Harvard-Westlake School
A.P. Chemistry--Mr. Marsden
Writing Chemical Reactions

Traditionally students have done consistently poor on the section of the A.P. exam that deals with writing net-ionic reactions. While the scores of HW students on this section have been considerably above average, we still have some distance to go in perfecting a teaching/learning strategy in this area of the exam.

On the actual exam in May you will have 10 minutes (calculator-free) to write 5 out of 8 possible net-ionic reactions. A survey of the last 15 years of A.P. exams indicates that most reactions given fall into one of these rather broad categories:

1. metathesis (double replacement)
2. single replacement
3. combustion
4. acid/base neutralization
5. combination
6. decomposition
7. reactions of anhydrides
8. organic
9. non-trivial redox
10. complex ion formation or decomposition
11. other*

* for these we invoke the standard "you can't know everything" clause and ignore them

In the past these have occurred in any combination on a test. And in the past I have placed them on my own tests in the same way. But last year I went systematically going through the list, giving sample exercises which you can either do or not do, as you see fit. This seemed to work well so I intend to do it again. With each set of exercises some general principles and hints will be given. Hopefully this approach will give you more exposure and therefore more confidence and greater success.

Beginning at the beginning we state the "obvious": most compounds can be divided into about 6 categories:

1. acids (formulas begin with H- except for some organic acids like acetic acid which are often written with the H- at the end, as in CH_3COOH)
2. bases (formulas end in -OH except for ammonia and organic bases which are similar to ammonia and contain nitrogen)
3. metal oxides (binary compounds of a metal and oxygen)
4. non-metal oxides (binary compounds of a non-metal and oxygen)
5. salts (compounds of metals that are NEITHER bases NOR oxides)
6. other (most compounds belong here!!!!!)

What should you know right now about these categories besides what is given above? The following is a start:

ACIDS : "strong" acids (which exist largely as ions in solution rather than molecules) are few in number and should be learned: HCl, HBr and HI are the only strong binary acids; ternary acids are usually strong if the number of oxygens exceeds the number of hydrogens by two or more

BASES : "strong" bases are also few in number and should be learned: LiOH, NaOH, KOH, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$

SALTS : the salts which are soluble include all of the salts of lithium, sodium, potassium and ammonium cations and of nitrate and acetate anions. All chlorides are soluble except silver, lead and mercury(I) [AP H]. All sulfates are soluble except those of calcium, lead, barium, and strontium [C PBS]. All other salts should be considered only slightly soluble unless you learn otherwise.

This is a *beginning*. Learn this **now**. More is coming in the near future.

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Metathesis Reactions

These reactions begin with two reactant compounds and produce two product compounds. They typically occur when the reactants are acids, bases or salts.

The products are predicted by simply switching the positive parts of the two reactants.

e.g. $HCl + NaOH \rightarrow NaCl + HOH$ (or H_2O)

$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$

These molecular equations can be converted into net-ionic form by considering the information given in the previous handout regarding the strengths of acids and bases as well as the solubility of salts. Strong electrolytes of any type exist in water solution as separated ions. Weak electrolytes exist primarily in molecular form. The intent of the net-ionic equation is to represent reactant and product species as accurately as possible. Thus the two examples above in net-ionic form would be:

$H^+ + OH^- \rightarrow H_2O$

$Ag^+ + Cl^- \rightarrow AgCl$

What follows are reactions taken from Part C of previous A.P. exams. You should practice them when you have a chance. These kind of reactions will be featured significantly on part C of your first exam.

[it is worth noting that in the the reaction section there are no "no-reactions"]

1. dilute sulfuric acid is added to a solution of barium acetate
2. solutions of sodium phosphate and calcium chloride are mixed
3. hydrogen sulfide gas is bubbled through a solution of silver nitrate
4. manganese(II) nitrate solution is mixed with sodium hydroxide solution
5. solutions of zinc sulfate and sodium phosphate are mixed
6. solutions of silver nitrate and sodium chromate are mixed
7. dilute solutions of lithium hydroxide and hydrobromic acid are mixed
8. a solution of ammonia is added to a dilute solution of acetic acid
9. a solution of sulfuric acid is added to a solution of barium hydroxide

(answers are on the back)

