Chemistry in archeology

Curiosity about natural substances has led to some of the earliest discoveries in isolating pure chemical materials from nature. Humans discovered that they could extract the colours from flowers and some insects. These dyes and pigments were used to dye cloth, create pictures and make cosmetics. But only in the last century have chemists learnt the detailed chemical structures of these natural colours.

figure ar.1 Throughout the ages, the ancient civilisations were often defined by the tools and materials they used.

As communities became established, people discovered that particular substances could be used for special purposes. Yeasts were used to prepare beer and wine, and foods were preserved by salting and smoking. Glass, first used as a glaze for beads or pottery, was being blown into shapes by 100 BC. From earliest times humans have been making new substances by performing chemical transformations.

* Section 6.1 **Types of chemical reactions** describes different types of chemical reactions (page 328).

Most of the early 'discoveries' were made by accident. After the early period of random discovery, humans began heating substances together intentionally to see what would happen. In fact, much of the rise of civilisations has involved humans creating new substances by transforming natural materials to better meet their needs. The development of metallurgy, ceramics, glass and mortar, to name a few, has shaped the way the human civilisations have developed over the last few thousands of years.

Ceramics

The word ceramics is derived from the Greek word 'keramikos', meaning 'having to do with pottery'. The term covers inorganic non-metallic materials, whose formation is due to the action of heat. Ceramic materials are usually ionic or covalently bonded. A material held together by either type of bond will tend to fracture, which results in poor toughness in these materials. Additionally, because these materials tend to be porous, the pores and other microscopic imperfections act as stress concentrators, further reducing their tensile strength. The primary clay comprises an average 98% of kaolinite ($Al_2O_32SiO_22H_2O$), which has a regular crystal structure that resists weathering. Its particle size is comparatively large so it is not very plastic.

figure ar.2 The potter's wheel being used to produce a whole range of wares.

Section 2.6 **Patterns in properties** refers to properties based on type of bonding (page 256).

Until recently, most important ceramic materials were the traditional clays, made into pottery, bricks and tiles, along with cements and glass.

The history of ceramics began about 30 000 years ago during the Paleolithic Age (the Stone Age) when our ancestors discovered that by baking clay figures in bonfires or simple kilns the soft crumbly clay could be made stronger and harder.

Until then, shells, skulls, nuts and scooped out fruit skins had been used to hold water, milk or blood. The development of pottery was a milestone in human history as it allowed people to boil and steam food for the first time, and thus to exploit new food sources, such as shellfish and leafy vegetables. Firing pottery may have been the first time mankind used fire for a purpose other than for cooking, heat and protection.

The invention of the potter's wheel in Mesopotamia (between 6000 and 2400 BC) revolutionised pottery production, as specialised potters were now able to meet the ever-increasing demands for their work.

Pottery production is a process, in which clay mixed with other minerals is shaped and allowed to dry. The formed clay body may be fired in a kiln to induce permanent changes that result in increased mechanical strength and then fired a second time after adding a glaze. Alternatively, appropriate glazes can be applied to the dry unfired clay and the piece fired once only. The intense heat drives out the water that is bonded chemically to the aluminium silicate in the clay. Once that is done, the fired vessel no longer reverts to loose clay when wet and can survive in the ground for centuries. Additives can be worked into moist clay, prior to forming, to produce desired characteristics to the finished ware. Colorants, usually metal oxides and carbonates, are added singly or in combinations to achieve a desired colour. Combustible particles can be mixed with clay or pressed into the surface to produce texture. Glazed pottery survived in the eastern part of the Roman Empire but was never widespread.

Cement

The use of cement as a filler to bind stones and bricks together is an ancient art. The early Egyptians and Greeks made use of it, and the Romans raised its use to the highest levels of quality. 'Roman cement', made by mixing lime (calcium oxide) with volcanic ash or crushed tiles, retained its popularity until the beginning of the nineteenth century. The large number of Roman structures still standing is probably the best evidence of the quality of the cement.

Calcium oxide, also known as quicklime, is a major constituent of cement. If limestone (calcium carbonate) is heated in a kiln, it will decompose to produce carbon dioxide gas and create the white solid calcium oxide as shown by a reaction below.

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

* Section 6.1 **Types of chemical reactions** describes this type of reaction as a decomposition reaction (page 328).

