Redox Practice Problems Key

For each of following skeletal redox reactions:

a. Identify the oxidized species and state how many electrons are lost per atom
b. Identify the reduced species and state how many electrons are gained per atom
c. Identify the oxidizing agent
d. Identify the reducing agent
e. Write balanced half reactions (in acid)
f. Write a balanced redox reaction (in acid)
g. Write a balanced redox reaction (in base)

1. $MnO_4^-{}_{(aq)} + H_2O_{2(l)} \rightarrow Mn^{2+}{}_{(aq)} + O_{2(g)}$

First write oxidation states for each element, per atom.

+7 4(-2) 2(+1) -2 +2 2(0)

$MnO_4^-{}_{(aq)} + H_2O_{2(l)} \rightarrow Mn^{2+}{}_{(aq)} + O_{2(g)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each O lost $1e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Mn gained $5e^-$
c.	Identify the oxidizing agent • $MnO_4^-{}_{(aq)}$
d.	Identify the reducing agent • $H_2O_{2(l)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $H_2O_{2(l)} \rightarrow O_{2(g)} + 1e^-$ $5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)}$ • Balance half reactions for same # of oxidized/reduced species $H_2O_{2(l)} \rightarrow O_{2(g)} + 2(1e^-)$ $5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $H_2O_{2(l)} \rightarrow O_{2(g)} + 2e^- + 2H^+{}_{(aq)}$ $8H^+{}_{(aq)} + 5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)} + 4H_2O_{(l)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $5(H_2O_{2(l)} \rightarrow O_{2(g)} + 2e^- + 2H^+{}_{(aq)})$ $2(8H^+{}_{(aq)} + 5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)} + 4H_2O_{(l)})$ • Rewriting the half reactions with the multiplication done $5H_2O_{2(l)} \rightarrow 5O_{2(g)} + 10e^- + 10H^+{}_{(aq)}$ $16H^+{}_{(aq)} + 10e^- + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $16H^+{}_{(aq)} + 10e^- + 5H_2O_{2(l)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 5O_{2(g)} + 8H_2O_{(l)} + 10e^- + 10H^+{}_{(aq)}$ • Cross out spectators $6H^+{}_{(aq)} + 5H_2O_{2(l)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 5O_{2(g)} + 8H_2O_{(l)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+{}_{(aq)}$. Add the same # of $OH^-{}_{(aq)}$ to both sides of the equation $6OH^-{}_{(aq)} + 6H^+{}_{(aq)} + 5H_2O_{2(l)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 5O_{2(g)} + 8H_2O_{(l)} + 6OH^-{}_{(aq)}$ • On the side with both $H^+{}_{(aq)}$ & $OH^-{}_{(aq)}$, those become water $6H_2O_{(l)} + 5H_2O_{2(l)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 5O_{2(g)} + 8H_2O_{(l)} + 6OH^-{}_{(aq)}$ • Cross out spectators $5H_2O_{2(l)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 5O_{2(g)} + 2H_2O_{(l)} + 6OH^-{}_{(aq)}$

2. $CrO_4^{2-}{}_{(aq)} + Cu_{(s)} \rightarrow Cr(OH)_{3(s)} + Cu(OH)_{2(s)}$

First write oxidation states for each element, per atom.

+6 4(-2) 0 +3 2(-1) +2 2(-1)