1. $H^+ + SO_4^{2-} + Ba^{2+} + CH_3COO^- \rightarrow BaSO_4 + CH_3COOH$
2. $Ca^{2+} + PO_4^{3-} \rightarrow Ca_3(PO_4)_2$
3. $H_2S + Ag^+ \rightarrow H^+ + Ag_2S$
4. $Mn^{2+} + OH^- \rightarrow Mn(OH)_2$
5. $Zn^{2+} + PO_4^{3-} \rightarrow Zn_3(PO_4)_2$
6. $Ag^+ + CrO_4^{2-} \rightarrow Ag_2CrO_4$
7. $H^+ + OH^- \rightarrow H_2O$
8. $NH_3 + CH_3COOH \rightarrow NH_4^+ + CH_3COO^-$
9. $H^+ + SO_4^{2-} + Ba^{2+} + OH^- \rightarrow BaSO_4 + H_2O$

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Single Replacement Reactions
Combustion Reactions
Combination Reactions
Decomposition Reactions

Single replacement (or simply displacement) reactions are a type of trivial redox reaction in which an element reacts with a compound. In that compound there must be an element similar in some way to the reacting element but less reactive. The similarity can be as fundamental as belonging to the same chemical family, or as loose as both having the same charge in compounds. In any case, the more reactive element takes the place of the less active element in the compound and the less active element is "displaced":

$Cl_2 + KBr \rightarrow KCl + Br_2$ [not balanced]

$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

The molecular equations can be converted to net-ionic form by applying solubility rules. Note that the activity of a given element is most easily predicted with a standard reduction potential table. <u>For metal displacements the metal with the more positive reduction potential will be replaced. For halogens, the displacement order follows the periodic table, fluorine being the most active.</u>

Examples of the above reactions in net-ionic form would be:

$Cl_2 + Br^- \rightarrow Cl^- + Br_2$ [not balanced]

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

Combustion reactions can vary a good deal as soon as one steps out of the realm of hydrocarbons and the exam seldom indulges in the more esoteric combustions unless they are simple combinations like the burning of a metal in air or oxygen. For the hydrocarbon combustions, the simple rule is that burning (combining with O_2) produces carbon dioxide and water. This is true whether the hydrocarbon contains oxygen or not. However, if halogens or nitrogen are present, oxides of these elements may form as well. These are difficult to predict, although in the case of nitrogen, NO or NO_2 would always be a reasonable guess. Some examples are found below:

$C_6H_{14} + O_2 \rightarrow CO_2 + H_2O$ [not balanced]
$Li + O_2 \rightarrow Li_2O$ [not balanced]

Note that net-ionic versions of these reactions really don't exist since liquid water is generally not present.

Combination reactions can refer to the very simple reaction of two elements (a redox process) to form a compound. However, some compounds also combine to form other compounds. These are sometimes less obvious. In the former case, the reaction is mostly challenging because the correct formula of the final product must be known (or guessed). Net-ionic form is usually not required because typically water would be absent:

$$S + O_2 \rightarrow SO_2$$

$$Mg + N_2 \rightarrow Mg_3N_2$$

In the latter case, there are some common categories which appear on the exam. It would be helpful to recognize them:

1. metal oxide + water → a base (non-redox)
2. non-metal oxide + water → an acid (non-redox)
3. metal oxide + non-metal oxide → salt (non-redox)

Examples (in net-ionic form) follow:

$$CaO + H_2O \rightarrow Ca^{2+} + OH^-$$

$$SO_2 + H_2O \rightarrow H_2SO_3$$

$$CaO + SO_2 \rightarrow CaSO_3$$

Decomposition reactions follow a similar pattern (although reversed). When a simple binary compound is decomposed the elements result. These are not a problem. When a ternary compound decomposes (usually by heating) there are some general rules:

1. base → metal oxide + water
2. acid containing oxygen → non-metal oxide + water
3. salt containing oxygen → metal oxide + non-metal oxide

Examples follow:

$$Ca(OH)_2 \rightarrow CaO + H_2O$$

$$H_2CO_3 \rightarrow CO_2 + H_2O$$

$$CaCO_3 \rightarrow CaO + CO_2$$

On the following page, there are some reactions from actual previous AP exams. Try them out.

