

# Chemistry Reference Tables Workbook

## 2<sup>nd</sup> Edition

### **About This Workbook –**

Many questions on the New York State Physical Setting/CHEMISTRY Regents Exam may be answered simply by using information given on the Reference Tables. Other questions may require information from the Reference Tables to set up calculations in order to determine the answer. Knowing what information is on the Reference Tables and where to find it are very important steps towards being successful on the Regents exam.

### **The Introduction – Overview, The Chart and Additional Information –**

In these sections, you will find an explanation of the information given on that table. Read each section carefully to fully understand the information given on that table.

### **Set 1 – Questions and Answers –**

After careful reading of the Introduction, Set 1 questions will test your understanding of that particular table. Do all questions in Set 1, and then correct your work by going to the answers for Set 1, which are at the end of the section. The explanation given will help you to understand any mistakes you may have made. If you need additional explanation, ask your teacher for help.

### **Set 2 – Questions –**

The answers to these questions are in a separate answer key. Correctly answering these questions will show yourself and your teacher that you understand the subject matter for that particular table.

Authors:

**Ron Pasto – Retired Chemistry Teacher**  
**William Docekal – Retired Science Teacher**

All of us at Topical Review Book Company hope that by gaining a complete understanding of the Chemistry Reference Tables, it will help you to increase your knowledge of chemistry and that your grades will improve.

© 2012, Topical Review Book Company, Inc. All rights reserved.

P. O. Box 328

Onsted, MI 49265-0328

[www.topicalrbc.com](http://www.topicalrbc.com)

This document may not, in whole or in part, be copied, photocopied, reproduced, translated, or reduced to any electronic medium or machine-readable form.

# Physical Setting/Chemistry Reference Tables Workbook Table of Contents

---

<b>Table A – Standard Temperature and Pressure</b> ... 1	<b>Table K – Common Acids</b> ..... 61
<b>Table B – Physical Constants for Water</b> ..... 2	Set 1 ..... 63
<b>Table C – Selected Prefixes</b> ..... 3	Set 2 ..... 65
Set 1 ..... 4	<b>Table L – Common Bases</b> ..... 69
Set 2 ..... 5	Set 1 ..... 70
<b>Table D – Selected Units</b> ..... 7	Set 2 ..... 71
<b>Table E – Selected Polyatomic Ions</b> ..... 8	<b>Table M – Common Acid - Base Indicators</b> ..... 74
Set 1 ..... 10	Set 1 ..... 75
Set 2 ..... 11	Set 2 ..... 77
<b>Table F – Solubility Guidelines for Aqueous Solutions</b> ..... 13	<b>Table N – Selected Radioisotopes</b> ..... 82
Set 1 ..... 15	Set 1 ..... 85
Set 2 ..... 17	Set 2 ..... 87
<b>Table G – Solubility Curves</b> ..... 21	<b>Table O – Symbols Used in Nuclear Chemistry</b> ... 91
Set 1 ..... 23	Set 1 ..... 93
Set 2 ..... 26	Set 2 ..... 95
<b>Table H – Vapor Pressure of Four Liquids</b> ..... 31	<b>Table P – Organic Prefixes</b> ..... 99
Set 1 ..... 33	Set 1 ..... 100
Set 2 ..... 35	Set 2 ..... 100
<b>Table I – Heats of Reaction</b> ..... 39	<b>Table Q – Homologous Series of Hydrocarbons</b> .. 102
Set 1 ..... 42	Set 1 ..... 104
Set 2 ..... 45	Set 2 ..... 107
<b>Table J – Activity Series</b> ..... 50	<b>Table R – Organic Functional Groups</b> ..... 114
Set 1 ..... 52	Set 1 ..... 116
Set 2 ..... 55	Set 2 ..... 118

<b>Periodic Table of The Elements</b> .....	123	<b>Mole Calculations</b> .....	184
<b>Atomic Structure</b>		Set 1 .....	185
Set 1 .....	129	Set 2 .....	186
Set 2 .....	133	<b>Percent Error</b> .....	188
<b>Metals – Metalloids – Nonmetals</b>		Set 1 .....	189
Set 1 .....	141	Set 2 .....	190
Set 2 .....	142	<b>Percent Composition</b> .....	192
<b>Electron Similarity</b>		Set 1 .....	193
Set 1 .....	144	Set 2 .....	194
Set 2 .....	145	<b>Concentration</b> .....	197
<b>Ions and Excited Atoms</b>		<b>ppm</b>	
Set 1 .....	147	Set 1 .....	198
Set 2 .....	149	Set 2 .....	199
<b>Table S – Properties of Selected Elements</b> .....	155	<b>Molarity</b>	
<b>Melting Point – Boiling Point – Density</b>		Set 1 .....	201
Set 1 .....	159	Set 2 .....	202
Set 2 .....	159	<b>Combined Gas Law</b> .....	204
<b>First Ionization Energy</b>		Set 1 .....	205
Set 1 .....	161	Set 2 .....	207
Set 2 .....	162	<b>Titration</b> .....	211
<b>Electronegativity</b>		Set 1 .....	212
Set 1 .....	164	Set 2 .....	214
Set 2 .....	166	<b>Heat</b> .....	219
<b>Atomic Radius</b>		Set 1 .....	222
Set 1 .....	170	Set 2 .....	224
Set 2 .....	172	<b>Temperature</b> .....	229
<b>Table T – Important Formulas and Equations</b> ....	176	Set 1 .....	230
<b>Density</b> .....	177	Set 2 .....	230
Set 1 .....	178		
Set 2 .....	180		



**Table E****Selected Polyatomic Ions**

Formula	Name	Formula	Name
$\text{H}_3\text{O}^+$	hydronium	$\text{CrO}_4^{2-}$	chromate
$\text{Hg}_2^{2+}$	mercury(I)	$\text{Cr}_2\text{O}_7^{2-}$	dichromate
$\text{NH}_4^+$	ammonium	$\text{MnO}_4^-$	permanganate
$\left. \begin{array}{l} \text{C}_2\text{H}_3\text{O}_2^- \\ \text{CH}_3\text{COO}^- \end{array} \right\}$	acetate	$\text{NO}_2^-$	nitrite
$\text{CN}^-$	cyanide	$\text{NO}_3^-$	nitrate
$\text{CO}_3^{2-}$	carbonate	$\text{O}_2^{2-}$	peroxide
$\text{HCO}_3^-$	hydrogen carbonate	$\text{OH}^-$	hydroxide
$\text{C}_2\text{O}_4^{2-}$	oxalate	$\text{PO}_4^{3-}$	phosphate
$\text{ClO}^-$	hypochlorite	$\text{SCN}^-$	thiocyanate
$\text{ClO}_2^-$	chlorite	$\text{SO}_3^{2-}$	sulfite
$\text{ClO}_3^-$	chlorate	$\text{SO}_4^{2-}$	sulfate
$\text{ClO}_4^-$	perchlorate	$\text{HSO}_4^-$	hydrogen sulfate
		$\text{S}_2\text{O}_3^{2-}$	thiosulfate

**Overview:**

Polyatomic ions are charged particles composed of two or more atoms. Most are composed of nonmetallic atoms combined with oxygen. Polyatomic ions are quite stable. Thus, in many chemical reactions, the polyatomic ion remains intact and is therefore written the same on the reactant and product side of a chemical equation. These ions are the negative component of many common compounds.

**The Table:**

The Formula, Name and charge of the ion are given in this table. This information is used in determining the name of a given compound or in writing the formula for a given compound involving a polyatomic ion. The name of these ions usually indicates the element present other than oxygen. For example, the polyatomic ion  $\text{CrO}_4^{2-}$  is chromate, containing the metal chromium.

### ***Additional Information:***

- The formula for a compound must represent a neutral group of atoms. The total positive oxidation state or number and the total negative oxidation state or number must be equal, leaving a net charge of zero for the group of atoms.

*Example 1:* What is the formula for sodium sulfate?

Answer:  $\text{Na}_2\text{SO}_4$

Explanation: From the Periodic Table, the oxidation number of Na is +1 ( $\text{Na}^+$ ) and from Table E, sulfate is  $\text{SO}_4^{2-}$ . The correct formula must be  $\text{Na}_2\text{SO}_4$ .

*Example 2:* What is the formula for calcium phosphate?

Answer:  $\text{Ca}_3(\text{PO}_4)_2$

Explanation: From the Periodic Table the oxidation number of Ca is +2 ( $\text{Ca}^{2+}$ ) and from Table E, phosphate is  $\text{PO}_4^{3-}$ . The correct formula must be  $\text{Ca}_3(\text{PO}_4)_2$ .

- In most compounds involving a polyatomic ion, there exist both covalent and ionic bonds. For example, in the compound  $\text{Na}_3\text{PO}_4$ , the phosphate ion ( $\text{PO}_4^{3-}$ ) is formed by the covalent bonding between the nonmetals P and O, while the sodium ion ( $\text{Na}^+$ ) and the phosphate ion are held together by an ionic bond.
- Most of the ions on this table are derived from ternary or oxo acids (acids composed of three elements, two of which are hydrogen and oxygen). If the acid name ends in *-ic*, it is modified to end in *-ate* to name the ion. Hence, sulfuric acid ( $\text{H}_2\text{SO}_4$ ) gives rise to the sulfate ion ( $\text{SO}_4^{2-}$ ). If the acid name ends in *-ous*, it is modified to end in *-ite* to name the ion. Sulfurous acid ( $\text{H}_2\text{SO}_3$ ) therefore gives rise to the sulfite ion ( $\text{SO}_3^{2-}$ ).
- In compounds between metals and nonmetals in which the metal shows more than one positive oxidation state, the *Stock System of Nomenclature* is used. In this system, the oxidation state of the metal in the compound is placed in Roman numerals in parentheses immediately following the name of the metal. For example,  $\text{CuSO}_4$  is copper(II) sulfate since copper has a +2 oxidation state ( $\text{Cu}^{2+}$ ) in this compound.

Specific uses of compounds containing a polyatomic ion:

- Sodium hydrogen carbonate ( $\text{NaHCO}_3$ ), also known as sodium bicarbonate, is baking soda or bicarbonate of soda.
- Sodium hypochlorite ( $\text{NaClO}$ ) is the substance in Clorox type bleaching solutions and the chlorinating agent used for swimming pools.
- Sodium nitrite ( $\text{NaNO}_2$ ) is used in prepared meats to preserve freshness and color.
- Sodium sulfite ( $\text{Na}_2\text{SO}_3$ ) is used in salad bars to preserve the freshness of greens.
- Phosphates ( $\text{PO}_4^{3-}$ ) are found in soft drinks.
- Ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) is used in agriculture as a high nitrogen fertilizer.

