Key plumbing principles covers the science of plumbing and acts as an introduction to the basic materials, theories and concepts that you will encounter and work with on a daily basis. This chapter includes:

- **Plumbing materials**
  - Standards and Regulations
  - materials and their properties

- **Plumbing science**
  - units and measurement
  - properties of water and heat
  - capillary action and siphonage
  - principles of electricity
Plumbing materials

A plumber’s job involves the installation, maintenance and service of the following systems:

- hot and cold water
- central heating
- above-ground drainage
- sheet lead weathering
- rainwater
- below-ground drainage (connection only).

The plumber will work with a range of materials used for system pipework, fittings and components, including:

- copper
- lead
- plastics
- steel
- brass
- ceramics.

It is important that you have a good understanding of the properties of these materials and their suitability for the type of work for which they will be used.

Standards and Regulations in the use of materials

Materials used in everyday plumbing work are required to meet minimum standards of performance. It is also important that there is standardisation for the sizes and dimensions of fittings and components. Imagine what it would be like if you could buy a range of 15 mm fittings that all had a slightly different internal diameter to the external diameter of a 15 mm pipe!

**British Standards**

You may be familiar with the BSI kitemark. This symbol can be used only on materials and equipment that meet the standards of the British Standards Institution (BSI), the organisation for standards in the UK.

The BSI ensures standards of quality and also sets standard dimensions for such items as pipes and fittings.

British Standards all start with the letters BS followed by the number of the standard. For example BS6700 is one of the main standards for the plumbing industry. It’s a specification for design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilages.

We will refer to BS6700 often throughout this book.
**Codes of Practice**

Codes of Practice (CoPs) make recommendations related to good practice. While they are not legal documents, CoPs are widely used by specifiers such as clients and architects.

**The Water Supply (Water Fittings) Regulations 1999**

These Regulations apply only to England and Wales, and have replaced Water Bye-laws. The Regulations are national Regulations made by the Government’s Department of the Environment, Food and Rural Affairs (DEFRA), while the Bye-laws that they replace were made locally and applied in that area, for example, Yorkshire Water, Thames Water, Northwest Water etc.

We will discuss these Regulations in more detail later. We mention them here because they cover materials and substances in contact with water.

**European Standards**

These start with the letters EN followed by the standard number, in the same way as British Standards. Where a product is certified to an EN standard it means the manufacturer will have taken the product through a series of tests that are regularly checked under EC Quality Control Schemes.

**International Standards**

International Standards start with ISO followed by the number, for example ISO9000, which refers to a standard for quality.

**Water Regulations Advisory Scheme (WRAS)**

Formally known as the Water Bye-laws Scheme, the WRAS has been carrying out fitting testing for many years and will continue to advise on Water Regulations in the future. As part of their work they produce a *Fittings and Material Directory*, which lists all approved fittings and is an important guide for all who aim to comply with or enforce The Water Regulations. Products approved by WRAS carry the symbols shown in the illustrations.

**Materials and their properties**

The properties of materials relate to things such as how strong they are, how well they conduct heat or electricity or how flexible they are. We will examine the different properties materials have before looking at common plumbing materials in more detail.

Materials are classified according to a variety of properties and characteristics. Properties can be measured by the way materials react to a variety of influences.
Hardness

Hardness is a measure of a material's resistance to permanent or plastic deformation by scratching or indentation. It is an important property in materials that have to resist wear or abrasion – moving parts in machinery, for example – and frequently needs to be considered along with the strength of materials. Hardness is measured on a scale of 1 to 10 based on the hardness of 10 naturally occurring minerals.

Strength

The strength of a material is the extent to which it can withstand an applied force or load (stress) without breaking. The load is expressed in terms of force per unit area (newtons per square metre, N/m²), and can be in the form of a:

- compression force, as applied to the piers of a bridge or a roof support
- tensile or stretching force, as applied to a guitar string, tow rope or crane cable
- shear force as applied by scissors or when materials are torn (see figure 4.5).

Materials are therefore described as having compressive, tensile or shear strength.
Materials that can withstand a high compression loading include cast iron, stone and brick, hence the common use of these materials for building purposes. However, they are brittle and will break if subjected to high tension. If a building is to be designed to resist tensile strain – in an earthquake-prone area, for example – steel, which has high tensile strength, would be a more suitable building material.

