Part 1 Pre-16

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Teacher's notes Zinc extraction at Avonmouth

This section describes the extraction of zinc, and can be used with two different sets of questions to test comprehension. Further stand-alone worksheets cover other aspects of the chemistry of zinc. This part contains:

- The information sheet *Zinc at Avonmouth*. This covers how zinc is extracted at Avonmouth by smelting. Three of the figures (sintering, smelting and refining) for this information sheet are printed separately so that the sheet can be supplied to pupils with or without them.

  Zinc at Avonmouth is designed for students to read, but it can also be used for teacher background information. It forms the basis of the following comprehension exercises:
- *Zinc smelting at Avonmouth* – a comprehension exercise based on the information sheet (using all the Figures).
- *The extraction of zinc*. This is a comprehension exercise based on the same information sheet but without using the figures sintering, smelting and refining. Instead, versions of these figures which are only partially labelled are supplied to the students with the questions, and they are asked to complete the labelling as part of the exercise. This exercise is easier than *Zinc smelting at Avonmouth*.
- *Zinc – ancient mystery, modern marvel* – a stand alone sheet suitable for classwork or homework for 11–16 year olds.
- *'Tutty' – the metal that turns copper into 'gold'* – a stand alone sheet suitable for classwork or homework for 14–16 year olds. Pupil access to data on the melting points of metals, either in book or database form, is required.
- *In the beginning, there was….ZINC* – a stand alone sheet suitable for classwork or homework for 14–16 year olds.
- *William Champion – Zinc smelter* – a stand alone sheet suitable for classwork or homework for 14–16 year olds.
- *From horizontal to vertical – Zinc smelting in the 20th century* – a stand alone sheet suitable for classwork or homework for 14–16 year olds.
- *Uses of zinc* – a stand-alone sheet suitable for class or homework for 14–16 year olds (It is useful to have *The different ways of coating with zinc* available as a reference to help answer question 4).
- *Zinc – for the roof over your head* – a stand alone sheet suitable for classwork for 14–16 year olds. This needs samples of the ores malachite, galena and sphalerite plus samples of the oxides and carbonates of zinc, lead and copper or student access to data with information about the colours of these substances.
- *Why do metal roofs need replacing?* – a follow on sheet for Zinc – for the roof over your head
- *The different ways of coating with zinc* – a stand alone sheet suitable for classwork or homework for 11–16 year olds.

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Answers

Zinc smelting at Avonmouth

1. a) It is near to Avonmouth docks where the raw materials are imported by ship

b) (i) zinc sulfide + oxygen → zinc oxide + sulfur dioxide
$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$

(ii) zinc oxide + carbon monoxide → zinc + carbon dioxide
$ZnO + CO \rightarrow Zn + CO_2$
or zinc oxide + carbon → zinc + carbon monoxide
$ZnO + C \rightarrow Zn + CO$

(iii) Reduction here means loss of oxygen

c) A temperature > 1000 °C ensures that zinc is produced as vapour. If the temperature < 1000 °C,
$Zn + CO_2 \rightarrow ZnO + CO$
takes place rather than the reverse reaction.

d) Quenching is rapid cooling of Zn(g) to Zn(l). It minimises the reaction
$2Zn(g) + O_2(g) \rightarrow ZnO(s)$.

2. a) (i) $2SO_2 + O_2 \rightarrow 2SO_3$

(ii) $SO_3 + H_2O \rightarrow H_2SO_4$

b) 98 tonnes

c) 92.7 tonnes

3 a) (i) Lead is associated with potential brain damage and is a cumulative poison.
Pregnant women could risk harm to their babies.
Traditionally there are fewer women employed in industry.
Sex discrimination may have operated.

(ii) Uses of lead include: lead-acid (storage) batteries; lead crystal glass; pigments in chemicals; a shield from radiation (*eg* X- or gamma-rays); building/roofing material.

b) Carbon monoxide – a poisonous gas
Sulfur dioxide – can cause breathing problems, produces acid rain

c) Slag has to be disposed of safely. This is particularly costly since the introduction of the landfill tax.

4. a) Zinc ores are bought and sold in dollars.

b) Some reasons for the fall in work force might be –
greater automation, computerisation, need to reduce costs, improved efficiency.

c) *Community Link* provides good public relations, keeps the local community informed, keeps the local community involved, maintains (or establishes) good relations, counteracts prejudice or misinformation.

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d) The correct mix is chosen to give an economic yield and depends on: the required composition of product, the availability of concentrate, the cost of concentrate.

5 **a)** Transition metals

b) The density of liquid zinc is less than that of liquid lead. Zinc floats on lead.

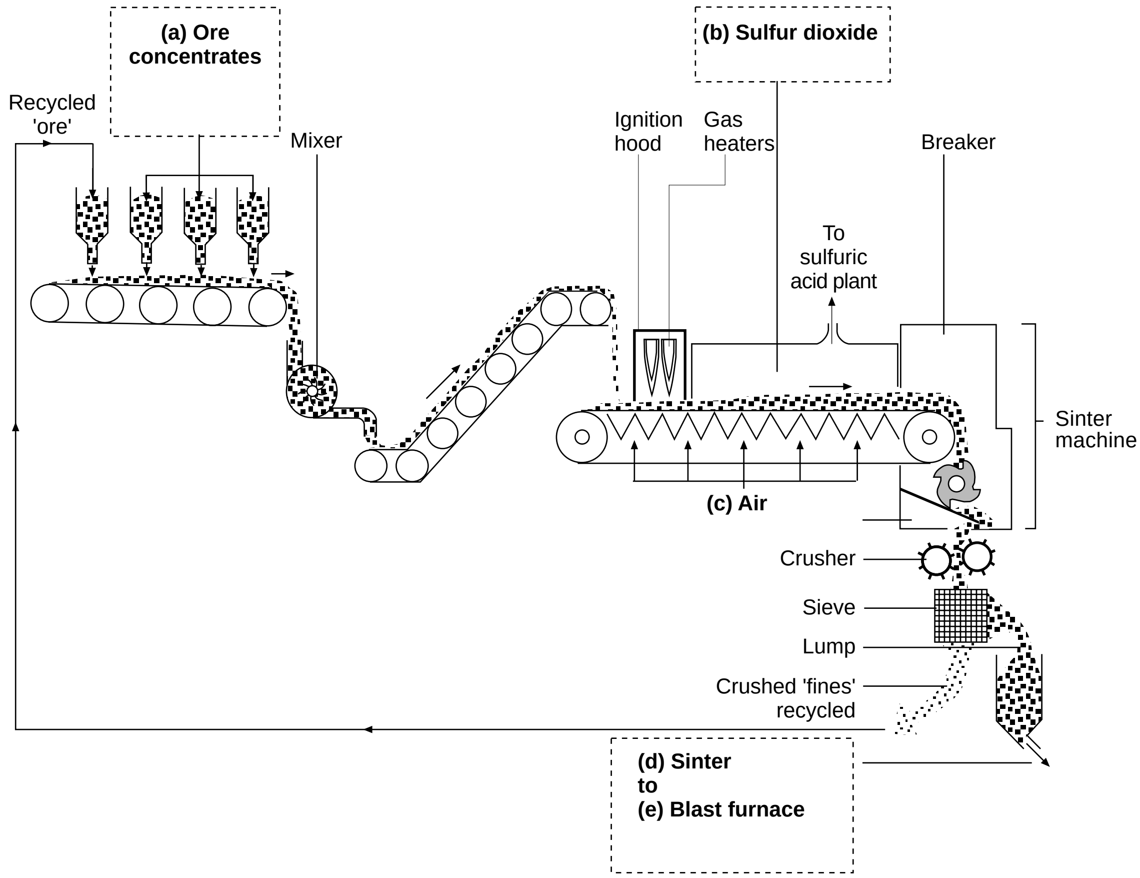
c) **(i)** Cadmium has a lower boiling temperature than zinc. Cadmium boils off first, or cadmium boils off from the top of the tower.

(ii) Fractional distillation

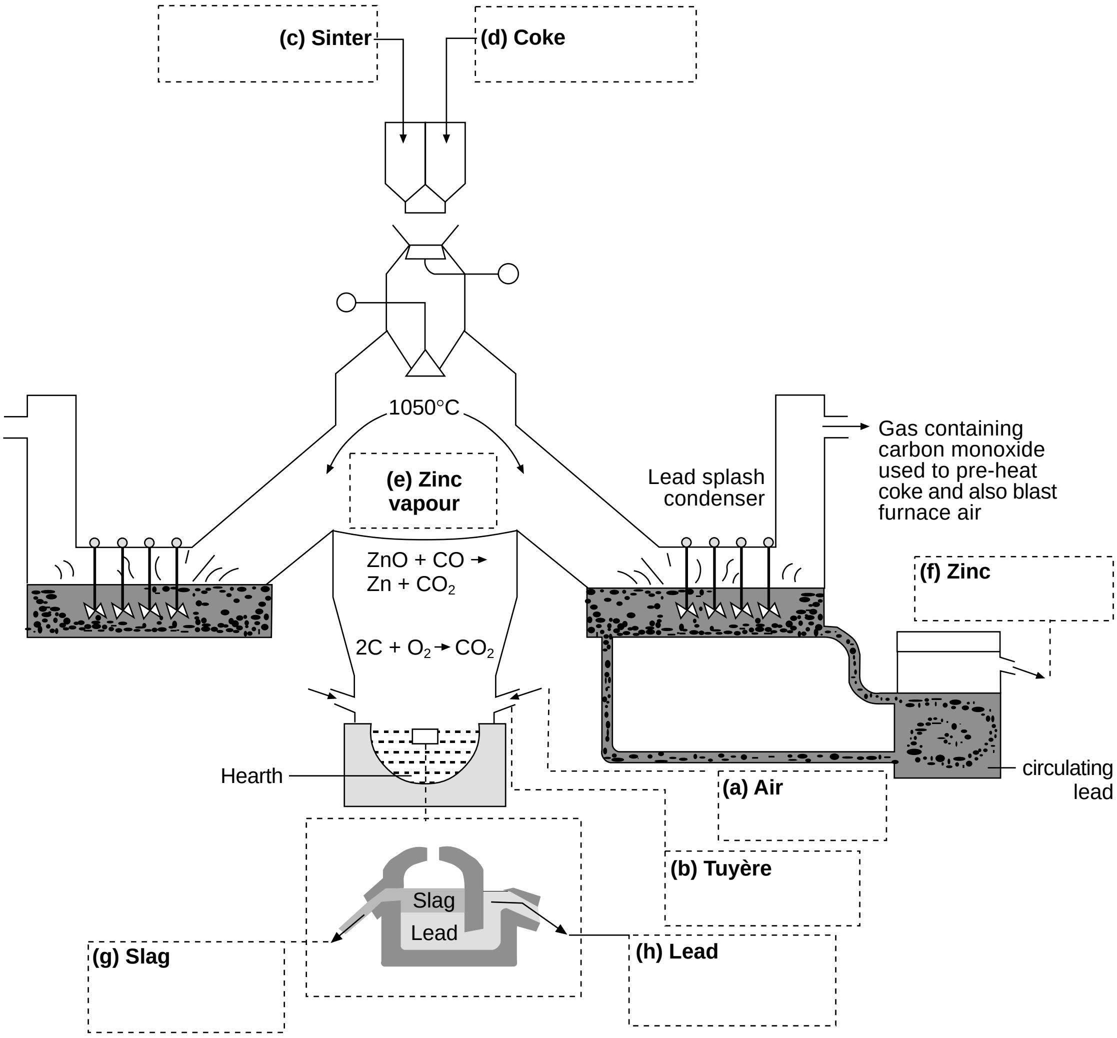
(iii) Other industrial separations are – separation of air, separation of crude oil.