---

---

**Set 1 — Selected Polyatomic Ions**

---

---

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. Which polyatomic ion contains the greatest number of oxygen atoms?<br/>(1) acetate      (3) hydroxide<br/>(2) carbonate   (4) peroxide      1 _____</p> <p>2. Which formula represents a hydronium ion?<br/>(1) <math>\text{H}_3\text{O}^+</math>      (3) <math>\text{OH}^-</math><br/>(2) <math>\text{NH}_4^+</math>      (4) <math>\text{HCO}_3^-</math>      2 _____</p> <p>3. What is the name of the polyatomic ion in the compound <math>\text{Na}_2\text{O}_2</math>?<br/>(1) hydroxide   (3) oxide<br/>(2) oxalate      (4) peroxide      3 _____</p> <p>4. The name of the compound <math>\text{KClO}_2</math> is potassium<br/>(1) hypochlorite   (3) chlorate<br/>(2) chlorite      (4) perchlorate      4 _____</p> | <p>5. Which element is found in both potassium chlorate and zinc nitrate?<br/>(1) hydrogen      (3) potassium<br/>(2) oxygen      (4) zinc      5 _____</p> <p>6. What is the chemical formula for sodium sulfate?<br/>(1) <math>\text{Na}_2\text{SO}_3</math>      (3) <math>\text{NaSO}_3</math><br/>(2) <math>\text{Na}_2\text{SO}_4</math>      (4) <math>\text{NaSO}_4</math>      6 _____</p> <p>7. What is the oxidation state of sodium in <math>\text{NaNO}_2</math>?<br/>(1) +1      (3) +2<br/>(2) -1      (4) -2      7 _____</p> <p>8. What is the chemical formula for copper(II) hydroxide?<br/>(1) <math>\text{CuOH}</math>      (3) <math>\text{Cu}_2(\text{OH})</math><br/>(2) <math>\text{CuOH}_2</math>      (4) <math>\text{Cu}(\text{OH})_2</math>      8 _____</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Base your answers to question 9 using the passage below and your knowledge of chemistry.

Acid rain lowers the pH in ponds and lakes and over time can cause the death of some aquatic life. Acid rain is caused in large part by the burning of fossil fuels in power plants and by gasoline-powered vehicles. The acids commonly associated with acid rain are sulfurous acid, sulfuric acid, and nitric acid.

9. a) Write the chemical formula of a negative ion present in an aqueous nitric acid solution. \_\_\_\_\_
- b) Write the chemical formula of a negative ion present in aqueous sulfurous acid. \_\_\_\_\_
10. A 2.0-liter aqueous solution contains a total of 3.0 moles of dissolved  $\text{NH}_4\text{Cl}$  at  $25^\circ\text{C}$  and standard pressure.  
Identify the two ions present in the solute. \_\_\_\_\_

---

---

**Set 2 — Selected Polyatomic Ions**

---

---

11. Which formula is correct for ammonium sulfate?  
(1)  $\text{NH}_4\text{SO}_4$  (3)  $\text{NH}_4(\text{SO}_4)_2$   
(2)  $(\text{NH}_4)_2\text{SO}_4$  (4)  $(\text{NH}_4)_2(\text{SO}_4)_2$  11 \_\_\_\_\_

12. Which formula represents a nitrate ion?  
(1)  $\text{NO}^-$  (3)  $\text{NO}_3^-$   
(2)  $\text{NO}_2^-$  (4)  $\text{NO}_4^-$  12 \_\_\_\_\_

13. Which formula represents lead(II) phosphate?  
(1)  $\text{PbPO}_4$  (3)  $\text{Pb}_3(\text{PO}_4)_2$   
(2)  $\text{Pb}_4\text{PO}_4$  (4)  $\text{Pb}_2(\text{PO}_4)_3$  13 \_\_\_\_\_

14. Which compound has both ionic and covalent bonds?  
(1)  $\text{CO}_2$  (3)  $\text{NaI}$   
(2)  $\text{CH}_3\text{OH}$  (4)  $\text{Na}_2\text{CO}_3$  14 \_\_\_\_\_

15. The name of the compound  $\text{Na}_2\text{S}_2\text{O}_3$  is  
(1) potassium sulfate  
(2) potassium thiosulfate  
(3) sodium sulfate  
(4) sodium thiosulfate 15 \_\_\_\_\_

16. What is the oxidation state of Ca in  $\text{CaSO}_4$ ?  
(1)  $-1$  (3)  $-2$   
(2)  $+1$  (4)  $+2$  16 \_\_\_\_\_

17. Which formula represents strontium phosphate?  
(1)  $\text{SrPO}_4$  (3)  $\text{Sr}_2(\text{PO}_4)_3$   
(2)  $\text{Sr}_3\text{PO}_8$  (4)  $\text{Sr}_3(\text{PO}_4)_2$  17 \_\_\_\_\_

18. The chemical bonding in sodium phosphate,  $\text{Na}_3\text{PO}_4$ , is classified as  
(1) ionic, only  
(2) metallic, only  
(3) both covalent and ionic  
(4) both covalent and metallic 18 \_\_\_\_\_

---

19. An antacid contains the acid-neutralizing agent sodium hydrogen carbonate. Write the chemical formula for sodium hydrogen carbonate. \_\_\_\_\_

20. Write the correct formula for hydrogen sulfate. \_\_\_\_\_

21. In terms of their formulas, what is the difference between the chlorate and perchlorate ions?  
\_\_\_\_\_

22. Write the chemical formula for the most abundant negative ion in an aqueous sodium phosphate solution. \_\_\_\_\_

23. Write the chemical formula for copper(I) sulfite. \_\_\_\_\_



---

---

## Table E – Selected Polyatomic Ions

---

---

### Answers

#### Set 1

- 2 From Table E, the carbonate ion has the formula  $\text{CO}_3^{2-}$ . The formula shows three oxygen atoms are present in this ion. The other choices have one or two oxygen atoms.
- 1 The hydrogen ion (a proton) combines with a water molecule to form the hydronium ion. This polyatomic ion is the first one given in Table E.
- 4 Sodium peroxide,  $\text{Na}_2\text{O}_2$ , contains the peroxide ion, having the formula  $\text{O}_2^{2-}$ .
- 2 Using Table E, the chlorite ion is  $\text{ClO}_2^-$ . Potassium, having an oxidation number +1, would join with the chlorite ion, forming the compound  $\text{KClO}_2$ , potassium chlorite.
- 2 Using Table E, potassium chlorate is  $\text{KClO}_3$ , and zinc nitrate is  $\text{Zn}(\text{NO}_3)_2$ . Both of these compounds contain oxygen.
- 2 As shown in the Periodic Table, sodium has an oxidation state of +1 ( $\text{Na}^+$ ). Shown in Table E, the formula for the sulfate ion is  $\text{SO}_4^{2-}$ . To maintain a neutral compound, two sodium ions are needed to form sodium sulfate,  $\text{Na}_2\text{SO}_4$ .
- 1 The formula of a compound must represent a neutral group of atoms. The nitrate ion ( $\text{NO}_3^-$ ) has a charge of  $-1$ . Thus Na must have an oxidation state of +1 in the formula of  $\text{NaNO}_3$ . This is the oxidation state of sodium as shown in the Periodic Table.
- 4 In the *Stock System of Nomenclature*, the oxidation state of the metal is shown by Roman numerals. Copper(II) has an oxidation state of +2. From Table E, the hydroxide ion ( $\text{OH}^-$ ) has a charge of  $-1$ . For the compound to be neutral, two hydroxide ions are needed. The formula for copper(II) hydroxide would be  $\text{Cu}(\text{OH})_2$ .
- a)  $\text{NO}_3^-$  If the acid name ends in  $-ic$ , it is modified to end in  $-ate$  to name the ion. Thus, nitric acid would produce the nitrate ion,  $\text{NO}_3^-$ .  
b)  $\text{SO}_3^{2-}$  Sulfurous acid produces the sulfite ion. Remember, if the acid name ends in  $-ous$ , it is modified to end in  $-ite$  to name the ion.
10. Answer:  $\text{NH}_4^+$  and  $\text{Cl}^-$  or ammonium and chloride  
Explanation: When this compound dissolves in water, it dissociates into the polyatomic ion  $\text{NH}_4^+$  and the  $\text{Cl}^-$  ion.

## Heats of Reaction at 101.3 kPa and 298 K

Reaction	$\Delta H$ (kJ)*
$\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\ell)$	-890.4
$\text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \longrightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\ell)$	-2219.2
$2\text{C}_8\text{H}_{18}(\ell) + 25\text{O}_2(\text{g}) \longrightarrow 16\text{CO}_2(\text{g}) + 18\text{H}_2\text{O}(\ell)$	-10943
$2\text{CH}_3\text{OH}(\ell) + 3\text{O}_2(\text{g}) \longrightarrow 2\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\ell)$	-1452
$\text{C}_2\text{H}_5\text{OH}(\ell) + 3\text{O}_2(\text{g}) \longrightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\ell)$	-1367
$\text{C}_6\text{H}_{12}\text{O}_6(\text{s}) + 6\text{O}_2(\text{g}) \longrightarrow 6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\ell)$	-2804
$2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{CO}_2(\text{g})$	-566.0
$\text{C}(\text{s}) + \text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g})$	-393.5
$4\text{Al}(\text{s}) + 3\text{O}_2(\text{g}) \longrightarrow 2\text{Al}_2\text{O}_3(\text{s})$	-3351
$\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{NO}(\text{g})$	+182.6
$\text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \longrightarrow 2\text{NO}_2(\text{g})$	+66.4
$2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{H}_2\text{O}(\text{g})$	-483.6
$2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{H}_2\text{O}(\ell)$	-571.6
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \longrightarrow 2\text{NH}_3(\text{g})$	-91.8
$2\text{C}(\text{s}) + 3\text{H}_2(\text{g}) \longrightarrow \text{C}_2\text{H}_6(\text{g})$	-84.0
$2\text{C}(\text{s}) + 2\text{H}_2(\text{g}) \longrightarrow \text{C}_2\text{H}_4(\text{g})$	+52.4
$2\text{C}(\text{s}) + \text{H}_2(\text{g}) \longrightarrow \text{C}_2\text{H}_2(\text{g})$	+227.4
$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \longrightarrow 2\text{HI}(\text{g})$	+53.0
$\text{KNO}_3(\text{s}) \xrightarrow{\text{H}_2\text{O}} \text{K}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$	+34.89
$\text{NaOH}(\text{s}) \xrightarrow{\text{H}_2\text{O}} \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq})$	-44.51
$\text{NH}_4\text{Cl}(\text{s}) \xrightarrow{\text{H}_2\text{O}} \text{NH}_4^+(\text{aq}) + \text{Cl}^-(\text{aq})$	+14.78
$\text{NH}_4\text{NO}_3(\text{s}) \xrightarrow{\text{H}_2\text{O}} \text{NH}_4^+(\text{aq}) + \text{NO}_3^-(\text{aq})$	+25.69
$\text{NaCl}(\text{s}) \xrightarrow{\text{H}_2\text{O}} \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$	+3.88
$\text{LiBr}(\text{s}) \xrightarrow{\text{H}_2\text{O}} \text{Li}^+(\text{aq}) + \text{Br}^-(\text{aq})$	-48.83
$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \longrightarrow \text{H}_2\text{O}(\ell)$	-55.8

\*The  $\Delta H$  values are based on molar quantities represented in the equations. A minus sign indicates an exothermic reaction.

