1. Using balanced chemical equations, explain why the pH of unpolluted natural rainwater is not 7.

Carbon dioxide from the atmosphere dissolves in rainwater to form carbonic acid, which partially dissociates to give H^+ ions thus making the water slightly acidic.
1-----mark for suggesting the water is acidic

1. $CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$. 1------ mark (balanced equation)
2. $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$. 1-----mark (balanced equation)

2. Using balanced equations, explain why minerals such as $PbCO_3$ and CuO are usually insoluble in neutral soils but soluble in acidic soils. (2 marks)

- $PbCO_3(s) + 2H^+(aq) \rightarrow Pb^{2+}(aq) + H_2O(l) + CO_2(g)$ 1-----mark
- $CuO(s) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l)$. 1-----mark

In neutral soil (low H^+) these minerals are insoluble; in acidic soil (higher H^+) the reactions proceed and release soluble metal cations. 1-----mark

3. Describe how carbonic acid can release toxic heavy metal ions into groundwater.

Carbonic acid reacts with metal carbonates and hydroxides, dissolving the solid and releasing metal cations as soluble species. 1-----mark

$CaCO_3(s) + H_2CO_3(aq) \rightarrow Ca^{2+}(aq) + 2HCO_3^-(aq)$
or

$PbCO_3(s) + H_2CO_3(aq) \rightarrow Pb^{2+}(aq) + 2HCO_3^-(aq)$. 1-----mark for any balanced appropriate equation

Dissolved metal ions (e.g. Pb^{2+}, Cu^{2+}, Al^{3+}) are then transported in groundwater. 1-----mark

4. Other than CO_2, what pollutants cause acid rain? Give two balanced equations. (2 marks)

1. *Sulfur dioxide → sulfuric acid formation:*
   $2SO_2(g) + H_2O(l) \rightarrow 2H_2SO_3(g)$ (sulphurous acid)
   or
   $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ (oxidation)
   $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$. (Sulphuric acid) 1-----mark for either balanced equation
2. *Nitrogen dioxide → nitric acid formation:*
   $2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)$. 1-----mark for balanced equation

5. Explain why natural rainwater (from CO_2) is only mildly acidic while acid rain has a much lower pH. Include the sources and balanced chemical equations. (4 marks)

Natural rain acquires acidity from dissolved CO_2 forming carbonic acid ($CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$) which is a weak acid 1-----mark for mention of carbonic acid being a weak acid. No equation is necessary.
Acid rain contains extra strong acids formed from anthropogenic emissions of SO_2 and NO_x. For example:

- *SO_2 oxidation: $2SO_2 + O_2 \rightarrow 2SO_3$; $SO_3 + H_2O \rightarrow H_2SO_4$ (sulfuric acid — strong acid). 1 -----mark*
- *NO_2 hydrolysis/oxidation: $2NO_2 + H_2O \rightarrow HNO_3 + HNO_2 \rightarrow$ (oxidation) $\rightarrow 2HNO_3$ (nitric acid — strong acid). 1-----mark*

These strong acids produce many more free H^+ per molecule than weak carbonic acid, so acid rain has a much lower pH. 1-----mark for mention of nitric and sulfuris acid being strong hence lower pH.

6. Write a balanced equation for the reaction between limestone ($CaCO_3$) and carbonic acid.

$CaCO_3(s) + H_2CO_3(aq) \rightarrow Ca^{2+}(aq) + 2HCO_3^-(aq)$.

***1**-----mark balanced equation*

1-----mark correct species with correct formulas

7. Write the balanced equation for malachite, $Cu_2CO_3(OH)_2$, reacting with nitric acid.

$Cu_2CO_3(OH)_2(s) + 4HNO_3(aq) \rightarrow 2Cu(NO_3)_2(aq) + CO_2(g) + 3H_2O(l)$.
***1**-----mark balanced equation*

1-----mark correct species with correct formulas

8. Explain how soil abundant with organic matter keeps metal ions in the soil.

Organic acids naturally present in organic matter or produce during decay, have many negatively charged functional groups (carboxyl COO^-) that adsorb metal cations such as Ca^{2+}, Pb^{2+} and Fe^{3+}. The attraction between the cation and the negative group (COO^-) forms strong bond preventing the metal cation from leaching (dissolving) into the soil hence keeping nutrient cations in the soil.
1-----mark for mentioning presence of negatively charged groups in organic matter

1-----mark for describing the strong bonds formed thus reducing the capacity of cations to be dissolved in the soil and washed away.