**Elasticity and deformation**

Almost all materials will stretch to some extent when a tensile force is applied to them. The increase in length on loading, compared to the original length of the material, is known as strain. As loading continues, a point is reached when the material will no longer return to its original shape and size on removal of the load, and permanent deformation occurs; the material is said to have exceeded its elastic limit or yield stress, and is suffering plastic deformation – it has been stretched irreversibly. Eventually, at maximum stress, the material reaches its breaking point – its ultimate tensile strength – and failure or fracture rapidly follows. This sequence is illustrated for a variety of materials below.
Mild steel has little elasticity but has the highest yield stress of all the samples; it is fairly ductile, i.e. it has a large range over which it can sustain plastic deformation, and it has the highest ultimate tensile strength.

Cast iron is brittle – it has the least elasticity of the four samples, and no ability to sustain plastic deformation, although its tensile strength is higher than that of concrete.

Copper has little elasticity but is the most ductile of the four samples. It has an ultimate tensile strength less than half that of mild steel.

Concrete has little elasticity, and the lowest tensile strength of the four samples.

Pipework materials
There is no perfect pipework material that is suitable for all applications; different materials perform better in relation to different factors and conditions such as pressure, type of water, cost, bending and jointing method, corrosion resistance, expansion and appearance. There are two basic types of pipework material:

- metal
- plastic.

**Metal**
Metals rarely occur in their pure form. More often they occur as ores, which are compounds of the metal and have unwanted impurities. To produce the required metal, a process of smelting is necessary. Metals commonly used in the manufacturing industry include iron, copper, lead, tin, zinc and aluminium.
The most common method of producing metals is by removing the oxygen from the ore by a process known as reduction.

The industrial production of iron and steel

Iron ore (haematite – iron oxide) is loaded into a blast furnace along with coke and limestone. Hot air is blasted into the base of the furnace and carbon from the coke reacts with oxygen from the air to form carbon monoxide. Carbon monoxide reacts with oxygen from the haematite (iron oxide) to form carbon dioxide and iron. Limestone combines with impurities in the ore (mainly silicates) to form slag. The molten iron is tapped from the base of the furnace and solidifies into billets known as ‘pigs’ – hence the term ‘pig iron’.

At this point the iron is impure. To form steel, which is an alloy of iron and carbon, it is necessary to reheat the iron to drive off the impurities, and then to add up to 1.5 per cent of carbon. Other metals can give the steel particular properties – the addition of chromium will produce stainless steel, for example. Alloys can be produced either by mixing different metals or by mixing metals with non-metallic elements, such as carbon.

Metals commonly used in the plumbing industry

Alloys

An alloy is a type of metal made from two or more other metals.

<table>
<thead>
<tr>
<th>Some commonly used alloys</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>Copper and zinc</td>
</tr>
<tr>
<td></td>
<td>Used for electrical contacts and corrosion-resistant fixings (screws, bolts etc.) and pipe fittings</td>
</tr>
<tr>
<td>Bronze</td>
<td>Copper and tin</td>
</tr>
<tr>
<td></td>
<td>Used for decorative or artistic purposes and corrosion-resistant pumps</td>
</tr>
<tr>
<td>Solder</td>
<td>Lead and tin, tin and copper</td>
</tr>
<tr>
<td></td>
<td>Used for electrical connections Used as a jointing material</td>
</tr>
<tr>
<td>Duralumin</td>
<td>Aluminium, magnesium, copper and manganese</td>
</tr>
<tr>
<td></td>
<td>Used in aircraft production</td>
</tr>
<tr>
<td>Gunmetal</td>
<td>Copper, tin and zinc</td>
</tr>
<tr>
<td></td>
<td>Used for underground corrosion-resistant fittings</td>
</tr>
</tbody>
</table>

Figure 4.7 Alloys
Copper

Copper tube has been used as a material for pipework for over 100 years. It is a malleable and ductile material which you will use frequently throughout your plumbing career. There are four main types of copper tube used in the plumbing industry:

- **R250 half hard** (Table X) is the copper tube most commonly used above ground for most plumbing and heating installations. It is fairly rigid and will usually need to be bent using a bending machine.

- **R290 hard** (Table Z) is a more rigid copper tube. Its increased hardness means that the walls of the pipe don’t need to be as thick, so the internal diameter of the tube or bore can be wider than that of the R250 type of tube; the tube cannot easily be bent.

- **R220 soft coils** (Table W) is a copper tube used for micro-bore pipework, typically on central heating systems.

- **R220 soft coils** (Table Y) is a softer copper tube which is most commonly used underground for the supply of water.

The outside diameter is the same for each type of pipe, but there are differences in the internal bore due to the variations in the pipe wall thickness. R250 half hard lengths and R220 soft coils are available with a plastic coating. This type of tube can be used in potentially corrosive environments as the plastic coating protects the copper from corroding.

