Electrochemistry Review Booklet

Topics

1. Oxidation numbers, Reduction, oxidation and half reactions
2. Spontaneity rule and redox tables
3. Redox Stoichiometry
4. Voltaic Cells
5. Electrolytic Cells and Cell Stoichiometry
6. Corrosion and Corrosion Prevention

Oxidation numbers, Reduction, oxidation and half reactions

I	$H_2S(aq) + NH_3(aq) \rightarrow NH_4^+(aq) + HS^-(aq)$
II	$Pb(s) + 2\,FeCl_3(aq) \rightarrow 2\,FeCl_2(aq) + PbCl_2(aq)$

Which of the following statements correctly describes **both** of the equations above?

A. Both equations represent redox reactions.

B. Equation I represents a redox reaction, but Equation II does not.

C. Equation II represents a redox reaction, but Equation I does not.

D. Neither equation represents a redox reaction.

The reaction that occurs when clays containing iron(II) persulphide, $FeS_2(s)$, are heated in a kiln is represented by the following equation.

$$4\,FeS_2(s) + 11\,O_2(g) \rightarrow 2\,Fe_2O_3(s) + 8\,SO_2(g)$$

In this reaction, the oxidation state of oxygen

A. changes from 0 to −2

B. changes from 0 to −4

C. changes from +2 to 0

D. does not change

Prairie spring wheat is used by some grain processors to produce ethanol. A starch slurry is made by grinding and washing the grain. The starch slurry is used to produce ethanol, as represented by the following equation.

$$C_6H_{12}O_6(aq) \xrightarrow{\text{yeast}} 2\,CO_2(g) + 2\,C_2H_5OH(aq)$$

Starch slurry

The oxidation numbers of the carbon in $C_6H_{12}O_6(aq)$, $CO_2(g)$, and $C_2H_5OH(aq)$ are, respectively,

A. 0, +4, −2

B. 0, +4, +2

C. 0, −4, −2

D. +6, −4, +2

In order to remove sulfur from a zinc sulfide ore, the ore and oxygen gas are heated, which results in the reaction represented by the following equation.

$$2\,ZnS(s) + 3\,O_2(g) \rightarrow 2\,ZnO(s) + 2\,SO_2(g)$$

Which of the following descriptions identifies what happens when the ore is heated?

A. Zinc atoms gain electrons and are reduced.
B. Zinc atoms lose electrons and are oxidized.
C. Sulfur atoms gain electrons and are reduced.
D. Sulfur atoms lose electrons and are oxidized.

The following reaction will occur at high temperatures.

$$2\,Na(g) + Cl_2(g) \rightarrow 2\,NaCl(g) + \text{energy}$$

The half-reaction for the reduction that occurs in this reaction is

A. $Na(g) \rightarrow Na^+(g) + e^-$
B. $Na(g) + e^- \rightarrow Na^+(g)$
C. $Cl_2(g) + 2\,e^- \rightarrow 2\,Cl^-(g)$
D. $Cl_2(g) \rightarrow 2\,Cl^-(g) + 2\,e^-$

reduction - e⁻ are on reactant side

oxidation - e⁻ are on product side

In the bleaching process used at a pulp mill, chlorate ions are converted to chlorine dioxide in an acidic environment. This conversion is represented by the following **incomplete** half-reaction.

$$1e^- + 2H^+ + ClO_3^-(aq) \rightarrow ClO_2(g) + H_2O(l)$$

The **complete** half-reaction for the conversion described above is

A. $ClO_3^-(aq) + 2\,H^+(aq) + e^- \rightarrow ClO_2(g) + H_2O(l)$
B. $ClO_3^-(aq) \rightarrow ClO_2(g) + e^-$
C. $ClO_3^-(aq) + 2\,H^+(aq) \rightarrow ClO_2(g) + H_2O(l) + 3\,e^-$
D. $ClO_3^-(aq) + H_2O(l) + e^- \rightarrow ClO_2(g) + 2\,OH^-(aq)$

Completing a half reaction

1. balance atoms other than O + H
2. balance O by adding H_2O
3. balance H by adding H^+
4. balance charge with e⁻

Use the following information to answer the next two questions.