Extraction of zinc

1. Figures for 'sintering', 'smelting' and 'refining' with labels filled in.

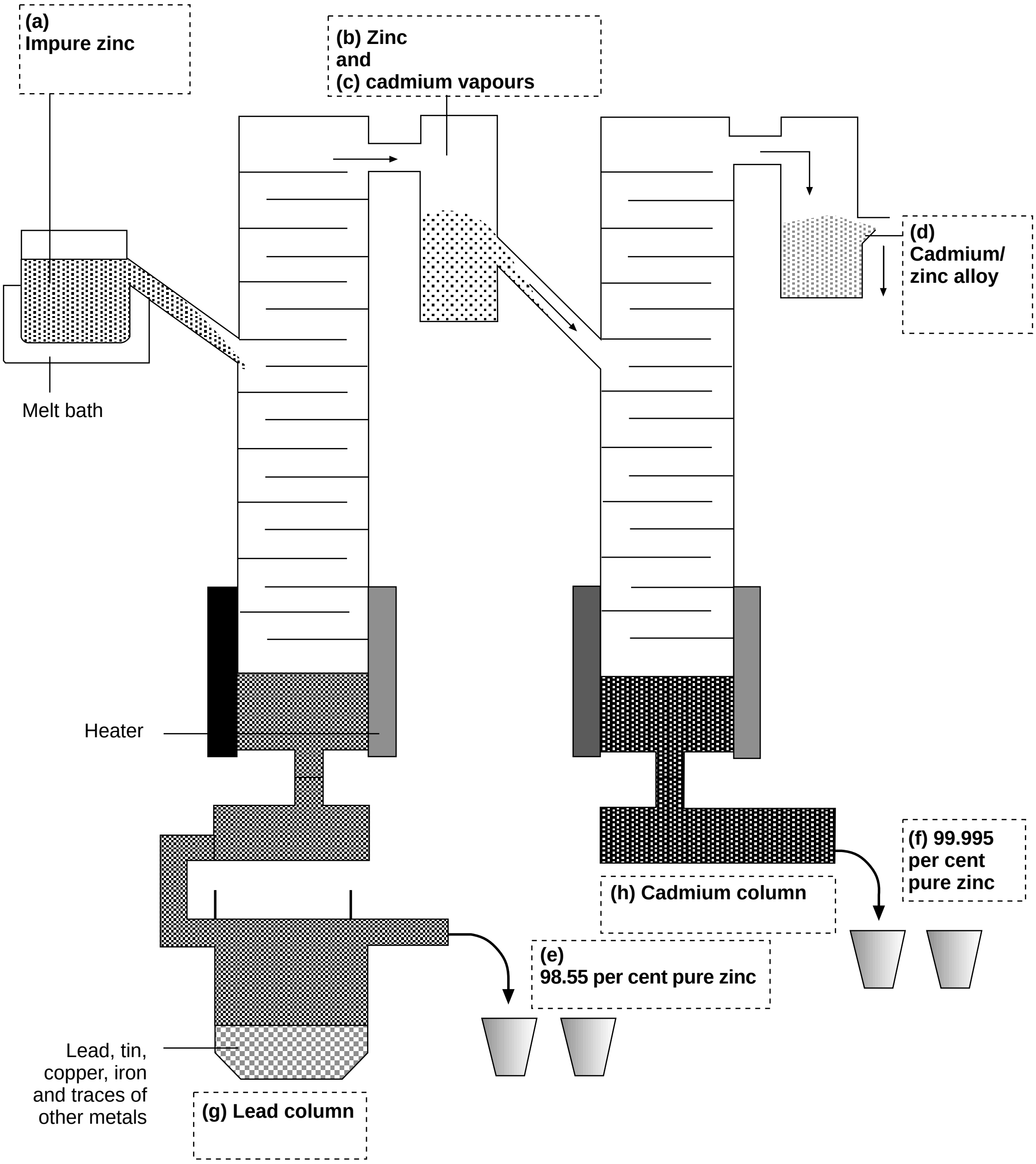


Sintering



(c) Sinter
(d) Coke
1050°C
(e) Zinc vapour
ZnO + CO → Zn + CO2
2C + O2 → CO2
Lead splash condenser
Gas containing carbon monoxide used to pre-heat coke and also blast furnace air
(f) Zinc
circulating lead
Hearth
(a) Air
(b) Tuyère
Slag
Lead
(g) Slag
(h) Lead

Smelting


(a)
Impure zinc
(b) Zinc
and
(c) cadmium vapours
(d)
Cadmium/
zinc alloy
Melt bath
Heater
(f) 99.995
per cent
pure zinc
(h) Cadmium column
(e)
98.55 per cent pure zinc
Lead, tin,
copper, iron
and traces of
other metals
(g) Lead column

Refining

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b) A large surface area allows more gas/solid reaction to take place with the carbon monoxide gas.

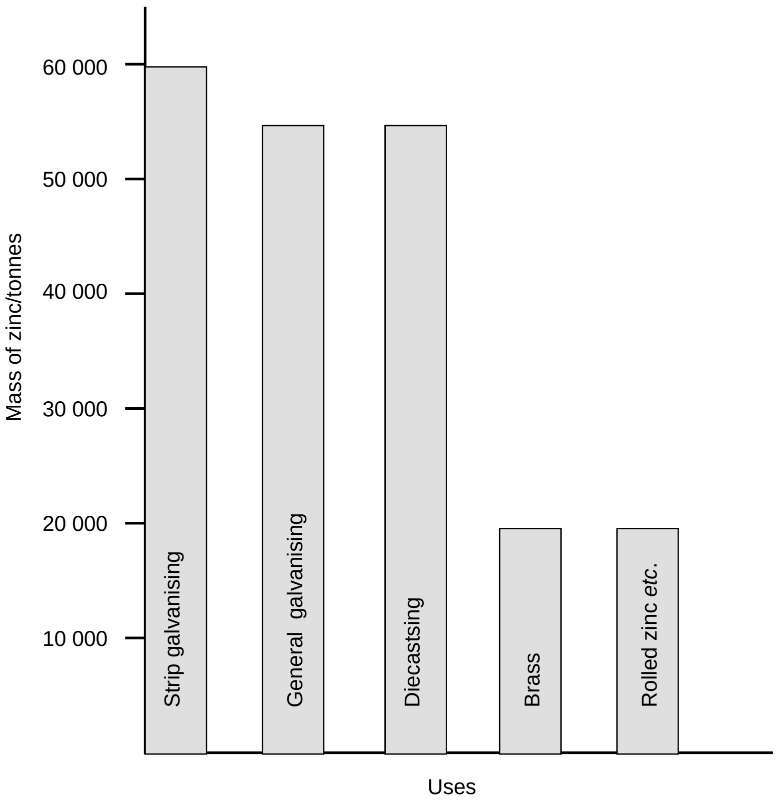
c) Zinc oxide loses oxygen to become zinc. This is a reduction.

d) Zinc oxide + carbon monoxide → zinc + carbon dioxide

$ZnO + CO \rightarrow Zn + CO_2$

e) Zinc has a much lower boiling temperature than iron and, unlike iron, can be boiled off as it is formed.

2. a)



b) i) Pie chart – this gives the per cent distribution of how zinc is used.

ii) Block graph – this gives the absolute numbers in tonnes.

Zinc – ancient mystery, modern marvel

1. a) Suitable properties might include: waterproof, weather resistant, tough, fire resistant, resistant to chemicals, available in small units, good appearance, easy to replace/repair, not too dense.

2. Zinc metal had only just been isolated and it must have been rather an unknown quantity.

3. Galvanised steel has a thin coating of zinc. This protects the steel from rusting even when the coating is damaged.

4. Uses of brass include:

taps, door knobs, ships' instruments	corrosion resistant
ornaments,	attractive appearance,
electrical connections, *eg* electrical plug pins.	good conductor of electricity

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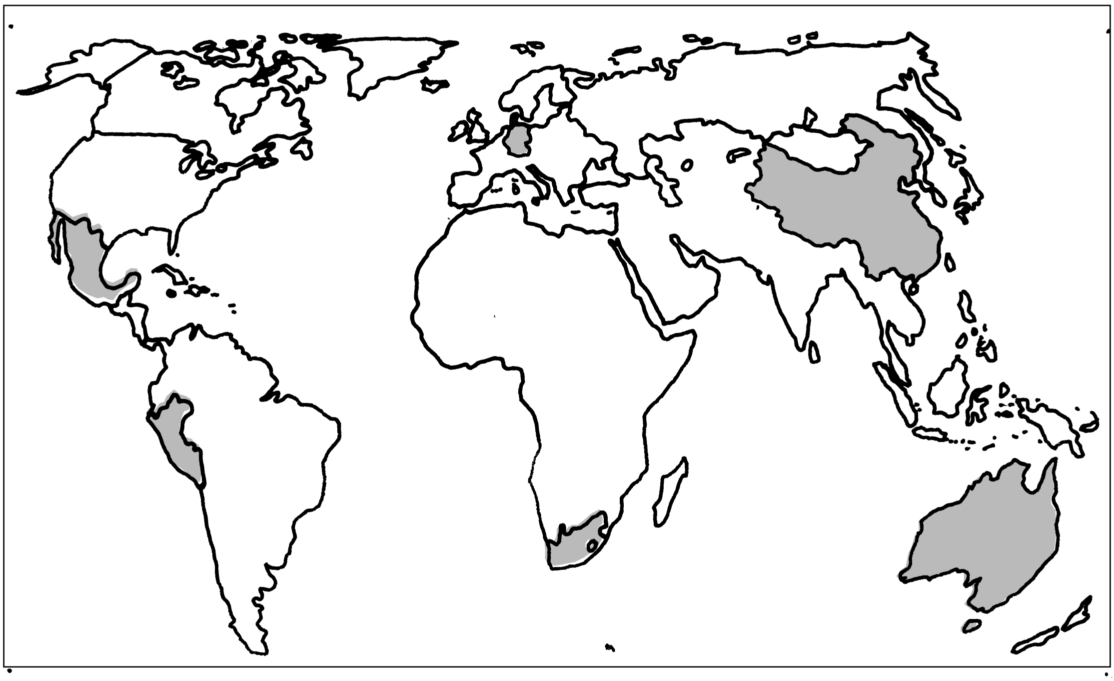
'Tutty' – the metal that turns copper into 'gold'

1. Copper, silver, gold, tin, lead, iron, mercury
2. zinc + oxygen → zinc oxide
   $2Zn + O_2 \rightarrow 2ZnO$
3.

Metal	Melting point/°C	Boiling point/°C
Copper	1083	2567
Lead	328	1740
Silver	962	2212
Zinc	420	907

   Zinc has a lower boiling temperature than the others.
4. Carbon + zinc oxide → carbon monoxide + zinc
   $C + ZnO \rightarrow CO + Zn$
   or Carbon + zinc oxide → carbon dioxide + zinc
   $C + 2ZnO \rightarrow CO_2 + 2Zn$
5. Uses of zinc might include – making die-cast models and components, rust prevention, making brass alloys, making zinc oxide (used in tyres and medicinal creams), batteries, zinc sheeting, galvanising.

In the beginning there was ZINC



1. Map
2. The stacked paper would be roughly 100 m tall (depending on the paper thickness).
3. **a)** Sedimentary rock is made of layers of particles of rock laid down over millions of years.

b) Igneous rock is formed from cooled magma.

c) Metamorphic rock is rock that has undergone rearrangement of its structure by the action of high pressures and temperatures.

d) An igneous intrusion is a rivulet of magma that has cooled to a solid under the ground, without reaching the surface.

4. The crystals will be large. The liquid magma will have cooled slowly under the surface, and slow cooling produces large crystals.
5. An ore is a rock which has enough mineral in it to make it worth mining commercially.
6. **a)** The iron ball bangs against the side of the vessel crushing any lumps to powder.

   b) The tiny fragments of metal ore cling to the surface of the bubbles and come to the top on the floating froth.
7. In the furnace the zinc oxide is losing oxygen leaving zinc on its own. (This is a reduction process).

William Champion – zinc smelter

1. Essentially paragraph 5.
2. The zinc vapour cooled to a liquid.
3. Any oxygen reacts with the zinc to give zinc oxide.
4. **a)**

Zinc oxide	+	carbon	→	zinc	+	carbon monoxide
ZnO	+	C	→	Zn	+	CO

   b) Reacting ratios:

81	12	65	28
1.62 kg	0.24 kg	1.3 kg	0.56 kg

   ie 1.62 kg of zinc and 0.24 kg of carbon.

   c) Zinc oxide 1.62 x 8 = 12.96 kg, carbon 0.24 x 8 = 1.92 kg

   d) More needed because the process is neither 100 per cent efficient, nor the ore and charcoal pure.
5. Mark by impression to evaluate communication skills.

From horizontal to vertical – zinc smelting in the 20th century

1. Easier automation; furnace does not have to cool between batches; no time lost when retorts have to be emptied of slag.
2. Less fuel used, lower labour costs.
3. $ZnO + CO \rightarrow Zn + CO_2$
4. $Zn + CO_2 \rightarrow ZnO + CO$
5. Capital costs of building new plant are too high in some countries. If labour costs are very low, labour-intensive processes are favoured (despite health and safety considerations).
6. U-boat attacks on convoys from the US could have left the UK without the zinc necessary to make arms to fight. Bullet and shell cases are made of brass – an alloy of zinc and copper.

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7. To prevent the UK from depending on foreign supplies in a future conflict; to maintain employment.

8. Avonmouth has a deep water port through which zinc ores can be imported (there are no commercially sized deposits of zinc in the UK) and good rail links (and now roads). It is near the South Wales coal field (which used to be the main source of coke), and near a source of labour (Bristol).

Uses of zinc

A Zinc for die-casting metal toys

1. Lead is toxic.

2. Plastic, because the paint solvent affects the plastic.

3. The lower the temperature, the cheaper and safer the process.

4. Steel and hot, molten zinc might form an alloy.

B Brasses

5. Brass is a harder and stronger metal alloy than copper and will therefore resist wear on being plugged and unplugged. Copper wire is flexible and cheaper than brass.

6. Any suitable suggestions of uses of brass, such as plumbing components or door handles. Comments on suitability depend on the use suggested.

C Zinc for making zinc oxide

7. Properties for a tyre material might include - elasticity, resistance to wear, to chemicals and to change at high temperature.

8. Zinc oxide prevents the growth of bacteria and fungi and is non-toxic.

Zinc – for the roof over your head.

1. Zinc, lead, copper.

2. Sphalerite – white
galena – black
malachite – dark green.

3. Zinc carbonate – white
lead carbonate – white
copper carbonate – green
zinc oxide – white
lead(II) oxide – white
copper(II) oxide – black.

4. The oxide and the carbonate of the metal are coating the metal. In the case of copper, first the oxide and then the carbonate form a coating.

5. a) zinc + oxygen → zinc oxide
$2Zn + O_2 \rightarrow 2ZnO$

b) copper oxide + carbon dioxide → copper carbonate
$CuO + CO_2 \rightarrow CuCO_3$

Why do metal roofs need replacing?