Steel

**1 Low carbon steel**

Low carbon steel (LCS) or mild steel is an alloy made from iron and carbon. It is frequently used in the plumbing and heating industry and is manufactured to BS1387. The tube comes in three grades of weight: light, medium and heavy. As with copper tube, the outer diameter is similar, but the internal bore and wall thickness varies.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Wall thickness</th>
<th>Bore</th>
<th>Colour code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light LCS tube</td>
<td>Thin walls</td>
<td>Larger bore</td>
<td>brown</td>
</tr>
<tr>
<td>Medium LCS tube</td>
<td>Medium walls</td>
<td>Medium bore</td>
<td>blue</td>
</tr>
<tr>
<td>Heavy LCS tube</td>
<td>Thick walls</td>
<td>Smaller bore</td>
<td>red</td>
</tr>
</tbody>
</table>

Light LCS is usually used for conduit. As a plumber, you will come across it on occasion, but you will work far more frequently with medium and heavy LCS. Medium and heavy LCS tubes are used for water-supply services, as they are capable of sustaining the pressures involved. When LCS tube is used for domestic water supplies, it must be galvanised.
2 Stainless steel

Stainless steel is the most recently developed pipe material used for water services. It is a complex alloy made up of a number of elements, as shown in the table.

The tube has a shiny appearance due to the chromium and nickel content and is protected from corrosion by a microscopic layer of chromium oxide, which quickly forms around the metal and prevents further oxidisation. This tube is produced with bores of 6mm to 35mm and has an average wall thickness of 0.7 mm. The outside diameters are similar to those of R250 copper tubes.

Stainless steel is commonly used where exposed pipework and sanitary appliances are needed, as it is a very strong metal (much stronger than copper) and is easy to clean. Stainless steel is also commonly used for:

- sink units
- urinal units and supply pipework
- commercial kitchen discharge pipework.

<table>
<thead>
<tr>
<th>Element</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td>18</td>
</tr>
<tr>
<td>Nickel</td>
<td>10</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.25</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.6</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.08</td>
</tr>
<tr>
<td>Iron</td>
<td>70 (approx)</td>
</tr>
<tr>
<td>Sulphur</td>
<td>trace</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>trace</td>
</tr>
</tbody>
</table>

**Figure 4.8 Composition of stainless steel**

Did you know?

The main use of lead in plumbing today is the weathering of buildings.

Lead

Lead is a very heavy, valuable metal which requires specialist handling. It is one of the oldest known metals and is highly ductile, malleable and corrosion-resistant. During your career, you will come into contact with lead in sheet form, which is used for weatherings on buildings. It was used in the past for mains, sanitary and rainwater pipework, but this practice stopped in 1986 with the Model Water Bye-laws, due to the possibility of lead poisoning. It has now been superseded by the use of such materials as plastics.

Cast iron

Cast iron is an alloy of iron and is approximately 3 per cent carbon. It is very heavy but quite brittle, although it can stand up to years of wear and tear. It has been used in the plumbing industry for many years for above- and below-ground sanitary pipework. You will probably come into contact with it on older properties and new industrial/commercial properties.

Plastics commonly used in the plumbing industry

Plastics (polymers) are products of the oil industry.

Ethene, a product of crude oil, is a building block of plastics. It is made up of carbon, hydrogen and oxygen atoms. Molecules of ethene (monomers) can link together into long chains (polymers) to make polythene (poly + ethene) when they are heated under pressure with a catalyst. If the ethene monomer is modified by the replacement of one of the hydrogen atoms with another atom or molecule, further monomers result, producing other plastics. This process is called polymerisation.
There are two main categories of plastics used in the plumbing industry:

- thermosetting plastics
- thermoplastics.

**Thermosetting plastics** are generally used for mouldings. They soften when first heated which enables them to be moulded, then they set hard and their shape is fixed; it cannot be altered by further heating. WC cisterns can be made of thermosetting plastic.

**Thermoplastics** can be resoftened by heating them. Most of the pipework materials you will come into contact with fall into this category. The different types of thermoplastics share many of the same characteristics:

- strong resistance to acids and alkalis
- low specific heat (that is, they do not absorb as much heat as metallic materials)
- poor conductors of heat
- affected by sunlight (this leads to the plastic becoming brittle, also called degradation).