Lime (also called quicklime) is a grayish-white powder made by heating limestone. It is one of the most important chemicals known and is used as a foundation for making many other chemicals including whitewash.

figure ar.3 This house has been painted with whitewash (a mixture of lime and water). Because lime picks up carbon dioxide from the air, it eventually turns back into chalk.

Lime has been used since early times as a simple form of cement known as mortar. When lime reacts with water, it gives off heat and changes to a new material that is an adhesive (glue). As the water evaporates, the mortar hardens. Over time carbon dioxide gas from the atmosphere reacts with the mortar, turning it back into the calcium carbonate from which it was originally made. It then falls away as a white powder. Lime is also used in the making of glass, where it adds hardness and makes the glass insoluble.

Lime is caustic (can burn the skin) and was traditionally used in burials to hasten the decomposition of bodies.

One of the main uses of calcium compounds is in the manufacture of cement. Like mortar, cement is an adhesive used to bond bricks together or to bind stones and gravel to make concrete. Most cement is called Portland cement, a general kind of cement mix named after the English limestone (Portland stone) that was used in the cement patented by Joseph Aspdin in 1824.

Cement is made from a combination of a limestone or chalk and clay. The raw materials are ground down and then mixed together. Once mixed, they are roasted in a kiln that constantly rotates. The roasting temperature is very high (~1350°C).

When clay and limestone are strongly heated together, they fuse and react to form 'cement clinker' (small lumps). Cement powder is mixed with water to make cement, a grey, pastry substance. The chemical reaction that takes place happens very quickly and if nothing were done to slow down the process, the cement would go hard in a few minutes and so be very difficult to use. Adding gypsum (calcium sulfate) slows down the reaction. Concrete is made by mixing cement with sand and stone aggregate, so that the sand fills the cavities between the stone and the cement fills the cavities between the sand. Since cement is set by chemical reaction with water rather than by drying out, the concrete gains in strength if it is kept wet during the hardening process.

Cement will last for many decades, but it is not as long-lasting as most other building materials. When exposed to weather, it will eventually return to the calcium carbonate from which it was made.

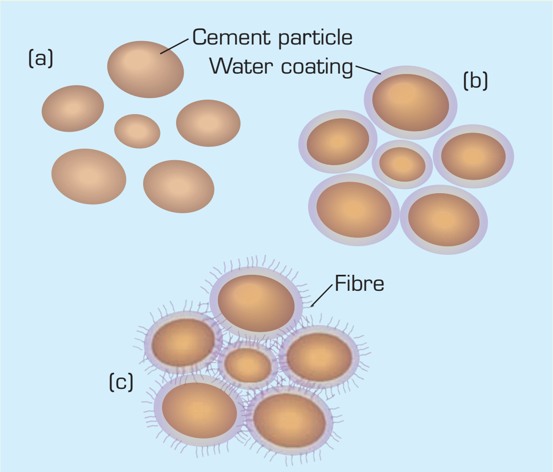

figure ar.4 This diagram shows the process of hardening of cement. When cement particles are mixed with water a coating forms around each particle (a). The fibres growing radially (b) and lock the particles together (c).

Plaster is made of calcium sulfate, which occurs naturally as a soft white rock—gypsum. The gypsum is heated to drive off some of the water, and then it is crushed to a fine powder. It can be used as a crack filler or poured into moulds to make plaster figures (plaster of Paris). When it is mixed with water, this fine powder takes up water again (hydrates) and then sets.

Pigments and dyes

Dyeing has been used for more than 5000 years, particularly in India and the Middle East. Plants were the main source of natural dyes until the first synthetic organic dye (mauveine) was made by William Henry Perkin in 1856. A distinction between a pigment and a dye is that a pigment is insoluble and a dye can be a liquid or a solution.

