UNIT 6
REDOX REACTIONS
Answers

Lesson 1 – What is oxidation, what is reduction and what are oxidation numbers?

Thinkabout Activity 1.1: What is oxidation and what is reduction?

- $2Mg + O_2 \rightarrow 2MgO$
- Mg loses its two valence electrons
- Mg is oxidised because it "gains oxygen"; it is also oxidised because it "loses electrons"
- $Mg \rightarrow Mg^{2+} + 2e$; $O_2 + 4e \rightarrow 2O^{2-}$

Test your knowledge 1.2: Deducing Oxidation Numbers

(a) +4
(b) -2
(c) +4
(d) +6
(e) +5
(f) +3
(g) 0
(h) +2
(i) +1
(j) +5
(k) +1
(l) -1
(m) -1
(n) $+3^-$
(o) +5
(p) +7
(q) +2
(r) +8/3
(s) +2.5
(t) +2

Test your knowledge 1.3: Using oxidation numbers to identify oxidation and reduction

(a) +4 to +2, so reduction
(b) -1 to 0, so oxidation
(c) +1 to -1, so reduction
(d) +2 to +2.5, so oxidation
(e) +5 to +2, so reduction

Lesson 2 – How can I use oxidation numbers to name inorganic compounds?

Test your knowledge 2.1: Naming binary inorganic compounds

(a) copper (II) oxide
(b) copper (I) oxide
(c) lead (IV) oxide
(d) calcium (II) nitride
(e) carbon (II) oxide
(f) nitrogen (IV) oxide
(g) nitrogen (III) chloride
(h) lead (II) sulphide
(i) hydrogen (I) nitride
(j) oxygen (II) fluoride
(k) hydrogen (I) telluride
(l) uranium (VI) fluoride
(m) aluminium (III) hydride
(n) iron (II) oxide
(o) iron (III) oxide
(p) manganese (IV) oxide
(q) carbon (IV) chloride
(r) chlorine (VII) oxide
(s) tin (IV) chloride
(t) tin (II) chloride
(u) sulphur (IV) oxide

Test your knowledge 2.2: Naming non-binary inorganic compounds

(a) sodium sulphate (IV)
(b) potassium chlorate (V)
(c) sodium chlorate (I)
(d) copper (II) carbonate
(e) magnesium nitrate

(a) sodium nitrate (III)
(b) ammonium sulphate
(c) potassium manganate (VIII)
(d) potassium chromate (VI)
(e) potassium hexafluoriplatinate (IV)

Note: the oxidation number not been used with the cation unless it is a d-block metal and has a number of stable oxidation numbers

Note: the oxidation number has been omitted with very common anions (eg sulphate, nitrate, carbonate) but is always used with lesson common anions or if the oxidation number is not the most common one (eg sulphate (IV) and nitrate (III)

Lesson 3 – What are half-equations and how can we construct them?

Test your knowledge 3.1: Writing half-equations

(a) $PbO_2 + 2H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O$
(b) $2Cl^- \rightarrow Cl_2 + 2e^-$
(c) $2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2e^-$
(d) $2IO_3^- + 12H^+ + 10e^- \rightarrow I_2 + 6H_2O$
(e) $2I^- \rightarrow I_2 + 2e^-$
(f) $ClO^- + 2H_2O \rightarrow ClO_3^- + 4H^+ + 4e^-$
(g) $ClO^- + 2H^+ + 2e^- \rightarrow Cl^- + H_2O$
(h) $H_2SO_4 + 2H^+ + 2e^- \rightarrow SO_2 + 2H_2O$
(i) $2Br^- \rightarrow Br_2 + 2e^-$
(j) $H_2SO_4 + 6H^+ + 6e^- \rightarrow S + 4H_2O$

Lesson 4 – What are redox reactions, and what are oxidising and reducing agents?

Test your knowledge 4.1: Writing equations for redox reactions

(a) $PbO_2 + 4H^+ + 2Cl^- \rightarrow Pb^{2+} + Cl_2 + 2H_2O$
(b) $4Al^{3+} + 6O^{2-} \rightarrow 3O_2 + 4Al$
(c) $2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$
(d) $IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$
(e) $3ClO^- \rightarrow ClO_3^- + 2Cl^-$
(f) $H_2SO_4 + 2Br^- + 2H^+ \rightarrow SO_2 + Br_2 + 2H_2O$
(g) $H_2SO_4 + 6H^+ + 6I^- \rightarrow 3I_2 + S + 4H_2O$
(h) $ClO^- + 2H^+ + 2I^- \rightarrow Cl^- + I_2 + H_2O$