$CrO_4^{2-}{}_{(aq)} + Cu_{(s)} \rightarrow Cr(OH)_{3(s)} + Cu(OH)_{2(s)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each Cu lost $2e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Cr gained $3e^-$
c.	Identify the oxidizing agent • $CrO_4^{2-}{}_{(aq)}$
d.	Identify the reducing agent • $Cu_{(s)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $Cu_{(s)} \rightarrow Cu(OH)_{2(s)} + 2e^-$ $3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr(OH)_{3(s)}$ • Balance half reactions for same # of oxidized/reduced species $Cu_{(s)} \rightarrow Cu(OH)_{2(s)} + 2e^-$ $3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr(OH)_{3(s)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $2H_2O_{(l)} + Cu_{(s)} \rightarrow Cu(OH)_{2(s)} + 2e^- + 2H^+_{(aq)}$ $5H^+_{(aq)} + 3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr(OH)_{3(s)} + H_2O_{(l)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $3(2H_2O_{(l)} + Cu_{(s)} \rightarrow Cu(OH)_{2(s)} + 2e^- + 2H^+_{(aq)})$ $2(5H^+_{(aq)} + 3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr(OH)_{3(s)} + H_2O_{(l)})$ • Rewriting the half reactions with the multiplication done $6H_2O_{(l)} + 3Cu_{(s)} \rightarrow 3Cu(OH)_{2(s)} + 6e^- + 6H^+_{(aq)}$ $10H^+_{(aq)} + 6e^- + 2CrO_4^{2-}{}_{(aq)} \rightarrow 2Cr(OH)_{3(s)} + 2H_2O_{(l)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $6H_2O_{(l)} + 3Cu_{(s)} + 10H^+_{(aq)} + 6e^- + 2CrO_4^{2-}{}_{(aq)} \rightarrow 3Cu(OH)_{2(s)} + 2Cr(OH)_{3(s)} + 2H_2O_{(l)} + 6e^- + 6H^+_{(aq)}$ • Cross out spectators $4H_2O_{(l)} + 4H^+_{(aq)} + + 3Cu_{(s)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 3Cu(OH)_{2(s)} + 2Cr(OH)_{3(s)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+_{(aq)}$. Add the same # of $OH^-_{(aq)}$ to both sides of the equation $4OH^-_{(aq)} + 4H_2O_{(l)} + 4H^+_{(aq)} + + 3Cu_{(s)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 3Cu(OH)_{2(s)} + 2Cr(OH)_{3(s)} + 4OH^-_{(aq)}$ • On the side with both $H^+_{(aq)}$ & $OH^-_{(aq)}$, those become water $4\ H_2O_{(l)} + 4H_2O_{(l)} + 3Cu_{(s)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 3Cu(OH)_{2(s)} + 2Cr(OH)_{3(s)} + 4OH^-_{(aq)}$ • Cross out spectators $8H_2O_{(l)} + 3Cu_{(s)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 3Cu(OH)_{2(s)} + 2Cr(OH)_{3(s)} + 4OH^-_{(aq)}$

3. $AsO_4^{3-}{}_{(aq)} + NO_2^-{}_{(l)} \rightarrow AsO_2^-{}_{(aq)} + NO_3^-{}_{(l)}$

First write oxidation states for each element, per atom.

+5 4(-2) +3 2(-2) +3 2(-2) +5 3(-2)

$AsO_4^{3-}{}_{(aq)} + NO_2^-{}_{(l)} \rightarrow AsO_2^-{}_{(aq)} + NO_3^-{}_{(l)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each N lost $2e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each As gained $2e^-$
c.	Identify the oxidizing agent

	• $AsO_4^{3-}{}_{(aq)}$
d.	Identify the reducing agent • $NO_2^-{}_{(l)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $NO_2^-{}_{(l)} \rightarrow NO_3^-{}_{(l)} + 2e^-$ $2e^- + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)}$ • Balance half reactions for same # of oxidized/reduced species $NO_2^-{}_{(l)} \rightarrow NO_3^-{}_{(l)} + 2e^-$ $2e^- + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $H_2O_{(l)} + NO_2^-{}_{(l)} \rightarrow NO_3^-{}_{(l)} + 2e^- + 2H^+{}_{(aq)}$ $4H^+{}_{(aq)} + 2e^- + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + 2H_2O_{(l)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $H_2O_{(l)} + NO_2^-{}_{(l)} \rightarrow NO_3^-{}_{(l)} + 2e^- + 2H^+{}_{(aq)}$ $4H^+{}_{(aq)} + 2e^- + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + 2H_2O_{(l)}$ • Rewriting the half reactions with the multiplication done $H_2O_{(l)} + NO_2^-{}_{(l)} \rightarrow NO_3^-{}_{(l)} + 2e^- + 2H^+{}_{(aq)}$ $4H^+{}_{(aq)} + 2e^- + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + 2H_2O_{(l)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $H_2O_{(l)} + NO_2^-{}_{(l)} + 4H^+{}_{(aq)} + 2e^- + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + 2H_2O_{(l)} + NO_3^-{}_{(l)} + 2e^- + 2H^+{}_{(aq)}$ • Cross out spectators $NO_2^-{}_{(l)} + 2H^+{}_{(aq)} + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + H_2O_{(l)} + NO_3^-{}_{(l)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+{}_{(aq)}$. Add the same # of $OH^-{}_{(aq)}$ to both sides of the equation $2OH^-{}_{(aq)} + NO_2^-{}_{(l)} + 2H^+{}_{(aq)} + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + H_2O_{(l)} + NO_3^-{}_{(l)} + 2OH^-{}_{(aq)}$ • On the side with both $H^+{}_{(aq)}$ & $OH^-{}_{(aq)}$, those become water $2H_2O_{(l)} + NO_2^-{}_{(l)} + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + H_2O_{(l)} + NO_3^-{}_{(l)} + 2OH^-{}_{(aq)}$ • Cross out spectators $H_2O_{(l)} + NO_2^-{}_{(l)} + AsO_4^{3-}{}_{(aq)} \rightarrow AsO_2^-{}_{(aq)} + NO_3^-{}_{(l)} + 2OH^-{}_{(aq)}$