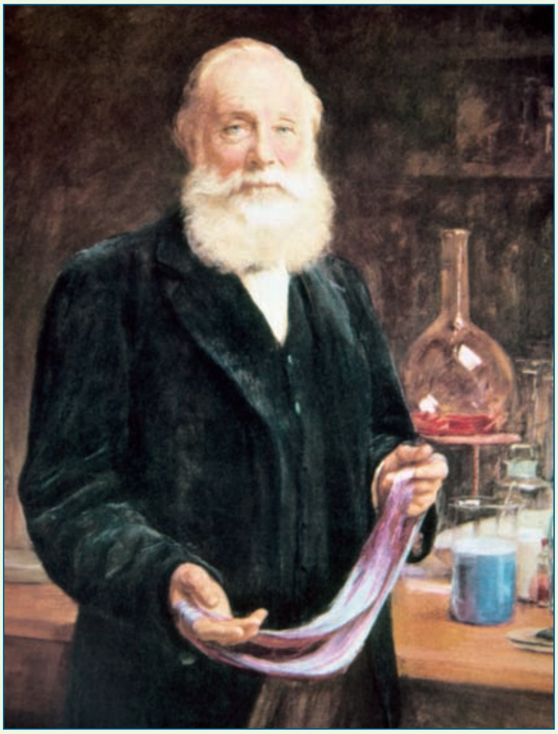

figure ar.5 William Henry Perkin produced the first synthetic dye.

Pigments form the basis of all paints. Early pigments (ground earth and clay) were made into paint with spit or fat. Commonly, all paints consist of ground pigment in some sort of a liquid. When the liquid dries, the ground pigment sticks to the painted surface.

The paint for the first cave paintings was made from dirt or charcoal. Buried bodies were often covered in red pigment, associated with blood, to symbolise life's meaning and end. Red often came from iron deposits in the earth and would not fade, whereas the dye colours derived from animal and vegetable sources would fade over time.

Many dyes do not adhere well to a fibre unless assisted by a 'mordant'. Mordants interact with both the dye and the fibre, forming a strong link between the two. Metal oxides (e.g. aluminium hydroxide) and tannic acid are two commonly used mordants.

Metals and their alloys throughout the ages

The word metal comes from a Greek word meaning 'to hunt for' or 'to search for', which is what early humans did to find these rare, heavy metals. Metals are crucial to our technology. Copper, lead, iron, tin, silver and gold were all readily available metals ores and became the targets of metal exploitation and exchange beginning as far back as the eighth millennium BC.

Different metals were first used by humans at different stages in history. Gold and silver were used very early on. They were found as the free metal (without need for separation) and were easy to work with. Copper was the next metal to be commonly used. It was quite easy to prepare and it was used as pure copper or mixed with tin to give the alloy bronze.

Iron was more difficult to prepare. Greater temperatures were needed to separate it from the raw material. The Iron Age did not commence until about 1500 BC because of the difficulty in obtaining these high temperatures. This new metal was found to be harder than copper or bronze. The discovery of smelting techniques for iron was therefore a great breakthrough. Steel is an alloy of iron and carbon. Very small amounts of carbon are added to iron to make it harder and so more useful. To smelt and also to combine carbon and iron, new techniques were needed. The technology for this was only found some 3000 years after the Iron Age, in about 1600 AD.

Gold

Gold has been used throughout the ages as money and in jewellery. It has long been considered as one of the most precious metals, and its value used as standard for many currencies. It is the most malleable and ductile metal known (1 g can be beaten into a sheet of 1 m^2). As heat, moisture, oxygen and most corrosive agents have very little effect on gold (although halogens can chemically alter it and aqua regia, a mixture of concentrated nitric and hydrochloric acids, can dissolve it), it is well suited for its use in coins, jewellery, decoration and dentistry.

The primary goal of alchemists was to produce gold from other substances such as lead. Even though they did not succeed, alchemists promoted an interest in working with chemical substances and laid a foundation for today's chemistry.

figure ar.6 Gold foil was used to line the cupola of St Mark's Cathedral, Venice.

*Sections 7.2 **Redox reactions** (page 341) and 7.3 **Oxidation numbers and half equations** (page 343) describe oxidation and reduction processes.*

Gold coins are one of the oldest forms of money. In order to withstand prolonged handling, gold needs to be alloyed with other metals. Gold was once used as a worldwide currency reserve and held in vaults as a guarantee of the paper money in circulation. Most of the world stopped making gold coins as currency by 1933.

Silver

Silver has also been known since ancient times and there are indications of it being separated from lead as early as 4000 BC. In ancient Egypt and Medieval Europe it was often more valuable than gold. Silver lies between copper and gold as one of the softest metals. It is the best conductor of heat and electricity of all metals but its softness and relative rarity mean that it has not been put into widespread use. Silver does not oxidise rapidly when heated and will not dissolve in most acids.