1. The roofing metal becomes thinner and eventually cracks.

2. In climates with extremes of temperature.

3. **a)** zinc oxide + sulfuric acid → zinc sulfate + water

$ZnO(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2O(l)$

b) zinc hydroxide + sulfuric acid → zinc sulfate + water

$Zn(OH)_2(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + 2H_2O(l)$

c) zinc carbonate + sulfuric acid → zinc sulfate + carbon dioxide + water

$ZnCO_3(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + CO_2(g) + H_2O(l)$

4. **a)** zinc oxide + nitric acid → zinc nitrate + water

$ZnO(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + H_2O(l)$

b) zinc hydroxide + nitric acid → zinc nitrate + water

$Zn(OH)_2(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + 2H_2O(l)$

c) zinc carbonate + nitric acid → zinc nitrate + carbon dioxide + water

$ZnCO_3(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + CO_2(g) + H_2O(l)$

The different ways of coating steel with zinc

1. Hot dip galvanising – produces hard, long-lasting coat.
(spraying is the next best).

2. Sherardising – it can cope with complicated shapes and it is cheap.

3. Spraying will reach all the parts of the bridge and give it a good thickness of coat. It can be renewed whenever it is needed.

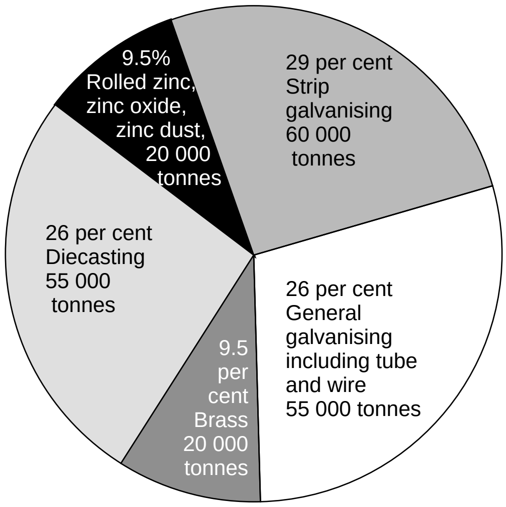
4. Zinc dust painting – it is suitable for small localised jobs.

Zinc at Avonmouth

The properties of Zinc (Zn)

- Atomic number 30
- Relative atomic mass 65.4
- Melting temperature 420 °C
- Boiling temperature 907 °C
- Density 7.1 g/cm^3

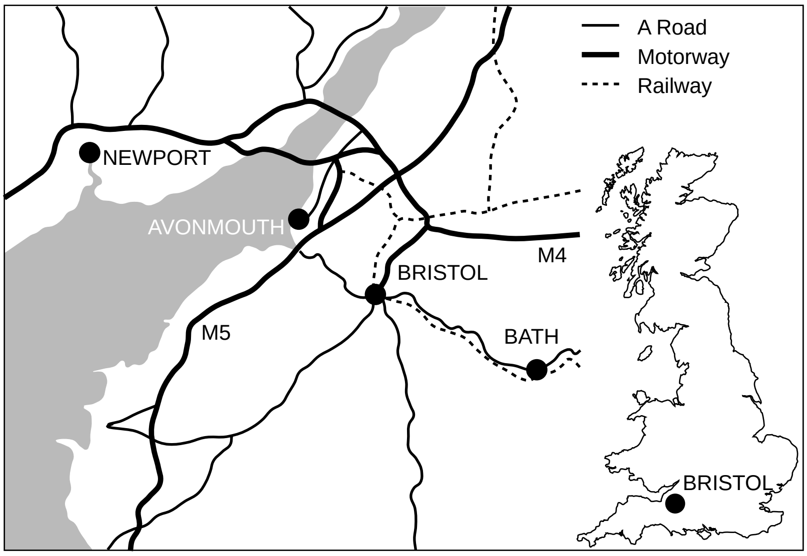
Zinc is a very important metal. It is the fourth most widely used in the world. Seven million tonnes of zinc metal is refined every year worldwide. Its principal uses are shown in the pie chart. Although it has been used for well over 2 000 years, especially in the form of the alloy brass (brass is copper with up to 40 per cent zinc), pure zinc was not isolated until about 200 years ago.



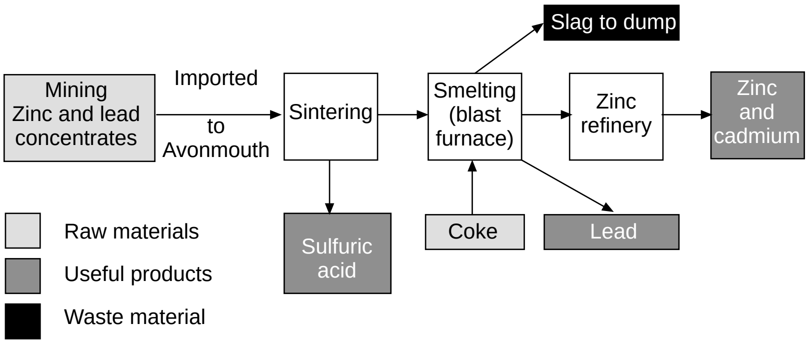
UK zinc market by end use – 1995 figures, 210 000 tonnes total

Zinc may be isolated from its ores by smelting (heating with carbon), in much the same way as iron, or by electrolysis. About 20 per cent of the world's zinc metal is produced by smelting. Unlike electrolysis, the smelting process can cope with a varied composition of ore input. Britannia Zinc at Avonmouth near Bristol, the only manufacturer of zinc in the UK, uses a blast furnace which smelts both lead and zinc at the same time.

Zinc and lead smelting at Avonmouth



Map of Avonmouth



The zinc extraction process

Ores

The most important zinc ores are shown in the table

Zinc ores

Name	**Chemical name of main zinc mineral**	**Formula**
Zinc blende	Zinc sulfide	ZnS
Marmatite	Zinc iron sulfide	$ZnFeS_2$
Calamine	Zinc carbonate	$ZnCO_3$

Shipment of ore concentrates

Approximately 320 000 tonnes each year of ore concentrates, (ores which have been ground and treated to raise the zinc content to 50 per cent or more) are imported into Avonmouth Docks from Australia, South America, Canada, Alaska, Iran, Scandinavia and Southern Ireland. A conveyor belt, approximately 1 km in length, is used to carry up to 600 tonnes/hour from the docks to the works. Here, the ore is weighed automatically at the conveyers before being deposited in a store on site which holds up to 50 000 tonnes under cover. From start to finish all the processes are regulated and monitored by computers and instruments in the centralised control room.

Sintering

The materials used in the zinc smelting blast furnace have to be strong enough to support the load above them in the furnace, must include zinc and lead as oxides, and must be porous and have a large surface area. This is done by producing sinter, a pumice-like material which is like a hard sponge in structure.

First the ore concentrates from various sources are mixed so that they will give the required yields of zinc, lead and other metals. Recycled materials are also used.

Then the mix is fed onto the sinter machine. This has iron bars – larger than, but similar to, those which form the base of a domestic coal fire – which are part of a moving trolley. Air passes up through the bars and the sinter mix is ignited using natural gas burners. The material fuses into lumps called agglomerate. It becomes porous as, during the process, sulfur is burnt off as sulphur dioxide gas. This gas is collected and converted into sulfuric acid by the Contact Process in which the sulfur dioxide reacts with further air and with water. The metals are now present as oxides.

The sintering process is shown in the figure 'Sintering'.

Smelting

The blast furnace at Avonmouth (the imperial smelting furnace or ISF) uses coke in very large quantities (up to 130 000 tonnes per year) provided by the Cwm coke ovens in South Wales. Every tonne of zinc produced requires nearly 0.9 tonnes of coke.

Hot air at 1000 °C is blown in at the base (hearth) of the furnace, through pipes called tuyères, and coke and sinter are added at the top.

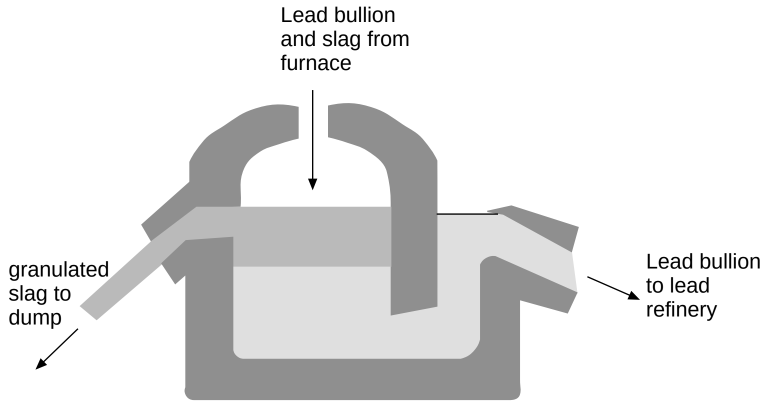
The coke burns in the air to produce carbon dioxide, carbon monoxide and intense heat. In the main process, zinc oxide is reduced to zinc by carbon monoxide (and carbon). The temperature at the top of the furnace is kept above 1000 °C for two reasons – to ensure that zinc is present as a vapour (it boils at 907 °C) and because at lower temperatures zinc reacts with carbon monoxide to go back to zinc oxide and carbon.

At the same time, lead oxide, which is also present in many of the ores, is reduced to lead and falls to the bottom of the furnace into the hearth.

The smelting process is shown in the figure 'smelting'.

Separation

Since zinc is produced as a vapour, it passes out in the gas stream from the top of the furnace. The molten lead (with other metals such as silver, gold and copper) and slag, a material formed from impurities, sink to the bottom of the furnace. They are tapped off through water-cooled copper blocks into the forehearth.



The forehearth – slag is separated from denser lead bullion

The slag and lead tapping is a spectacular process which is carried out around every $1^1/_2$ hours. The operator, wearing protective clothing, uses an oxygen lance to melt a hole in the solid slag plug in the copper block. The bright, molten river of slag and lead bursts out with a flying, sparkling spray. After 20 minutes or so a water-cooled check bar is inserted into the tap hole to cool the slag/lead melt in the hole and re-seal the hole. The lead separates to the bottom of the forehearth and flows out into moulds; the slag is run out from the top. The lead is recovered together with its silver, gold and copper content as four-tonne blocks. Granulated slag is a fairly inert material and is transported to a suitable dump. Research to find uses for the slag is currently in progress. It is formed from impurities in the ore concentrates such as lime (calcium oxide), aluminium oxide and sand (silica).

Slagging the furnace

Condensing the zinc

A lead splash condenser is an important feature of the Avonmouth process. This process rapidly cools (quenches) the zinc vapour from 1000 °C to 550 °C.

- Zinc vapour from the furnace passes into the condenser.
- In the condenser, the zinc vapour dissolves in a spray of fine droplets of lead, produced by rotors splashing a pool of molten lead.
- Zinc dissolved in molten lead is cooled further. It flows into a separator bath where the zinc floats on top of the molten lead, is separated and then taken to the refinery.

Refining

The zinc from the imperial smelting furnace (98.5 per cent purity; but still containing some lead, cadmium, tin, copper, iron and other metals) is refined in a two stage distillation process.

- The zinc is fed into a 'lead' column where approximately 33 per cent of the zinc is boiled off from the top, together with all the cadmium.
- This mixture is then cooled to a liquid and fed to a 'cadmium' column to produce a cadmium alloy and a special high grade zinc (up to 99.995 per cent purity).
- The liquid zinc from the base of the 'lead' column is separated before being treated with metallic sodium to remove small traces of arsenic. This cast zinc (98.55 per cent pure) is suitable for galvanising and making brass.

The process is very similar to the fractional distillation of crude oil – the metals with the lower boiling points come off at the top of the column, while the metals with the highest boiling points remain at the bottom.

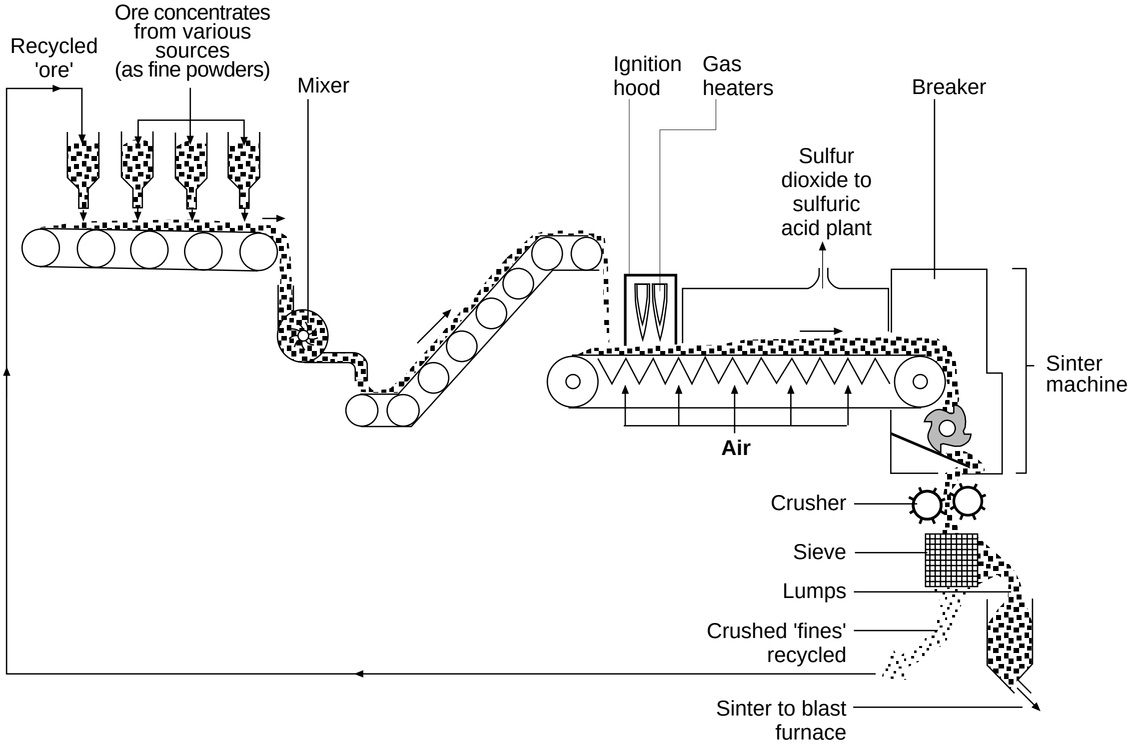
The refining process is shown in the figure ‘Refining’.