4. $BH_4^-{}_{(aq)} + ClO_3^-{}_{(aq)} \rightarrow H_2BO_3^-{}_{(aq)} + Cl^-{}_{(aq)}$

First write oxidation states for each element, per atom.

-5 4(+1) +5 3(-2) 2(+1) +3 3(-2) -1

$BH_4^-{}_{(aq)} + ClO_3^-{}_{(aq)} \rightarrow H_2BO_3^-{}_{(aq)} + Cl^-{}_{(aq)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each B lost $8e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Cl gained $6e^-$
c.	Identify the oxidizing agent • $ClO_3^-{}_{(aq)}$
d.	Identify the reducing agent • $BH_4^-{}_{(aq)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $BH_4^-{}_{(aq)} \rightarrow H_2BO_3^-{}_{(aq)} + 8e^-$ $6e^- + ClO_3^-{}_{(aq)} \rightarrow Cl^-{}_{(aq)}$ • Balance half reactions for same # of oxidized or reduced species $BH_4^-{}_{(aq)} \rightarrow H_2BO_3^-{}_{(aq)} + 8e^-$ $6e^- + ClO_3^-{}_{(aq)} \rightarrow Cl^-{}_{(aq)}$

	• Balance half reactions for # of O, with H_2O, and # of H, with H^+ $3H_2O_{(l)} + BH_4^-{}_{(aq)} \rightarrow H_2BO_3^-{}_{(aq)} + 8e^- + 8H^+{}_{(aq)}$ $6H^+{}_{(aq)} + 6e^- + ClO_3^-{}_{(aq)} \rightarrow Cl^-{}_{(aq)} + 3H_2O_{(l)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $3(3H_2O_{(l)} + BH_4^-{}_{(aq)} \rightarrow H_2BO_3^-{}_{(aq)} + 8e^- + 8H^+{}_{(aq)})$ $4(6H^+{}_{(aq)} + 6e^- + ClO_3^-{}_{(aq)} \rightarrow Cl^-{}_{(aq)} + 3H_2O_{(l)})$ • Rewriting the half reactions with the multiplication done $9H_2O_{(l)} + 3BH_4^-{}_{(aq)} \rightarrow 3H_2BO_3^-{}_{(aq)} + 24e^- + 24H^+{}_{(aq)}$ $24H^+{}_{(aq)} + 24e^- + 4ClO_3^-{}_{(aq)} \rightarrow 4Cl^-{}_{(aq)} + 12H_2O_{(l)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $9H_2O_{(l)} + 3BH_4^-{}_{(aq)} + 24H^+{}_{(aq)} + 24e^- + 4ClO_3^-{}_{(aq)} \rightarrow 4Cl^-{}_{(aq)} + 12H_2O_{(l)} + 3H_2BO_3^-{}_{(aq)} + 24e^- + 24H^+{}_{(aq)}$ • Cross out spectators $3BH_4^-{}_{(aq)} + 4ClO_3^-{}_{(aq)} \rightarrow 4Cl^-{}_{(aq)} + 3H_2O_{(l)} + 3H_2BO_3^-{}_{(aq)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+{}_{(aq)}$. Add the same # of $OH^-{}_{(aq)}$ to both sides of the equation $3BH_4^-{}_{(aq)} + 4ClO_3^-{}_{(aq)} \rightarrow 4Cl^-{}_{(aq)} + 3H_2O_{(l)} + 3H_2BO_3^-{}_{(aq)}$ • No $H^+{}_{(aq)}$ so it's balanced in acid and in base $3BH_4^-{}_{(aq)} + 4ClO_3^-{}_{(aq)} \rightarrow 4Cl^-{}_{(aq)} + 3H_2O_{(l)} + 3H_2BO_3^-{}_{(aq)}$