Test your knowledge 4.2: Identifying oxidising and reducing agents in redox reactions

(a) oxidising agent is PbO_2; reducing agent is Cl^-
(b) oxidising agent is Al^{3+}; reducing agent is O^{2-}
(c) oxidising agent is I_2; reducing agent is $S_2O_3^{2-}$
(d) oxidising agent is IO_3^-; reducing agent is I^-
(e) oxidising agent is ClO^-; reducing agent is ClO^-
(f) oxidising agent is H_2SO_4; reducing agent is Br^-
(g) oxidising agent is H_2SO_4; reducing agent is I^-
(h) oxidising agent is ClO^-; reducing agent is I^-

Lesson 5 – What are the some common examples of redox reactions?

Practical 5.1: Prepare a sample of zinc sulphate from zinc and sulphuric acid

Equipment needed per group: 100 cm^3 beaker, tripod, gauze, Bunsen burner, thermometer, 20 cm^3 of 0.5 $moldm^{-3}$ H_2SO_4, 1 g zinc granules, 2 pieces filter paper, funnel, spatula

Make sure students do not overheat the mixture

- Moles of H_2SO_4 = 20/1000 x 0.5 = 0.01
- Moles of Zn = 1/65.4 = 0.015
- Excess zinc can be easily removed by filtration; excess H_2SO_4 cannot easily be removed

Test your knowledge 5.2: Common redox reactions

(a) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$ or $Zn + 2H^+ \rightarrow Zn^{2+} + H_2$ (o = Zn; r = H)
(b) $2Al + 6HNO_3 \rightarrow 2Al(NO_3)_3 + 3H_2$ or $2Al + 6H^+ \rightarrow 2Al^{3+} + 3H_2$ (o = Al; r = H)
(c) $ZnSO_4 + Mg \rightarrow MgSO_4 + Zn$ or $Zn^{2+} + Mg \rightarrow Mg^{2+} + Zn$ (o = Mg; r = Zn)
(d) $2AgNO_3 + Cu \rightarrow Cu(NO_3)_2 + 2Ag$ or $2Ag^+ + Cu \rightarrow Cu^{2+} + 2Ag$ (o = Cu; r = Ag)
(e) $4Ag + O_2 \rightarrow 2Ag_2O$ (o = Ag; r = O)
(f) $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$ (o = C; r = Fe)
(g) $TiCl_4 + 2Mg \rightarrow Ti + 2MgCl_2$ (o = Mg; r = Ti)

Lesson 6 – How can we identify oxidising and reducing agents?

Summary Activity 6.1: What can you remember about qualitative analysis?

- Identification of ions or molecules by simple tests
- CO_3^{2-}: add HCl (aq) and observe fizzing, or add $CaCl_2$ (aq) and observe white precipitate, then add HCl (aq) and observe fizzing as the precipitate dissolves; gas should be odourless
- SO_3^{2-}: add HCl (aq) and observe fizzing, or add $CaCl_2$ (aq) and observe white precipitate, then add HCl (aq) and observe fizzing as the precipitate dissolves; gas should smell like burning matches
- NH_4^+: add NaOH (aq) and warm; pungent gas should be given off
- H^+: add $CaCO_3$(s) and observe fizzing, or add blue litmus paper – it will turn red
- OH^-: add NH_4Cl (aq) and warm; pungent gas should be given off or add red litmus paper – it will turn blue
- CO_2: turns limewater milky and then colourless; no smell
- SO_2: turns limewater milky and then colourless; smell of burning matches; will turn damp blue litmus paper red
- NH_3: pungent smell, will turn damp red litmus paper blue, will give white smoke with filter paper soaked in concentrated HCl
- HCl: will turn damp blue litmus paper red, will give white smoke with filter paper soaked in concentrated NH_3

Practical 6.2: testing for oxidising and reducing agents in solution

Chemicals required per group: access to bottles of 0.1 moldm^{-3} $FeCl_3$ (labelled A), 0.1 moldm^{-3} $FeSO_4$ (labelled B), 0.1 moldm^{-3} KNO_3 (labelled C), 0.1 moldm^{-3} Na_2SO_3 (labelled D), 1 moldm^{-3} NaOH, 1 moldm^{-3} HCl, 0.02 moldm^{-3} $K_2Cr_2O_7$ in 1 moldm^{-3} H_2SO_4, 0.02 moldm^{-3} $KMnO_4$ in 1 moldm^{-3} H_2SO_4, each with its own dropping pipette (approx 3 cm^3 of each needed per group), access to pots of Na_2SO_3 and Al powder, each with a spatula (approx 1 g per group), access to litmus paper, access to dichromate paper