1. calcium metal is added to a dilute solution of hydrochloric acid
2. liquid bromine is added to a solution of potassium iodide
3. magnesium turnings are added to a solution of iron(III) chloride
4. hydrogen gas is passed over hot iron(III) oxide
5. small chunks of solid sodium are added to water
6. propanol is burned completely in air
7. acetic acid is burned in an excess of oxygen
8. calcium metal is heated strongly in the presence of oxygen
9. solid calcium oxide is exposed to a stream of carbon dioxide gas
10. a mixture of solid calcium oxide and tetraphosphorus decaoxide is heated
11. sulfur trioxide gas is added to excess water
12. ammonia gas and carbon dioxide are bubbled into water
13. solid magnesium carbonate is heated
14. solid potassium chlorate is heated in the presence of a manganese(IV) oxide catalyst
15. a solution of hydrogen peroxide is heated

(answers on the back)

1. $Ca + H^+ \rightarrow Ca^{2+} + H_2$
2. $Br_2 + I^- \rightarrow I_2 + Br^-$
3. $Mg + Fe^{3+} \rightarrow Mg^{2+} + Fe$ (or Fe^{2+})
4. $H_2 + Fe_2O_3 \rightarrow Fe + H_2O$
5. $Na + H_2O \rightarrow Na^+ + OH^- + H_2$
6. $C_3H_7OH + O_2 \rightarrow CO_2 + H_2O$
7. $CH_3COOH + O_2 \rightarrow CO_2 + H_2O$
8. $Ca + O_2 \rightarrow CaO$
9. $CaO + CO_2 \rightarrow CaCO_3$
10. $CaO + P_4O_{10} \rightarrow Ca_3(PO_4)_2$
11. $SO_3 + H_2O \rightarrow H^+ + SO_4^{2-}$ (or HSO_4^-)
12. $NH_3 + CO_2 + H_2O \rightarrow NH_4^+ + CO_3^{2-}$
13. $MgCO_3 \rightarrow MgO + CO_2$
14. $KClO_3 \rightarrow KCl + O_2$
15. $H_2O_2 \rightarrow H_2O + O_2$

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Hydrolysis Reactions

Hydrolysis is generally understood as a reaction of something with water. Reaction should not be confused with dissolving. Many compounds dissolve in water and are essentially unchanged. We can count here even the ionic solids which, while they may dissociate into ions are still fundamentally the same. In a hydrolysis reaction, some new substance or species forms that is not found in the original compound.

The most common examples of hydrolysis are reactions of the anions of weak acids or the cations of weak bases with water. These are typical of the processes which occur when salts of these compounds enter water. For example, sodium acetate is the salt of a strong base and a weak acid (sodium hydroxide and acetic acid). Because of the high affinity of the acetate ion for hydrogen ions, addition of acetate ions to water actually results in some of the minuscule amounts of H^+ present in water being grabbed by the acetate ions:

$$CH_3COO^- + H^+ \leftrightarrows CH_3COOH$$

As you can see, this is an equilibrium process. The equilibrium lies far to the right, so that most of the acetate ions added disappear and become part of acetic acid molecules. Meanwhile, since H^+ ions are being tied up that would otherwise establish the K_w equilibrium for water, more water begins to dissociate:

$$H_2O \leftrightarrows H^+ + OH^-$$

This results in a net excess of OH^- in the mixture (i.e., solutions of sodium acetate are basic). Thus the net ionic reaction for something as innocent sounding as the dissolving of sodium acetate in water becomes:

$$NaCH_3COO + H_2O \leftrightarrows CH_3COOH + OH^- + Na^+$$

which is the sum of the two reactions that came before (plus the liberation of the sodium ion into the solution). When writing such a reaction for the exam the equilibrium arrows are not required but would be impressive.

The general form for such a reaction might be written:

anion of weak acid + water $\leftrightarrows$ weak acid + hydroxide ion

By a similar analysis there is a reaction that could be written for the cations of weak bases, although there is really only one common one (NH_4^+):

cation of weak base + water $\leftrightarrows$ weak base + hydrogen ion

It is possible to argue that this reaction actually occurs with small, highly charged metal ions which form otherwise weak bases. For example, dissolving $Fe(NO_3)_3$ in distilled water almost always results in some reddish brown $Fe(OH)_3$ clouding the solution. However, I have never seen this kind of thing on the reaction section of the exam.

The hydrolysis reactions of salts are at least predictable. There are also some compounds belonging to the Other category mentioned on the first of these handouts which react with water. Historically, non-metallic halides have been popular as reactants in such processes on the exam. Chlorides of phosphorus or sulfur are common as question material. You can just skip these, or you can hazard a guess. In general, if water is thought of as HOH, the H^+ will combine with the more (or most) electronegative atom in the non-metal halide. This gives one product. The other product consists of the remaining elements.