5. $CrO_4^{2-}{}_{(aq)} + N_2O_{(g)} \rightarrow Cr^{3+}{}_{(aq)} + NO_{(g)}$
First write oxidation states for each element, per atom.
+6 4(-2) 2(+1) -2 +3 +2 -2
$CrO_4^{2-}{}_{(aq)} + N_2O_{(g)} \rightarrow Cr^{3+}{}_{(aq)} + NO_{(g)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each N lost $1e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Cr gained $3e^-$
c.	Identify the oxidizing agent • $CrO_4^{2-}{}_{(aq)}$
d.	Identify the reducing agent • $N_2O_{(g)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $N_2O_{(g)} \rightarrow NO_{(g)} + 1e^-$ $3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr^{3+}{}_{(aq)}$ • Balance half reactions for same # of oxidized/reduced species $N_2O_{(g)} \rightarrow 2NO_{(g)} + 2(1e^-)$ $3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr^{3+}{}_{(aq)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $H_2O_{(l)} + N_2O_{(g)} \rightarrow 2NO_{(g)} + 2e^- + 2H^+{}_{(aq)}$ $8H^+{}_{(aq)} + 3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr^{3+}{}_{(aq)} + 4H_2O_{(l)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $3(H_2O_{(l)} + N_2O_{(g)} \rightarrow 2NO_{(g)} + 2e^- + 2H^+{}_{(aq)})$ $2(8H^+{}_{(aq)} + 3e^- + CrO_4^{2-}{}_{(aq)} \rightarrow Cr^{3+}{}_{(aq)} + 4H_2O_{(l)})$ • Rewriting the half reactions with the multiplication done $3H_2O_{(l)} + 3N_2O_{(g)} \rightarrow 6NO_{(g)} + 6e^- + 6H^+{}_{(aq)}$ $16H^+{}_{(aq)} + 6e^- + 2CrO_4^{2-}{}_{(aq)} \rightarrow 2Cr^{3+}{}_{(aq)} + 8H_2O_{(l)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions

	$3H_2O_{(l)} + 3N_2O_{(g)} + 16H^+_{(aq)} + 6e^- + 2CrO_4^{2-}{}_{(aq)} \rightarrow 2Cr^{3+}_{(aq)} + 8H_2O_{(l)} + 6NO_{(g)} + 6e^- + 6H^+_{(aq)}$ • Cross out spectators $3N_2O_{(g)} + 10H^+_{(aq)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 2Cr^{3+}_{(aq)} + 5H_2O_{(l)} + 6NO_{(g)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+_{(aq)}$. Add the same # of $OH^-_{(aq)}$ to both sides of the equation $10OH^-_{(aq)} + 3N_2O_{(g)} + 10H^+_{(aq)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 2Cr^{3+}_{(aq)} + 5H_2O_{(l)} + 6NO_{(g)} + 10OH^-_{(aq)}$ • On the side with both $H^+_{(aq)}$ & $OH^-_{(aq)}$, those become water $10H_2O_{(l)} + 3N_2O_{(g)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 2Cr^{3+}_{(aq)} + 5H_2O_{(l)} + 6NO_{(g)} + 10OH^-_{(aq)}$ • Cross out spectators $5H_2O_{(l)} + 3N_2O_{(g)} + 2CrO_4^{2-}{}_{(aq)} \rightarrow 2Cr^{3+}_{(aq)} + 6NO_{(g)} + 10OH^-_{(aq)}$