Apparatus required per group: 12 test tubes, 1 test tube rack, Bunsen burner, tongs

- Solution A should give a brown colour with KI
- Solutions B and D should decolorise $KMnO_4$ and turn $K_2Cr_2O_7$ green
- Solution C should not give a positive test for the above but will give off a pungent gas when warmed with NaOH and Al; the gas should turn red litmus blue
- Na_2SO_3 should fizz on addition of HCl and the gas evolved should turn dichromate paper green

Test your knowledge 6.3: Qualitative analysis using redox reactions

(a) Warm with NaOH and Al powder; pungent-smelling gas should be evolved which turns red litmus blue
(b) Add acidified $KMnO_4$; SO_3^{2-} will decolorise it but CO_3^{2-} will not OR add acidified $K_2Cr_2O_7$; SO_3^{2-} will turn it green it but CO_3^{2-} will not
(c) Add HCl; SO_3^{2-} sample will evolve gas with burning-match smell which turns dichromate paper green; CO_3^{2-} sample will evolve odourless gas which has no effect on dichromate paper
(d) SO_2 has burning-match smell and turns dichromate paper green; CO_2 is odourless and has no effect on dichromate paper
(e) Fe^{2+} decolorises acidified $KMnO_4$ but does not react with KI; Fe^{3+} turns KI brown but has no effect on acidified $KMnO_4$

Lesson 7 – What is a Galvanic cell?

Practical 7.1: prepare a simple electrochemical cell

Equipment needed per group: 2 x 100 cm^3 beakers, 1 copper strip, 1 zinc strip, 1 strip filter paper (1 x 15 cm), 2 crocodile clips, 2 electrical wires, 1 voltmeter, access to 1 moldm^{-3} $CuSO_4$, 1 moldm^{-3} $ZnSO_4$ (50 cm^3 per group), saturated KNO_3 (10 cm^3 per group)

The voltmeter should read around 1.1 V; either +1.1 V (if the Cu electrode is on the RHS) or -1.1 V (if the Cu electrode is on the left hand side; the Cu is the positive electrode

$Cu^{2+} + 2e \rightarrow Cu$; $Zn \rightarrow Zn^{2+} + 2e$

Test your knowledge 7.2: Understanding how Galvanic cells work

(a) Voltmeter reading -ve so positive electrode is on LHS, and is therefore the zinc electrode, so magnesium electrode is negative
(b) Zn electrode +ve so reduction: $Zn^{2+} + 2e \rightarrow Zn$; Mg electrode -ve so oxidation: $Mg \rightarrow Mg^{2+} + 2e$
(c) $Zn^{2+} + Mg \rightarrow Zn + Mg^{2+}$
(d) Electrons move from Mg (oxidised) to Zn (reduced)
(e) Sulphate ions move from Zn^{2+} (which is decreasing in concentration) to Mg^{2+} (which is increasing in concentration)

Lesson 8 – What are electrode potentials and how can we measure them?

Test your knowledge 8.1: Conventional Representation of Cells

(a) $Mg|Mg^{2+}||Zn^{2+}|Zn$
(b) $Zn|Zn^{2+}||Fe^{2+}|Fe$
(c) $Zn|Zn^{2+}||Ag^{+}|Ag$
(d) $Al|Al^{3+}||Pb^{2+}|Pb$
(e) $Mg|Mg^{2+}||Al^{3+}|Al$

Test your knowledge 8.2: Using standard electrode potentials

a) (i) $Cu|Cu^{2+}||Ag^{+}|Ag$; emf = +0.46 V; $2Ag^{+} + Cu \rightarrow Cu^{2+} + 2Ag$
(ii) $Zn|Zn^{2+}||Pb^{2+}|Pb$; emf = +0.63 V; $Pb^{2+} + Zn \rightarrow Zn^{2+} + Pb$
(i) $Al|Al^{3+}||Fe^{2+}|Fe$; emf = +1.22 V; $3Fe^{2+} + 2Al \rightarrow 2Al^{3+} + 3Fe$
(ii) $Mg|Mg^{2+}||Al^{3+}|Al$; emf = +0.71 V; $2Al^{3+} + 2Mg \rightarrow 2Mg^{2+} + 2Al$
(iii) $Pb|Pb^{2+}||Ag^{+}|Ag$; emf = +0.93 V; $2Ag^{+} + Pb \rightarrow Pb^{2+} + 2Ag$

b) (i) emf -ve so oxidation on RHS so $V \rightarrow V^{2+} + 2e$, so $Cu^{2+} + 2e \rightarrow Cu$: $Cu^{2+} + V \rightarrow V^{2+} + Cu$
(ii) emf = $E_r - E_l$ so $-1.46 = V^{2+}|V - 0.34$ so $V^{2+}|V = -1.46 + 0.34 = -1.12$ V

Lesson 9 – What are the different types of Galvanic cell?