Airbags in vehicles contain the chemicals sodium azide, $NaN_3(s)$, and iron(III) oxide. When activated by an electrical spark, the sodium azide decomposes rapidly and the gas produced causes the airbag to expand. The reactions that occur in the airbag are represented below.

Equation I	$2\,NaN_3(s) \rightarrow 2\,Na(s) + 3\,N_2(g)$	
Equation II	$Na(s) \rightarrow Na(l)$	$\Delta H = 2.61$ kJ
Equation III	$6\,Na(l) + Fe_2O_3(s) \rightleftharpoons 3\,Na_2O(s) + 2\,Fe(s)$	$\Delta H = -439.9$ kJ

Numerical Response

4. In Equation III, the oxidation number for the metal in

$Na_2O(s)$ is +1 (Record in the **first** column)

$Na(l)$ is 0 (Record in the **second** column)

$Fe(s)$ is 0 (Record in the **third** column)

$Fe_2O_3(s)$ is +3 (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Use the following information to answer the next question.

Copper can undergo a series of reactions known as the cycle of copper. In this cycle, the initial copper reactant is changed into different compounds before being recovered as copper metal in the last step. The series of reactions is represented by the following equations.

Reactions in the Cycle of Copper

Equation I	$Cu(s) + 4\,HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\,NO_2(g) + 2\,H_2O(l)$
Equation II	$Cu(NO_3)_2(aq) + 2\,NaOH(aq) \rightarrow Cu(OH)_2(s) + 2\,NaNO_3(aq)$
Equation III	$Cu(OH)_2(s) \rightarrow CuO(s) + H_2O(l)$
Equation IV	$CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$
Equation V	$CuSO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + Cu(s)$

11. The oxidation–reduction reactions in the equations given above are

A. I and II only

B. I and V only

C. I, III, and V

D. I, II, III, and IV

Use the following information to answer the next question.

Volcanoes on Jupiter's moons emit hydrogen sulfide gas and sulfur dioxide gas. These gases react to form gaseous products, as represented by the following equation.

$$16\,H_2S(g) + 8\,SO_2(g) \rightarrow 16\,H_2O(g) + 3\,S_8(g)$$

12. Which of the following rows identifies the reducing agent and the substance being oxidized when the gases react?

Row	Reducing Agent	Substance Being Oxidized
A.	$H_2S(g)$	$H_2S(g)$
B.	$H_2S(g)$	$SO_2(g)$
C.	$SO_2(g)$	$H_2S(g)$
D.	$SO_2(g)$	$SO_2(g)$

reducing agent - gets oxidized

oxiding agent - gets reduced

"Hand Blasters" are a novelty toy item consisting of two ceramic balls that are approximately the size of table-tennis balls. Each ball is coated with a mixture of potassium chlorate and sulfur, and when the balls are struck together, they make a loud popping sound. The reaction that occurs is represented below.

$$3\,S_{8(s)} + 16\,KClO_{3(s)} \rightarrow 24\,SO_{2(g)} + 16\,KCl_{(s)} + \text{heat}$$

If balanced in acidic conditions, the balanced oxidation half-reaction equation for the reaction that occurs when the Hand Blasters collide is

A. $S_{8(s)} + 2\,H_2O_{(l)} \rightarrow SO_{2(g)} + 4\,H^+_{(aq)} + 4\,e^-$

B. $S_{8(s)} + 16\,H_2O_{(l)} \rightarrow 8\,SO_{2(g)} + 32\,H^+_{(aq)} + 32\,e^-$

C. $KClO_{3(s)} + 6\,H^+_{(aq)} + 6\,e^- \rightarrow KCl_{(s)} + 3\,H_2O_{(l)}$

D. $KClO_{3(s)} + 3\,H^+_{(aq)} + 3\,e^- \rightarrow KCl_{(s)} + 3\,H_2O_{(l)}$

The reducing agent in this reaction is

A. $S_{8(s)}$

B. $KClO_{3(s)}$

C. $SO_{2(g)}$

D. $KCl_{(s)}$

oxidized

$S_8 + 16H_2O \rightarrow 8SO_2 + 32H^+ + 32e^-$

During the reaction, the oxidation number of each sulfur atom

A. decreases by 2

B. increases by 2

C. decreases by 4

D. increases by 4

S_8: 0 → SO_2: +4 (O: −2)