6. $Br_{2(l)} \rightarrow BrO_3^-{}_{(aq)} + Br^-_{(aq)}$

7. $NO_{2(g)} \rightarrow NO_3^-{}_{(aq)} + NO_{2(g)}$

8. $Zn_{(s)} + NO_3^-{}_{(aq)} \rightarrow Zn(OH)_4^{2-}{}_{(s)} + NH_{3(g)}$
First write oxidation states for each element, per atom.
0 +5 3(-2) +2 4(-1) -3 3(+1)
$Zn_{(s)} + NO_3^-{}_{(aq)} \rightarrow Zn(OH)_4^{2-}{}_{(s)} + NH_{3(g)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each Zn lost $2e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each N gained $8e^-$
c.	Identify the oxidizing agent • $NO_3^-{}_{(aq)}$
d.	Identify the reducing agent • $Zn_{(s)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $Zn_{(s)} + NO_3^-{}_{(aq)} \rightarrow Zn(OH)_4^{2-}{}_{(s)} + NH_{3(g)}$ $Zn_{(s)} \rightarrow Zn(OH)_4^{2-}{}_{(s)} + 2e^-$ $8e^- + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)}$ • Balance half reactions for same # of oxidized/reduced species $Zn_{(s)} \rightarrow Zn(OH)_4^{2-}{}_{(s)} + 2e^-$ $8e^- + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $4H_2O_{(l)} + Zn_{(s)} \rightarrow Zn(OH)_4^{2-}{}_{(s)} + 2e^- + 4H^+_{(aq)}$ $9H^+_{(aq)} + 8e^- + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 3H_2O_{(l)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $4(4H_2O_{(l)} + Zn_{(s)} \rightarrow Zn(OH)_4^{2-}{}_{(s)} + 2e^- + 4H^+_{(aq)})$ $9H^+_{(aq)} + 8e^- + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 3H_2O_{(l)}$ • Rewriting the half reactions with the multiplication done $16H_2O_{(l)} + 4Zn_{(s)} \rightarrow 4Zn(OH)_4^{2-}{}_{(s)} + 8e^- + 16H^+_{(aq)}$ $9H^+_{(aq)} + 8e^- + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 3H_2O_{(l)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $16H_2O_{(l)} + 4Zn_{(s)} + 9H^+_{(aq)} + 8e^- + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 3H_2O_{(l)} + 4Zn(OH)_4^{2-}{}_{(s)} + 8e^- + 16H^+_{(aq)}$ • Cross out spectators $13H_2O_{(l)} + 4Zn_{(s)} + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 4Zn(OH)_4^{2-}{}_{(s)} + 7H^+_{(aq)}$
g.	Write a balanced redox reaction (in base)

	• Count the # of $H^+_{(aq)}$. Add the same # of $OH^-_{(aq)}$ to both sides of the equation $7OH^-_{(aq)} + 13H_2O_{(l)} + 4Zn_{(s)} + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 4Zn(OH)_4^{2-}{}_{(s)} + 7H^+_{(aq)} + 7OH^-_{(aq)}$ • On the side with both $H^+_{(aq)}$ & $OH^-_{(aq)}$, those become water $7OH^-_{(aq)} + 13H_2O_{(l)} + 4Zn_{(s)} + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 4Zn(OH)_4^{2-}{}_{(s)} + 7H_2O_{(l)}$ • Cross out spectators $7OH^-_{(aq)} + 6H_2O_{(l)} + 4Zn_{(s)} + NO_3^-{}_{(aq)} \rightarrow NH_{3(g)} + 4Zn(OH)_4^{2-}{}_{(s)}$

9. $SO_3^{2-}{}_{(aq)} + Cl_{2(g)} \rightarrow SO_4^{2-}{}_{(aq)} + Cl^-_{(aq)}$

First write oxidation states for each element, per atom.