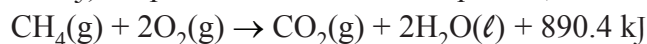
**Overview:**

Any reaction, chemical or physical, involves either the absorption or release of energy. This energy is usually measured in the form of heat, expressed in kJ, and is called the enthalpy or simply the heat of reaction. The symbol for heat of reaction is  $\Delta H$ . The conditions of 101.3 kPa and 298 K are the standard conditions for the measurement of heats of reaction.

### The Table:

The chemical equations for many reactions are given on this table. Notice that the phases of the reactants and products are given in each reaction. The heats of reaction ( $\Delta H$ ) are given at the right hand side of the table. As indicated at the bottom of the table by the asterisk, a minus sign indicates an exothermic reaction. An exothermic reaction is one that produces or releases energy. This is indicated by a negative heat of reaction. When included in the chemical equation, the heat is included on the product side.

*For example:* The first reaction on the chart is an exothermic reaction since it has a negative heat of reaction ( $-890.4$  kJ). Expressed as a chemical equation, it would be written as:



An endothermic reaction is one that absorbs energy. This is indicated by a positive heat of reaction. When included in the chemical equation, the heat is included on the reactant side.

*For example:* The first endothermic reaction given on the chart is  $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$  as shown by the positive heat of reaction ( $182.6$  kJ). This reaction would absorb  $182.6$  kJ.

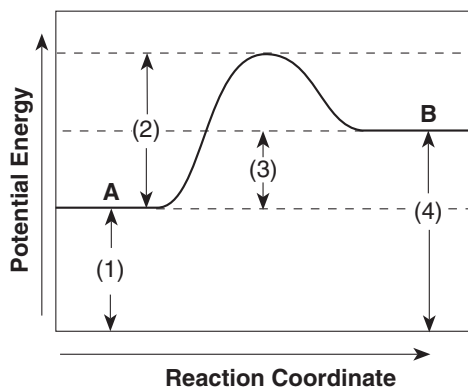
Expressed as a chemical equation, it would be written as:



**Potential Energy Diagrams:** Chemical reactions can be shown by a potential energy diagram. Below is a potential energy diagram of an endothermic reaction.

#### Endothermic Reaction

In endothermic reactions, the potential energy of the products is greater than the potential energy of the reactants. Endothermic reactions absorb heat from the surroundings.



#### Explanation of the Arrows:

*Arrow (1)* represents the potential energy of the reactants,  $2\text{C}(\text{s}) + \text{H}_2(\text{g})$ . This potential energy is illustrated by plateau A.

*Arrow (2)* is the activation energy. This is the minimum amount of energy needed to start the reaction.

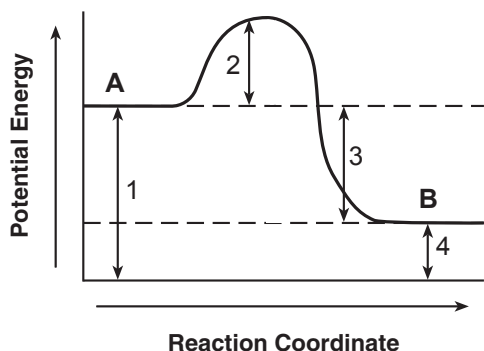
*Arrow (3)* is the heat of reaction ( $\Delta H$ ). The heat of reaction is the potential energy of the product minus the potential energy of the reactant. Since B is greater than A, the  $\Delta H$  for an endothermic reaction is positive ( $\Delta H = 227.4$  kJ).

Notice that, in the chemical equation, the heat is included on the reactant side of the equation since it is absorbed. This is true for all endothermic reactions.

*Arrow (4)* represents the potential energy of the product,  $\text{C}_2\text{H}_2(\text{g})$ , plateau B.

## Exothermic Reaction

In exothermic reactions, the potential energy of the products is lower than the potential energy of the reactants. Exothermic reactions release heat into the surroundings.



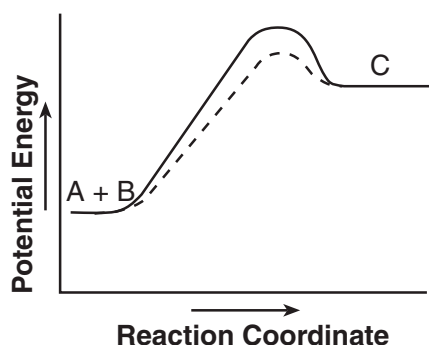
Arrow (1) represents the potential energy of the reactants,  $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g})$ .

Arrow (2) represents the activation energy.

Arrow (3) is the heat of reaction ( $\Delta H$ ). Since 4 is less than 1, the  $\Delta H$  for an exothermic reaction is negative ( $\Delta H = -890.4 \text{ kJ}$ ). Notice that, in the chemical equation, the heat is included on the product side of the equation since it is released. This is true for all exothermic reactions.

Arrow (4) represents the potential energy of the products,  $\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\ell)$ , plateau B.

## Catalyst



A catalyst is a substance that increases the speed at which a reaction takes place or equilibrium is reached. The catalyst accomplishes this by lowering the activation energy needed for the forward and reverse reaction. In the diagram to the left, the solid line represents the change in potential energy that occurs during the given reaction:  $\text{A} + \text{B} \rightarrow \text{C}$ . The dotted line represents the pathway of the same reaction when a catalyst is added. Notice that a different reaction pathway occurs with the peak of the potential energy graph (the top of the curve) being lowered. Thus the activation energy is decreased, without changing the positions of the potential energy of the plateaus (reactants and products).

## Additional Information:

- Melting and evaporation are endothermic phase changes. Condensation and freezing are exothermic phase changes.
- The greater the negative  $\Delta H$ , the more stable the products of the reaction.
- The greater the positive  $\Delta H$ , the more unstable the products of the reaction.
- Entropy is a measure of the randomness or disorder in a system. As a system becomes more random (less ordered), the entropy increases. As the temperature of a system increases, the entropy increases. As a substance changes from a solid to a liquid to a gas, the entropy increases.

---

---

**Set 1 — Heats of Reaction**

---

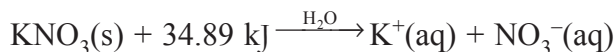
---

1. Which statement best describes a chemical reaction in which energy is released?
- (1) It is exothermic and has a negative  $\Delta H$ .  
(2) It is exothermic and has a positive  $\Delta H$ .  
(3) It is endothermic and has a negative  $\Delta H$ .  
(4) It is endothermic and has a positive  $\Delta H$ .
- 1 \_\_\_\_\_
2. Which change of phase is exothermic?
- (1) solid to liquid (3) solid to gas  
(2) gas to liquid (4) liquid to gas
- 2 \_\_\_\_\_
3. Which equation represents an exothermic reaction at 298 K?
- (1)  $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$   
(2)  $\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$   
(3)  $\text{KNO}_3(\text{s}) \rightarrow \text{K}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$   
(4)  $\text{NH}_4\text{Cl}(\text{s}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{Cl}^-(\text{aq})$
- 3 \_\_\_\_\_
4. Based on Reference Table I, which change occurs when pellets of solid NaOH are added to water and stirred?
- (1) The water temperature increases as chemical energy is converted to heat energy.  
(2) The water temperature increases as heat energy is stored as chemical energy.  
(3) The water temperature decreases as chemical energy is converted to heat energy.  
(4) The water temperature decreases as heat energy is stored as chemical energy.
- 4 \_\_\_\_\_
5. Which reaction releases the greatest amount of energy per 2 moles of product?
- (1)  $2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g})$   
(2)  $4\text{Al}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{Al}_2\text{O}_3(\text{s})$   
(3)  $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$   
(4)  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$
- 5 \_\_\_\_\_
6. In a potential energy diagram, the difference between the potential energy of the products and the potential energy of the reactants is equal to the
- (1) heat of reaction  
(2) entropy of the reaction  
(3) activation energy of the forward reaction  
(4) activation energy of the reverse reaction
- 6 \_\_\_\_\_
7. Which balanced equation represents an endothermic reaction?
- (1)  $\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$   
(2)  $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\ell)$   
(3)  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$   
(4)  $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$
- 7 \_\_\_\_\_
8. Which statement correctly describes an endothermic chemical reaction?
- (1) The products have higher potential energy than the reactants, and the  $\Delta H$  is negative.  
(2) The products have higher potential energy than the reactants, and the  $\Delta H$  is positive.  
(3) The products have lower potential energy than the reactants, and the  $\Delta H$  is negative.  
(4) The products have lower potential energy than the reactants, and the  $\Delta H$  is positive.
- 8 \_\_\_\_\_

9. According to Table I, which salt releases energy as it dissolves?

- (1)  $\text{KNO}_3$       (3)  $\text{NH}_4\text{NO}_3$   
 (2)  $\text{LiBr}$       (4)  $\text{NaCl}$       9 \_\_\_\_\_

10. Given the balanced equation:

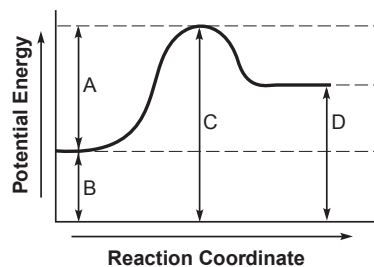


Which statement best describes this process?