Spontaneity rule and redox tables OA = spontaneous RA

Four metals represented by the symbols R, S, T, and V and their ions combine with each other in the following manner:

$S^{2+}(aq) + 2\,T(s) \rightarrow 2\,T^{+}(aq) + S(s)$

$R^{3+}(aq) + T(s) \rightarrow$ No Reaction

$2\,R^{3+}(aq) + 3\,V(s) \rightarrow 3\,V^{2+}(aq) + 2\,R(s)$

When the oxidizing agents above are arranged from **strongest** to **weakest**, the order is

A. $S^{2+}(aq)$, $T^{+}(aq)$, $R^{3+}(aq)$, $V^{2+}(aq)$

B. $V^{2+}(aq)$, $R^{3+}(aq)$, $T^{+}(aq)$, $S^{2+}(aq)$

C. V(s), R(s), T(s), S(s)

D. S(s), T(s), R(s), V(s)

$S^{2+} \rightleftharpoons S_{(s)}$

$T^{+} \rightleftharpoons T_{(s)}$

$R^{3+} \rightleftharpoons R_{(s)}$

$V \rightleftharpoons V_{(s)}$

Use the following information to answer the next question.

Restorers of antique cars often refinish chrome-plated parts by electroplating them. The part is attached to one electrode of an electrolytic cell in which the other electrode is lead. The electrolyte is a solution of dichromic acid, $H_2Cr_2O_7(aq)$.

A metal that will react spontaneously with $Cr^{3+}(aq)$ in a chromium-plating solution is

A. aluminium

B. cadmium

C. lead

D. tin

A student dipped 12.50 g strips of four different metals, Ag(s), Cu(s), Pb(s), and Mg(s), into a beaker containing 250 mL of 1.00 mol/L HCl(aq) in order to determine an activity series. One of the metals reacted immediately and vigorously with the acid.

↳ order of reactivity

The balanced net ionic equation for the metal that reacted first is

A. $2\,Ag(s) + 2\,H^{+}(aq) \rightarrow H_2(g) + 2\,Ag^{+}(aq)$

B. $Cu(s) + 2\,H^{+}(aq) \rightarrow H_2(g) + Cu^{2+}(aq)$

C. $Pb(s) + 2\,H^{+}(aq) \rightarrow H_2(g) + Pb^{2+}(aq)$

D. $Mg(s) + 2\,H^{+}(aq) \rightarrow H_2(g) + Mg^{2+}(aq)$

Use the following information to answer the next question.

Equations of Redox Reactions

I	$2\,Ce^{4+}(aq) + Pd(s) \rightarrow 2\,Ce^{3+}(aq) + Pd^{2+}(aq)$
II	$Pd^{2+}(aq) + 2\,In^{2+}(aq) \rightarrow Pd(s) + 2\,In^{3+}(aq)$
III	$Cd^{2+}(aq) + Pd(s) \rightarrow$ no reaction
IV	$In^{3+}(aq) + Cd(s) \rightarrow$ no reaction

10. The strongest oxidizing agent in the equations given above is

A. $Ce^{3+}(aq)$

B. $Ce^{4+}(aq)$

C. $Cd^{2+}(aq)$

D. $In^{3+}(aq)$

Use the following information to answer the next question.

Species

~~**1**~~	~~$Al(s)$~~	~~**5**~~	~~$Fe^{2+}(aq)$~~
2	$F_2(g)$	**6**	$Ni^{2+}(aq)$
3	$AgI(s)$	**7**	$O_2(g)$ and $H_2O(l)$
~~**4**~~	~~$H_2O(l)$~~		

Numerical Response

5. The species above that will oxidize $Cr^{2+}(aq)$ are numbered 2, 3, 6, and 7.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Redox Stoichiometry

A 75.0 mL sample of $Na_2S_2O_3(aq)$ is titrated to a pink endpoint with 25.0 mL of 12.3 mmol/L acidified $KMnO_4(aq)$. This titration reaction is represented by the following equation.

$$5\,S_2O_3^{2-}(aq) + 8\,MnO_4^{-}(aq) + 14\,H^+(aq) \rightarrow 10\,SO_4^{2-}(aq) + 8\,Mn^{2+}(aq) + 7\,H_2O(l)$$

The concentration of the $Na_2S_2O_3(aq)$ solution is 2.56 mmol/L.