+4 3(-2) 2(0) +6 4(-2) -1

$SO_3^{2-}{}_{(aq)} + Cl_{2(g)} \rightarrow SO_4^{2-}{}_{(aq)} + Cl^-_{(aq)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each S lost $2e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Cl gained $1e^-$
c.	Identify the oxidizing agent • $Cl_{2(g)}$
d.	Identify the reducing agent • $SO_3^{2-}{}_{(aq)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $SO_3^{2-}{}_{(aq)} \rightarrow SO_4^{2-}{}_{(aq)} + 2e^-$ $1e^- + Cl_{2(g)} \rightarrow Cl^-_{(aq)}$ • Balance half reactions for same # of oxidized/reduced species $SO_3^{2-}{}_{(aq)} \rightarrow SO_4^{2-}{}_{(aq)} + 2e^-$ $2(1e^-) + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $H_2O_{(l)} + SO_3^{2-}{}_{(aq)} \rightarrow SO_4^{2-}{}_{(aq)} + 2e^- + 2H^+_{(aq)}$ $2e^- + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $H_2O_{(l)} + SO_3^{2-}{}_{(aq)} \rightarrow SO_4^{2-}{}_{(aq)} + 2e^- + 2H^+_{(aq)}$ $2e^- + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)}$ • Rewriting the half reactions with the multiplication done $H_2O_{(l)} + SO_3^{2-}{}_{(aq)} \rightarrow SO_4^{2-}{}_{(aq)} + 2e^- + 2H^+_{(aq)}$ $2e^- + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $H_2O_{(l)} + SO_3^{2-}{}_{(aq)} + 2e^- + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)} + SO_4^{2-}{}_{(aq)} + 2e^- + 2H^+_{(aq)}$ • Cross out spectators $H_2O_{(l)} + SO_3^{2-}{}_{(aq)} + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)} + SO_4^{2-}{}_{(aq)} + 2H^+_{(aq)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+_{(aq)}$. Add the same # of $OH^-_{(aq)}$ to both sides of the equation $2OH^-_{(aq)} + H_2O_{(l)} + SO_3^{2-}{}_{(aq)} + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)} + SO_4^{2-}{}_{(aq)} + 2H^+_{(aq)} + 2OH^-_{(aq)}$ • On the side with both $H^+_{(aq)}$ & $OH^-_{(aq)}$, those become water $2OH^-_{(aq)} + H_2O_{(l)} + SO_3^{2-}{}_{(aq)} + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)} + SO_4^{2-}{}_{(aq)} + 2H_2O_{(l)}$ • Cross out spectators $2OH^-_{(aq)} + SO_3^{2-}{}_{(aq)} + Cl_{2(g)} \rightarrow 2Cl^-_{(aq)} + SO_4^{2-}{}_{(aq)} + H_2O_{(l)}$

10. $Fe(CN)_6^{3-}{}_{(aq)} + Re_{(s)} \rightarrow Fe(CN)_6^{4-}{}_{(aq)} + ReO_4^-{}_{(g)}$

First write oxidation states for each element, per atom.

+3 6(-1) 0 +2 6(-1) +7 4(-1)

$Fe(CN)_6^{3-}{}_{(aq)} + Re_{(s)} \rightarrow Fe(CN)_6^{4-}{}_{(aq)} + ReO_4^-{}_{(g)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each Re lost $7e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Fe gained $1e^-$
c.	Identify the oxidizing agent • $Fe(CN)_6^{3-}{}_{(aq)}$
d.	Identify the reducing agent • $Re_{(s)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $Re_{(s)} \rightarrow ReO_4^-{}_{(g)} + 7e^-$ $1e^- + Fe(CN)_6^{3-}{}_{(aq)} \rightarrow Fe(CN)_6^{4-}{}_{(aq)}$ • Balance half reactions for same # of oxidized/reduced species $Re_{(s)} \rightarrow ReO_4^-{}_{(g)} + 7e^-$ $1e^- + Fe(CN)_6^{3-}{}_{(aq)} \rightarrow Fe(CN)_6^{4-}{}_{(aq)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $4H_2O_{(l)} + Re_{(s)} \rightarrow ReO_4^-{}_{(g)} + 7\ e^- + 8H^+{}_{(aq)}$ $1e^- + Fe(CN)_6^{3-}{}_{(aq)} \rightarrow Fe(CN)_6^{4-}{}_{(aq)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $4H_2O_{(l)} + Re_{(s)} \rightarrow ReO_4^-{}_{(g)} + 7\ e^- + 8H^+{}_{(aq)}$ $7(1e^- + Fe(CN)_6^{3-}{}_{(aq)} \rightarrow Fe(CN)_6^{4-}{}_{(aq)})$ • Rewriting the half reactions with the multiplication done $4H_2O_{(l)} + Re_{(s)} \rightarrow ReO_4^-{}_{(g)} + 7\ e^- + 8H^+{}_{(aq)}$ $7e^- + 7Fe(CN)_6^{3-}{}_{(aq)} \rightarrow 7Fe(CN)_6^{4-}{}_{(aq)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $4H_2O_{(l)} + Re_{(s)} + 7e^- + 7Fe(CN)_6^{3-}{}_{(aq)} \rightarrow 7Fe(CN)_6^{4-}{}_{(aq)} + ReO_4^-{}_{(g)} + 7\ e^- + 8H^+{}_{(aq)}$ • Cross out spectators $4H_2O_{(l)} + Re_{(s)} + 7Fe(CN)_6^{3-}{}_{(aq)} \rightarrow 7Fe(CN)_6^{4-}{}_{(aq)} + ReO_4^-{}_{(g)} + 8H^+{}_{(aq)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+{}_{(aq)}$. Add the same # of $OH^-{}_{(aq)}$ to both sides of the equation $8OH^-{}_{(aq)} + 4H_2O_{(l)} + Re_{(s)} + 7Fe(CN)_6^{3-}{}_{(aq)} \rightarrow 7Fe(CN)_6^{4-}{}_{(aq)} + ReO_4^-{}_{(g)} + 8H^+{}_{(aq)} + 8OH^-{}_{(aq)}$ • On the side with both $H^+{}_{(aq)}$ & $OH^-{}_{(aq)}$, those become water $8OH^-{}_{(aq)} + 4H_2O_{(l)} + Re_{(s)} + 7Fe(CN)_6^{3-}{}_{(aq)} \rightarrow 7Fe(CN)_6^{4-}{}_{(aq)} + ReO_4^-{}_{(g)} + 8H_2O_{(l)}$ • Cross out spectators $8OH^-{}_{(aq)} + Re_{(s)} + 7Fe(CN)_6^{3-}{}_{(aq)} \rightarrow 7Fe(CN)_6^{4-}{}_{(aq)} + ReO_4^-{}_{(g)} + 4H_2O_{(l)}$