- (1) It is endothermic and entropy increases.  
 (2) It is endothermic and entropy decreases.  
 (3) It is exothermic and entropy increases.  
 (4) It is exothermic and entropy decreases.

10 \_\_\_\_\_

11. Given the potential energy diagram of a chemical reaction:

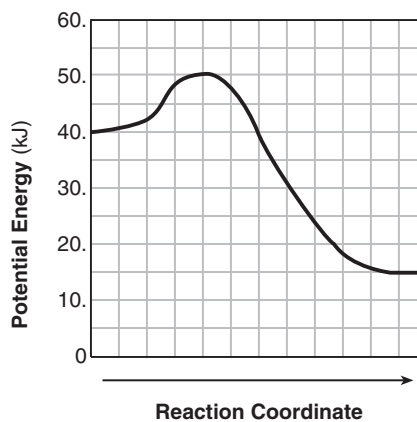


Which arrow represents the potential energy of the reactants?

- (1) *A*                      (3) *C*  
 (2) *B*                      (4) *D*                      11 \_\_\_\_\_

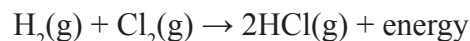
12. Given the potential energy diagram for a chemical reaction. Which statement correctly describes the energy changes that occur in the forward reaction?

- (1) The activation energy is 10. kJ and the reaction is endothermic.  
 (2) The activation energy is 10. kJ and the reaction is exothermic.  
 (3) The activation energy is 50. kJ and the reaction is endothermic.  
 (4) The activation energy is 50. kJ and the reaction is exothermic.



12 \_\_\_\_\_

13. Given the balanced equation representing a reaction:



Which statement describes the energy changes in this reaction?

- (1) Energy is absorbed as bonds are formed, only.  
 (2) Energy is released as bonds are broken, only.  
 (3) Energy is absorbed as bonds are broken, and energy is released as bonds are formed.  
 (4) Energy is absorbed as bonds are formed, and energy is released as bonds are broken.      13 \_\_\_\_\_

Base your answer to question 14 using the information below and your knowledge of chemistry.

Given the balanced equation for dissolving  $\text{NH}_4\text{Cl}(\text{s})$  in water:



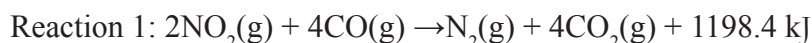
14. A student is holding a test tube containing 5.0 milliliters of water. A sample of  $\text{NH}_4\text{Cl}(\text{s})$  is placed in the test tube and stirred. Describe the heat flow between the test tube and the student's hand.

---

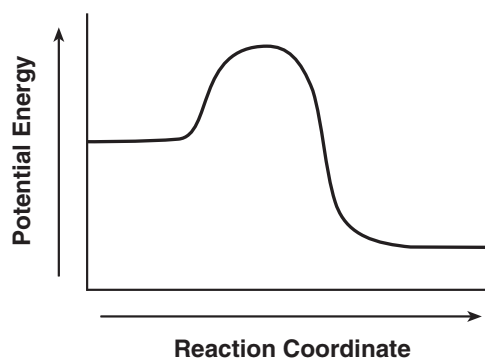
---

Base your answers to question 15 on the information below.

The catalytic converter in an automobile changes harmful gases produced during fuel combustion to less harmful exhaust gases. In the catalytic converter, nitrogen dioxide reacts with carbon monoxide to produce nitrogen and carbon dioxide. This reaction is represented by the balanced equation below.



15. The accompanying potential energy diagram represents reaction 1 without a catalyst. On the same diagram, draw a dashed line to indicate how potential energy changes when the reaction is catalyzed in the converter.

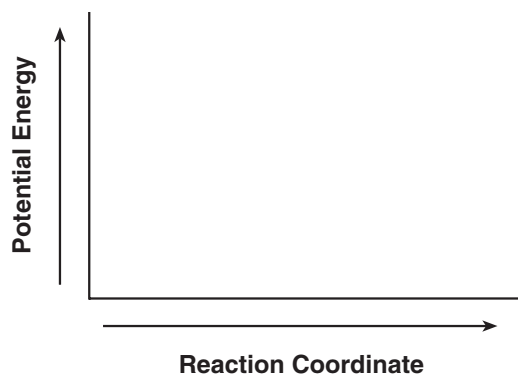


Given the balanced equation representing a reaction:



16. a) On the accompanying labeled axes, draw a potential energy diagram for this reaction.
- b) What is the  $\Delta H$  for this reaction?

\_\_\_\_\_ kJ



## Set 2 — Heats of Reaction

17. Which phase change is endothermic?

- (1) gas  $\rightarrow$  solid    (3) liquid  $\rightarrow$  solid  
 (2) gas  $\rightarrow$  liquid    (4) liquid  $\rightarrow$  gas    17 \_\_\_\_\_

18. Of the following reactions, which one releases the most heat?

- (1)  $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\ell)$   
 (2)  $2\text{C}_8\text{H}_{18}(\ell) + 25\text{O}_2(\text{g}) \rightarrow 16\text{CO}_2(\text{g}) + 18\text{H}_2\text{O}(\ell)$   
 (3)  $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$   
 (4)  $2\text{C}(\text{s}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_2(\text{g})$                   18 \_\_\_\_\_

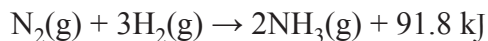
19. Given the balanced equation representing a reaction:



Which statement is true about energy in this reaction?

- (1) The reaction is exothermic because it releases heat.  
 (2) The reaction is exothermic because it absorbs heat.  
 (3) The reaction is endothermic because it releases heat.  
 (4) The reaction is endothermic because it absorbs heat.                  19 \_\_\_\_\_

20. Given the balanced equation representing a reaction at 101.3 kPa and 298 K:



Which statement is true about this reaction?

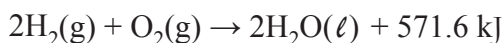
- (1) It is exothermic and  $\Delta H$  equals  $-91.8 \text{ kJ}$ .  
 (2) It is exothermic and  $\Delta H$  equals  $+91.8 \text{ kJ}$ .  
 (3) It is endothermic and  $\Delta H$  equals  $-91.8 \text{ kJ}$ .  
 (4) It is endothermic and  $\Delta H$  equals  $+91.8 \text{ kJ}$ .

20 \_\_\_\_\_

21. When lithium bromide crystals are dissolved in water, the temperature of the water increases. What does this temperature change indicate about the dissolving of lithium bromide in water?

- (1) It is an endothermic reaction because it absorbs heat.  
 (2) It is an endothermic reaction because it releases heat.  
 (3) It is an exothermic reaction because it absorbs heat.  
 (4) It is an exothermic reaction because it releases heat.                  21 \_\_\_\_\_

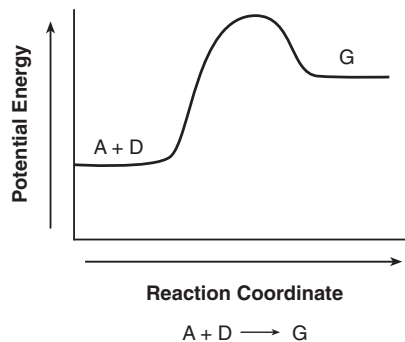
22. Given the reaction:



What is the approximate  $\Delta H$  for the formation of 1 mole of  $\text{H}_2\text{O}(\ell)$ ?

- (1)  $-285.8 \text{ kJ}$     (3)  $-571.6 \text{ kJ}$   
 (2)  $+285.8 \text{ kJ}$     (4)  $+571.6 \text{ kJ}$                   22 \_\_\_\_\_

23. Given the potential energy diagram and equation representing the reaction between substances  $A$  and  $D$ :



According to Table I, substance  $G$  could be

- (1)  $\text{HI}(\text{g})$                   (3)  $\text{CO}_2(\text{g})$   
 (2)  $\text{H}_2\text{O}(\text{g})$               (4)  $\text{C}_2\text{H}_6(\text{g})$                   23 \_\_\_\_\_



24. For a given reaction, adding a catalyst increases the rate of the reaction by
- (1) providing an alternate reaction pathway that has a higher activation energy
  - (2) providing an alternate reaction pathway that has a lower activation energy
  - (3) using the same reaction pathway and increasing the activation energy
  - (4) using the same reaction pathway and decreasing the activation energy
- 24 \_\_\_\_\_

25. Which phase change results in the release of energy?
- (1)  $\text{H}_2\text{O}(\text{s}) \rightarrow \text{H}_2\text{O}(\ell)$
  - (2)  $\text{H}_2\text{O}(\text{s}) \rightarrow \text{H}_2\text{O}(\text{g})$
  - (3)  $\text{H}_2\text{O}(\ell) \rightarrow \text{H}_2\text{O}(\text{g})$
  - (4)  $\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\ell)$
- 25 \_\_\_\_\_

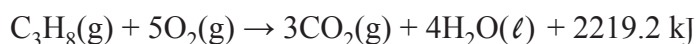
26. Given the balanced equation representing a phase change:
- $$\text{C}_6\text{H}_4\text{Cl}_2(\text{s}) + \text{energy} \rightarrow \text{C}_6\text{H}_4\text{Cl}_2(\text{g})$$
- Which statement describes this change?
- (1) It is endothermic, and entropy decreases.
  - (2) It is endothermic, and entropy increases.
  - (3) It is exothermic, and entropy decreases.
  - (4) It is exothermic, and entropy increases.
- 26 \_\_\_\_\_

27. Which balanced equation represents a chemical change?
- (1)  $\text{H}_2\text{O}(\ell) + \text{energy} \rightarrow \text{H}_2\text{O}(\text{g})$
  - (2)  $2\text{H}_2\text{O}(\ell) + \text{energy} \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$
  - (3)  $\text{H}_2\text{O}(\ell) \rightarrow \text{H}_2\text{O}(\text{s}) + \text{energy}$
  - (4)  $\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\ell) + \text{energy}$
- 27 \_\_\_\_\_

---

Base your answers to question 28 using the information below and your knowledge of chemistry.

