from 12°C to 67°C in one hour.

9. One tonne of lead is to be heated from 100°C to 327°C in 18 minutes. Calculate the power required to carry out this operation. Specific heat capacity of lead = 0.125.
10. A hot water storage cylinder has a capacity of 136 litres. Calculate the time in hours it will take to raise the temperature of the water from 10°C to 60°C by means of a 3kW immersion heater.

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