V = 75.0mL
= 0.0750L
n = 0.000192...mol
C = n/V
= 0.00256...mol/L
x 1000
= 2.56mmol/L

V = 0.025L
C = 12.3mmol/L
= 0.0123mol/L
n = CV
= 0.000307 5mol
x 5/8

"Tin" cans used to store food are made from steel electroplated with a thin layer of tin. The standard electrical potential for the reduction of $Sn^{2+}(aq)$ ions for this process is

↳ data booklet

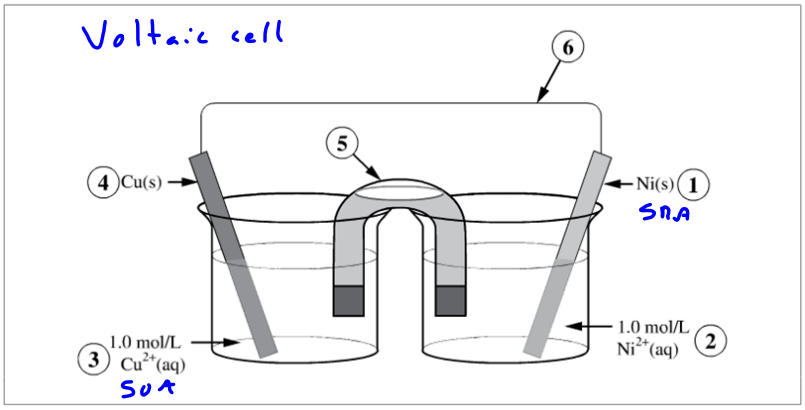
A. −0.15 V
B. −0.14 V
C. +0.14 V
D. +0.15 V

$$Cr_2O_7^{2-}(aq) + 14\,H^+(aq) + 3\,Pb(s) \rightarrow 2\,Cr^{3+}(aq) + 3\,Pb^{2+}(aq) + 7\,H_2O(l)$$

The electrical potential for the reaction above is +/− 1.36 V.

cell potential
voltage
$E°_{cell}$

$E_{cell} = E_{cathode} - E_{anode}$
$= +1.23V - -0.13$
$= +1.36V$



Identify the parts of the electrochemical cell numbered above that correspond to each of the terms listed below.

Cathode	4	(Record as the **first** digit)
External electron circuit	6	(Record as the **second** digit)
Oxidizing agent	3	(Record as the **third** digit)
Anode	1	(Record as the **fourth** digit)

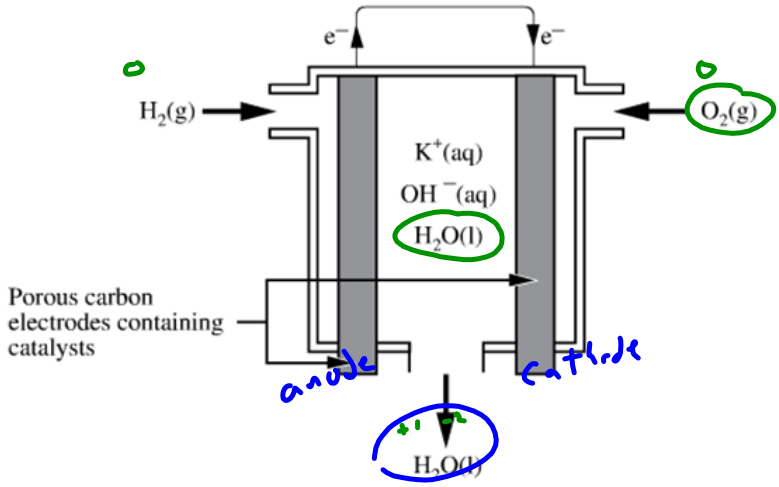
RED CAT
AN OX

In all electrochemical cells:
- reduction occurs at the cathode
  - SOA gets reduced
- oxidation occurs at the anode
  - SRA gets oxidized
- electrons move from anode → cathode
- cations move to cathode
- anions move to anode

Use the following information to answer the next two questions.