Economics

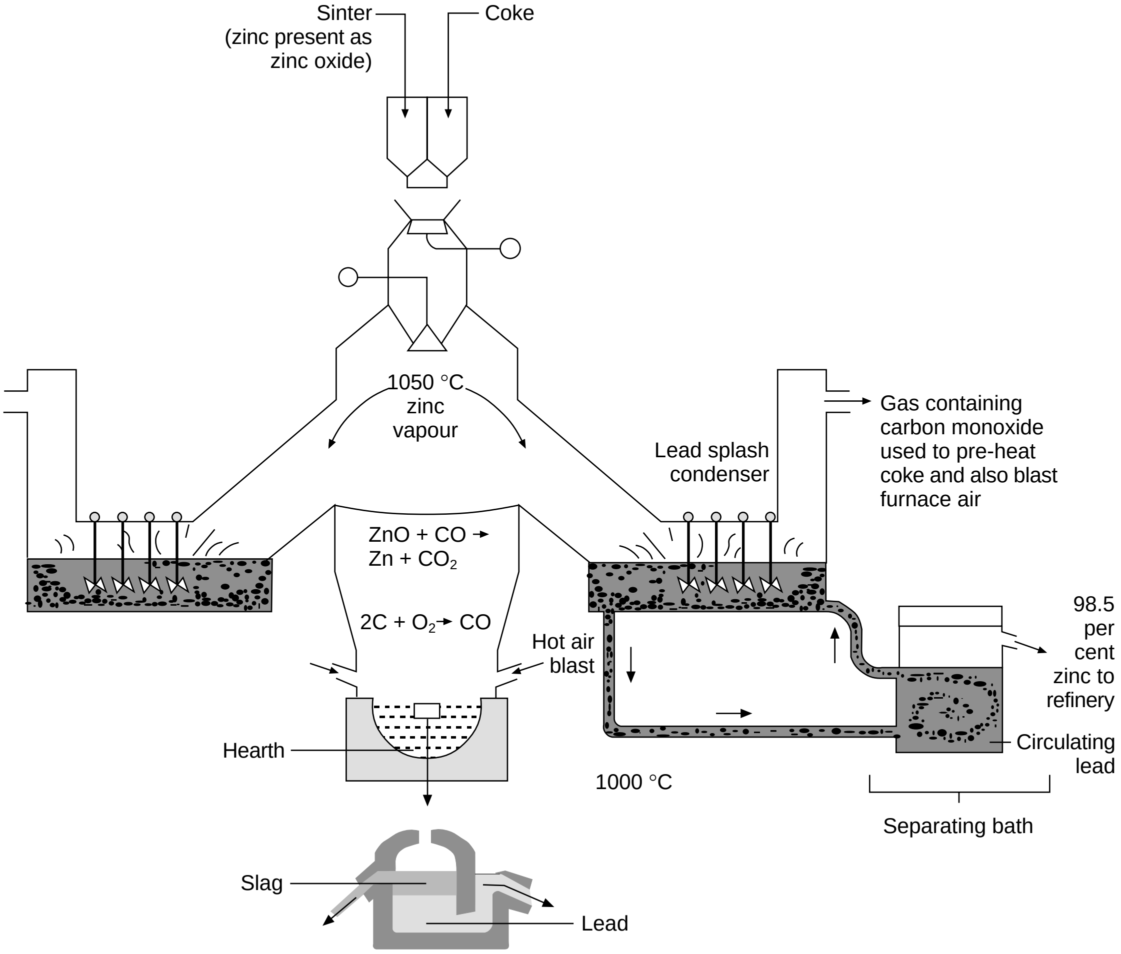
Zinc production is an international operation. The ore concentrates and other raw materials are bought and the products sold in US dollars. This means that changes in the $/£ exchange rate can significantly affect the profitability of the company.

Environment

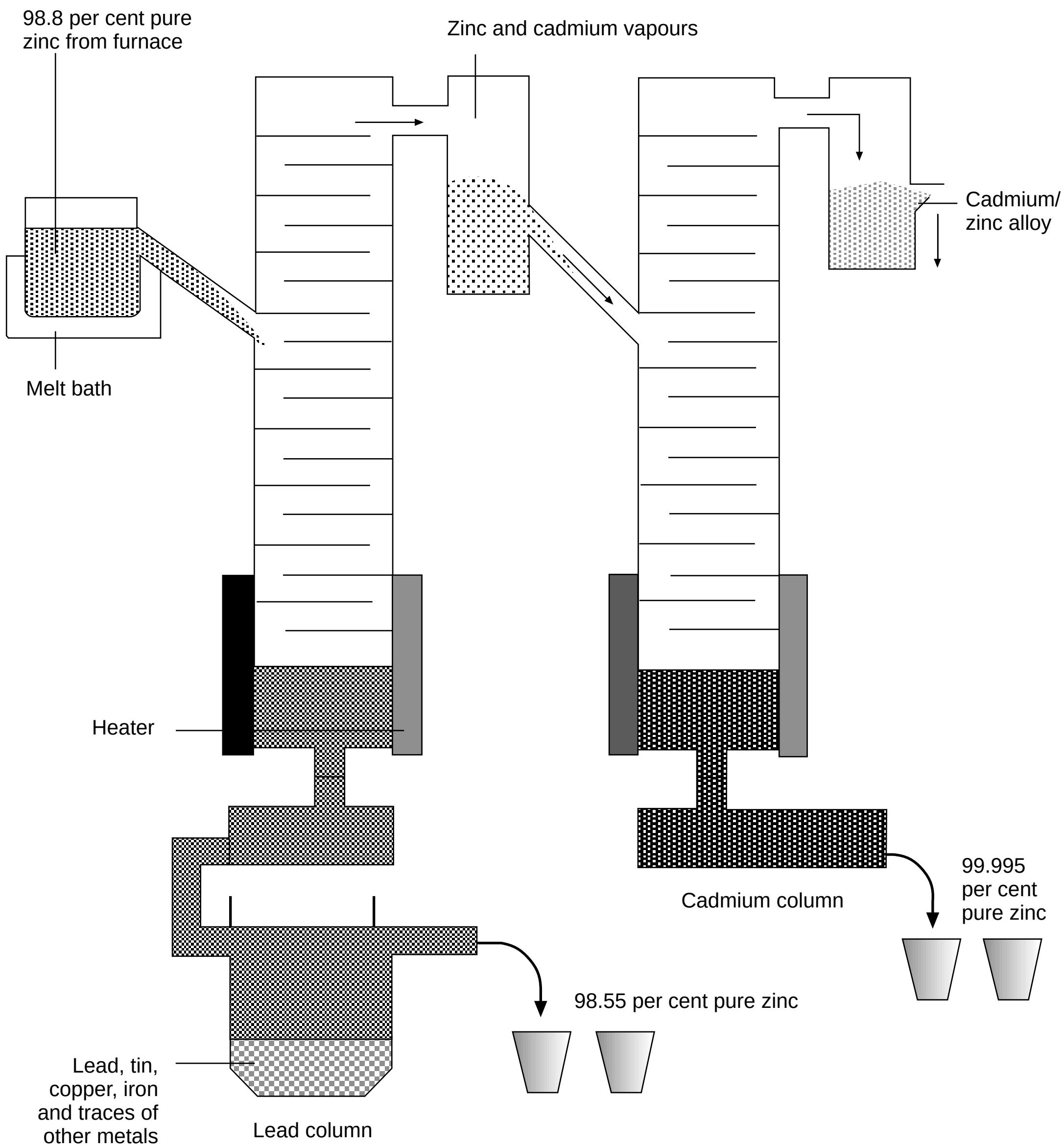
The authorised limit of lead emissions from the whole plant is 3.0 kg per hour. The company gives a quarterly magazine *Community Link*, to local residents, which informs them of current emission levels. Since 1989/90 emissions of lead have been kept well below the permitted level through continuous process improvement.


Recycled 'ore'
Ore concentrates from various sources (as fine powders)
Mixer
Ignition hood
Gas heaters
Breaker
Sulfur dioxide to sulfuric acid plant
Sinter machine
Air
Crusher
Sieve
Lumps
Crushed 'fines' recycled
Sinter to blast furnace

Sintering


Sinter
(zinc present as
zinc oxide)
Coke
1050 °C
zinc
vapour
Lead splash
condenser
Gas containing
carbon monoxide
used to pre-heat
coke and also blast
furnace air
ZnO + CO →
Zn + CO2
2C + O2 → CO
Hot air
blast
Hearth
98.5
per
cent
zinc to
refinery
Circulating
lead
1000 °C
Separating bath
Slag
Lead

Smelting


98.8 per cent pure
zinc from furnace
Zinc and cadmium vapours
Cadmium/
zinc alloy
Melt bath
Heater
Cadmium column
99.995
per cent
pure zinc
98.55 per cent pure zinc
Lead, tin,
copper, iron
and traces of
other metals
Lead column

Refining

Zinc smelting at Avonmouth

Use the passage and your knowledge of chemistry to answer the following questions.

1. **(a)** Why is Avonmouth a suitable location for the zinc smelting works?

   (b) Write word and then balanced chemical equations to represent:

   (i) zinc sulfide (ZnS) being heated in air (oxygen) to give zinc oxide and sulfur dioxide;

   (ii) zinc oxide (ZnO) being reduced to zinc in the furnace by either carbon monoxide, CO, or carbon, C.

   (iii) Explain simply what is meant in the passage by the term *reduced*.

   (c) Give two reasons why the furnace temperature has to be carefully controlled.

   (d) The passage refers to the *rapid quenching* of zinc vapour. Explain what this means and why it is important in this process.

2. In the zinc smelting process, sulfur dioxide is produced which is made into sulfuric acid by the Contact Process.

   (a) Write balanced chemical equations for the following reactions which are part of the Contact Process:

   (i) sulfur dioxide reacting with oxygen to give sulfur trioxide

   (ii) the reaction of sulfur trioxide with water to give sulfuric acid.

(b) Calculate the maximum mass of sulfuric acid which could be produced from 64 tonnes of sulfur dioxide.
(Relative atomic masses: H = 1; S = 32; O = 16.)

(c) If the sulfur dioxide came from pure marmatite, how much of this mineral would be needed?

3. (a) The lead industry is always under close scrutiny as far as health and safety issues are concerned. Employees undergo regular and frequent blood tests. Until very recently women were not allowed to work on the smelting plant.

(i) Suggest reasons for these statements.

(ii) Give one important use of lead.

(b) Wherever possible in this works, materials and chemical plant are under fume hoods so that the vapours can be removed and treated.

(i) Give two harmful vapours (apart from lead) present in this smelting works and say how each is potentially harmful.

(c) Suggest one problem posed by the slag

4. (a) Suggest why managers in the zinc works keep a close watch on the US $/£ sterling currency exchange rates.

(b) The number of employees at the plant has fallen from 750 to around 500 in recent years. Suggest two reasons for this.

(c) Write down two reasons a manager in the company might give for publishing *Community Link* and sending it to local residents.

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____

(d) Suggest two factors which would influence the proportion of ores that are mixed to make the furnace feed.

____

____

5. a) The lead bullion produced contains copper, silver and gold. What name is given to the area of the Periodic Table containing copper, silver and gold?

____

(b) Deduce from the passage which is denser, molten lead or molten zinc. Give a reason to support your answer.

____

____

(c) The difference in boiling points of zinc and cadmium is used to separate them.

(i) Deduce from the passage which has the higher boiling point, zinc or cadmium. Give a reason to support your answer.

____

(ii) What name is given to this type of separation process?

____

(iii) Give one other important industrial application of this separation process.

____

____

Zinc extraction

1. a) Use the passage *Zinc at Avonmouth* to help you fill in the labels on the diagrams 'sintering', 'smelting' and 'refining'.
Write short notes under each diagram to explain what is happening.

b) Suggest why a large surface area is useful for the material for the blast furnace produced after sintering.

____

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____

c) Explain why the process of obtaining zinc from zinc oxide in the blast furnace is called a reduction.

____

d) Write a word and balanced symbol equation to represent this reduction, which uses carbon monoxide (CO) as the reducing agent and produces carbon dioxide (CO_2) in the process.

