Part D — Metathetical or Double Displacement Reaction: **$CuO(s) \rightarrow CuCl_4^{2-}(aq)$**

The black copper (II) oxide was filtered and HCl was added.
The black solid dissolves in the acid and became a bright green solution.

1. Copy the equation for the reaction: $CuO(s) + 2HCl(aq) \rightarrow CuCl_2(aq) + H_2O(\ell)$
   Assign oxidation numbers to each element.
   Why is the reaction classified as a double displacement reaction?

$$\overset{+2\ -2}{CuO(s)} + \overset{+1\ -1}{2HCl(aq)} \rightarrow \overset{+2\ -1}{CuCl_2(aq)} + \overset{+1\ -2}{H_2O(\ell)}$$

Notice that no oxidation numbers changed. This is known as a metathesis reaction, in contrast to redox reactions, the oxidation numbers do not change; that is no electrons are lost or gained. A new arrangement results in a change in phase. The ions may leave solution as either a new combination that is insoluble – a precipitate forms, or molecules that leave solution as either a gas or water molecules. Double displacement reaction may be described as the ions in an ionic compound switching partners. This may however be misleading as when the ions are in solution they are not actually bonded with the other ion. But one of the new combinations of ions will leave solution.

This net ionic equation better shows the changes. In this reaction one of the ionic compounds was an insoluble precipitate, so these ions were together in the solid. The hydrogen ions in solution react with oxide ions to form water. As this occurs more copper oxide dissolves until all has reacted.

$$CuO(s) + H+(aq) + Cl(aq) \rightarrow Cu^{2+}(aq) + Cl^{-}(aq) + H_2O(\ell)$$

2. Copper (II) oxide is a metal oxide, which act as bases.
   a. Describe the oxide ion. Draw the electron configuration. Draw the Lewis structure.

   The oxide ion is an oxygen atom with two extra electrons filling the 2s and 2p orbitals. $1s^2\ 2s^2\ 2p^6$

   b. The oxide ion reacts with hydrogen ions to form hydroxide ions. Describe the bond formed between the oxide ion and the hydrogen ion.

   The oxide ion has four lone pairs of electrons. Thus it can form a covalent bond with the hydrogen ion (proton). The oxide ion acts as a Bronsted Lowry base as well as a Lewis base (e-pair donor). The pair of electrons in one of the p orbitals of the oxide ion is shared between the oxygen atom and the hydrogen ion. The overlap of orbitals and sharing of the electron pair results in a sigma bond – sharing electrons between nuclei along the internuclear axis. This is a polar covalent bond just like in water molecules. The electron density is greater around the oxygen due its greater electronegativity.

   c. How does this allow a metal oxide to act as a base? Address changes in ion concentration.

   Since the oxide ions react with the hydrogen ions this reduces the concentration of hydrogen ions – increasing the pH. More obvious is the increase in hydroxide ions since they are formed in the reaction. The increase in hydroxide fits the operational definition of a base.

DOUBLE DISPLACEMENT REACTIONS examples

1) **Precipitate** – forming a solid $2KI_{(aq)} + Pb(NO_3)_{2(aq)} \rightarrow PbI_{2(s)} + 2KNO_{3(aq)}$
2) **Neutralization** – forming water $HNO_{3(aq)} + KOH_{(aq)} \rightarrow KNO_{3(aq)} + H_2O_{(l)}$
3) **Gas Forming** $Na_2S_{(aq)} + 2HCl_{(aq)} \rightarrow H_2S_{(g)} + 2NaCl_{(aq)}$
   $Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2CO_{3(aq)}$ and $H_2CO_{3(aq)}$ breaks down to $H_2O_{(l)} + CO_{2(g)}$

$$Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$$

$Na_2SO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2SO_{3(aq)}$ and the $H_2SO_{3(aq)} \rightarrow H_2O_{(l)} + SO_{2(g)}$

3. The reaction of copper(II) oxide with hydrochloric acid is an acid/base reaction.
Copy the equation for the reaction that occurs:
$CuO(s) + 2HCl(aq) \rightarrow \quad CuCl_2(aq) + H_2O(\ell)$

a. Identify the species acting as the acid and the base.
b. Which one of these fits the Arrhenius model? Which one does not? Explain.
c. Describe the formation of water molecules in this reaction. Include equations for both steps that must occur.