Hydrogen–oxygen fuel cells are used in spacecraft and small-scale power plants for electricity generation. Government and industry are working together to perfect this type of fuel cell for automotive use.

Schematic Diagram of a Hydrogen–Oxygen Fuel Cell



During the operation of this fuel cell, at the anode,

A. oxygen gas is oxidized

B. oxygen gas is reduced

C. hydrogen gas is oxidized

D. hydrogen gas is reduced

SOA: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

SRA: $[H_2 + 2OH^- \rightarrow 2H_2O + 2e^-] \times 2$

net: $O_2 + 2H_2 \rightarrow 2H_2O$

The net equation for the fuel-cell reaction is

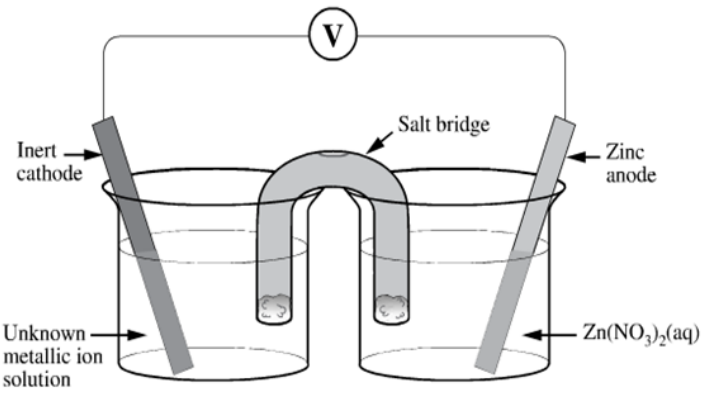
A. $O_2(g) + H_2(g) \rightarrow H_2O_2(l)$

B. $H_2O(l) \rightarrow OH^-(aq) + H^+(aq)$

C. $2\,H_2O(l) \rightarrow 2\,H_2(g) + O_2(g)$

D. $2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(l)$

To determine the identity of an unknown metallic ion in a solution, a student designed the voltaic cell shown below.



The student chose zinc for the anode because zinc

A. gains electrons easily
B. can be easily reduced
C. is an oxidizing agent
D. is a reducing agent

$E_{cell} = E_{cat} - E_{anode}$

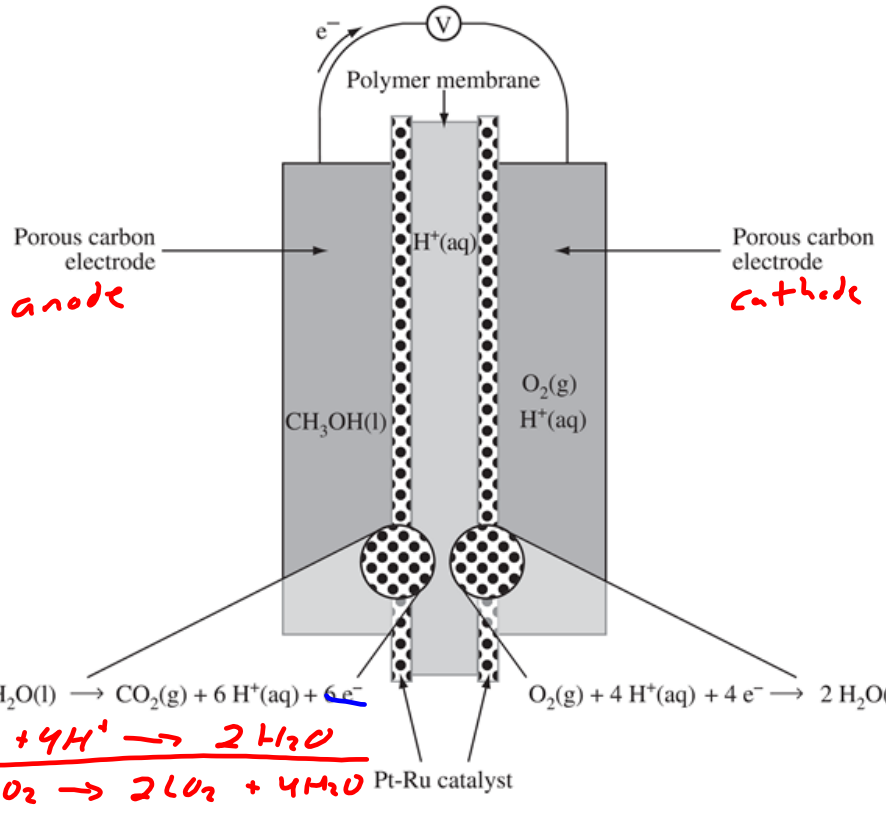
If the cell generates a voltage of +1.24 V under standard conditions, the half-reaction occurring at the cathode will have an electrode potential of