____

____

e) Iron is also extracted in a blast furnace, but it is not separated from impurities in the same way as zinc. What difference in the properties of the two metals explains this.

____

____

2. a) Represent the pie chart on the 'uses of zinc' as a block graph (using the values for tonnes)

b) Which way of presenting data would be most useful for:

i) a zinc manufacturer who must decide in which form to produce zinc

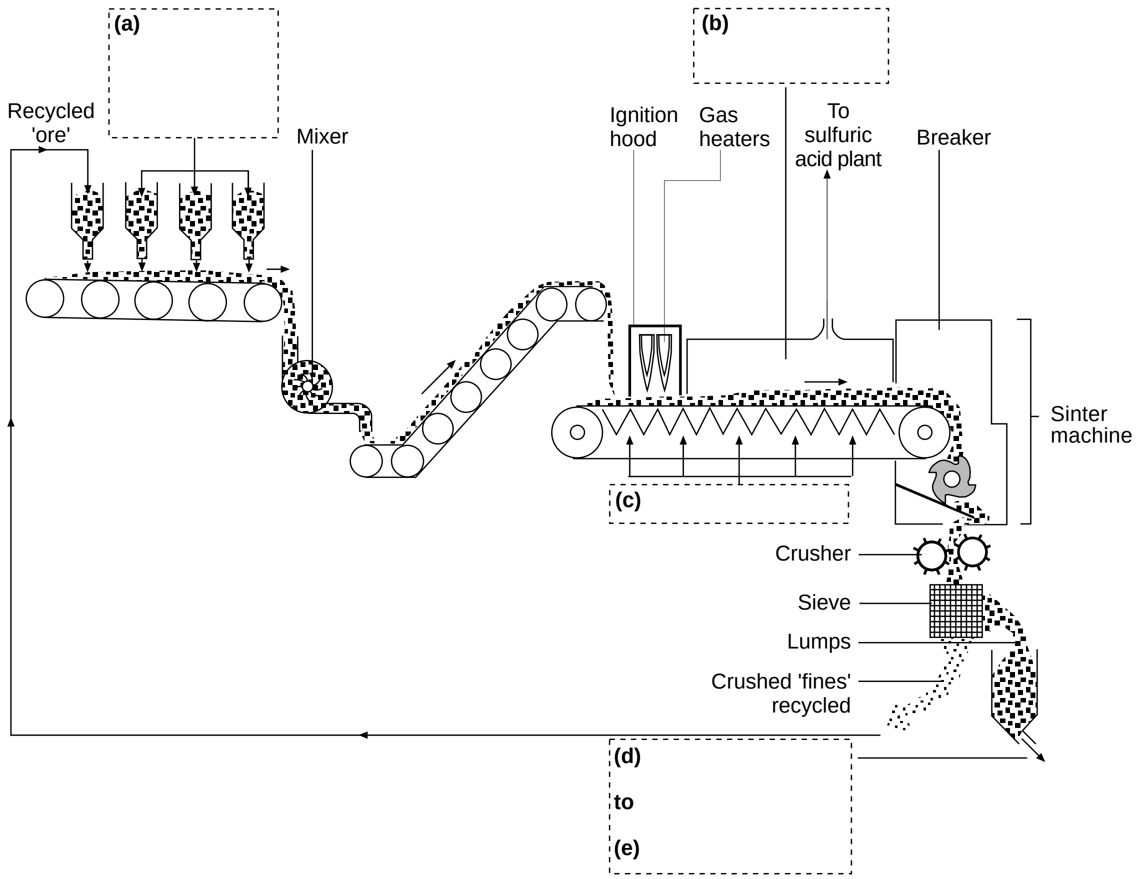
____

____

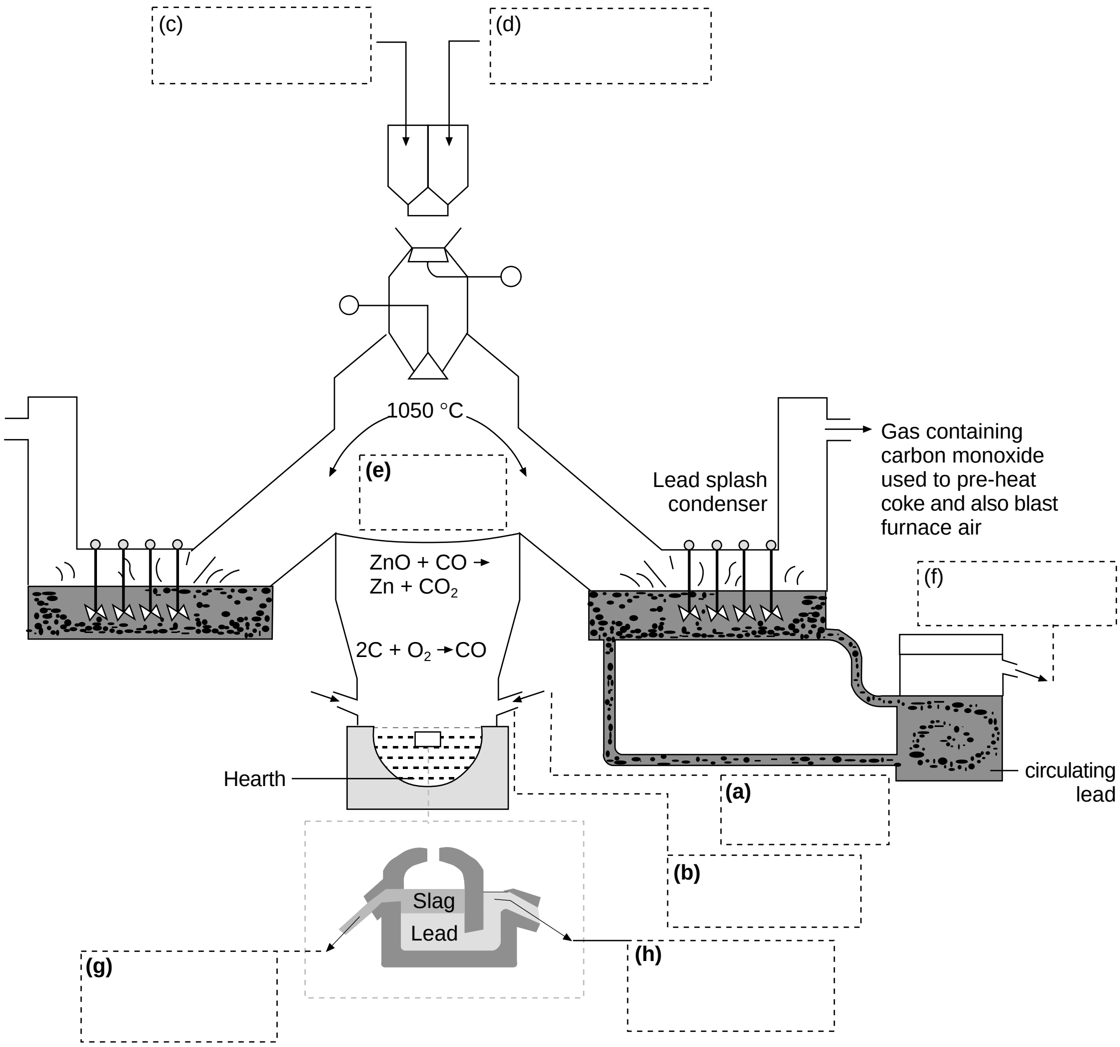
ii) a zinc manufacturer who must decide how much ore to import? Explain your answers.

____

____

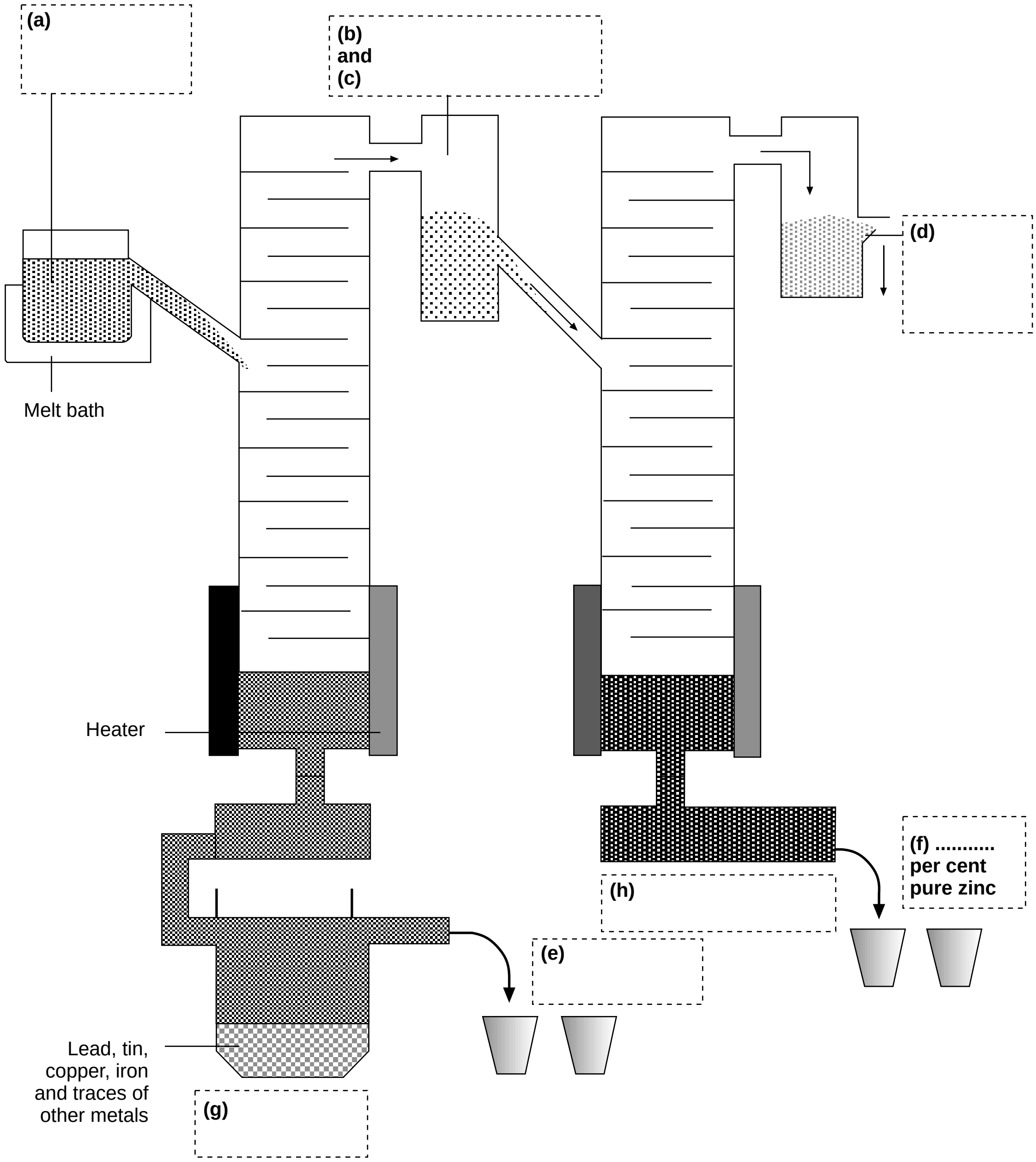

(a)
(b)
Recycled 'ore'
Mixer
Ignition hood
Gas heaters
To sulfuric acid plant
Breaker
Sinter machine
(c)
Crusher
Sieve
Lumps
Crushed 'fines' recycled
(d)
to
(e)

Sintering



(c)
(d)
1050 °C
(e)
ZnO + CO → Zn + CO2
2C + O2 → CO
Lead splash condenser
Gas containing carbon monoxide used to pre-heat coke and also blast furnace air
(f)
Hearth
(a)
(b)
circulating lead
Slag
Lead
(g)
(h)

Smelting



(a)
(b)
and
(c)
Melt bath
(d)
Heater
(f) ....
per cent
pure zinc
(h)
(e)
Lead, tin,
copper, iron
and traces of
other metals
(g)

Refining

Zinc – ancient mystery, modern marvel

Blue roofs

The roofs of Paris

When the architect Baron Haussman was rebuilding Paris after the Napoleonic wars of the early nineteenth century he had a vision of a new city with wide streets and elegant buildings. He chose zinc sheet as the material to roof all the buildings. Zinc does not corrode, but when it weathers it produces a light blue effect which is now one of the features of France's capital city. Some zinc roofs have lasted over 100 years without having to be repaired.

Baron Haussman's choice was a bold one, because it was only in 1805 that a way of rolling zinc sheet was invented and in the early 1800s the extraction of zinc from its ores on a large scale was very new.

In 1836 another use for zinc was found. This was galvanising. Carefully prepared steel sheet is dipped in molten zinc, giving the steel a thin, protective coating of zinc. The layer of zinc does not rust and only corrodes very slowly, developing a layer of zinc oxide and zinc carbonate. Even when scratched the remaining zinc continues to protect the iron. Corrugated galvanised iron sheet soon became a cheaper if less elegant form of lightweight roofing material than zinc.

New England galvanised roofs

While the benefits of galvanising iron were recognised, one of the main uses of zinc up to the 20th century was in making an alloy that had been used for hundreds of years – brass.

Questions

The table below compares different materials used to make roofs.