11. $MnO_4^-{}_{(aq)} + HCOOH_{(aq)} \rightarrow Mn^{2+}{}_{(aq)} + CO_{2(g)}$

First write oxidation states for each element, per atom.

+7 4(-2) +1+2-2-2+1 +2 +4 2(-2)

$MnO_4^-{}_{(aq)} + HCOOH_{(aq)} \rightarrow Mn^{2+}{}_{(aq)} + CO_{2(g)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each C lost $2e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Mn gained $5e^-$
c.	Identify the oxidizing agent • $MnO_4^-{}_{(aq)}$
d.	Identify the reducing agent • $HCOOH_{(aq)}$
e.	Write balanced half reactions (in acid)

	• Write Unbalanced half reactions including electron change per atom $HCOOH_{(aq)} \rightarrow CO_{2(g)} + 2e^-$ $5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)}$ • Balance half reactions for same # of oxidized/reduced species $HCOOH_{(aq)} \rightarrow CO_{2(g)} + 2e^-$ $5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $HCOOH_{(aq)} \rightarrow CO_{2(g)} + 2e^- + 2H^+{}_{(aq)}$ $8H^+{}_{(aq)} + 5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)} + 4H_2O_{(l)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost • Balance half reactions for # of electrons gained and lost $5(HCOOH_{(aq)} \rightarrow CO_{2(g)} + 2e^- + 2H^+{}_{(aq)})$ $2(8H^+{}_{(aq)} + 5e^- + MnO_4^-{}_{(aq)} \rightarrow Mn^{2+}{}_{(aq)} + 4H_2O_{(l)})$ • Rewriting the half reactions with the multiplication done $5HCOOH_{(aq)} \rightarrow 5CO_{2(g)} + 10e^- + 10H^+{}_{(aq)}$ $16H^+{}_{(aq)} + 10e^- + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $5HCOOH_{(aq)} + 16H^+{}_{(aq)} + 10e^- + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)} + 5CO_{2(g)} + 10e^- + 10H^+{}_{(aq)}$ • Cross out spectators $5HCOOH_{(aq)} + 6H^+{}_{(aq)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)} + 5CO_{2(g)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+{}_{(aq)}$. Add the same # of $OH^-{}_{(aq)}$ to both sides of the equation $6OH^-{}_{(aq)} + 5HCOOH_{(aq)} + 6H^+{}_{(aq)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)} + 5CO_{2(g)} + 6OH^-{}_{(aq)}$ • On the side with both $H^+{}_{(aq)}$ & $OH^-{}_{(aq)}$, those become water $6H_2O_{(l)} + 5HCOOH_{(aq)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)} + 5CO_{2(g)} + 6OH^-{}_{(aq)}$ • Cross out spectators $5HCOOH_{(aq)} + 2MnO_4^-{}_{(aq)} \rightarrow 2Mn^{2+}{}_{(aq)} + 2H_2O_{(l)} + 5CO_{2(g)} + 6OH^-{}_{(aq)}$

12. $Mn^{2+}{}_{(aq)} + Co^{3+}{}_{(aq)} \rightarrow MnO_{2(s)} + Co^{2+}{}_{(aq)}$

First write oxidation states for each element, per atom.