<table>
<thead>
<tr>
<th>Material</th>
<th>Max usage Temp °C</th>
<th>Main plumbing industry purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polythene – low density</td>
<td>80</td>
<td>Flexible pipe material used to channel chemical waste</td>
</tr>
<tr>
<td>Polythene – high density</td>
<td>104</td>
<td>More rigid, again used for chemical or laboratory waste</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>120</td>
<td>Tough plastic with a relatively high melting temperature, can be used to channel boiling water for short periods of time</td>
</tr>
<tr>
<td>Polyvinyl Chloride (PVC)</td>
<td>40–65</td>
<td>One of the most common pipework materials, used for discharge and drainage pipework</td>
</tr>
<tr>
<td>Unplasticised Polyvinyl Chloride (UPVC)</td>
<td>65</td>
<td>More rigid than PVC, used for cold water supply pipework</td>
</tr>
<tr>
<td>Acrylonitrile Butadiene Styrene</td>
<td>90</td>
<td>Able to withstand higher temperatures than PVC, used for small-diameter waste, discharge and overflow pipework</td>
</tr>
</tbody>
</table>

*Figure 4.9 Types of thermoplastic*
Other materials relevant to the plumbing industry

Ceramics include those products that are made by baking or firing mixtures of clay, sand and other minerals: bricks, tiles, earthenware, pottery and china. The kiln firing process fuses together the individual ingredients of the product into a tough matrix. The main constituent of all these products is the element silicon (Si) – clay is aluminium silicate; sand is silicon dioxide (silica). Ceramics also includes those products made by ‘curing’ mixtures of sand, gravel and water with a setting agent (usually cement) to form concrete, or mortar, using a sand, water and cement mixture.

Glass is also produced by the melting together of minerals. The basic ingredients are sand (silicon dioxide), calcium carbonate (CaCO₃) and sodium carbonate (NaCO₃). The resulting mixture of calcium and sodium silicates cools to form glass. Again, additives can change the character of the product: boron will produce heat-resistant ‘Pyrex’– type glass, and lead will produce hard ‘crystal’ glass.

Knowledge check 1

1. What is the key quality standards sign used by the British Standards Institution known as?
2. What is the ability of a material to be stretched then to resume its normal shape known as?
3. What colour code is medium duty low carbon steel tube?
4. What is the most common type of copper tube used in plumbing systems?
5. What type of plastics when formed or moulded can be re-softened by heating?

Plumbing science

Units of measurement

In the UK there are two principle systems of measurement: metric and imperial. The units of measurement you will come across in the plumbing trade will usually be metric (metres, kilograms etc.), although you may hear reference to imperial measurements such as feet, inches, pounds and ounces.

The standard international measurement system, commonly known as SI units, predominantly uses metric measurements. The table overleaf gives an indication of the basic SI units and appropriate metric and imperial equivalents:
<table>
<thead>
<tr>
<th>Attribute</th>
<th>SI unit</th>
<th>Abbreviation</th>
<th>Imperial unit(s)</th>
<th>Imperial abbreviation</th>
<th>Conversion</th>
</tr>
</thead>
</table>
| Length          | metre         | m            | inches, feet, miles | ins, ft.              | 1 in = 2.54 cm  
1 ft = 0.3048 m                          |
| Mass            | kilogram      | kg           | ounces, pound     | ozs., lb.             | 1 oz = 28.35 g  
1 lb = 0.4536 kg                          |
| Time            | second        | s            | 60 s = 1 min  
60 mins = 1 hour |                                       |
| Electric current| ampere        | A            |                   |                       |                                     |
| Temperature     | kelvin        | K            | degrees          | degrees, Fahrenheit   | °C = °F – 32                           |
| Angle           | radian        | rad          | 1 rad = 57 degrees (°)  
1 degree = 60 mins (°)  
1 min = 60 seconds (°) |                       |                                     |
| Area            | square metres | m²           | 1 hectare = 10,000 m² | square inches, acre   |                                     |
| Volume          | cubic metres  | m³           | cc = cm³         | cubic inches          |                                     |
| Capacity        | litre         | l            | 1 ml = 1 cc or cm³ | pints, gallons        | 1 pint = 0.5663 l                     |
| Speed           | metres per second | m/s       | miles per hour  
feet per second | mph, fps |                                     |
| Acceleration    | metres per second per second | m/s² or ms² |                   |                       |                                     |
| Force           | newtons       | N            | pounds per square inch | lb/in² |                                     |

**Figure 4.10 SI Units**

**FAQ**

*Why do I need to know all this stuff about science?*

This all affects the way in which plumbing systems are chosen, installed and work, so it is essential to have a good awareness of the key science principles.
Mass and weight

In its simplest terms, mass is the amount of matter in an object and is measured in grams (or for larger weights, kilograms). Under normal circumstances and as long as it remains intact, an object should always maintain the same mass. For example, a nail will maintain the same mass whether it is:

- on a workbench
- on the moon.

But will it weigh the same?

The weight of an object is the force exerted by its mass as a result of acceleration due to gravity. On earth all objects are being accelerated towards the centre of the planet due to the earth's gravitational pull. The ‘pull’ exerted by gravity on the mass of an object is known as its weight, which is measured in newtons. A newton is a unit of measurement equivalent to 1 metre per second (m/s) per 1 kg of mass.