A. +2.00 V
B. −2.00 V
C. +0.48 V
D. −0.48 V

$1.24V = E_{cat} + 0.76V$
-0.76
$E_{cat} = +0.48V$

Methanol fuel cells produce electricity by reacting methanol and oxygen gas from the air. A simplified diagram of a methanol fuel cell is shown below.

Methanol Fuel Cell



$2[CH_3OH(l) + H_2O(l) \longrightarrow CO_2(g) + 6\,H^+(aq) + 6\,e^-]$

$3[4e^- + O_2 + 4H^+ \longrightarrow 2H_2O]$

$2CH_3OH + 3O_2 \longrightarrow 2CO_2 + 4H_2O$

$O_2(g) + 4\,H^+(aq) + 4\,e^- \longrightarrow 2\,H_2O(l)$

Numerical Response

6. When the equation for the overall reaction in the methanol fuel cell is balanced with the lowest whole number coefficients, the coefficient for

$O_2(g)$ is 3 (Record in the **first** column)

$H_2O(l)$ is 4 (Record in the **second** column)

$CO_2(g)$ is 2 (Record in the **third** column)

$CH_3OH(l)$ is 2 (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

$0.80\,V = +1.23\,V - E_{anode}$

$E_{anode} = +0.43\,V$

Numerical Response

7. If the cell potential for the methanol fuel cell is +0.80 V, then the reduction potential for the half-reaction involving $CH_3OH(l) + H_2O(l)$ will be +/– _____ V.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Use the following information to answer the next two questions.

The lead storage battery is the most common battery used in automobiles. The half-reactions that occur in a cell of the battery during discharge are represented by the following equations.

Reactions that Occur in the Lead Storage Battery

Equation I $PbO_2(s) + SO_4^{2-}(aq) + 4\,H^+(aq) + 2\,e^- \rightarrow PbSO_4(s) + 2\,H_2O(l)$

Equation II $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2\,e^-$

16. *During discharge of the lead storage battery,* ___*i*___ *move toward the cathode and the species at the cathode* ___*ii*___ *electrons.*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	anions	loses
B.	anions	gains
C.	cations	loses
D.	cations	gains

$E_{cell} = +1.69\,V - -0.36\,V$

Numerical Response

10. In a cell in the lead storage battery above, the E°_{cell} is +/– 2.05 V.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Restorers of antique cars often refinish chrome-plated parts by electroplating them. The part is attached to one electrode of an electrolytic cell in which the other electrode is lead. The electrolyte is a solution of dichromic acid, $H_2Cr_2O_7(aq)$.

The plating of chromium metal will take place at the

A. anode where oxidation occurs

~~**B.** anode where reduction occurs~~

~~**C.** cathode where oxidation occurs~~

D. cathode where reduction occurs

cathode

$Cr^{3+} + 3e^- \rightarrow Cr(s)$

I = current
t = time (sec)
F = Faraday's constant
n_e = moles of electrons

If the electrochemical cell $Cd(s) \mid Cd^{2+}(aq) \parallel Ag^+(aq) \mid Ag(s)$ produces a 6.00 A current for 2.00 h, the mass change of the anode will be a