Test your knowledge 9.1: Applications of Galvanic Cells

(a) A primary cell is non-rechargeable (eg most typical batteries); a secondary cell is rechargeable (eg a lead-acid battery)
(b) It is rechargeable and can withstand a large current for a short time
(c) The electrolyte is in the form of a paste rather than a liquid or solution; they can be turned around and used in any orientation
(d) Reaction between fuel and oxygen; fuel is constantly entering the cell at one electrode and oxygen at the other; the products leave the electrode as they are made; they are more effiecient than combustion engines

Lesson 10 – What is electrolysis?

Test your knowledge 10.1: Electrolysis

(a) (i) cathode: $Na^{+} + e^{-} \rightarrow Na$; anode: $2Cl^{-} \rightarrow Cl_2 + 2e^{-}$; overall: $2NaCl \rightarrow 2Na + Cl_2$
(ii) cathode: $Al^{3+} + 3e^{-} \rightarrow Al$; anode: $2O^{2-} \rightarrow O_2 + 4e^{-}$; overall: $2Al_2O_3 \rightarrow 4Al + 3O_2$
(iii) cathode: $2H_2O + 2e^{-} \rightarrow H_2 + 2OH^{-}$; anode: $2Cl^{-} \rightarrow Cl_2 + 2e^{-}$; overall: $2H_2O + 2Cl^{-} \rightarrow H_2 + Cl_2 + 2OH^{-}$
(iv) cathode: $2H^{+} + 2e^{-} \rightarrow H_2$; anode: $2H_2O \rightarrow O_2 + 4e^{-} + 4H^{+}$; overall: $2H_2O \rightarrow 2H_2 + O_2$
(v) cathode: $Cu^{2+} + 2e^{-} \rightarrow Cu$; anode: $2H_2O \rightarrow O_2 + 4e^{-} + 4H^{+}$; overall: $2Cu^{2+} + 2H_2O \rightarrow 2Cu + O_2 + 4H^{+}$

(b) cathode: $Cu^{2+} + 2e^{-} \rightarrow Cu$; anode: $Cu \rightarrow Cu^{2+} + 2e^{-}$; used in purification of copper

Lesson 11 – How can we predict the quantity of each substance produced during electrolysis?

Summary Activity 11.1: Units of charge and amount of substance

- Pipette: very accurate but can only deliver one volume
- Volumetric flask: very accurate but can only store one volume
- Burette: slightly less accurate than a pipette but can deliver any volume up to 50 cm^3
- Measuring cylinder: not accurate
- Pipettes and burettes are most useful for carrying out titrations

Test your knowledge 11.2: Calculating the quantities produced during electrolysis

(a) Electrolyse dilute NaCl or dilute H_2SO_4 using electrodes fully submerged; place inverted measuring cylinders filled with water above the electrodes and collect the gases produced at each electrode; the gas at the cathode will have twice the volume of the gas at the anode

(b) 20/58.5 = 0.34 moles of NaCl; each NaCl needs 1 electron for separation so 0.34 F needed = 33,000 C

(c) 2000/96500 = 0.02 moles; which will produce 0.01 moles of H_2 and 0.05 moles of O_2; V = nRT/P = 2.6 x 10^{-4} m^3 = 0.26 dm^3 of hydrogen and 0.13 dm^3 of oxygen

(d) 1000 g of Al_2O_3 = 0.98 moles; each Al_2O_3 requires 6e for electrolysis so 0.98 x 6 = 5.88 F = 568,000 C

(e) 1000/96500 = 0.0104 F; each Cu requires 2e so moles of Cu = 0.00518 so mass = 0.00518 x 63.5 = 0.33 g

(f) n = PV/RT = (100000 x 100 x 10^{-6})/(8.31 x 298) = 0.00403; 2e required per H_2 so 0.00808 F required; 0.00808 x 96500 = 779 C

(g) 2/107.9 = 0.0185 moles Ag; each Ag needs 1 e so 0.0185 C required = 1790 C

Lesson 12 – What is rusting and how can we prevent it?