Therefore: \[ \text{weight (in newtons)} = \text{mass} \times \text{acceleration due to gravity} \]

To give an example of the difference between mass and weight we need to go to the moon:

On earth

The gravitational pull of the earth is 9.8 m/s²

Therefore an object with a mass of 1 kg on earth would weigh 9.8 newtons.

On the moon

The gravitational pull of the moon is approximately 1.633 m/s²

Therefore an object with a mass of 1 kg on the moon would weigh 1.633 newtons.

The mass of the object does not change whether it is on the earth or the moon, but the weight of an object changes considerably because of the reduced gravitational pull of the moon.

Density

Density of solids

Solid materials, which have the same size and shape, can frequently have a completely different mass. This relative lightness or heaviness is referred to as density. In practical terms the density of an object or material is a measure of its mass (grams) compared to its volume (cm³) and can be worked out using the following formula:

\[ \text{density} = \frac{\text{mass}}{\text{volume}} \]

The densities of all common materials you'll come into contact with during your plumbing career are known. Lists of these comparative densities can be found in a variety of reference sources.
Density of liquids

Like solids, liquids and gases also have differing densities depending on the number of molecules that are present within a particular volume of the substance. As a plumber it will be important to understand the density of water and that this changes with the water’s temperature. Water is less dense when it is heated:

- 1 m³ of water at 4ºC has a mass of 1,000 kg
- 1 m³ of water at 82ºC has a mass of 967 kg.

This is because heat energy excites the molecules so that they move further apart and the water becomes less dense.

Relative density

Relative density (also occasionally known as specific gravity) is an effective way of measuring the density of a substance or object by comparing its weight per volume to an equal volume of water. Water has a relative density (specific gravity) of 1.0. For example:

- 1 m³ of water has a mass of 1,000 kg
- 1 m³ of mild steel has a mass of 7,700 kg.

The mild steel is 7.7 times heavier than water and therefore has a relative density of 7.7.

Density of gases

In the same way that water is said to have a relative density of 1.0 to enable comparisons of relative density for solids and liquids, air has a relative density of 1.0 to enable comparisons between gases which are classified by whether they are lighter or heavier than air. Think about helium-filled balloons for instance – do you think helium is lighter or heavier than air?

Pressure

Pressure is defined as force applied per unit area and is measured in newtons per square metre (N/m²), a unit also known as a Pascal (Pa).

You will probably come across other terms used to identify pressure such as the ‘bar’ or ‘pounds per square inch’ (lbs/in²). These can be expressed as:

- 1 bar = 100,000 N/m²
- 1 lbs/in² = 6,894 N/m²

Pressure is therefore a measurement of a concentration of force. The effect of a concentration of pressure can be seen if water flowing through a pipe is forced through a smaller gap by reducing the diameter of the pipe. (Think about a hosepipe, and how to maximise the force of the jet of water.)
Pressure can also be lowered by ‘spreading’ the applied force over a wider area. For example, rescue teams will often spread themselves over fragile roofs or on thin ice to minimise the chance of the surface giving way.

As a plumber you will need to have a basic understanding of the effects pressure has on the pipes and fittings you will install. The internal pressure in a pipe or vessel will be affected by what is being transported (water or gas), and must be considered when deciding which material and which size of pipe or vessel should be used.

**Pressure in liquids**

The pressure in a liquid increases with depth, so in a plumbing system water pressure is higher at the lowest points of the system and lower at the highest points of the system.

Water is measured using a number of different units –

- metres head (m)
- the pascal (Pa), also the Newton, per metre squared (N/m²)
- bar pressure (bar).

![](image)

**Figure 4.11** The effects of pressure in solids and liquids

1 metre head = approx. 10,000 Pa (10kPa) = approx. 0.1 bar

An understanding of the **pressure head** created in systems is important in determining component sizes, for example pipe sizes and confirming that components will be able to withstand the pressure of water created within them.
Intensity of pressure and total pressure

Intensity of pressure is the force created (kPa) by the weight of a given mass of water acting on a unit area (m²).

Total pressure is the intensity of pressure multiplied by the area acted on.