Propane is a fuel that is sold in rigid, pressurized cylinders. Most of the propane in a cylinder is liquid, with gas in the space above the liquid level. When propane is released from the cylinder, the propane leaves the cylinder as a gas. Propane gas is used as a fuel by mixing it with oxygen in the air and igniting the mixture, as represented by the balanced equation below.



28. a) Determine the total amount of energy released when 2.50 moles of propane is completely reacted with oxygen. \_\_\_\_\_ kJ
- b) Is the above reaction exothermic or endothermic? \_\_\_\_\_

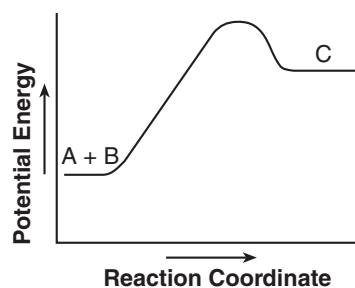
Base your answers to question 29 on the information below and your knowledge of chemistry.

A hot pack contains chemicals that can be activated to produce heat. A cold pack contains chemicals that feel cold when activated.

29. a) Based on energy flow, state the type of chemical change that occurs in a hot pack.
- \_\_\_\_\_
- b) A cold pack is placed on an injured leg. Indicate the direction of the flow of energy between the leg and the cold pack.
- \_\_\_\_\_

Base your answer to question 30 using your knowledge of chemistry and the information and accompanying diagram, which represent the changes in potential energy that occur during the given reaction.

Given the reaction:  $A + B \rightarrow C$



30. Does the diagram illustrate an exothermic or an endothermic reaction? State one reason, in terms of energy, to support your answer.

---



---

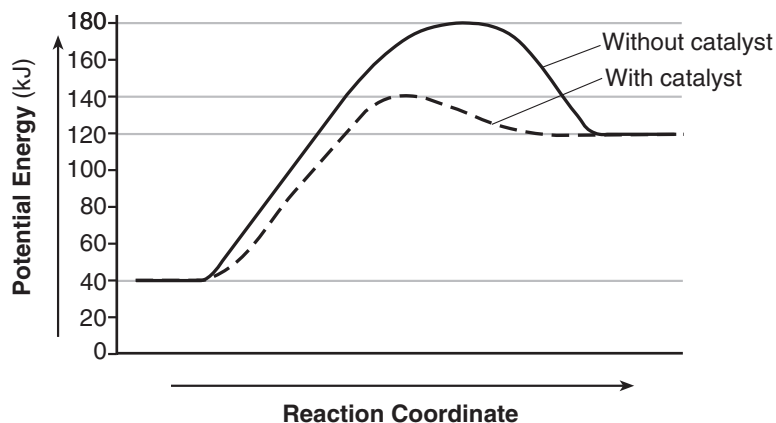
Base your answers to question 31 on the potential energy diagram.

31. a) What is the heat of reaction for the forward reaction?

\_\_\_\_\_ kJ

b) What is the activation energy for the forward reaction with the catalyst?

\_\_\_\_\_ kJ



c) Explain, in terms of the function of a catalyst, why the curves on the potential energy diagram for the catalyzed and uncatalyzed reactions are different.

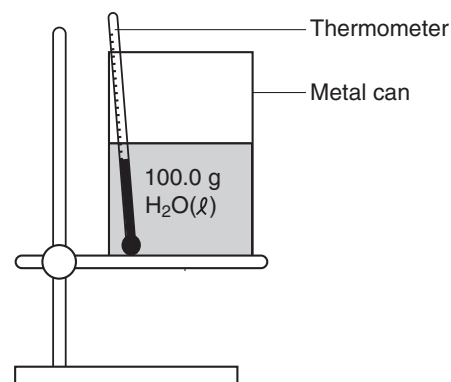
---



---

32. Explain what will happen to the thermometer reading when 22 grams of NaOH(s) is dissolved in the water.

---



---

---

## Table I – Heats of Reaction

---

---

### Answers

#### Set 1

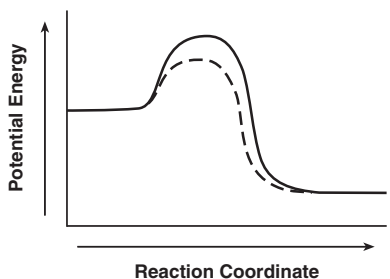
1. 1 All exothermic reactions release heat and have a negative (minus)  $\Delta H$ . This information is given at the bottom of Table I.
2. 2 Melting and evaporation are phase changes that absorb heat making them endothermic phase changes. Condensation and freezing are phase changes that release heat making them exothermic phase changes. Condensation is when a gas changes to a liquid.
3. 2 An exothermic reaction releases energy. Open to Table I. It shows that  $\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$  releases 393.5 kJ of heat, indicated by a negative  $\Delta H$ . At the bottom of this chart it states “Minus sign indicates an exothermic reaction”.
4. 1 In Table I, locate the equation involving the reactant NaOH. The  $\Delta H$  for this reaction is  $-44.51$  kJ, making this an exothermic reaction. This reaction releases heat as chemical energy, which converted to heat energy.
5. 2 When a reaction releases energy it is an exothermic reaction, having a negative  $\Delta H$ . The reaction shown in choice 2 releases 3351 kJ of energy per 2 moles of product. This is the greatest amount of energy of the given choices.
6. 1 The reactants involved in a chemical reaction will be at a specific potential energy, measured in kilojoules (kJ). After the reaction, the products will be at a different potential energy level. The net difference between these two energy levels, as shown by two plateaus on a potential energy graph, is the referred to as the heat of reaction.
7. 4 In Table I, locate this equation. Its  $\Delta H$  is  $+182.6$  kJ. All endothermic reactions have a positive  $\Delta H$ .
8. 2 When the products have a higher potential energy than the reactants, the chemical reaction must have absorbed energy, which makes it an endothermic reaction. A graph would show the reactants at a lower potential energy than the products.
9. 2 As shown on Table I, when  $\text{LiBr(s)}$  is dissolved, an exothermic reaction takes place releasing 48.83 kJ of energy. All other choices are endothermic reactions, which would absorb heat.
10. 1 The equation shows that 34.89 kJ of energy being absorbed by the reactants, making it endothermic reaction. Entropy is a measure of the disorder of a system. The greater the disorder, the greater the entropy. The equation shows that the solid  $\text{KNO}_3$  is being dissolved to form an aqueous solution. Whenever a solid is dissolved, entropy increases.

11. 2 The potential energy of the reactants is shown by the initial plateau, which is letter B. The potential energy of the products is shown by the second plateau, letter D.
12. 2 The graph shows that it took 10 kJ (40 kJ to 50 kJ) of activation energy for this reaction to occur. The graph also shows that the potential energy of the products is lower than that of the reactants. This is true for all exothermic reactions.
13. 3 The equation shows the reaction between two diatomic molecules ( $\text{H}_2$  and  $\text{Cl}_2$ ) to produce a single product ( $\text{HCl}$ ). The bonds between the Cl atoms in  $\text{Cl}_2$  and the H atoms in  $\text{H}_2$  must first be broken, which requires the absorption of energy. The separate H atoms and Cl atoms then bond to each other to form the product,  $\text{HCl}$ . Bond formation releases energy.

14. Answer: Heat flows from the student's hand to the test tube.  
*or* The test tube absorbs heat from the hand.

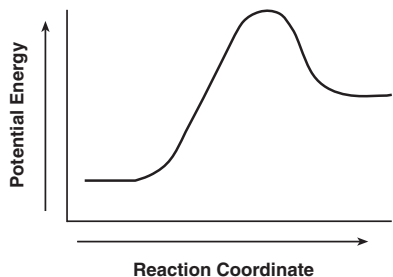
Explanation: As shown in Table I, this reaction is endothermic absorbing 14.78 kJ. The reaction will absorb heat from the water and from the student's hand. As heat is removed (being absorbed) from the student's hand, the test tube will feel colder.

15.



Explanation: Refer to page 41 and the given explanation for the catalyst diagram.

16. a)



Explanation: The given equation is an endothermic reaction since the heat is included on the reactant side of the chemical equation. On a graph, the potential energy of the products must be greater than the potential energy of the reactants for endothermic reactions.

b) Answer: + 182.6 kJ

Explanations: This is an endothermic reaction. Endothermic reactions will always have a positive heat of reaction ( $\Delta H$ ).

**Overview:**

You have probably noticed that if iron is not painted or coated, it starts to rust in days, especially if moisture is present. But silver, and especially gold, seem to be unaffected by substances in the environment and keep their brilliant luster. The reason for this is that different metals exhibit different chemical activity. In other words, some metals are very reactive, while other metals are less reactive. By studying the chemical activities of elements (metals and nonmetals), chemists have been able to arrange them based upon chemical reactivity.

**The Table:**

This table shows the relative chemical activity of metals and nonmetals, both arranged in order of decreasing chemical activity. Although  $H_2$  is not a metal, it is listed on the metallic side because the table is based on the hydrogen standard.

In a chemical reaction, a more active metal (higher up on Table J) will replace a less active metal when placed in an aqueous solution containing the ion of the less active metal. For example, lithium (Li), being the most active metal, will replace any metallic ion found below it from a solution of its salt. Rubidium (Rb) will replace any metal found below it from a solution of its salt, but because it is under Li, indicating that it is less active than Li, it will not replace Li from a solution of its salt.

Metals found above  $H_2$  are more active than hydrogen.

Therefore, it will replace the  $H^+$  in an aqueous acidic solution, producing hydrogen gas and a solution of a salt containing that metal. Those metals below  $H_2$  will not react with acids in this fashion.

*For example:*  $Mg + 2HCl \rightarrow MgCl_2 + H_2\uparrow$  reacted, because Mg is more active (being above  $H_2$ ) than  $H_2$ , as shown on Table J.

$Ag + HCl \rightarrow$  no reaction, because Ag is less active (being lower than  $H_2$ ) than  $H_2$ , as shown on Table J.

In a similar fashion, in a chemical reaction, a nonmetal will replace a less active nonmetal when interacting with a solution containing the ion of the less active nonmetal. For example, fluorine ( $F_2$ ) will replace  $Cl^-$ ,  $Br^-$  and  $I^-$  in solutions containing those ions, but chlorine ( $Cl_2$ ) cannot replace  $F^-$  from a solution containing the  $F^-$  ion; however, chlorine will replace  $Br^-$  and  $I^-$  in solutions containing these ions.

