Unit 10 · Metallurgy

ANSWER KEY · FOR TEACHERS

Full marks 50

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

K · 4

1. ore
2. gangue
3. flux
4. slag
5. calcination
6. pig iron
7. wrought iron
8. aqua regia

Each carries 0.5 mark.

2 Multiple choice

i. **c.** limestone — K · 1

Limestone breaks down to lime, CaO, which joins the silica of the gangue to form slag, $CaSiO_3$.

ii. **a.** zone of combustion — K · 1

The zone of combustion, at the bottom near the tuyeres, where the coke burns in the hot blast: 1,300–1,500 °C, and near 2,000 °C right in front of the tuyeres.

iii. **d.** wrought iron — U · 1

Wrought iron has less than 0.1% carbon; steel up to about 2%; cast iron 2–4.5%; pig iron about 3.5–4.5%.

iv. **b.** nitric oxide — U · 1

$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$. Nitric oxide is colorless, and turns brown (NO_2) in air.

v. **d.** silver — A · 1

Silver forms insoluble silver chloride, which coats it and stops the reaction. Gold, copper and iron all dissolve.

3 Label the diagram

K · 4

1. zone of reduction 400–700 °C
2. zone of slag formation 700–1,000 °C
3. zone of fusion 1,200–1,300 °C
4. zone of combustion 1,300–1,500 °C

Each carries 1 mark.

4 Very short answers

a. MARKING SCHEME — K · 1

✓ Fe_2O_3.

b. MARKING SCHEME — K · 1

✓ Carbon monoxide, CO.

c. MARKING SCHEME — U · 1

✓ Silver.

d. MARKING SCHEME — A · 1

✓ 9 g.

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5 Short answers

a. MARKING SCHEME — U · 2

- ✓ An ore gives its metal easily and profitably; every ore is a mineral.
- ✓ Some minerals cost too much to extract the metal from: clay contains aluminium, but bauxite is the ore.

b. MARKING SCHEME — U · 2

- ✓ $CaCO_3 \rightarrow CaO + CO_2$: limestone is the flux.
- ✓ $CaO + SiO_2 \rightarrow CaSiO_3$: the slag carries away the gangue.

c. MARKING SCHEME — A · 2

- ✓ A thin, tough oxide layer keeps the acid off the metal.
- ✓ Once it dissolves, $2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$ goes fast.

d. MARKING SCHEME — A · 2

- ✓ It is a strong oxidizing agent: its nitrate takes the metal's electrons more readily than its H^+.
- ✓ The nitrogen is reduced to an oxide of nitrogen (or ammonium nitrate); the hydrogen ends up in water.

6 Long answers

a. ANSWER — U · 4

- **Zone of combustion (1,300–1,500 °C):** coke burns in the hot air, giving heat: $C + O_2 \rightarrow CO_2$.
- **Zone of fusion (1,200–1,300 °C):** carbon dioxide meets hot coke and is reduced to carbon monoxide, $CO_2 + C \rightarrow 2CO$, taking in heat. Spongy iron and slag melt; iron dissolves carbon ($3Fe + C \rightarrow Fe_3C$); leftover oxide is reduced by carbon, $Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$.
- **Zone of slag formation (700–1,000 °C):** limestone decomposes, $CaCO_3 \rightarrow CaO + CO_2$, and lime joins silica to form slag, $CaO + SiO_2 \rightarrow CaSiO_3$.
- **Zone of reduction (400–700 °C):** carbon monoxide reduces the ore to spongy iron: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$.

Molten iron (pig iron) collects in the hearth under the slag, and each is tapped off.

MARKING SCHEME

- ✓ Combustion (1,300–1,500 °C): $C + O_2 \rightarrow CO_2$.
- ✓ Fusion (1,200–1,300 °C): $CO_2 + C \rightarrow 2CO$; the iron melts.
- ✓ Slag formation (700–1,000 °C): $CaCO_3 \rightarrow CaO + CO_2$; $CaO + SiO_2 \rightarrow CaSiO_3$.
- ✓ Reduction (400–700 °C): $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$.

b. ANSWER — A · 4

$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$ (blue solution).
$3Ag + 4HNO_3 \rightarrow 3AgNO_3 + NO + 2H_2O$ (colorless solution).
Iron, with cold, very dilute acid: $4Fe + 10HNO_3 \rightarrow 4Fe(NO_3)_2 + NH_4NO_3 + 3H_2O$; with somewhat stronger dilute acid: $Fe + 4HNO_3 \rightarrow Fe(NO_3)_3 + NO + 2H_2O$.
The nitric oxide given off is colorless, but at the mouth of the tube it meets air and is oxidized to brown nitrogen dioxide: $2NO + O_2 \rightarrow 2NO_2$.