1. Fill in the table with the answers to the following.

a) Make a list of the properties needed for a material to be a good choice for a roof and put them in the column marked 'properties'.

b) Go down the list and tick if a thatched roof has this property.

c) Choose another material that you know is used for roofs. Write its name in the space in the table and tick the list if it has the property.

d) Now do the same for zinc as a roofing material.

Properties	Thatch	Other material	Zinc

2. Why was it a bold move to use zinc for roofs in the early 1800s?

3. Dustbins are often made from galvanised steel. What is galvanised steel, and why is it better than plain steel?

4. Zinc is used to make brass. Give examples of uses of brass and for each use explain why brass is a suitable material.

‘Tutty’ – the metal that turns copper into ‘gold’

Ancient civilisations (before about 1600 BC) knew only seven metals and zinc was not one of them. However they knew that if copper was mixed with a whitish mineral, called calamine, and charcoal and then heated fiercely in a fire the copper became changed into a hard, golden metal that we call brass.

1. Suggest the names of seven metals known to the ancients? (Hint: think about the reactivity series or use a data book, database or CD-ROM.)

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____

Calamine is impure zinc carbonate but when it is heated alone with charcoal no metal is produced. The metal smelters did not realise that zinc was being formed as a vapour and that when it met the atmosphere it immediately re-oxidised to form zinc oxide.

2. Write a word and a symbol equation for the reaction of zinc vapour with oxygen.

____

____

The metal workers of Rajastan in Northern India were the first to solve the problem of extracting zinc around about the 14th century. The Indians had long experience in smelting copper, lead and silver and also had access to large amounts of zinc ore.

3. Use a data book or CD-ROM to find out the melting and boiling points of copper, lead, silver and zinc. What do you notice about the boiling point of zinc?

____

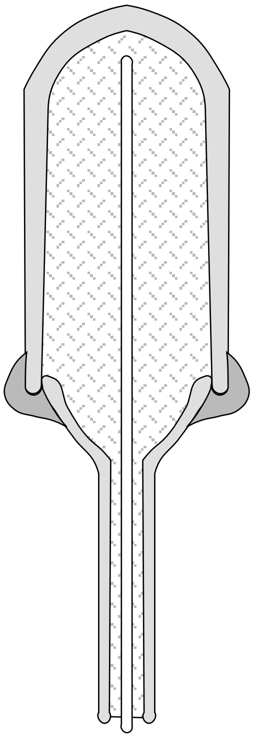
____

____

____

____

After first roasting the ore to get rid of sulfur it was mixed with charcoal and a number of other materials such as treacle, which were supposed to have magical properties. The mixture was then packed into clay retorts about the size and shape of an aubergine,. A wooden stick pushed into the retort would, when burnt out, provide an escape hole for the zinc vapour.



A clay retort used for extracting zinc

The retorts were stacked in a closed furnace and heated to over 1100 °C. The zinc ore was reduced to zinc which boiled off. The zinc vapour escaped from the retorts and was collected in a condenser. Because air was not allowed into the furnace, the zinc was prevented from returning to its oxide. The liquid metal was cast into ingots.

4. Charcoal is mainly the element carbon. Write a word and symbol equation to show how carbon reacts to reduce zinc oxide to zinc.

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In the 17th century the Chinese copied the Indian method and samples of zinc began to arrive in western Europe. There was great excitement over this new metal which was known as 'tutty'. The method of its extraction and even the ore it was obtained from were unknown in Europe but it was very useful for mixing with copper to make better brass alloys. In the early 1700s zinc imported from the East was very expensive. However, the secrets of its origin were known by this time, and calamine, the main zinc ore, was cheap and available. It was not long before a European discovered the Indian methods.

5. Find out some of the uses of zinc.

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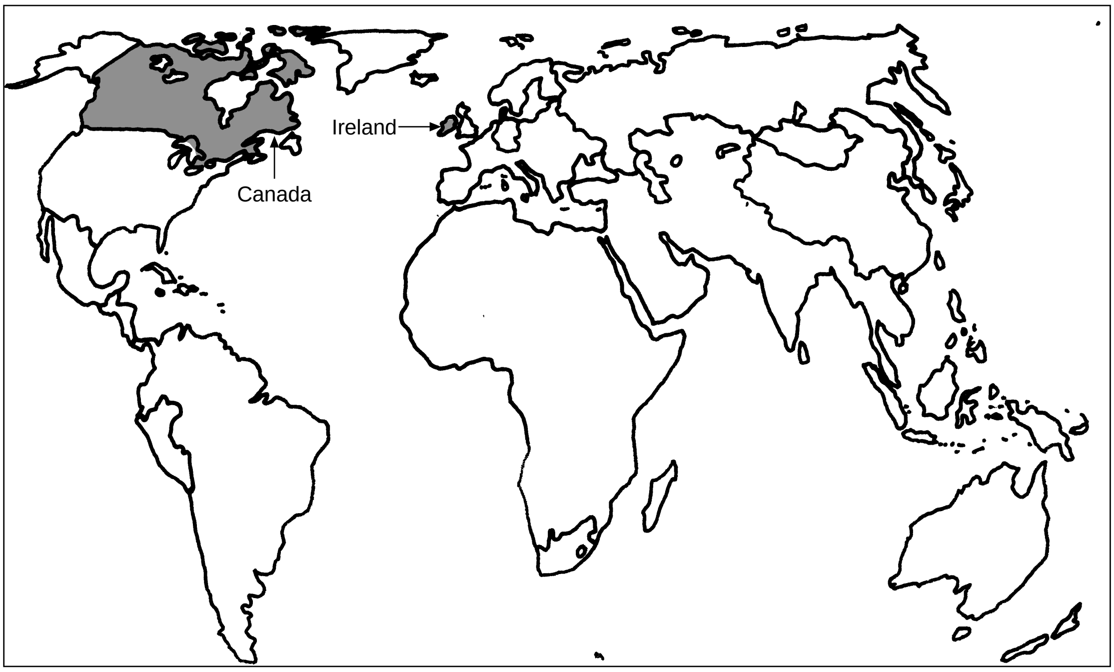
In the beginning, there was… ZINC

Where in the world do we mine zinc?



1. Use an atlas to mark on the map these other zinc producing countries: Mexico, Germany, Peru, South Africa, China, Australia.

   Is zinc abundant? Here are the average concentrations of zinc worldwide:

Rocks	70 ppm
Soil	150 ppm
Fresh water	20 ppm
Sea water	1 ppm

   (ppm = parts per million)

2. To help you to imagine what 70 ppm means, try the following. Count the number of pages in an exercise book
   Write down roughly how many books you need for a million (1 000 000) pages.

   Work out and write down how tall a stack of this many books would be.

   ____

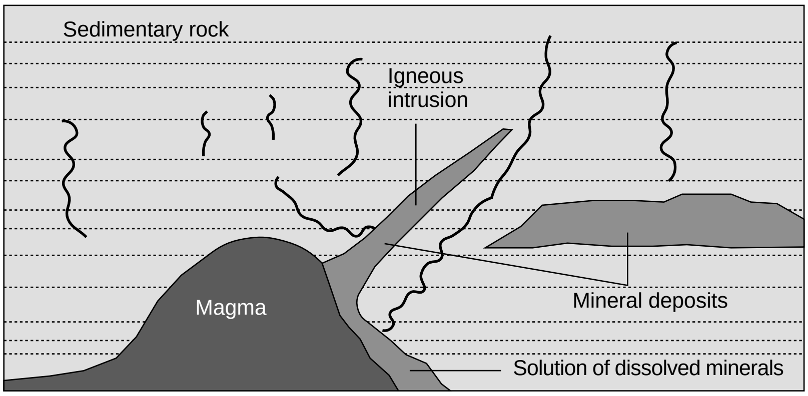
Now imagine hiding 70 £5 notes at random in the stack.

Would it be easy to find the £5 notes?

You can see that, on average, zinc is not a very abundant element (in fact it is slightly less abundant than nickel and slightly more abundant than copper). Luckily, natural processes in the rock cycle have concentrated zinc minerals in several places. When the concentration is high enough, it may be worthwhile mining this ore body.

The formation of zinc deposits

The figure below shows some of the ways that the rock cycle gathers together (concentrates) zinc minerals.



Formation of mineral deposits

- Water flows down rock cracks and becomes trapped deep within the Earth's crust.
- Compounds (called minerals) of zinc and some other metals, which are present in the magma, will dissolve in hot, pressurised water so a solution forms.
- This can be carried upwards in an igneous intrusion, or pass upwards into sedimentary rocks (often limestone).
- The minerals are then deposited as the solution cools.
- Sedimentary or igneous rocks can be metamorphosed (changed) by heat and pressure, still carrying their enriched mineral deposits. There is a a very large deposit of zinc minerals in Australia which was formed in this way.

3. What is meant by

a) sedimentary rock

____

____

b) igneous rock

____

____

c) metamorphic rock?

____

____

d) an igneous intrusion?

____

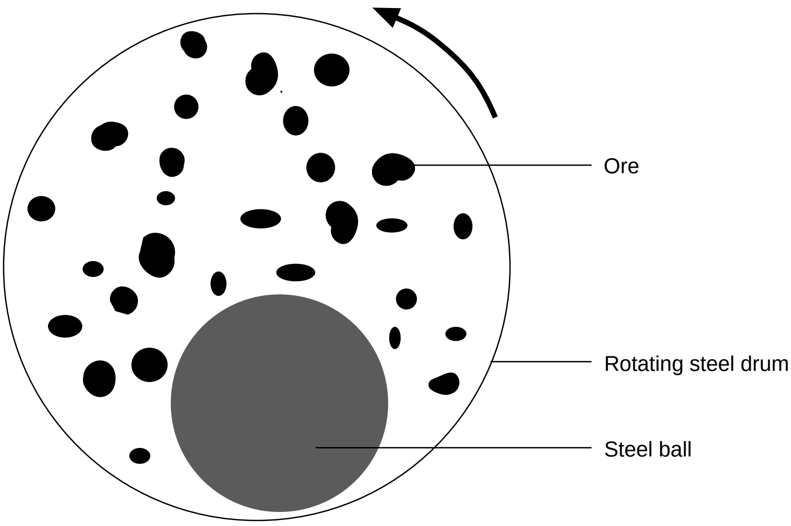
____

4. Would you expect the crystal size of the rock in an igneous intrusion be large or small? Explain your answer.

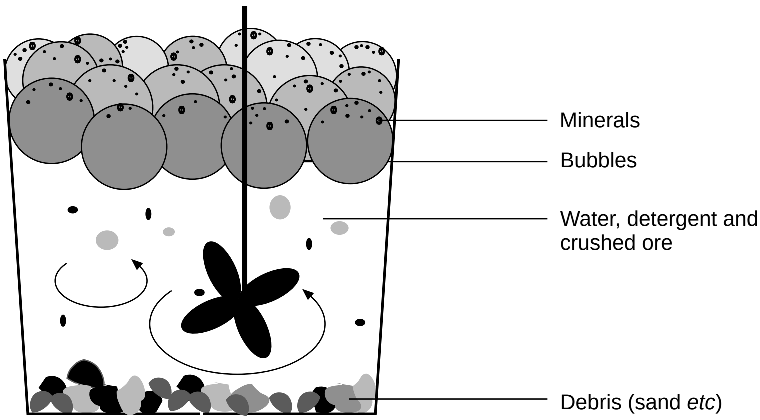
A commercial ore might contain 50 000 ppm of zinc. Now you're looking for 50 000 £5 notes in the stack of pages.

5. What is meant by the word ore?

Even a rich ore body has lots of useless sandy minerals in it. These must be removed and the ore (such as zinc sulphide) concentrated. Nowadays it is done by crushing followed by froth flotation



1. Crushing



2. Froth flotation

6. a) How does the crushing process work?

b) Why is process 2 called froth flotation?

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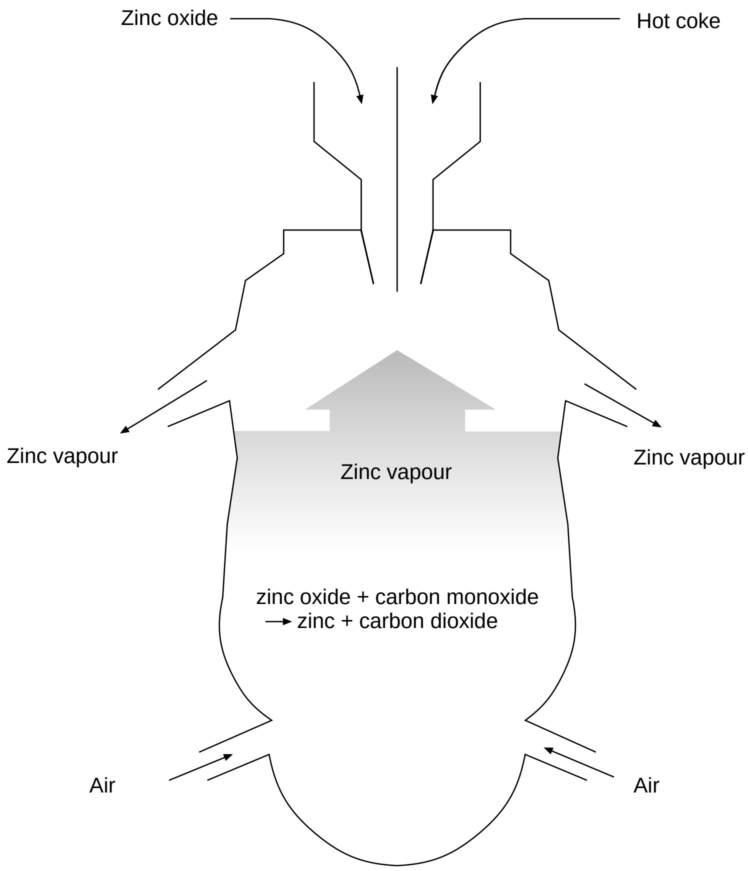
After further processes the ore is ready for smelting in a blast furnace.