Most Active	Metals	Nonmetals	Most Active
	Li	$F_2$	
	Rb	$Cl_2$	
	K	$Br_2$	
	Cs	$I_2$	
	Ba		
	Sr		
	Ca		
	Na		
	Mg		
	Al		
	Ti		
	Mn		
	Zn		
	Cr		
	Fe		
	Co		
	Ni		
	Sn		
	Pb		
	$H_2$		
	Cu		
	Ag		
	Au		
Least Active			Least Active

\*\*Activity Series is based on the hydrogen standard.  $H_2$  is *not* a metal.

## Voltaic Cell:

An electrochemical or voltaic cell uses a spontaneous redox reaction to produce an electric current. It consists of two different metals, called electrodes, immersed in a solution of that metals salt, called an electrolyte. The electrodes are connected by a wire conductor. The electrolytes are connected by a salt bridge. The more active metal, higher up on Table J, undergoes oxidation and is called the anode (the negative electrode). The electrons flow through the wire to the less active metal, lower down on Table J, where they reduce that metals ions in the electrolyte. This electrode is called the cathode (the positive electrode).

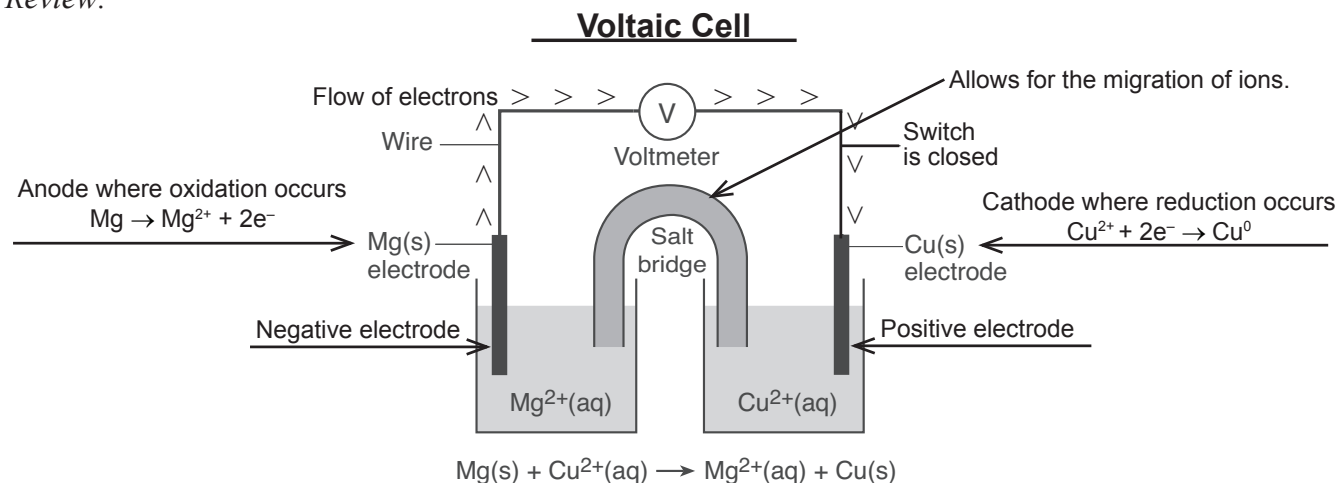
### Example:

A voltaic cell with magnesium and copper electrodes is shown in the above diagram. The copper electrode has a mass of 15.0 grams. Below the diagram is the balanced ionic equation for the reaction in the cell.

When the switch is closed, the salt bridge allows ions to flow between the half-cells and the reaction in the cell begins. The more active metal, Mg being higher up on Table J, will undergo oxidation (acting as a reducing agent) and the less active metal, Cu will undergo reduction (acting as an oxidizing agent). The electrons flow from the Mg electrode (losing electrons during oxidation) to the copper electrode where they will be used in the reduction of the  $\text{Cu}^{2+}$  ions found in the electrolyte. As  $\text{Cu}^{2+}$  ions become reduced to  $\text{Cu}^0$  (a neutral copper atom), the atoms become part of the copper electrode, increasing its mass.

In an electrolytic cell, an electric current is used to cause a nonspontaneous redox reaction to occur. It needs a power source, such as a battery, to begin and sustain the reaction. In this reaction, electrical energy is converted to chemical energy. In the voltaic cell, chemical energy is converted to electrical energy.

### Review:



**Additional Information:**

- In the single replacement reaction  $A + BC \rightarrow B + AC$  where  $A$  is a metal, the reaction will occur spontaneously if  $A$  is above  $B$  on Table J. If  $A$  is below  $B$ , the reaction will not occur.
- The most active metals are those that readily lose an electron, thus are easily oxidized. They tend to be the strongest reducing agents. Typically, they are Group 1 and Group 2 elements.
- In the single replacement reaction  $A + BC \rightarrow C + BA$  where  $A$  is a nonmetal, the reaction will occur spontaneously if  $A$  is above  $C$  on Table J. If  $A$  is below  $C$ , the reaction will not occur.
- The most active nonmetals are those that more readily gain an electron, thus most easily reduced. They tend to be the strongest oxidizing agents. Typically, they are Group 17 elements.
- Fluorine is the most active of all the elements.
- Gold (Au) a very inactive metal, which is why it keeps its brilliant luster. Being inactive, it is used in electrical connections that are exposed to hostile conditions, such as those found in space vehicles.

---

---

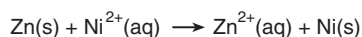
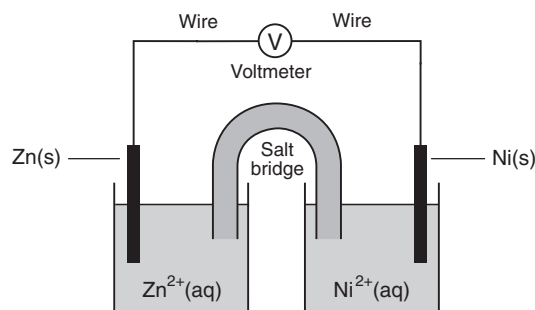
**Set 1 — Activity Series**

---

---

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. According to Reference Table J, which of these metals will react most readily with 1.0 M HCl to produce <math>H_2(g)</math>?</p> <p>(1) Ca            (3) Mg<br/>(2) K            (4) Zn            1 _____</p> <p>2. Which metal is more active than <math>H_2</math>?</p> <p>(1) Ag            (3) Cu<br/>(2) Au            (4) Pb            2 _____</p> <p>3. According to Reference Table J, which metal will react with <math>Zn^{2+}</math> but will not react with <math>Mg^{2+}</math>?</p> <p>(1) Al(s)        (3) Ni(s)<br/>(2) Cu(s)        (4) Ba(s)        3 _____</p> <p>4. Which metal reacts spontaneously with a solution containing zinc ions?</p> <p>(1) strontium    (3) copper<br/>(2) nickel        (4) silver        4 _____</p> | <p>5. Which of the following metals is most active?</p> <p>(1) Ag            (3) Sn<br/>(2) Zn            (4) Li            5 _____</p> <p>6. Which metal is more active than Ni and less active than Zn?</p> <p>(1) Cu            (3) Cr<br/>(2) Mg            (4) Pb            6 _____</p> <p>7. Which half-reaction equation represents the reduction of an iron(II) ion?</p> <p>(1) <math>Fe^{2+} \rightarrow Fe^{3+} + e^-</math><br/>(2) <math>Fe^{2+} + 2e^- \rightarrow Fe</math><br/>(3) <math>Fe^{3+} + e^- \rightarrow Fe^{2+}</math><br/>(4) <math>Fe \rightarrow Fe^{2+} + 2e^-</math>            7 _____</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

8. The diagram below represents an operating electrochemical cell and the balanced ionic equation for the reaction occurring in the cell.



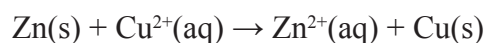
Which statement identifies the part of the cell that conducts electrons and describes the direction of electron flow as the cell operates?

- (1) Electrons flow through the salt bridge from the Ni(s) to the Zn(s).
  - (2) Electrons flow through the salt bridge from the Zn(s) to the Ni(s).
  - (3) Electrons flow through the wire from the Ni(s) to the Zn(s).
  - (4) Electrons flow through the wire from the Zn(s) to the Ni(s). 8 \_\_\_\_\_
9. Which statement is true for any electrochemical cell?
- (1) Oxidation occurs at the anode, only.
  - (2) Reduction occurs at the anode, only.
  - (3) Oxidation occurs at both the anode and the cathode.
  - (4) Reduction occurs at both the anode and the cathode. 9 \_\_\_\_\_
10. Which energy conversion occurs during the operation of an electrolytic cell?
- (1) chemical energy to electrical energy
  - (2) electrical energy to chemical energy
  - (3) nuclear energy to electrical energy
  - (4) electrical energy to nuclear energy 10 \_\_\_\_\_

11. Which process occurs at the anode in an electrochemical cell?

- (1) the loss of protons
- (2) the loss of electrons
- (3) the gain of protons
- (4) the gain of electrons 11 \_\_\_\_\_

12. Given the balanced ionic equation representing the reaction in an operating voltaic cell:



The flow of electrons through the external circuit in this cell is from the

- (1) Cu anode to the Zn cathode
- (2) Cu cathode to the Zn anode
- (3) Zn anode to the Cu cathode
- (4) Zn cathode to the Cu anode 12 \_\_\_\_\_

13. A student collects the materials and equipment below to construct a voltaic cell.

- two 250-mL beakers
- wire and a switch
- one strip of magnesium
- one strip of copper
- 125 mL of 0.20 M  $\text{Mg}(\text{NO}_3)_2(\text{aq})$
- 125 mL of 0.20 M  $\text{Cu}(\text{NO}_3)_2(\text{aq})$

Which additional item is required for the construction of the voltaic cell?

- (1) an anode
- (2) a battery
- (3) a cathode
- (4) a salt bridge 13 \_\_\_\_\_



14. Identify one metal from Reference Table J that is more easily oxidized than Mg(s). \_\_\_\_\_

Base your answer to question 15 using the information below and your knowledge of chemistry.