Here are a few examples:

phosphorus trichloride + water $\rightarrow$

$PCl_3 + H_2O \rightarrow H^+ + Cl^- + H_3PO_3$ [note that the H^+ and Cl^- are just HCl]

phosphorus pentachloride + water $\rightarrow$

$PCl_5 + H_2O \rightarrow H^+ + Cl^- + H_3PO_4$

How can you tell which phosphorus acid forms????? The oxidation number of phosphorus remains constant!

sulfur tetrachloride + water $\rightarrow$

$SCl_4 + H_2O \rightarrow H^+ + Cl^- + H_2SO_3$

Anyway, here are some mixed examples from actual tests of past years:

1. phosphorus tribromide is added to water
2. gaseous hydrogen chloride is dissolved in water
3. phosphorus oxytrichloride is added to water
4. solid sodium sulfite is added to water
5. sodium phosphate crystals are added to water
6. solid sodium cyanide is added to water
7. solid aluminum sulfide is added to water

(answers on the back)

1. $PBr_3 + H_2O \rightarrow H_3PO_3 + H^+ + Br^-$
2. $HCl + H_2O \rightarrow H_3O^+ + Cl^-$ [Arrhenius version also accepted]
3. $POCl_3 + H_2O \rightarrow H_3PO_4 + H^+ + Cl^-$
4. $Na_2SO_3 + H_2O \rightarrow Na^+ + HSO_3^- + OH^-$
5. $Na_3PO_4 + H_2O \rightarrow Na^+ + OH^- + HPO_4^{2-}$ [or $H_2PO_4^-$]
6. $NaCN + H_2O \rightarrow Na^+ + HCN + OH^-$
7. $Al_2S_3 + H_2O \rightarrow Al(OH)_3 + H_2S$

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Organic Reactions

The subject of organic reactions is very large and rather complicated. There are hundreds of "named" reactions or reaction types which have accumulated throughout the history of modern organic chemistry, generally carrying the name of their discoverer (or explainer). These are NOT the type of things you should be worrying about at this level.

While it *is* possible to give you some very basic and general types of reactions that appear infrequently on the exam, this will not help you unless you can remember some fundamental information about organic compounds such as:

1) general formulas for alkanes, alkenes and alkynes
AND how Greek prefixes are used to name them
according to the length of the carbon chain
2) some common functional groups and how they are
attached to the (usually) alkane chain

As far as names of compounds, branched isomers are generally not used in questions in this section of the exam. Remember, however, that the first four (or three) members of each aliphatic family have trivial names (meth-, eth-, prop-, but-) rather than names based on the chain length. Common functional groups would almost certainly include alcohols, acids, esters, and halides.

The types of reactions which have been featured historically fall more or less into these groups:

1. combustive oxidation (products are always the same, CO_2 and H_2O)
   hexane + oxygen $\rightarrow$ carbon dioxide + water
   $C_6H_{14} + O_2 \rightarrow CO_2 + H_2O$
2. addition (requires alkenes or alkynes, halogens, halogen acids or just hydrogen)
   propene + chlorine $\rightarrow$ 1,2-dichloropropane
   $C_3H_6 + Cl_2 \rightarrow C_3H_6Cl_2$ [too easy, huh?!]
3. substitution (a hydrogen atom in the molecule is "displaced" by something)
   methane + excess bromine $\rightarrow$ carbon tetrabromide
   $CH_4 + Br_2 \rightarrow CBr_4 + HBr$
4. esterification (carboxylic acid + alcohol $\rightarrow$ ester + water)
   methanol + acetic acid $\rightarrow$ methyl acetate + water
   $CH_3OH + CH_3COOH \rightarrow CH_3COOCH_3 + H_2O$
5. saponification (ester + base $\rightarrow$ salt + alcohol)
   ethyl acetate + sodium hydroxide $\rightarrow$ sodium acetate + ethanol
   $CH_3COOC_2H_5 + OH^- \rightarrow CH_3COO^- + C_2H_5OH$

(an argument could be made for writing this last one in molecular form, but the NaOH is most likely aqueous and therefore water would be present)

There are not a lot of examples from past tests to give you, but a few are on the back for you to try. Remember, you wouldn't need to name anything. I just did that to show off.