BASE ACID
$CuO(s) + 2HCl(aq) \rightarrow \quad CuCl_2(aq) + H_2O(\ell)$

The HCl fits the classic definition of an acid. An Arrhenius acid is an ionic compound with a hydrogen ion with a negative ion. An Arrhenius base has hydroxide ion with a positive ion. The copper oxide does not fit this model.

4. Copy both forms of the net ionic equation:
$CuO(s) + \quad 2H^+(aq) \rightarrow \quad Cu^{2+}(aq) + H_2O(l)$
$CuO(s) + \quad H_3O^+(aq) \rightarrow \quad Cu^{2+}(aq) + H_2O(l) + OH^-(aq)$
The second equation can be used with a Bronsted-Lowry model
a. Identify the Bronsted-Lowry acid (proton donor) and its conjugate base.
b. Identify the Bronsted-Lowry base (proton acceptor) and its conjugate acid

$CuO(s) + H_3O^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l) + OH^-(aq)$
Base (CuO), Acid (H_3O^+), Base (H_2O), **Base** (OH^-)

Identify the acid by looking for the substance that lost a H. To find its conjugate base connect it with the substance it becomes on the other side after losing the H.

Identify the acid by looking for the substance that gained a H. To find its conjugate acid connect it with the substance it becomes on the other side after gaining the H.

c. Explain why a Bronsted-Lowry base must have a lone pair of elections to accept a proton.

The Bronsted-Lowry base accepts a proton (H+) by forming a covalent bond with it. Since the hydrogen ion has no electrons to share, the Lewis base must bring both electrons to share in the covalent bond.

d. Explain the formation and eventual neutralization of the hydroxide shown in the second equation.

$O^{2-}(aq) + H^+(aq) \rightarrow OH^-(aq)$
$OH^-(aq) + H^+(aq) \rightarrow H_2O(l)$

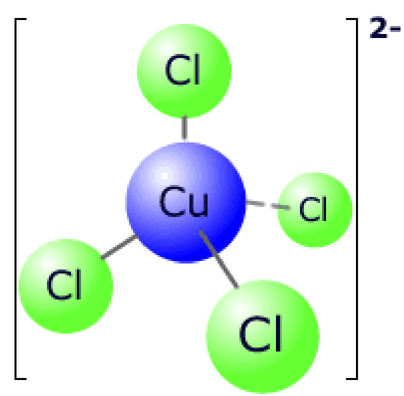
The oxide ions react with hydrogen ions leading to a decrease in the hydrogen ion concentration and increase hydroxide ion concentration - the operational definition of a base. As more acid is added the hydrogen ions react with the hydroxide ions to form water molecules.

5. Explain the green color of the copper (II) solution.
a. Draw and describe the complex ion formed.

$$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightleftharpoons [CuCl_4]^{2-} + 6H_2O$$

The green color is the result of the formation of the copper-chloride complex ion. The separation of energy is related to the emission of the green light.

tetrachloro cuprate (II) ion



b. Describe the covalent bond that forms between chloride ions and copper ion. This is an example of a Lewis acid/base. Which ion donated an electron pair (Lewis base)? Which ion accepted the electron pair (Lewis Acid)?

The chloride ion has lone pairs of electrons. The copper (II) ions have empty orbitals. The lone pair of electrons is shared between the copper ion and the chloride ion. The chloride ion acts as a Lewis base donating its pair of electrons to share with copper (II) ion, which acts as a Lewis acid accepting the electron pair. This is a coordination complex or complex ion.

The empty s and p orbitals hybridize (sp_3) and the hybrid orbitals overlap with orbitals from chloride ion.