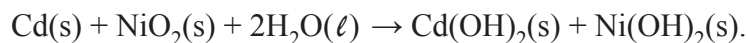
Two chemistry students each combine a different metal with hydrochloric acid. Student *A* uses zinc, and hydrogen gas is readily produced. Student *B* uses copper, and no hydrogen gas is produced.

15. State one chemical reason for the different results of students *A* and *B*.

---

---

16. When a nickel-cadmium battery produces electricity, the following reaction takes place:



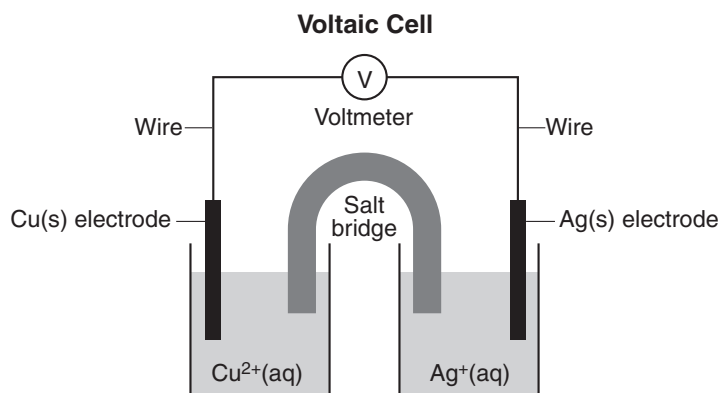
Explain why Cd would be above Ni if placed on Table J.

---

---

Base your answers to question 17 on the information below.

The diagram and balanced ionic equation represent a voltaic cell with copper and silver electrodes and the reaction that occurs when the cell is operating.



17. a) Describe the direction of electron flow in the external circuit in this operating cell.

---

b) State the purpose of the salt bridge in this voltaic cell.

---

c) Write a balanced half-reaction equation for the oxidation that occurs in this cell.

---

**Set 2 — Activity Series**

18. Based on Reference Table J, which metal will react spontaneously with  $\text{Al}^{3+}$ ?

- (1) Co(s)                      (3) Cu(s)  
 (2) Cr(s)                      (4) Ca(s)                      18 \_\_\_\_\_

19. Given the balanced equation representing a reaction occurring in an electrolytic cell:



Where is  $\text{Na}(\ell)$  produced in the cell?

- (1) at the anode, where oxidation occurs  
 (2) at the anode, where reduction occurs  
 (3) at the cathode, where oxidation occurs  
 (4) at the cathode, where reduction occurs  
 19 \_\_\_\_\_

20. Under standard conditions, which metal will react with 0.1 M HCl to liberate hydrogen gas?

- (1) Ag                              (3) Cu  
 (2) Au                              (4) Mg                              20 \_\_\_\_\_

21. Which reaction occurs spontaneously?

- (1)  $\text{Cl}_2(\text{g}) + 2\text{NaBr}(\text{aq}) \rightarrow \text{Br}_2(\ell) + 2\text{NaCl}(\text{aq})$   
 (2)  $\text{Cl}_2(\text{g}) + 2\text{NaF}(\text{aq}) \rightarrow \text{F}_2(\text{g}) + 2\text{NaCl}(\text{aq})$   
 (3)  $\text{I}_2(\text{s}) + 2\text{NaBr}(\text{aq}) \rightarrow \text{Br}_2(\ell) + 2\text{NaI}(\text{aq})$   
 (4)  $\text{I}_2(\text{s}) + 2\text{NaF}(\text{aq}) \rightarrow \text{F}_2(\text{g}) + 2\text{NaI}(\text{aq})$   
 21 \_\_\_\_\_

22. Which of the following metals has the least tendency to undergo oxidation?

- (1) Ag                              (3) Zn  
 (2) Pb                              (4) Li                              22 \_\_\_\_\_

23. Which of the following nonmetals is most active?

- (1)  $\text{F}_2$                               (3)  $\text{Br}_2$   
 (2)  $\text{Cl}_2$                               (4)  $\text{I}_2$                               23 \_\_\_\_\_

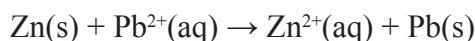
24. Which half-reaction correctly represents reduction?

- (1)  $\text{Mn}^{4+} \rightarrow \text{Mn}^{3+} + \text{e}^-$   
 (2)  $\text{Mn}^{4+} \rightarrow \text{Mn}^{7+} + 3\text{e}^-$   
 (3)  $\text{Mn}^{4+} + \text{e}^- \rightarrow \text{Mn}^{3+}$   
 (4)  $\text{Mn}^{4+} + 3\text{e}^- \rightarrow \text{Mn}^{7+}$                       24 \_\_\_\_\_

25. Which energy change occurs in an operating voltaic cell?

- (1) chemical to electrical  
 (2) electrical to chemical  
 (3) chemical to nuclear  
 (4) nuclear to chemical                      25 \_\_\_\_\_

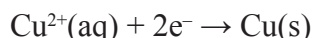
26. Given the balanced equation representing the reaction occurring in a voltaic cell:



In the completed external circuit, the electrons flow from

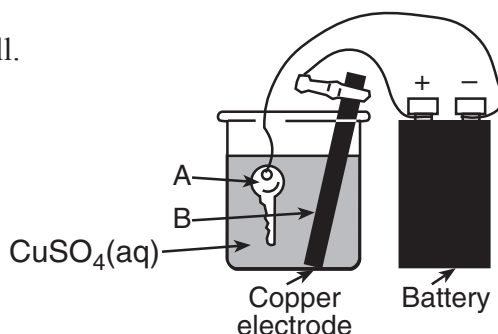
- (1) Pb(s) to Zn(s)  
 (2)  $\text{Pb}^{2+}(\text{aq})$  to  $\text{Zn}^{2+}(\text{aq})$   
 (3) Zn(s) to Pb(s)  
 (4)  $\text{Zn}^{2+}(\text{aq})$  to  $\text{Pb}^{2+}(\text{aq})$                       26 \_\_\_\_\_

27. The accompanying diagram shows a key being plated with copper in an electrolytic cell. Given the reduction reaction for this cell:



This reduction occurs at

- (1) *A*, which is the anode
- (2) *A*, which is the cathode
- (3) *B*, which is the anode
- (4) *B*, which is the cathode



27 \_\_\_\_\_

Base your answer to question 28 using the information below and your knowledge of chemistry.

The outer structure of the Statue of Liberty is made of copper metal. The framework is made of iron. Over time, a thin green layer (patina) forms on the copper surface.

28. Where the iron framework came in contact with the copper surface, a reaction occurred in which iron was oxidized. Using information from Reference Table J, explain why the iron was oxidized.

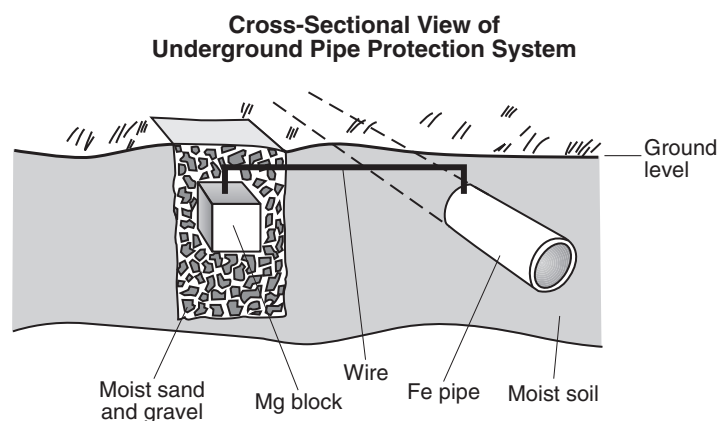
---



---

Base your answers to question 29 on the information below.

Underground iron pipes in contact with moist soil are likely to corrode. This corrosion can be prevented by applying the principles of electrochemistry. Connecting an iron pipe to a magnesium block with a wire creates an electrochemical cell. The magnesium block acts as the anode and the iron pipe acts as the cathode. A diagram of this system is shown to the right.



29. a) State the direction of the flow of electrons between the electrodes in this cell.

---

- b) Explain, in terms of reactivity, why magnesium is preferred over zinc to protect underground iron pipes. Your response must include both magnesium and zinc.

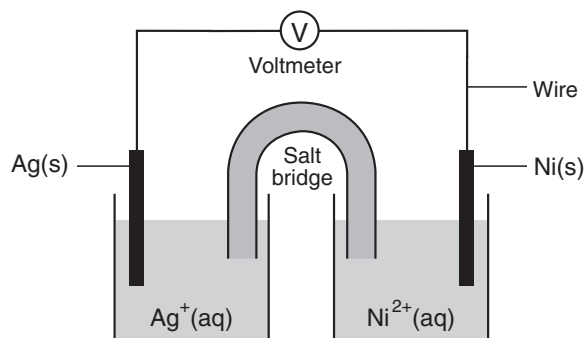
---



---

Base your answers to question 30 on the information below.

The accompanying diagram represents an operating voltaic cell at 298 K and 1.0 atmosphere in a laboratory investigation. The reaction occurring in the cell is represented by the balanced ionic equation below the diagram.



30. a) Identify the anode in this cell.

\_\_\_\_\_

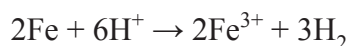
- b) Determine the total number of moles of  $\text{Ni}^{2+}(\text{aq})$  ions produced when 4.0 moles of  $\text{Ag}^+(\text{aq})$  ions completely react in this cell. \_\_\_\_\_

- c) Write a balanced half-reaction equation for the reduction that occurs in this cell.

\_\_\_\_\_

31. Based on Table J, identify one metal that does not react spontaneously with  $\text{HCl}(\text{aq})$ . \_\_\_\_\_

32. Because tap water is slightly acidic, water pipes made of iron corrode over time, as shown by the balanced ionic equation below:



Explain, in terms of chemical reactivity, why copper pipes are less likely to corrode than iron pipes.

\_\_\_\_\_

33. Explain, in terms of electrical energy, how the operation of a voltaic cell differs from the operation of an electrolytic cell used in the Hall process. Include both the voltaic cell and the electrolytic cell in your answer.

\_\_\_\_\_

34. Identify *one* metal from Reference Table J that is more easily oxidized than  $\text{Ba}(\text{s})$ . \_\_\_\_\_

Base your answers to question 35 on the diagram and balanced equation, which represent the electrolysis of molten NaCl.