[Can I write structures instead of formulas????????? Yes, I'm sure that would be accepted]

1. a sample of 2-butene is treated with hydrogen bromide gas
2. an excess of chlorine gas is added to acetylene gas (ethyne)
3. acetic acid is refluxed with ethanol for several hours
4. propene and bromine gases are mixed
5. propanol is burned completely in air
6. methane is mixed with excess bromine gas
7. propene reacts with water in the presence of a catalyst

(answers on the back)

1. $C_4H_8 + HBr \rightarrow C_4H_9Br$
2. $C_2H_2 + Cl_2 \rightarrow C_2H_2Cl_4$
3. $CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O$
4. $C_3H_6 + Br_2 \rightarrow C_3H_6Br_2$
5. $C_3H_7OH + O_2 \rightarrow CO_2 + H_2O$
6. $CH_4 + Br_2 \rightarrow CBr_4 + HBr$
7. $C_3H_6 + H_2O \rightarrow C_3H_7OH$

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Complexation Reactions

Reactions of coordination compounds and ions are not covered in depth on the exam but you will sometimes see them in the reaction-writing section and they are easy enough to complete with a few basic principles in mind. Most can be recognized by the choice of reactants: generally a transition metal ion or compound (also the amphoteric species from Group 3A such as Al) and a source of ligands. The most common ligands involved in questions are ammonia and the hydroxide ion. Key to such questions is often the word "excess", indicating that enough of the complexation agent has been added to eliminate the possibility of precipitation of lesser-coordinated species.

One of the hurdles to get over is some knowledge of the likely coordination numbers for metal ions. Unfortunately there is no simple way to remember all of them. Some you may recognize from work done in the lab or something you read. Others may just "look right". In a pinch, it may be helpful to know that *often* the coordination number is twice the cation charge. In any case, you will seldom lose all points just because you used a coordination number of 4 instead of 6.

Historically, reactions involving complex ions on the exam fall into three broad categories:

1. complexation of a soluble salt

e.g. a concentrated solution of ammonia is added to a solution of copper(II) chloride

$NH_3 + Cu^{2+} \rightarrow Cu(NH_3)_4^{2+}$

2. complexation of an insoluble salt

e.g. excess concentrated potassium hydroxide is added to a precipitate of zinc hydroxide

$OH^- + Zn(OH)_2 \rightarrow Zn(OH)_4^{2-}$

3. destruction of a complex by acid/base neutralization

e.g. dilute hydrochloric acid is added to a solution of diamminesilver nitrate

$H^+ + Cl^- + Ag(NH_3)_2^+ \rightarrow AgCl + NH_4^+$

Below are some examples of actual reactions from past A.P. exams.

1. excess dilute nitric acid is added to a solution of tetramminecadmium(II) ion
2. pellets of aluminum metal are added to a solution containing an excess of sodium hydroxide
3. an excess of ammonia gas is bubbled through a solution saturated with silver chloride
4. a concentrated solution of ammonia is added to a suspension of zinc hydroxide
5. a solution of ammonium thiocyanate is added to a solution of iron(III) chloride

(answers on the back)

1. $H^+ + Cd(NH_3)_4^{2+} \rightarrow Cd^{2+} + NH_4^+$
2. $Al + OH^- \rightarrow Al(OH)_4^-$
3. $NH_3 + AgCl \rightarrow Ag(NH_3)_2^+ + Cl^-$
4. $NH_3 + Zn(OH)_2 \rightarrow Zn(NH_3)_4^{2+} + OH^-$
5. $SCN^- + Fe^{3+} \rightarrow FeSCN^{2+}$ [other species up to CN6 accepted]

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Non-trivial Redox Reactions

Well, here we are at the end of the line. We have already looked at simple reactions which involve changes in oxidation number. These include single displacement reactions and combination reactions between elements (also decomposition reactions yielding elements...). Such reactions can be completed by following simple rules. The non-trivial sort require knowledge of common oxidizer/reducer pairs or at the very least some common-sense elimination of unlikely products and then guessing. Memorizing the "common" pairs may help but you will probably get farther by trying to reason through the process since there is no guarantee that the pairs you memorize will be used on the exam.