Example 1:
Calculate the intensity of pressure and total pressure acting on the base of the lower cistern.

\[
\text{Intensity of pressure} = \text{head} \times 9.81 \text{ kPa} \\
= 3 \times 9.81 \\
= 29.43 \text{ kPa/m}^2 \text{ or approximately 0.3 bar pressure.}
\]

An alternative method of calculating this is to multiply the head \( \times 0.1 \text{ bar} \) (0.1 bar = 1m head) = \( 3 \times 0.1 \text{ bar} = 0.3 \text{ bar pressure.} \)

\[
\text{Total pressure} = \text{intensity of pressure} \times \text{area of base} \\
= 29.43 \times (2 \times 1.5) \\
= 88.29 \text{ kPa}
\]

Example 2:
If a tap is sited 5 metres below a plumbing cistern feeding it, the pressure created at the tap will be

\[
5.0 \text{ metres head} \times 0.1 \text{ bar pressure} = 0.5 \text{ bar}
\]

Atmospheric pressure

The pressure exerted by the weight of the earth's atmosphere pressing down on the ground varies depending on height above sea level. The pressure at the top of Mount Everest is not as high as the pressure in the bottom of a valley below sea level (such as the Great Rift Valley in Africa). The pressure at sea level is 101,325 N/m² (approximately 1 bar).

Plumbers must be aware of the effects of atmospheric pressure to ensure that they avoid creating 'negative' pressure or vacuums within pipework systems. Negative pressure can damage components.

The siphon

The siphon uses atmospheric pressure to operate. A quantity of water is forced through a short leg of pipe (column A) and over the crown of the siphon. The weight of water in column B longer leg (under positive pressure) is greater than in column A. The water continues to flow owing to the difference in the weight of water with positive (atmospheric pressure in column B) and negative (suction pressure) in column A.
The principle of the siphon is used to good effect in plumbing applications. Examples include:

- siphonic WC pan
- WC flushing siphon
- siphoning the contents of a hot water storage cylinder using a hose pipe.

**Properties of water**

Water is a chemical compound of two gases: hydrogen and oxygen (H₂O). It is formed when hydrogen gas is burned.

One of the most important properties of water is its solvent power. It can dissolve numerous gases and solids to form solutions. The purest natural water is rainwater collected in the open countryside. It contains dissolved gases such as nitrogen, oxygen and carbon dioxide, but this does not affect its potability (suitability for drinking).

Water may be classified as having varying degrees of hardness or softness.
**Hard water**

Water is classified as hard if it is difficult to obtain a lather with soap. Hard water is created when it falls on ground containing calcium carbonates or sulphates (chalk, limestone and gypsum), which it has dissolved and taken into solution.

**Soft water**

Water is said to be soft when it is easy to produce a lather with soap. This is because of the absence of dissolved salts such as calcium carbonates and calcium sulphates. Soft water can cause corrosion in plumbing components because it is relatively acidic.

**Water hardness**

Hard water is undesirable in domestic installations as it can produce limescale in pipework, heating equipment and sanitary appliances. This can lead to high maintenance costs. Hard water also requires the use of much more soap and detergent for washing purposes, as the ‘hardness’ makes it far more difficult to produce a lather.

Water hardness can be described as temporary or permanent.

- Permanent hardness is a result of ions of nitrates and sulphates. It makes it difficult to form a lather and cannot be removed by boiling.
- Temporary hardness is a result of the amount of carbonate ions in the water. Temporary hardness can be removed from the water by boiling, which results in the carbonate being precipitated out as limescale. This hard scale accumulates inside boilers and circulating pipes, restricting the flow of water, reducing the efficiency of appliances and components and ultimately causing damage and system failure.

**pH value and corrosion**

The term pH value refers to the level of acidity or alkalinity of a substance. As a plumber, you will need to be particularly aware of the potential effects the acidity or alkalinity of water can have upon materials, appliances and components.

Both acids and alkalis can cause corrosion and thereby damage plumbing materials; metals are at particular risk.

**FAQ**

Why is it more difficult to obtain a good lather in different parts of the country?

This is because the hardness of water varies in different parts of the country. The harder the water, the more difficult it is to obtain a lather. Is the water where you live soft or hard?
All water has a ‘pH value’. Rainwater is naturally slightly acidic, due to small amounts of carbon dioxide and sulphur dioxide in the atmosphere being dissolved into it, forming very weak carbonic and sulphuric acids. The pH value of groundwater is affected by the different rock types it passes though. For instance, water with dissolved carbonate from chalk or limestone is alkali.

The pH scale of acidity

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<td>Acid</td>
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The main causes of corrosion are:

- the effects of air
- the effects of water
- the direct effects of acids, alkalis and chemicals, e.g. from environmental sources
- electrolytic action.

Atmospheric corrosion

Pure air and pure water have little corrosive effect, but together in the form of moist air (oxygen + water vapour) they can attack ferrous metals such as steel and iron very quickly to form iron oxide or rust. The corrosive effects of rusting can completely destroy metal.