SRA SRA SRA

6.00 C/s

A. ~~25.2 g increase~~

B. 25.2 g decrease

C. ~~48.3 g increase~~

D. 48.3 g decrease

$1\,Cd_{(s)} \rightarrow Cd^{2+}_{(aq)} + 2e^-$

$m = ?$

$n = 0.223\ldots\ mol \times \frac{1}{2}$

$M = 112.41\ g/mol$

$m = nM$

$= 25.2\ g$

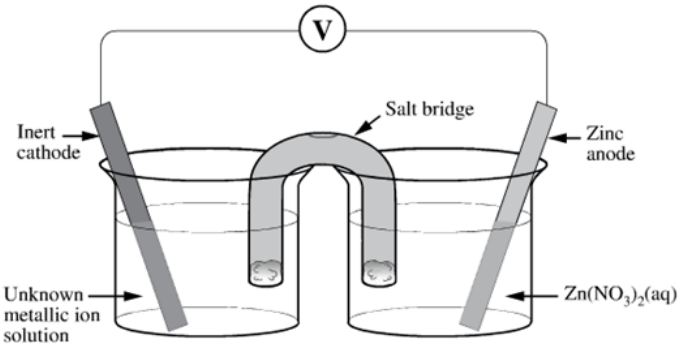
$n_e = \frac{It}{F}$

$n_e = \frac{(6.00\ A)(7200\ s)}{9.65 \times 10^4\ C/mol}$

$= 0.447\ldots\ mol$

Use the following information to answer the next question.

To determine the identity of an unknown metallic ion in a solution, a student designed the voltaic cell shown below.



If the zinc anode loses 200 g of mass during the operation of the cell, then the number of moles of electrons transferred is

A. 1.53 mol

B. 3.06 mol

C. 6.12 mol

D. 12.2 mol

$Zn_{(s)} \rightarrow Zn^{2+} + 2e^-$

$m = 200\ g$

$M = 65.41\ g/mol$

$n = 3.057\ldots\ mol$

$\times \frac{2}{1}$

$n_e = 6.12\ldots\ mol$

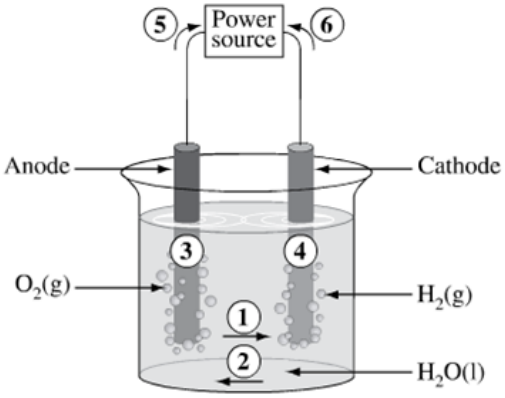
An electrolytic cell differs from a voltaic cell in that the electrolytic cell

A. is spontaneous
B. consumes electricity
C. has an anode and a cathode
D. has a positive $E°_{net}$ value

voltaic	electrolytic
spont.	non spont.
produce electricity	consume electricity
E_{cell} = +	E_{cell} = −

In vehicles, hydrogen fuel cells are about twice as efficient as gasoline engines. One method used to produce the hydrogen for the fuel cell is the electrolysis of water, as represented by the diagram below.

Electrolysis of Water



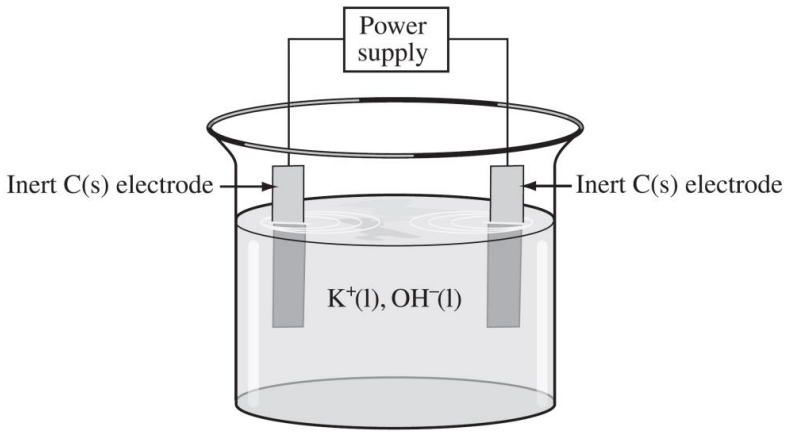
Match four of the numbers in the diagram above with their appropriate labels given below.