Silver has been treasured since ancient times, when it was used mostly for coins and jewellery. Although, even there, its softness was a problem and silver jewellery and coins were actually alloys of silver and copper, with silver coins being at least one-tenth copper.

figure ar.7 An example of a Greek tetradrachma showing Apollo. It was minted between 261 and 246 BC.

One of the uses of silver was as a mirror. The earliest form of mirror was a disk of polished bronze but its poor reflecting properties and the fact that it tarnishes quickly were a serious drawback. The next improvement (commonly used in the Middle Ages) was to use sheets of glass with metal foil attached to the back. Silver was used for this as it is soft and could be beaten into thin sheets and it is highly reflective. However, silver tarnishes over time by reacting with hydrogen sulfide in the air, resulting in a black film of silver sulfide:

$$4Ag(s) + 2H_2S(g) + O_2(g) \rightarrow 2Ag_2S(s) + 2H_2O(l)$$

To produce a durable mirror it was necessary to combine the strength of glass and the reflective properties of silver by binding the silver to the glass so that hydrogen sulfide in the polluted air could not tarnish the surface. This method, known as silvering, is still in use today.

*Section 7.1 **Oxidation and reduction** describes redox reactions (page 338).*

Copper and tin

Metallurgy developed first in Turkey, where the mountainous region contained large deposits of copper and tin. From there, the technology spread rapidly to the Near East.

Most copper ores are difficult to refine, although smelting removes most of the impurities from the enriched ore. The reduction of copper ore containing both oxides and sulfides is shown by the equation below:

$$2CuO(s) + CuS(s) \rightarrow 3Cu(s) + SO_2(g)$$

In about 4000 BC it was discovered, probably by accident, that when copper ore is heated strongly enough metallic copper is produced. The copper combines with oxygen in air to form metallic copper and sulfur dioxide gas.

Tin has been refined by reducing the tin ore in a furnace containing coke according to the following reaction:

$SnO_2(s)$	+	$C(s)$	$\rightarrow$	$Sn(s)$	+	$CO_2(g)$
tin oxide		carbon (coke)		liquid tin		carbon dioxide

Tin is one of the earliest metals known and was probably first used by ancient civilisations accidentally combined with copper. In this way they discovered bronze (5–10% tin combined with copper), the metal alloy that gave its name to the period of ancient history called the Bronze Age. Because of its hardening effect on copper, tin was used in bronze implements as early as 3500 BC. The Bronze Age people, however, did not know about alloying metals but used copper ores that contained tin impurities. (Before tin was used to make bronze, early humans used arsenic, but this caused death to those who worked with it.)

Tools, weapons and armour made of bronze were harder and more durable than their stone and copper predecessors. Bronze was stronger than the era's iron (quality steels were not available until thousands of years later) and it is superior to iron in nearly every application. It is considerably less brittle than iron and has a lower casting temperature. Bronze resists corrosion (especially seawater corrosion) and metal fatigue better than steel. It also has very little metal-on-metal friction, which made it invaluable for the building of cannons (iron cannonballs would otherwise stick in the barrel). The rule is the more tin there is in the alloy, the harder and more brittle it becomes.

figure ar.8 This bronze coin has a portrait of the Roman Emperor Hadrian, who reigned between 117 and 138 AD. Despite being in the damp soil for almost 2000 years, the coin still shows a lot of detail from the original casting.

Below 13°C the atoms of tin very slowly change their packing arrangements. Tin in this form is grey and crumbly. However, tin-plated cans can survive long periods at low temperatures (e.g. in the fridge) very well because of reinforcing by the underlying steel.

Bronze is still widely used today for springs and bearings (e.g. in small electric motors). It is stronger than pure copper and it often used for screws and wires.

Iron and its alloys

Iron is the most abundant metal on Earth. It is extracted from iron ore and is hardly ever found in the free (elemental) state. In the crust it can be found only in combination with oxygen (typically Fe_2O_3—hematite) or sulfur (FeS_2—pyrite). In order to obtain elemental iron, the impurities must be removed by chemical reduction. Iron is extracted from its ore by removing the oxygen by combining it with a preferred chemical partner, such as carbon. This process, known as smelting, was first applied to metals with lower melting points (tin, 250°C, and copper, 1000°C), for which the temperatures could be reached with ancient methods that have been used for at least 6000 years (since the Bronze Age).

Earlier civilisations found iron difficult to use, because they couldn't produce temperatures high enough to work the iron (iron melts at 1535°C).