Some essential principles to keep in mind are these:

- elements in their highest positive oxidation state (same as group #, whether A or B) can ONLY be reduced
- elements in their lowest oxidation state (0 for metals, negative for non-metals, corresponding to distance from noble gases) can ONLY be oxidized
- intermediate oxidation states can go either way!!!
- if the mixture is acidic, H^+ should be included as a reactant; water is one product
- if the mixture is basic, OH^- should be included as a reactant; water is one product
- occasionally the acid anion or base cation may precipitate with a product ion

Below are some of the more common redox pairs:

oxidizers [remember, oxidizers will become reduced]

MnO_4^- (in acid) $\rightarrow$ Mn^{2+}
MnO_4^- (in neutral or basic) $\rightarrow$ MnO_2
MnO_2 (in acid) $\rightarrow$ Mn^{2+}
$Cr_2O_7^{2-}$ (in acid) $\rightarrow$ Cr^{3+}
HNO_3 (conc.) $\rightarrow$ NO_2
HNO_3 (dilute) $\rightarrow$ NO
H_2SO_4 (hot, concentrated) $\rightarrow$ SO_2 [if not hot and conc., this acts like HCl or other normal acids]
metal cations $\rightarrow$ lower charge cations or (rarely) free metals
free halogens $\rightarrow$ halide ions

reducers [remember, reducers will become oxidized]

halide ions $\rightarrow$ free halogens
free metals $\rightarrow$ metal cations
SO_3^{2-} (or SO_2) $\rightarrow$ SO_4^{2-}
NO_2^- $\rightarrow$ NO_3^-
free halogens (dil. basic) $\rightarrow$ hypohalite ions [like XO^-]
free halogens (conc. basic) $\rightarrow$ halate ions [like XO_3^-]
metal cations $\rightarrow$ higher charge cations

Whew! That seems like a lot to remember for such little payback, but if you look at the list carefully you will see that none of the species are really exotic after two years of chemistry (with the possible exception of the hypohalite and halate ions---we did see them in the KBr/$KBrO_3$ lab). So the real task is to see the changes in oxidation state as possibilities when a reaction does not fit other categories and then use your chemical imagination: one has to go up and the other has to go down! The products should not be weird or exotic, i.e., you should recognize them. If you don't, you probably deserve to miss the question.

How important are these? On the real exam there are 8 reactions. You need to write 5. Here is the number of non-trivial redox reactions for the past few years of exams. Judge for yourself.

1998	0 (!)
1999	1
2000	0 (!)
2001	1
2002	0 (!)
2003	0 (!)

A look at a similar list from years previous to those shown would have shown more of these reactions. Sadly, the tests *are* getting wimpier (if that’s a word). So can you skip them?????? Yes, <u>if</u> you can do all of the other nonsense they throw at you.

Below are some reactions from past tests for you to try.

1. hydrogen peroxide is added to an acidified solution of potassium dichromate
2. sulfur dioxide gas is bubbled through an acidified solution of potassium permanganate
3. a solution containing tin(II) ions is added to acidified potassium dichromate solution
4. powdered iron is added to a solution of iron(III) sulfate
5. copper(II) sulfide is added to dilute nitric acid
6. concentrated hydrochloric acid is added to solid manganese(IV) oxide and heated
7. chlorine gas is bubbled through a solution of dilute sodium hydroxide
8. solutions of potassium iodide and potassium iodate are mixed
9. solid silver is added to dilute nitric acid

(answers on the back)

1. $H_2O_2 + Cr_2O_7^{2-} + H^+ \rightarrow Cr^{3+} + O_2 + H_2O$
2. $SO_2 + MnO_4^- + H^+ \rightarrow Mn^{2+} + SO_4^{2-} + H_2O$
3. $Sn^{2+} + H^+ + Cr_2O_7^{2-} \rightarrow Sn^{4+} + Cr^{3+} + H_2O$
4. $Fe + Fe^{3+} \rightarrow Fe^{2+}$
5. $CuS + H^+ + NO_3^- \rightarrow S + NO + Cu^{2+} + H_2O$
6. $H^+ + Cl^- + MnO_2 \rightarrow Mn^{2+} + Cl_2 + H_2O$
7. $Cl_2 + OH^- \rightarrow H_2O + ClO^- + Cl^-$
8. $H^+ + I^- + IO_3^- \rightarrow I_2 + H_2O$
9. $Ag + H^+ + NO_3^- \rightarrow Ag^+ + NO + H_2O$