The direction of cation flow ___1___ (Record in the **first** column)
The direction of electron flow ___5___ (Record in the **second** column)
The site where oxidation occurs ___3___ (Record in the **third** column)
The site where electrons are gained ___4___ (Record in the **fourth** column)

Use the following information to answer the next two questions.

Metallic potassium was first prepared by Humphry Davy in 1807 by the electrolysis of molten potassium hydroxide at a temperature of 410 °C.

Electrochemical Cell



13. *In the electrochemical cell above, the calculated E°_{cell} value is* ___***i***___ *, and the reaction is* ___***ii***___ .

The statement above is completed by the information in row

Row	*i*	*ii*
A.	positive	spontaneous
B.	positive	nonspontaneous
C.	negative	spontaneous
D.	negative	nonspontaneous

14. The equation that represents the reaction that occurs at the cathode is

A. $K^+(l) + e^- \rightarrow K(l)$

B. $2\,H_2O(l) + 2\,e^- \rightarrow H_2(g) + 2\,OH^-(aq)$

C. $H_2(g) + 2\,OH^-(aq) \rightarrow 2\,H_2O(l) + 2\,e^-$ OX - anode

D. $4\,OH^-(aq) \rightarrow O_2(g) + 2\,H_2O(l) + 4\,e^-$ OX - anode

Use the following information to answer the next question.

Magnesium is a lightweight, abundant, and relatively inexpensive metal often used for cathodic protection. Magnesium is produced by the electrolysis of molten magnesium chloride derived from sea water, as represented by the following equation.

$$MgCl_2(l) \rightarrow Mg(l) + Cl_2(g)$$

$Mg^{2+} + Cl^-$

Numerical Response

8. If 0.893 mol of $Cl_2(g)$ is produced at one electrode of the electrolytic cell, then the mass of Mg(l) produced at the other electrode is 21.7 g.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

$Mg^{2+}_{(l)} + 2e^- \rightarrow Mg_{(l)}$

$n = 1.786 \text{ mol}$ $n = 0.893 \text{ mol}$

$m = ?$

$2Cl^- \rightarrow Cl_{2(g)} + 2e^-$

0.893 mol $n_e = 1.786 \text{ mol}$

Corrosion and Corrosion Prevention

→ oxidation of metals by a RA

Iron objects will readily corrode when exposed to air and moisture, as represented by the following equation.

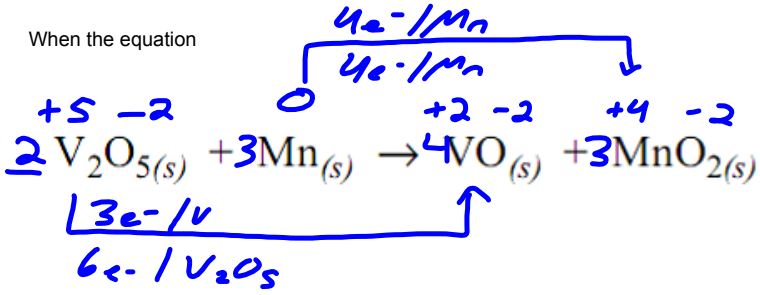
$$O_2(g) + 2\,H_2O(l) + 2\,Fe(s) \rightarrow 2\,Fe^{2+}(aq) + 4\,OH^-(aq)$$

Which of the following metals can be attached to an iron object to prevent corrosion of the iron?

A. Copper
B. Nickel
C. Lead
D. Zinc

sacrificial anode: metal that gets oxidized better than the metal we want to protect
- better RA

1. When the equation



is balanced using the lowest whole number coefficients, the coefficient of

- $V_2O_{5(s)}$ is 2
- $Mn_{(s)}$ is 3
- $VO_{(s)}$ is 4
- $MnO_{2(s)}$ is 3