(g) The Rusting of Iron

Practical 12.1: Demonstrate that oxygen and water are both required for rusting

Equipment needed per group: 3 test tubes, 3 bungs which fit the test tubes, 1 test tube rack, three small nails (2 - 4 cm), 1 g of vegetable oil, access to anhydrous $CaCl_2$ and a spatula (1 g per group), access to vegetable oil with dropping pipette (1 cm^3 per group), 5 cm^3 of recently boiled water, access to distilled water

- The nail in tubes B and C should show no signs of rusting after one week, but the nail in tube A should show clear signs of rusting

Practical 12.2: Demonstrate that acids, bases, salts and heating increase the rate of rusting

Equipment needed per group: 5 test tubes, two test tube racks, 5 small nails (2 – 4 cm), access to distilled water, access to 0.1 moldm^{-3} solutions of HCl and NaOH, each with dropping pipette (2 cm^3 per group) and NaCl with dropping pipette (4 cm^3 per group), access to a fridge

- The test tubes containing HCl, NaOH and NaCl should all have rusted significantly more than the test tube containing water only; the acid test tube may not appear rusty as rust dissolves in acid; the solution may appear green/orange; the test tube containing NaCl in the fridge should rust less than the test tube containing NaCl in a warm place

Test your knowledge 12.3: Rusting

(a) $4Fe + 6H_2O + 3O_2 \rightarrow 4Fe(OH)_3$; Fe oxidised from 0 to 3; O reduced from 0 to -2
(b) Oxygen (air) and water
(c) Salt, acids, alkalis (ie electrolytes), heat
(d) Oiling, painting, galvanisation
(e) Attaching pieces of a more reactive metal to the iron surface; the more reactive metal is oxidised preferentially; zinc can provide sacrificial protection but tin cannot

Lesson 13 – What have I learned and understood about redox reactions?

13.1 END-OF-TOPIC QUIZ

UNIT 6 – ACIDS, BASES AND SALTS

1. (a) +1, sodium chlorate (I); (b) +4, potassium sulphate (IV); (c) +7, potassium manganate (VII)
2. (a) reduction: $ClO^- + 2H^+ + 2e^- \rightarrow Cl^- + H_2O$; (b) oxidation: $SO_3^{2-} + H_2O \rightarrow SO_4^{2-} + 2H^+ + 2e^-$; (c) reduction: $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$; (d) oxidation: $Fe^{2+} \rightarrow Fe^{3+} + e^-$; (e) reduction: $H_2SO_4 + 8H^+ + 8e^- \rightarrow H_2S + 4H_2O$; (f) oxidation: $2I^- \rightarrow I_2 + 2e^-$
3. (a) $H_2SO_4 + 8H^+ + 8I^- \rightarrow H_2S + 4I_2 + 4H_2O$; (b) $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$; (c) $ClO^- + SO_3^{2-} \rightarrow Cl^- + SO_4^{2-}$
4. Add excess Mg to dilute HNO_3; filter off excess magnesium; heat solution until 75% evaporated; then leave until crystals form; dry crystals in filter paper; $Mg + 2H^+ \rightarrow Mg^{2+} + H_2$; Mg oxidised from O to +2; H reduced from +1 to 0
5. (a) Warm with dilute NaOH and Al powder; a pungent gas will be given off which turns red litmus blue and/or gives a white smoke when in contact with HCl; (b) Add dilute HCl; a gas will be given off which smells like burning matches and which turns dichromate paper from orange to green
6. (a) $Zn|Zn^{2+}||Ni^{2+}|Ni$; (b) +0.62 V, $Zn + Ni^{2+} \rightarrow Zn^{2+} + Ni$
7. (a) cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$; anode: $2Cl^- \rightarrow Cl_2 + 2e^-$; (b) $2H_2O + 2Cl^- \rightarrow H_2 + Cl_2 + 2OH^-$; 2000/96500 = 0.0207 F; 1 H_2 needs 2e so 0.0104 mol H_2 produced; V = nRT/P = 0.0104 x 8.31 x 298 / 100000 = 2.57×10^{-4} m^3 = 0.257 dm^3
8. Make it the cathode of an electrolytic cell containing $AgNO_3$ as the electrolyte and with an anode made of silver, and pass a current through
9. (a) $4Fe + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$; (b) dissolved electrolytes and heat; (c) attaching the iron to a piece of a more reactive metal; (d) oiling, greasing, painting