When an iron ore is heated in a charcoal fire, two reactions occur—reactions that together started the Iron Age.

The oxygen in the ore is removed as carbon monoxide gas and the iron reacts to form iron carbide (cementite), a compound with 6.7% carbon. Some pure iron is formed at the same time.

$$3Fe_2O_3 + 11C \rightarrow 2Fe_3C + 9CO(g)$$
$$Fe_2O_3 + 3C \rightarrow 2Fe + 3CO(g)$$

Iron and iron carbide are mutually soluble and the mixture of the two compounds has a lower melting point than either of the components. While pure iron melts at 1535°C, the mixture melts at around 1150°C. Cast iron can be 'wrought' at 800–900°C by hammering, which mechanically squeezes out most of the solid impurities (slag) and also burns out most of the carbon. The heated iron forms an oxide layer (FeO) on the surface.

When the iron is beaten and folded over, the surface layer can react with the bulk material.

$$Fe_3C + FeO \rightarrow 4Fe + CO(g)$$

This process needed to be repeated many times in order to produce pure iron. To produce swords, the wrought iron had to be 'case hardened' by inducing retention of a certain amount of carbon, but only on the surface. For best results the 'steel' was quenched by cooling it suddenly in the liquid.

It was important for the steel to be cooled as quickly as possible to prevent the carbon atoms from moving. When water is poured on hot metal, steam is formed, preventing the liquid from touching the metal, so that the transfer of heat from the metal to the water is poor. Early iron smelting used charcoal as both the heat source and the reducing agent.

Figure ar.9 Iron is prone to rust.

* Section 7.1 **Oxidation and reduction** discusses the reduction of iron oxide by carbon monoxide in the iron smelting process (page 338).

Wrought iron was used by the ancient Greeks and Romans for beams to construct buildings and for weapons. In addition, it was used for tools, vehicles, art and coins. Its use spread to most other ancient countries, including India, China and the Arab world.

Iron is cheap to obtain, easy to shape and very strong. For all these reasons it is used more widely than any other metal. But all the advantages of iron have to be balanced against one major disadvantage: it is a fairly reactive element and prone to rust when exposed to damp air.

$$4Fe(s) + 6H_2O(l) + 3O_2(g) \rightarrow 4Fe(OH)_3(s) \rightarrow 2Fe_2O_3(s) + 6H_2O(l)$$

iron + water + oxygen → ferric hydroxide → ferric oxide (rust) + water

The rusting of iron occurs because an incoherent oxide layer is formed, that is, the iron oxide crumbles off.

Experiment ar.1

Modifying the properties of metals (heating iron)

materials

- 3 × sewing needles or hair pins
- 250 mL beaker of cold water
- safety glasses
- Bunsen burner
- heatproof mat
- tongs
- pliers (optional)

safety

- Remember not to touch hot metal.
- Wear safety glasses for this experiment.

Purpose

To modify the properties of iron by heating.

Procedure

1. Keep one of the needles or hair pins as a control.
2. Strongly heat the other two needles or hair pins one at a time in the flame of the Bunsen burner.
3. Drop one of the hot needles or hair pins directly into the beaker of cold water. Allow the other needle or hair pin to cool very slowly by gradually moving it away from the flame of the burner and allowing it to cool in the air.
4. When the needles or hair pins are quite cool, try to bend them and to break them. Record your observations.

Theory

The **macroscopic** properties of a metal will depend on its **microstructure** (the arrangement of its atoms into crystals). When a metal is cooled slowly, the atoms have time to arrange themselves into larger crystals. The metal tends to be more malleable and ductile. If, however, a metal is cooled quickly, the atoms form small crystals only. There are weaknesses where these small crystals join one another and so the metal tends to be more brittle.

Question

How does the rate of cooling affect the brittleness and hardness of the metal?

Glass

Glass is a mixture of silicon dioxide and metal oxides. It is a disordered solid.

Glass has been made by fusing mixtures of sand, limestone and sodium carbonate at temperatures of up to 1000°C in charcoal furnaces. This causes the crystalline order of the added minerals to be lost. Glass can also be made with only sodium carbonate and sand, but this glass is soluble in water.

$$Na_2CO_3(s) + SiO_2(s) \xrightarrow{\text{heat}} Na_2SiO_3(s) + CO_2(g)$$

The addition of calcium makes glass insoluble in water and much harder. Sodium and calcium are added as carbonates and lose carbon dioxide to form oxides in the glass.