Various other gases (carbon dioxide, sulphur dioxide, sulphur trioxide), which are present in our atmosphere, also increase the corrosive effect air can have on particular metals, especially iron, steel and zinc. These gases tend to be more abundant in industrial areas as they are often waste products from various industrial processes.

Coastal areas also suffer from increased atmospheric corrosion due to the amount of sodium chloride (salt) from the sea which becomes dissolved into the local atmosphere.

Non-ferrous metals, such as copper, aluminium and lead, have significant protection against atmospheric corrosion. Protective barriers (usually sulphates) form on these metals to prevent further corrosion. This protection is also known as patina.

Corrosion by water

Ferrous metals are again particularly vulnerable to the effects of corrosion caused by water. These are commonly seen in central heating systems as black ferrous oxide and red rust build-up in radiators. A by-product of this process is hydrogen gas, which accumulates in the radiator, leading to the need to be ‘bled’. See Chapter 9.
In certain areas of highly acidic water, copper may become slightly discoloured. This won’t affect the quality or safety of the drinking water. However, in areas where lead pipework is still in use, if the water is very soft (acidic) there is a risk of it dissolving minute quantities of lead, thus contaminating the water – with potentially toxic effects, especially for children.

**Corrosive effects of building materials and underground conditions**

Some types of wood (such as oak) have a corrosive effect on lead, and latex cement and foamed concrete will adversely affect copper. Certain types of soil can damage underground pipework. Heavy clay soils may contain sulphates which can corrode lead, steel and copper. Ground containing ash and cinders is also very corrosive as they are strongly alkaline; if pipes are to be laid in such ground they should be wrapped in protective material.

**Electrolytic action and corrosion**

Electrolytic action describes a flow of electrically charged ions from an anode to a cathode through a medium known as the electrolyte (usually water) as shown in figure 4.15 on page XXX.

Electrolytic corrosion takes place when the process of electrolysis leads to the destruction of the anode. The length of time it takes for the anode to be destroyed will depend on:

- the properties of the water that acts as the electrolyte: if the water is hot or acidic the rate of corrosion will be increased
- the position of the metals that make up the anode and the cathode in the electromotive series.
The electromotive series

The list below shows the common elements used in the plumbing industry; the order in which they appear indicates their electromotive properties.

- Copper
- Tin
- Lead
- Nickel
- Cadmium
- Iron
- Chromium
- Zinc
- Aluminium
- Magnesium

![Figure 4.15 The process of electrolysis](image)

The elements higher up in the list will destroy those lower down through the process of electrolytic corrosion. The further apart in the list the materials appear, the faster the corrosion will take place. For example, copper will destroy magnesium at a faster rate than lead will destroy chromium.

As a plumber you will need to be aware of the potential for electrolytic corrosion when two very dissimilar metals such as a galvanised tube and a copper fitting are in direct metallic contact. If these metallic elements are then surrounded by water (of a certain type) or damp ground, a basic electrical cell is effectively created and electrolytic corrosion can take place.

![Figure 4.16 Example of possible electrolytic corrosion in pipework systems](image)
**Behaviour of water at different temperatures**

Matter, such as water, can exist in what is known as three different states:

- Solid (ice) → Liquid → Gas (steam)

In moving from one state to another a **change of state** must take place, during which the water is either cooled or heated.

![Change of state diagram – atmospheric pressure](image)

**Figure 4.17** Change of state diagram – atmospheric pressure

Referring to the diagram showing the behaviour of water at atmospheric pressure, in its natural state between 0°C to 100°C water is in the form of a **liquid**. When heated during its liquid state the water will increase in volume by up to 4% (it will expand). Using the information previously covered on density, for the same mass of water when heated an increase in volume will take place, the result will be a decrease in density, and i.e. it will become lighter. Water is at its maximum density at a temperature of 4°C.

The **freezing point** of water is 0°C and at temperatures of 0°C and below water changes state to **ice**.

On cooling below 0°C the water turns to ice and expands. This expansion or increase in volume in an enclosed space can result in components rupturing, for example a burst pipe.

The **boiling point** of water is 100°C, at temperatures of 100°C and above water under atmospheric conditions changes state to **steam**.

When changing to steam a rapid increase in volume takes place (up to 1,600 times). Its original volume when in liquid form can have explosive effects if the water is stored in an enclosed space.
Water stored at above atmospheric pressure

It is also worth noting that the pressure at which the water is stored is also linked to water temperature and water volume. So if water is stored in an enclosed space, such as a storage cylinder (a constant volume), at above atmospheric pressure, when water is heated, the temperature at which it boils will rise above 100°C.

As an example the boiling point of water at 1 bar pressure is approximately 120°C. So why is water stored at above atmospheric pressure and above temperatures of 100°C so dangerous if it is not boiling?