MARKING SCHEME

- ✓ $3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$.
- ✓ $3Ag + 4HNO_3 \rightarrow 3AgNO_3 + NO + 2H_2O$.
- ✓ Cold, very dilute: $4Fe + 10HNO_3 \rightarrow 4Fe(NO_3)_2 + NH_4NO_3 + 3H_2O$.
- ✓ Colorless NO meets air: $2NO + O_2 \rightarrow 2NO_2$, brown.

c. ANSWER

Aqua regia is a mixture of three parts of concentrated hydrochloric acid and one part of concentrated nitric acid, by volume. The acids react to give nitrosyl chloride and chlorine: $HNO_3 + 3HCl \rightarrow NOCl + 2H_2O + 2[Cl]$. The chlorine turns gold into gold(III) chloride, $Au + 3[Cl] \rightarrow AuCl_3$, which dissolves in hydrochloric acid as chloroauric acid: $AuCl_3 + HCl \rightarrow HAuCl_4$. Overall: $Au + HNO_3 + 4HCl \rightarrow$

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$HAuCl_4 + NO + 2H_2O$. The gold dissolves as a yellow solution, because the chloride ions hold the gold ions as $AuCl_4^-$ as soon as the nitric acid forms them. A · 4

MARKING SCHEME

- ✓ 3 parts concentrated HCl to 1 part concentrated HNO_3, by volume.
- ✓ $HNO_3 + 3HCl \rightarrow NOCl + 2H_2O + 2[Cl]$.
- ✓ $Au + 3[Cl] \rightarrow AuCl_3$; $AuCl_3 + HCl \rightarrow HAuCl_4$, a yellow solution.
- ✓ Overall $Au + HNO_3 + 4HCl \rightarrow HAuCl_4 + NO + 2H_2O$.

7 Numerical problems

a. **ANSWER** A · 2

Moles of iron = $5.6 \div 56 = 0.1$ mol, so 0.1 mol of H_2 is formed.

i. Mass of $H_2 = 0.1 \times 2 =$ **0.2 g**.

ii. Volume at STP = $0.1 \times 22.4 =$ **2.24 L**.

MARKING SCHEME

- ✓ 0.1 mol Fe gives 0.1 mol $H_2 = 0.2$ g.
- ✓ $0.1 \times 22.4 = 2.24$ L.

b. **ANSWER** A · 3

Aluminium: $2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2$. Moles of Al = $2.7 \div 27 = 0.1$ mol, giving $0.1 \times 3/2 = 0.15$ mol $H_2 = 0.15 \times 22.4 = 3.36$ L.

Iron: $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$. Moles of Fe = $5.6 \div 56 = 0.1$ mol, giving 0.1 mol $H_2 = 2.24$ L.

The aluminium gives more: 3.36 L against 2.24 L, though it has less than half the mass, because each aluminium atom gives three electrons and each iron atom only two.

MARKING SCHEME

- ✓ 0.1 mol Al gives 0.15 mol $H_2 = 3.36$ L.
- ✓ 0.1 mol Fe gives 0.1 mol $H_2 = 2.24$ L.
- ✓ The aluminium gives more.

c. **ANSWER** A · 3

Moles of Cu = $19.05 \div 63.5 = 0.3$ mol.

Moles of NO = $0.3 \times 2/3 = 0.2$ mol.

Volume = $0.2 \times 22.4 =$ **4.48 L at STP**.

MARKING SCHEME

- ✓ $19.05 \div 63.5 = 0.3$ mol Cu.
- ✓ $0.3 \times 2 \div 3 = 0.2$ mol NO.
- ✓ $0.2 \times 22.4 = 4.48$ L.

d. **ANSWER** A · 2

$$\rho = \frac{23.3}{1.30} = 17.9 \text{ g/cm}^3$$

It is not pure gold: its density, 17.9 g/cm^3, is less than gold's 19.3 g/cm^3, so it is mixed with a lighter metal such as copper or silver (as all gold jewelry is, to make it hard enough to wear). A volume found by dipping the bangle in water, as Archimedes did, is the jeweler's simplest test.

MARKING SCHEME

- ✓ $23.3 \div 1.30 = 17.9$ g/cm^3.
- ✓ Less than 19.3, so not pure gold.

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8 Think

ANSWER HA · 3

The percentages are for the pure minerals. A rock from a mine is mixed with gangue, so what matters is how much of the rock is the mineral. A rock that is mostly siderite can give more iron than one with little hematite in it: 90% siderite gives about 434 kg of iron a tonne, 50% hematite only 350 kg.

MARKING SCHEME

- ✓ The percentages are for the pure minerals.
- ✓ Real rock carries gangue: what counts is how much mineral it holds.
- ✓ A worked example, or a clear statement that more mineral can outweigh a lower percentage.

9 Activity: Flow sheet of the extraction of iron

(not marked)

WHAT STUDENTS SHOULD FIND

Crushing: jaw crushers and ball mills. Concentration: gravity separation (magnetic for magnetite); gangue removed. Calcination: heating with little air; H_2O, CO_2, SO_2 and As_2O_3 removed. Smelting: the blast furnace, reduction by carbon monoxide; coke, limestone and hot air added; slag and waste gases removed. Out comes pig iron.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **The Giant Periodic Table** (exhibit): Turn the cubes of iron, copper, silver and gold: each shows a use, steel structures, electric wires, jewelry, that fits the metal's properties.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	12	11	24	3	**50**