Figure ar.10 Egyptian hieroglyphics showing what is thought to be glassmaking.

Pieces of Egyptian glass have been found dating back 4000 years. To produce vessels, the raw glass was heated in pans up to 750°C and then again in crucibles to as high as 1000°C. A clay-and-sand core was made in the shape of the cavity of the intended vessel, covered with cloth and stuck onto a metal rod. This was plunged into the molten mass and given several quick twists to spread the glass evenly over it. (This did not always work out, as we can see from the uneven thickness of some vessels.)

Ancient Egyptian glass was usually tinted with pigments added to the raw glass. A milky-white colour was produced with tin or lead oxide, yellow with antimony and lead or ferrous compounds, red or orange with oxides of copper, violet with manganese salts, greenish blue (in imitation of lapis lazuli) with cobalt compounds, and black with a larger proportion of copper and manganese or with ferric compounds. The finished artifacts—little bottles, vases, goblets and bowls—were chiefly destined to hold cosmetics and fragrant unguents in the boudoirs of queens and high-born ladies.

The revolutionary invention of glassblowing took place, probably in Syria, during the 1st century BC.

The Venetians were the first to add lead to the glassmaking mixture. The lead allows the glass to be moulded over a wide range of temperatures, allowing the glass to be made in more complicated shapes. The use of lead also made the glass even clearer and more transparent, as the lead changed the optical properties of the glass, giving cut glass a special sparkle.

Beer and wine

Another example of the early use of chemistry is the discovery of fermentation. A very early discovery involved what occurred when fruit juices, left uncovered, turned into wine. During fermentation, glucose molecules (sugar) are broken down into smaller molecules of carbon dioxide and alcohol. It is thought that early farmers made wine from wild fruits, including wild grapes. Since the early Bronze Age, domesticated grapes became more abundant in the Near East and there is evidence for winemaking in Egypt and Sumeria since about 3000 BC.

Beer is one of the oldest beverages produced by humans. The basis of all beer and wine is alcohol. The principal type of alcohol found in wines and beers is ethyl alcohol or ethanol. Ethanol has the chemical formula C_2H_5OH. The manufacture of ethanol by fermentation is one of the oldest processes known. One reason wine has been made since ancient times is the fact that it is easy to make. The grape has all the main ingredients in one package—sugar, water, flavour and yeast. The yeast exists on the skin of the grape. In fermentation, the action of enzymes in yeasts causes the breakdown of any starches to glucose, and then to ethanol and carbon dioxide.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{ethanol}}{2\,C_2H_5OH} + \underset{\text{carbon dioxide}}{2\,CO_2}$$

table ar.1 Products of fermentation and the approximate percentages of alcohol.

Source of must*	Fermentation product
grapes	wine (11–13%)
apples	cider (4–10%)
barley	beer (2–7%)

* The 'must' refers to the prepared liquid that is going to be fermented.

Fermentation can proceed to about 12% alcohol. At this point the action of the yeast is inhibited by the concentration of alcohol. More concentrated solutions of alcohol are obtained by distillation of wine or grain mashes. Beer is produced by the fermentation of cereal sugars. The product is left undistilled after fermentation.

When yeast cells do not obtain an adequate supply of oxygen, they carry out the process of fermentation, which is actually an incomplete form of cellular respiration. Fermentation occurs because the second and third stages of cellular respiration (the aerobic citric acid cycle and the electron transport to produce ATP) cannot proceed in the absence of sufficient oxygen. In fermentation, the enzymes in yeast break down glucose to pyruvic acid, $CH_3COCOOH$, (using glycolysis), but instead of proceeding on with the citric acid cycle (which they would if enough oxygen were available), they convert the pyruvic acid to ethanol and carbon dioxide.