Quite simply if someone were to open a tap, or a storage cylinder ruptured, then the water pressure would rapidly reduce to atmospheric pressure, almost instantly causing the water to boil. This would result in a change of state from water to steam, causing a rapid increase in volume of the gas (up to 1,600 times its original volume) which the vessel or system more than likely could not withstand so would rupture, like a bomb in fact!

Properties of heat

*Difference between heat and temperature*

The main difference between heat and temperature is that heat is recognised as a unit of energy, measured in joules (J).

- temperature is the degree of hotness of a substance
- heat is the amount of heat energy (J) that is contained within a substance.

For example, imagine an intensely heated short length of wire and a bucket of hot water:

The wire has a temperature of 350°C

The water has a temperature of 70°C

The wire is far hotter, but actually contains less heat energy.

*Measuring temperature*

The SI unit of temperature measurement is the degree kelvin, but the unit you’ll deal with most frequently is degrees Celsius (or centigrade), written as °C.

Temperature is measured using thermometers. There are many types, but the most common depend upon the expansion of either a liquid or a bi-metallic strip.

The two most common liquids used in thermometers are alcohol and mercury. These liquids are used because they expand at a uniform rate when exposed to heat.

Bi-metallic strips work on the principle of thermal expansion and contraction (covered in more detail later) and the fact that some metals expand and contract at a faster rate than others. Bi-metallic strips are frequently used in thermostats, where they will bend (see illustration) when a particular temperature is reached. This process will break an electrical circuit and turn off the heating.
Simple temperature measuring devices

Simple thermometer

In its simplest form a thermometer is a glass tube containing a substance such as alcohol or mercury that expands or contracts at a constant rate in response to temperature changes. A metal bulb is sited at one end of the thermometer for taking the temperature or immersing in water. This type of thermometer can be used for checking the water temperature at taps or outlets.

Clip-on thermometer

The clip-on, clamp-on or often called pipe thermometer, is used for taking surface temperatures of pipes. The thermometer uses the bi-metallic strip principle as its method of operation. This type of thermometer can be used when commissioning central heating systems where two clip-on thermometers are used to measure the temperature of both the flow and return pipework in order to establish the correct water flow through each.

Differential digital thermometer

This device comes with a range of attachments that can be used to measure simple water temperatures by immersing a probe in the water stream, or by connecting a device known as a thermistor to pipe surfaces. When commissioning central heating systems two thermistors are attached by means of a strap to the flow and return pipework and the digital thermometer can measure the temperature of each pipe and the difference in temperature between each pipe.

**Figure 4.18** A bi-metallic strip. The brass expands more than the iron on heating, thus bending the strip.

**Figure 4.19** Simple thermometer

**Figure 4.20** Differential digital thermometer

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**Definition**

Thermistor – a device that changes electrical resistance in response to a temperature change.
**Specific heat capacity**

To size various plumbing components, such as boilers and radiators, plumbers need to be able to understand the concept of heat. Heat is different from temperature. Heat is a measure of the amount of energy in a substance. The standard unit of measurement of heat is the joule.

In order to work out the amount of heat required to heat a substance we need to be able to measure the amount of heat required over time or the power required. This is a measure of the energy divided by the time/time taken to heat the substance measured in kW/hrs.

\[
1 \text{ kW/hr} = \frac{1000 \text{ joules}}{1 \text{ second}} \times 3,600 \text{ seconds (number of seconds in one minute)}
\]

In order to be able to undertake plumbing calculations involving heat we usually need to be able to work out the amount of heat required to raise a quantity of a substance such as water from one particular temperature to another. To do this we need to know the substance's **specific heat capacity**.

The specific heat capacity of a substance is the amount of heat required to raise 1kg of a substance by 1°C. The specific heat capacity of water is 4.186 kJ/kg/°C.

**Example:**

Calculate the heat energy and power required to raise 200 litres of water from 10°C to 60°C (assume 1 litre of water to roughly weighs 1kg).

Heat energy = 200 litres \times 4.186 kJ/kg/°C \times (60°C – 10°C)  
= 41,860kJ

Power required to heat the water in 1 hour (assuming no energy is lost)  
\[
= \frac{41,860}{3600} = 11.63\text{kW}
\]

The power calculation is essential in determining factors such as the amount of energy required to re-heat a hot water storage cylinder against a specific period of time. For example had the water required to be reheated in a 30 minute time period in our example power calculation, then the power required would be double as the re-heating period has been halved (from 3,600 seconds to 1,800 seconds).

\[
= \frac{41,860}{1800} = 23.26\text{kW}
\]