Blast furnace

7. What is happening to the zinc oxide in the furnace?

____

____

William Champion – zinc smelter

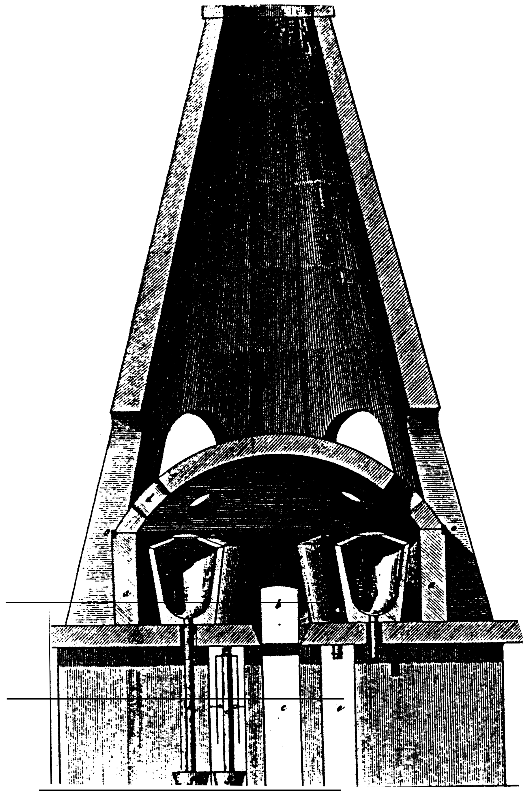
William Champion began the production of zinc in the UK. William was born in 1710, the youngest member of a well-off family that lived in Bristol. William's father, Nehemiah, a landowner, had started a company in 1700 to manufacture brass. William worked for his father in the foundry as a young man but in 1732, perhaps impatient and ambitious, he left to set up his own works. There are stories that he travelled in Europe dressed in rags to learn the secrets of foreign metal smelters and that he had contacts with a sailor from China who had seen zinc smelters working.

William Champion's house in Kingswood, Bristol

In 1737 William had a zinc smelting furnace operating in Bristol and he took out a patent in 1738. By 1746 he had moved to a much larger site on the city's outskirts in the village of Warmley. Here 600 workers, mainly local but some from abroad, laboured at William's copper and zinc smelters and brass foundries and 1400 people were employed by other companies turning the brass into containers, plates, and enough wire to make ten million pins a week.

William was a Quaker and showed some concern for his employees and provided them with housing at the Warmley works. He also built a large house for himself in the fashionable Dutch style. The factory site was powered by water-wheels fed by a large artificial lake which had a huge statue of the Roman god Neptune at its centre.

William's method of smelting zinc became known as the English method. An octagonal cone-shaped furnace contained up to eight crucibles.



William Champion's furnace

After the charge of preheated calamine (zinc oxide) and charcoal (carbon) was poured into the crucible, the cover was sealed. An iron pipe passed through the bottom of the crucible and into pans of water outside the furnace. When the furnace was fired, the temperature in the crucibles rose to over 1100 °C and zinc vapour was formed which passed down the iron pipes. Zinc condensed and ran into the pans of water. No air was allowed to enter the pipe or crucible so the hot zinc was prevented from reacting with oxygen. Only about 1–2 kg of zinc was produced by each charge of the crucibles. It was very hot work for the workers looking after the fires and emptying out the slag from the crucibles.

Brass making was profitable but William's ambitions lead him into some unsuccessful business projects at Bristol docks. In 1769 he was bankrupt and forced to sell his company to his rivals in brass manufacturing, the Bristol Brass Wire Company. William died in 1789 but the works that he built continued to operate for another 100 years.

Questions

1. Highlight or underline the section in the passage about the process of making zinc.

2. Explain what is meant by 'zinc condensed and ran into the water'.

____

3. Why was it important that no oxygen was allowed to react with the zinc?

____

4 **a)** Write a word and a balanced symbol equation for the production of zinc from zinc oxide, assuming that carbon monoxide, CO, is produced in the reaction.

____

____

b) If one crucible produced 1.3 kg of zinc, how much
i) zinc oxide and ii) carbon are needed in theory in the crucible to produce this amount?
(Relative atomic masses: Zn = 65, O = 16, C = 12.)

____

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c) How much of each is needed for the whole furnace?

____

d) Would you expect the crucibles to need more or less than this amount, or this amount exactly? Explain your answer.

____

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5. Imagine that you are one of Champion's workers employed to operate the zinc furnaces. Describe a day in your life.

From horizontal to vertical – zinc smelting in the 20th century

In 1914 nearly all the UK's zinc supplies were imported from Belgium and Germany. These two countries took almost all the zinc ore mined from the vast deposits in Australia.

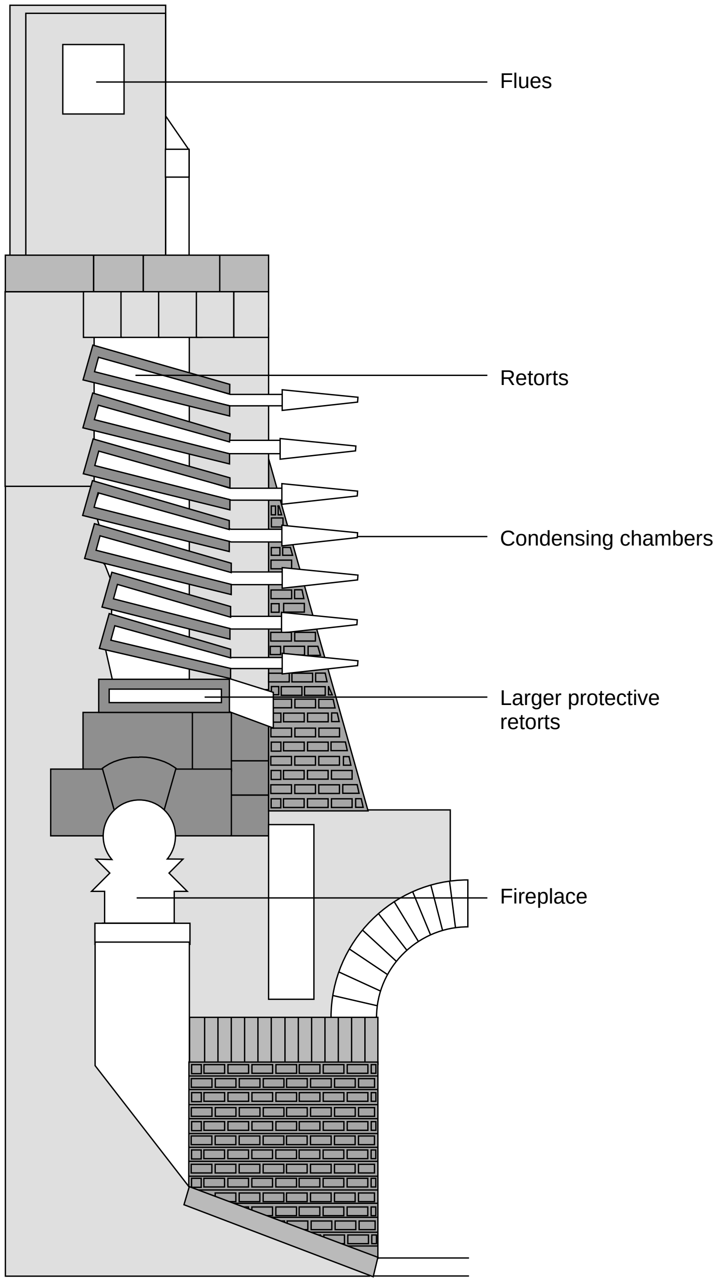
The outbreak of World War I exposed the UK industry's shortsightedness. Zinc was in demand for the arms industry and for most of the war the UK relied on supplies imported from the US. The government decided that the country must not be dependent on foreign sources of zinc. After a mismanaged attempt in 1916 which foundered in 1923 the UK zinc industry was finally established in 1929 under the name National Smelting Company and later the Imperial Smelting Corporation Limited. Avonmouth, near Bristol on the Bristol Channel, had been chosen as the site back in 1916 and the first plant to be built used the traditional **Belgian method**

The Belgian process (see following page), consisted of furnaces packed with small horizontal retorts. The retorts were charged with zinc ore and coke and then sealed to stop air entering. On heating, the zinc formed as a vapour which was collected at the end of the retorts and condensed. The Avonmouth plant was intended to have 24 furnaces with 9216 retorts in all, producing 70 000 tonnes of zinc a year. It was never completed. However, the ore roasting plant was built as it gave off sulfur dioxide which could be turned into sulfuric acid, a valuable commodity.

In the 1930s Imperial Smelting adopted the **vertical retort process**, developed in the US, in which briquettes of zinc ore and coke were fed in a vertical column.

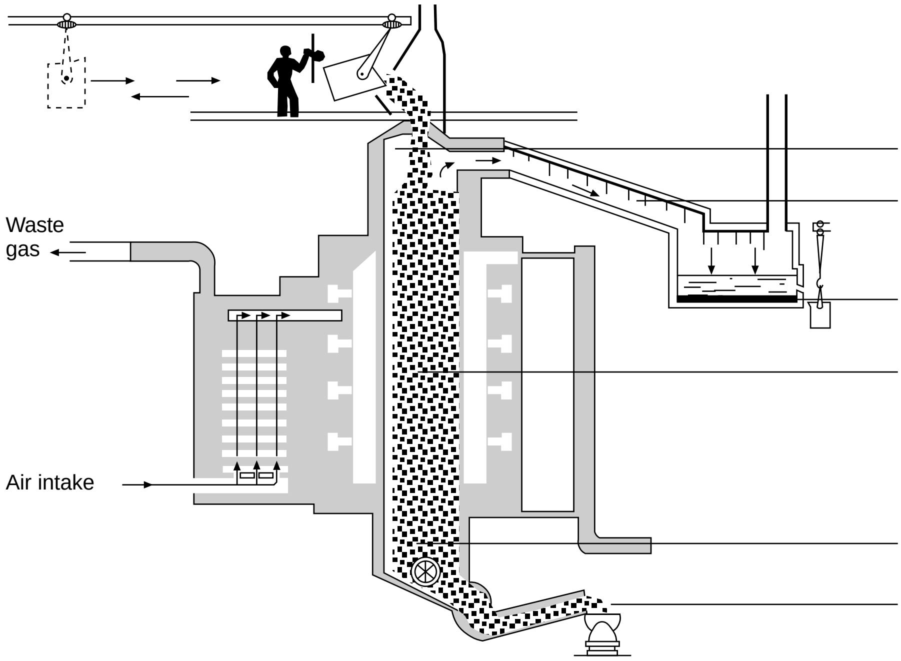
When the column was heated, the zinc boiled off to be collected in an airtight condenser. The vertical retorts were a great improvement as they required less back-breaking labour and could produce far more zinc in a continuous process. Their biggest disadvantage was the cost of fuel required to heat the outside of the retorts and the high cost of the refractory bricks, made from silicon carbide, which were needed to line the furnace.

Imperial Smelting hoped to use a blast furnace method where hot air would ignite the coke and reduce the zinc ore to zinc vapour. But blast furnaces had a big problem. The air that was blown in oxidised carbon monoxide to carbon dioxide. When the temperature of the zinc vapour and carbon dioxide fell below 1000 °C they would react to re-form zinc oxide. In 1943 L.J.Derham had an idea. He suggested that to remove the zinc, the zinc vapour from a blast furnace could be passed into a chamber containing molten lead. A paddle wheel splashed the lead, and the zinc vapour dissolved in the lead droplets. The solution of zinc in lead was then pumped off. When the mixture was cooled to approximately 430 °C, molten zinc settled out on the surface of the lead to be skimmed off. The blast furnace also produced lead from the mixture of ores that were used as the charge and cadmium, a common impurity in zinc ores, could also be recovered by redistilling the zinc.



The Belgian process
(from W.R. Ingall. Lead and zinc in the United States. Hill Publishing Company, 1808)

Experiments showed that Derham's idea worked, but there were many problems to be solved. In 1949 the first full scale Imperial Smelting Furnace was built at Avonmouth followed in 1952 by the second. Over the next 40 years the process was adopted in the many parts of the world where electrolysis of zinc ores is not an economic possibility. Also, mixed ore concentrates of zinc and lead can be used in the blast furnace, whereas the rival electrolytic process requires clean zinc concentrates. Today Avonmouth produces about 100 000 tonnes of zinc a year from one furnace and supplies nearly half of the UK's needs.



The vertical retort process

From E.J. Cocks and B. Walters,

A history of the zinc smelting industry in Britain. London: Harrup, 1968

Questions

1. The horizontal retort method was a batch process while the vertical retorts allowed continuous production of zinc. Why is continuous production an advantage over batch processes?