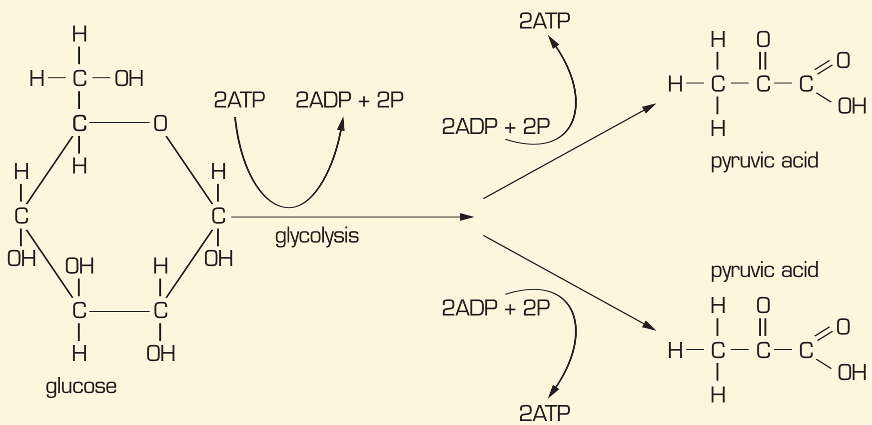

figure ar.11 The process of glycolysis (in the absence of oxygen) results in the formation of two molecules of pyruvic acid from one molecule of glucose.

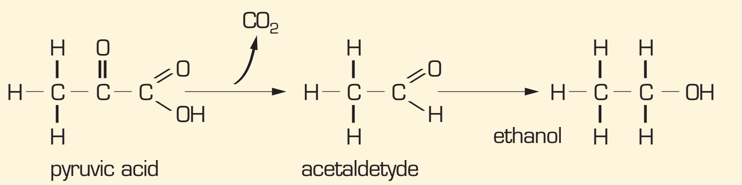

figure ar.12 The diagram above shows the conversion of pyruvic acid to alcohol by yeast.

The equation below shows how yeasts convert pyruvic acid to ethanol. Pyruvic acid is converted first to acetaldehyde, liberating carbon dioxide. Acetaldehyde is then converted into ethanol.

$$\underset{\text{pyruvic acid}}{CH_3COCOOH} \rightarrow \underset{\text{acetaldehyde}}{CH_3CHO} \rightarrow \underset{\text{ethanol}}{CH_3CH_2OH}$$

Fermentation produces energy-carrying molecules (ATP), but not as many as would be produced in aerobic cellular respiration, so the process is less efficient. Glucose is the raw material for fermentation. Although grape juice contains mainly fructose, the enzymes in the yeast present on the skins of the grapes also break down more complex substances such as starches and complex sugars to glucose.

* Section 2.5 **Organic compounds** describes reactions of hydrocarbons (page 246).

Further investigations

1 Choose one of the metals used by ancient civilisations and find out how this metal was extracted and refined. Include all relevant equations. You may want to present the information in a flow chart.

2 Explain why the development of pottery was seen as a milestone in human history. Present your findings as a report or a PowerPoint presentation.

3 Some metals have physical or chemical properties that make them hard to use in their natural (pure) state and, in order to be useful in everyday life, these metals often need to be alloyed with another substance.

Choose one such metal and research its properties in the natural state, the alloys that it can form, and how these properties are influenced by the alloying process. Focus on how the alloying process was achieved by the ancient civilisations. Present your findings in class as a report or as a PowerPoint presentation.

4 The fermentation process responsible for the production of beer and wine relies heavily on anaerobic respiration in yeast. Research the differences between the aerobic and anaerobic respiration in yeast. Why is the process of anaerobic respiration less energy efficient than that of aerobic respiration? Discuss how ancient civilisations were able to use fermentation to obtain alcoholic drinks. Present your research in the form of a pamphlet, and include all relevant chemical equations.

5 Explain the ways in which ancient civilisations used ceramics. Compare this with present and possible future uses of ceramics.

Consider this

Use the information presented in the context and related chapters to answer the following questions.

1 Explain, using equations, how ancient civilisations extracted iron from its ore and the techniques used
to purify it.

2 List the main physical and chemical properties of three metals used by the ancient civilisations that have been discussed in this context. Explain how these properties made these metals useful to the ancient mankind. Present your findings in the form of a table.

3 Briefly explain why all metals cannot be found free in nature.

4 Cast iron is heavy, it rusts easily, it is brittle, and it cannot be welded. Steel avoids these problems. Explain why this is so.

5 In organic chemistry, oxidation can be described as the addition of oxygen to a molecule or the removal of hydrogen. If oxygen is added to the hydrocarbon chain, an alcohol results. Give an example, using a balanced equation.

6 One of the oldest chemical processes is fermentation, used in making wine. How are hydrocarbons fermented? Is fermentation an oxidation or a reduction reaction?