+2 +3 +4 2(-2) +2

$Mn^{2+}{}_{(aq)} + Co^{3+}{}_{(aq)} \rightarrow MnO_{2(s)} + Co^{2+}{}_{(aq)}$

a.	Identify the oxidized species and state how many electrons are lost per atom • Each Mn lost $2e^-$
b.	Identify the reduced species and state how many electrons are gained per atom • Each Co gained $1e^-$
c.	Identify the oxidizing agent • $Co^{3+}{}_{(aq)}$
d.	Identify the reducing agent • $Mn^{2+}{}_{(aq)}$
e.	Write balanced half reactions (in acid) • Write Unbalanced half reactions including electron change per atom $Mn^{2+}{}_{(aq)} \rightarrow MnO_{2(s)} + 2e^-$ $1e^- + Co^{3+}{}_{(aq)} \rightarrow Co^{2+}{}_{(aq)}$ • Balance half reactions for same # of oxidized/reduced species $Mn^{2+}{}_{(aq)} \rightarrow MnO_{2(s)} + 2e^-$ $1e^- + Co^{3+}{}_{(aq)} \rightarrow Co^{2+}{}_{(aq)}$ • Balance half reactions for # of O, with H_2O, and # of H, with H^+ $2H_2O_{(l)} + Mn^{2+}{}_{(aq)} \rightarrow MnO_{2(s)} + 2e^- + 4H^+{}_{(aq)}$ $1e^- + Co^{3+}{}_{(aq)} \rightarrow Co^{2+}{}_{(aq)}$ Now the half reactions are balanced within themselves, but not balanced for # of electrons gained and lost

	• Balance half reactions for # of electrons gained and lost $2H_2O_{(l)} + Mn^{2+}_{(aq)} \rightarrow MnO_{2(s)} + 2e^- + 4H^+_{(aq)}$ $2(1e^- + Co^{3+}_{(aq)} \rightarrow Co^{2+}_{(aq)})$ • Rewriting the half reactions with the multiplication done $2H_2O_{(l)} + Mn^{2+}_{(aq)} \rightarrow MnO_{2(s)} + 2e^- + 4H^+_{(aq)}$ $2e^- + 2Co^{3+}_{(aq)} \rightarrow 2Co^{2+}_{(aq)}$
f.	Write a balanced redox reaction (in acid) • Combine half reactions $2H_2O_{(l)} + Mn^{2+}_{(aq)} + 2e^- + 2Co^{3+}_{(aq)} \rightarrow 2Co^{2+}_{(aq)} + MnO_{2(s)} + 2e^- + 4H^+_{(aq)}$ • Cross out spectators $2H_2O_{(l)} + Mn^{2+}_{(aq)} + 2Co^{3+}_{(aq)} \rightarrow 2Co^{2+}_{(aq)} + MnO_{2(s)} + 4H^+_{(aq)}$
g.	Write a balanced redox reaction (in base) • Count the # of $H^+_{(aq)}$. Add the same # of $OH^-_{(aq)}$ to both sides of the equation $4OH^-_{(aq)} + 2H_2O_{(l)} + Mn^{2+}_{(aq)} + 2Co^{3+}_{(aq)} \rightarrow 2Co^{2+}_{(aq)} + MnO_{2(s)} + 4H^+_{(aq)} + 4OH^-_{(aq)}$ • On the side with both $H^+_{(aq)}$ & $OH^-_{(aq)}$, those become water $4OH^-_{(aq)} + 2H_2O_{(l)} + Mn^{2+}_{(aq)} + 2Co^{3+}_{(aq)} \rightarrow 2Co^{2+}_{(aq)} + MnO_{2(s)} + 4H_2O_{(l)}$ • Cross out spectators $4OH^-_{(aq)} + Mn^{2+}_{(aq)} + 2Co^{3+}_{(aq)} \rightarrow 2Co^{2+}_{(aq)} + MnO_{2(s)} + 2H_2O_{(l)}$