____

____

____

2. State two other advantages of the imperial smelting furnace (ISF) over the original Belgian horizontal retorts.

____

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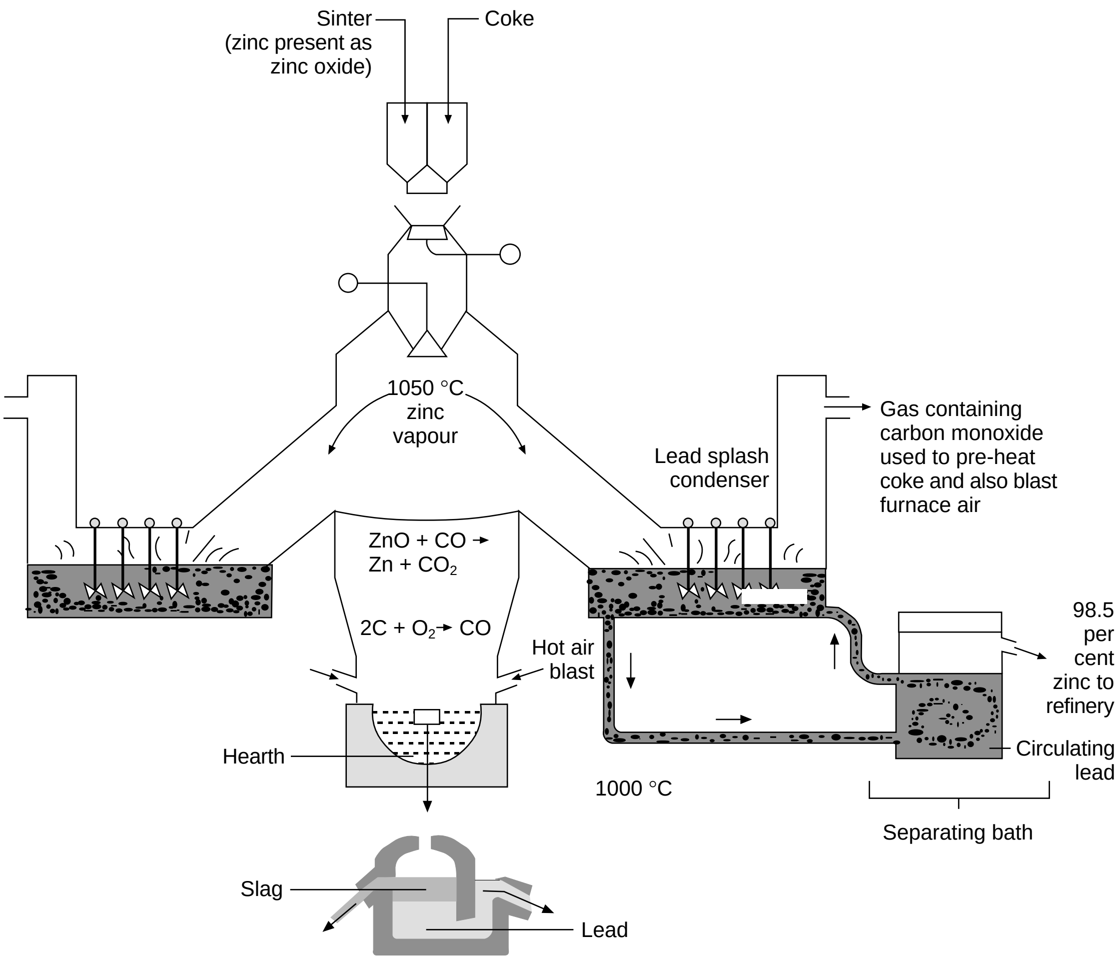
3. Write an equation for the reaction of zinc oxide with carbon monoxide.

____

4. Write an equation for the reaction of zinc with carbon dioxide.

____



Derham's blast furnace

5. Some countries still operate the vertical retort first used in the 1930s and there are even some of the original Belgian horizontal retorts in use. Suggest a reason why these outdated processes are still used.

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____

____

6. What might have been the consequences in World War II if the UK had not established its own zinc industry?

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____

____

7. Zinc manufactured in the UK by the imperial smelting furnace (ISF) process is in competition with imported zinc for many uses. If imported zinc is cheaper what reasons are there to maintain the UK industry?

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____

8. Why was Avonmouth considered a good site for establishing the UK zinc industry?

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Uses of zinc

A Zinc for die-casting metal toys

The metal that was once used to make detailed models, for example of toy soldiers, was lead. Now, zinc-based die-casting alloys are used.

Here are some properties that make zinc alloys suitable.

- **Density** – Being a lot denser than plastic, metal toys have a pleasantly heavy feel.
- **Melting point** – Zinc melts at around 420 °C, similar to lead (328 °C), and much lower than copper or steel.
- **Fluidity** – When alloyed with a few per cent of magnesium and aluminium, zinc makes a molten metal which can be forced under pressure through a tiny hole into a steel die (like a mould) where it quickly cools and sets without shrinking.
- **Precision** – The finished toy is tough, strong and accurately shaped.
- **Corrosion resistant** – The finished toy will not rust away,

Questions

1. Which is very toxic – zinc, lead or plastic?

____

2. Which of these three materials cannot be given a high gloss paint finish?

____

____

3. Why is it useful to have a low melting point material for model making?

____

____

4. Why must molten zinc alloy cool and solidify quickly in the steel die?

____

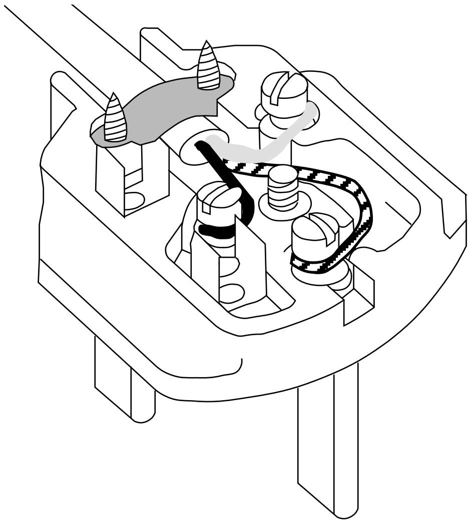
____

B Zinc for brasses

Brass is an alloy (metal mixture) of copper and zinc. Rather than brass we ought to say brasses, because brass alloys can have anything between 20 per cent and 45 per cent zinc. The alloy gives a harder and stronger metal than zinc or copper alone, has high electrical conductivity, and is fairly corrosion resistant.

Brass is a good metal for ornamental use because it can be given such a high shine.

Questions



An electrical plug

5. Explain why brass is more suitable than copper for the pins on a plug, yet copper is used for the wiring.

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____

6. Give two more places in the house where you often see brass, and suggest why brass is a suitable metal for each use.

____

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C Zinc for making zinc oxide, ZnO

- Zinc oxide helps to keep your wheels bouncing along.
  Tyres contain about 5 per cent by weight of zinc oxide. Rubber in its natural state is a soft and stretchy material with long tangled chains of molecules. Zinc oxide is an important ingredient for the vulcanisation of rubber – the process that makes a tougher structure with more crosslinks between the molecules.
- Zinc oxide makes it all better.
  Plasters and ointments with zinc oxide in them help heal wounds. This is because zinc oxide prevents both bacteria and fungi from reproducing (it is called a bacteriostat and a fungistat).
- Zinc oxide is used as a sunscreen too, being a good absorber of ultraviolet light and a white, opaque compound. It has a low toxicity.
- Zinc oxide is also used in 'cattle-lick' because the cows are healthier if it is included in their diet. When zinc oxide is added to pig food it minimises skin warts.

Questions

7. Write down some properties of a material which would make a good tyre.

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____

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8. Why is zinc oxide used so much in nappy creams?

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Zinc – for the roof over your head

The rain falling on a building must be drained away safely so that the wooden roof beams do not rot and the house below stays free from damp. Metal sheets are sometimes used as roofing material.

In Copenhagen they use copper

In London they use lead

In Paris they use zinc

Remember (or look up) the reactivity series.

1. Write down the three metals above in order of reactivity with the most reactive at the top of the list.

____

____

____

Zinc may seem too reactive to be left out in all weathers. In fact a chemical reaction occurs which takes place as it weathers, and protects it from further attack.

2. Find the colours of the minerals which are ores of the metals used as roofing materials and fill them in the spaces in the table.

Mineral	Chemical name	Formula	Colour
Sphalerite	Zinc sulfide	ZnS	
Galena	Lead sulfide	PbS	
Malachite	Hydrated copper(II) carbonate	$CuCO_3.Cu(OH)_2$	

Weathering – ageing well

3. The table below shows what happens to the different roofing metals as they weather in wind and rain. Fill in the last two columns. You may need a book of data, database or CD ROM.

Metal	Colour of roof when new	Colour after weathering (may take many years)	Colour of metal carbonate	Colour of metal oxide
Zinc	Shiny light grey	Dull bluish grey		
Lead	Shiny dark silvery grey	Dull whitish grey		
Copper	Shiny red-brown	Black, then green		

4. Explain what seems to be happening to the metals on the roofs.

____

____

5. Write word and balanced symbol equations for:

a) the reaction of zinc with oxygen

____

____

b) the reaction of copper(II) oxide (CuO) with carbon dioxide.

____

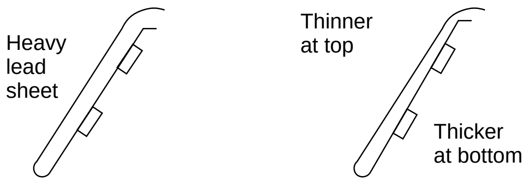
____

As it weathers, zinc slowly forms a thin layer of a mixture of zinc oxide, zinc hydroxide, zinc carbonate and zinc sulfide. All these compounds have the important properties of being insoluble in pure water and sticking strongly to the metal. This layer of weathered metal, called the patina, protects it from further attack. The same is true of copper and lead.

Why do metal roofs need replacing?

Metal roofing can deteriorate over the years for three main reasons.

1. Creep



Creep in lead roofing

A roof is under the stress of its own weight. Gradually that force can change the shape of the metal even though it stays in the solid state all the time. Lead, being so heavy and rather soft, is especially prone to this creep which is caused by layers of atoms sliding over one another.

2. Thermal expansion stress cracking

In the full glare of the sun, roofs warm up quickly and then cool by night. As a result, they expand and contract in daily cycles. This may cause stress cracks, or weaken the fixings which hold the metal onto the roofs. Alloying zinc with tiny percentages of copper and titanium reduces its coefficient of thermal expansion. This means that it expands and contracts less for a given temperature difference and so the thermal stresses are reduced.

3. Chemical weathering

Acid rain means that sulfuric and nitric acids are present in rain. These acids will react with the patina and form soluble sulfates and nitrates. Then the fresh metal below is also attacked.

Questions

1. What problems are caused by metal creep?

____

2. In what sort of climate would stress cracking be the greatest problem?

____

3. Rewrite the equations which show how the components of the patina react with sulfuric acid, filling in the missing words and formulae.

a) zinc oxide + sulfuric acid → ________ ________ + water

ZnO(s) + ________ (aq) → $ZnSO_4$(aq) + ________ (l)

b) zinc hydroxide + sulfuric acid → ________ ________ + water

$Zn(OH)_2$(s) + __________ → ________ + 2________ (l)

c) zinc carbonate + sulfuric acid → ________ ________ + ________ ________ + water

$ZnCO_3$ + ________ (aq) → ________(aq) + ________ (g) + ________(l)

4. Write word and balanced symbol equations for the reactions of the following compounds with nitric acid

a) zinc oxide,

____

____

b) zinc hydroxide

____

____

c) zinc carbonate

____

____

The different ways of coating steel with zinc

There are several ways to put a zinc coat on steel. Zinc is expensive, nearly eight times more expensive than steel, so the method is chosen to suit the cost of the object.

Hot dip galvanising

The whole steel object is plunged into a bath of molten zinc at 460 °C for several minutes. The zinc does more than just coat the steel. It forms strong metallic bonds where iron and zinc atoms change places in their structures. This makes the coat into an alloy, which is harder than either metal on its own. Galvanising is costly, but puts on a thickish layer which is useful for more valuable objects. However, modern techniques for making continuous sheets of galvanised steel reduce the thickness of the zinc coating, and the use of special zinc alloys reduces the thickness still further.

Zinc dust painting

This is the simplest method of all and it can be done by anyone. The dust is in a solvent which evaporates away, leaving the zinc coat.

It is easy and cheap to do but tricky if shapes are intricate.

Zinc spraying

A gas flame blows molten zinc onto the object, which can be any size. A really thick layer can be built up by spraying several times. This is suitable for something which needs to last for many years and which may be hard to respray.

Electroplating

The cathode is the steel object to be plated and the anode is pure zinc. This is good for smaller objects because the zinc layer is thin but very even.

Sherardizing

Hot but not quite molten zinc dust at 375 °C is rolled around in a box with clean sand and the object to be plated. A thin, not very even coat of metal sticks to the steel object even if it has a very intricate shape. This is a fast and relatively cheap method of protection.

Questions

1. A typical use for zinc-coated iron is for a climbing frame in a playground. The end product must be hard, smooth and long lasting. Which method(s) of coating are most suitable for this use and why?

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2. Which method is most suitable for coating nuts, bolts, nails and screws. Explain your answer.

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3. The Forth road bridge in Scotland is made of steel. Why is spraying with zinc suitable to protect it?

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4. Which method is best for treating a rust spot on a car?

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