9. Acid rain falls on marble monuments. Give one chemical equation predicting a lasting effect and explain the chemistry using nitric acid as an example.

Surface dissolution and loss of detail:
$CaCO_3(s) + 2HNO_3 (aq) \rightarrow Ca(NO_3)_2 (aq) + CO_2(g) + H_2O(l)$. 1-----mark balanced equation using any acid sulfuric or nitric or carbonic..
Nitric acid from acid rain reacts with marble ($caCO_3$) to form soluble $Ca(NO_3)_2$, causing surface erosion and loss of sculptural detail. 1-----mark

10. A forest near a coal fired power station shows dying back. Describe how soil acidification could be responsible and the mechanism that kills trees.

Acid deposition increases soil H^+, displacing nutrient cations (Ca^{2+}, Mg^{2+}, K^+) from being attacjed to negative ions in the organic matter and thus increasing Al^{3+} solubility. 1-----mark

High Al^{3+} is toxic to roots and blocks Ca^{2+} uptake; nutrient loss plus Al toxicity damages root systems, reduces water/nutrient uptake and weakens trees, causing dieback. 1-----mark

11. A lake's pH drops from 7 to 5. Predict what may happen to organisms with calcium carbonate shells.

Lower pH increases $[H^+]$ and shifts carbonate equilibria, lowering carbonate ion concentration and increasing $CaCO_3$ solubility: $CaCO_3(s) + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$. 1-----mark

Shells may dissolve or grow more slowly; juvenile organisms can die, population declines follow.
1-----mark for recognising the reduced survivability of organisms with a damaged shell or exoskeleton.

12. Explain why regions with high rainfall and abundant organic matter tend to show more rapid chemical weathering. (

High rainfall increases water available for reactions and transport of dissolved ions.

1-----mark

Abundant organic matter produces CO_2 from decomposition, increasing local carbonic acid ($CO_2 + H_2O \rightarrow H_2CO_3$) and organic acids, which enhance chemical weathering rates. More leaching also removes products, allowing more reaction to proceed.
1-----mark

13. Experimental design: effect of pH on rate of limestone dissolution

- *Title 1-----mark for including IV and DV*
- *Aim: Investigate how initial solution pH affects the rate of dissolution of limestone (mass loss of $CaCO_3$). 1-----mark*
- *Hypothesis 1-----mark if it is in the format If __IV__ then __DV*

  1-----mark if it has sound scientific reasoning for the relationship between IV and DV and written without personal pronouns.
- *Variables*
  - *Independent - starting pH of the solution (pH 3, 4, 5, 6, 7) 1-----mark*
  - *Dependent - rate of dissolution measured as mass loss of limestone (g s^{-1}) . 1-----mark (units must be stated for the mark to be awarded)*
  - *Controlled Variables*

    - Same mass and particle size / surface area of limestone samples.

    - Same solution volume, temperature, agitation rate, and duration.

    - Use deionised water with pH adjusted using a strong acid (e.g. HCl) or a weak acid (choose and state) and checked with a calibrated pH meter.

    2-----marks for listing four appropriate controlled variable, such as the ones above.

    1-----mark For listing two or three valid controlled variables

    Select one controlled variable

    1----- mark an explanation of validity

    1-----mark for predicting how changes in the chosen variable may impact results and compromise validity.
- *Materials & apparatus . 1-----mark for an exhaustive and detailed list of equipment (eg. 250 mL beaker)*

  1-----mark for quantities (eg 2 X 250 mL beakers)
- *Procedure*

  1----- mark for clearly numbered stepwise method,

  1----- mark for logical

  1----- mark for using repeat statements that clearly address the controlled variables.

  1----- mark for suggesting how the IV will change and how the DV will be measured.

  2----- marks for identifying 4 possible safety risks and outlining mitigation and treatment steps.

  1----- mark for identifying less than 4 possible safety risks and outlining mitigation and treatment steps.