35. a) When the switch is closed, which electrode will attract the sodium ions?

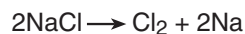
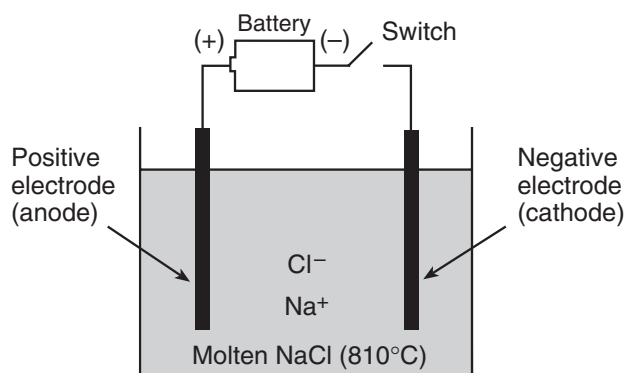
---

- b) What is the purpose of the battery in this electrolytic cell?

---

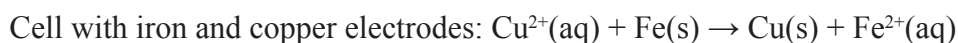
- c) Write the balanced half-reaction for the reduction that occurs in this electrolytic cell.

---



Base your answers to question 36 on the information below.

In a laboratory investigation, a student constructs a voltaic cell with iron and copper electrodes. Another student constructs a voltaic cell with zinc and iron electrodes. Testing the cells during operation enables the students to write the balanced ionic equations below.



36. a) State evidence from the balanced equation for the cell with iron and copper electrodes that indicates the reaction in the cell is an oxidation-reduction reaction.

---

- b) Identify the particles transferred between  $\text{Fe}^{2+}$  and Zn during the reaction in the cell with zinc and iron electrodes.

---

- c) Write a balanced half-reaction equation for the reduction that takes place in the cell with zinc and iron electrodes.

---

- d) State the relative activity of the three metals used in these two voltaic cells.

---

---

---

## Table J – Activity Series

---

---

### Answers – Set 1

- 2 The more active a metal is, the more readily it will react with a 1.0 M solution of HCl. In Table J, K (potassium) is the highest up on the metal activity list and is therefore more active than the other metals given as choices.
- 4 Metals found above  $H_2$  on Table J are more active than hydrogen. This would be lead (Pb).
- 1 Any metal that is more active (higher up on Table J) will react with any metallic ion that is less active. Al is higher than Zn on the metal activity list, thus it will react with  $Zn^{2+}$ . However, Al is lower on the metal activity list than Mg, therefore it would not react with  $Mg^{2+}$ .
- 1 A spontaneous reaction will occur with zinc ions with any metal that is higher than Zn on Table J. Strontium would have a spontaneous reaction with zinc ions.
- 4 The most active metal of the given choices would be the one that is higher up on Table J. This would be lithium (Li).
- 3 Using Table J, the higher up a metal is on this table, the more active it is. Notice that Cr is between Zn and Ni. This makes Cr more active than Ni, but less active than Zn.
- 2 In a reduction reaction, electrons are gained and the oxidation state is lowered or reduced. In choice 2,  $Fe^{2+}$  gains 2 electrons, becoming  $Fe^0$ .
- 4 Electrons flow from the electrode where oxidation or a loss of electrons occurs to the electrode where reduction or a gain of electrons occurs. The equation shows that Zn(s) is oxidized and the  $Ni^{2+}$  is reduced. The electrons therefore flow from the Zn(s) to the Ni(s), allowing the  $Ni^{2+}$  to be reduced. Ions, not electrons, flow through the salt bridge.
- 1 In any chemical cell (voltaic or electrolytic cell), oxidation (loss of electrons) always occurs at the anode.
- 2 See last paragraph on page 51.
- 2 The anode is the electrode where oxidation occurs. Here, a metal gives up or loses electrons.
- 3 Electrons flow from the anode, where oxidation occurs, to the cathode, where reduction occurs. In the equation, Zn is undergoing oxidation by losing two electrons, thus Zn is the anode. The  $Cu^{2+}$  is gaining these electrons, therefore the Cu(s) is the cathode.
- 4 A salt bridge is an essential part of a voltaic cell. It allows the flow of ions between each half-cell, completing the circuit, allowing the cell to function.

14. Answer: Li *or* Ba *or* Rb *or* Sr *or* K *or* Ca *or* Cs *or* Na

Explanation: Any metal that is higher up on Table J than Mg would be more active, thus more easily oxidized than Mg.

15. Answer: Cu is less active than hydrogen gas (weaker reducing agent).

*or* Zn is more reactive (stronger reducing agent than H<sub>2</sub> gas).

*or* Cu is below H<sub>2</sub> on the activity series and Zn is above H<sub>2</sub>.

Explanation: Any metal that is above hydrogen on Table J will react with hydrochloric acid releasing hydrogen gas. Any metal below hydrogen will not react with hydrochloric acid and will not produce hydrogen gas. Therefore, student *A*, using Zn, produced hydrogen gas and student *B*, using copper, did not have a reaction with hydrochloric acid.

16. Answer: Cd is more active than Ni. *or* Cd oxidizes in the presence of Ni<sup>4+</sup>.

Explanation: The higher up a metal is on Table J, the more active it is and the greater its tendency to undergo oxidation. In this reaction, Cd is shown to be more active than Ni since it undergoes oxidation, replacing Ni.

17. a) Answer: From the copper electrode to the silver electrode.

Explanation: Electrons flow from the anode, where oxidation occurs, to the cathode, where reduction occurs. The equation shows that copper loses electrons and therefore must be the anode.

b) Answer: Migration of ions *or* allows ions to flow between half-cells *or* maintains electrical neutrality *or* prevents polarization

Explanation: The salt bridge allows migration of ions between the half-cells, completing the circuit, allowing the cell to function.

c) Answer:  $\text{Cu}^0 \rightarrow \text{Cu}^{2+} + 2\text{e}^-$

Explanation: In oxidation there is a loss of electrons. The copper metal loses two electrons, becoming a copper ion.

**Table O****Symbols Used in Nuclear Chemistry**

Name	Notation	Symbol
alpha particle	${}^4_2\text{He}$ or ${}^4_2\alpha$	$\alpha$
beta particle	${}^0_{-1}\text{e}$ or ${}^0_{-1}\beta$	$\beta^-$
gamma radiation	${}^0_0\gamma$	$\gamma$
neutron	${}^1_0\text{n}$	n
proton	${}^1_1\text{H}$ or ${}^1_1\text{p}$	p
positron	${}^0_{+1}\text{e}$ or ${}^0_{+1}\beta$	$\beta^+$

**Overview:**

Radioactive elements emit particles and/or energy from their nuclei. These nuclear particles or energy have different effects on the nuclei of these elements. This radioactive decay process can be represented by nuclear equations, showing the identity of the reactants, products and the radiation released. In these equations, both charge and mass must be conserved. To balance a nuclear equation, the sum of the atomic or charge numbers on each side must be equal, and the sum of the mass numbers on each side must be equal.

**The Table:**

This table gives the Name, Notation (used in writing nuclear equations) and Symbol of the common types of radiation.

Going down this chart in order:

- The alpha particle ( $\alpha$ ) is a helium nucleus and is therefore positively charged.
- The beta particle ( $\beta^-$ ) is an ordinary electron and is therefore negatively charged.
- Gamma radiation ( $\gamma$ ), is the emission of pure energy from the nucleus – it carries no charge or mass.
- The neutron (n) is a neutral particle of unit mass found in the nucleus of atoms.
- The proton (p) is a hydrogen nucleus, a positive particle of unit mass found in the nucleus of atoms.
- The positron ( $\beta^+$ ) is a positive electron.

As shown in the Notation section, the mass number is the number at the upper left and the atomic number is the number at the lower left. When a particle is emitted, conservation of these numbers must take place with the reactants and products. If the emission of the particle affects the atomic number, the identity of the element changes. The specifics of these changes are given on the next page.



### ***Additional Information:***

Going down the chart in order:

- During alpha decay or emission, the atomic number decreases by 2 and the mass number decreases by 4. Example:  ${}_{88}^{226}\text{Ra} \rightarrow {}_{86}^{222}\text{Rn} + {}_2^4\text{He}$
- During negative beta decay or emission, the atomic number increases by 1 and the mass number remains the same. Example:  ${}_{92}^{235}\text{U} \rightarrow {}_{93}^{235}\text{Np} + {}_{-1}^0\text{e}$
- During gamma emission, both the atomic number and mass number remain the same. Example:  ${}_{92}^{239}\text{U} \rightarrow {}_{92}^{239}\text{U} + {}_0^0\gamma$
- During neutron emission, the atomic number remains the same and the mass number decreases by 1. Example:  ${}_{88}^{226}\text{Ra} \rightarrow {}_{88}^{225}\text{U} + {}_0^1\text{n}$
- During proton emission, both the atomic number and mass number decrease by 1. Example:  ${}_{27}^{53}\text{Co} \rightarrow {}_{26}^{52}\text{Fe} + {}_1^1\text{H}$
- During positron emission, also known as positive beta emission, the atomic number decreases by 1 and the mass number remains the same. Example:  ${}_{29}^{58}\text{Cu} \rightarrow {}_{28}^{58}\text{Ni} + {}_{+1}^0\text{e}$
- In natural transmutation, the identity of a nucleus or element changes due to a change in the number of protons (atomic number) in the nucleus. Example:  ${}_{94}^{239}\text{Pu} \rightarrow {}_{92}^{235}\text{U} + {}_2^4\text{He}$
- Artificial transmutation occurs when a stable (nonradioactive) nucleus is bombarded with particles, causing it to become radioactive. Example:  ${}_4^9\text{Be} + {}_2^4\text{He} \rightarrow {}_6^{12}\text{C} + {}_0^1\text{n}$
- Nuclear fusion is the combining of lightweight nuclei to produce a heavier nucleus. This usually involves hydrogen nuclei combining to produce a helium nucleus. This is the source of solar energy. Example:  ${}_1^2\text{H} + {}_1^2\text{H} \rightarrow {}_2^4\text{He} + \text{energy}$
- Nuclear fission is the splitting of a heavier nucleus into lighter weight nuclei. U-235 and Pu-239 are the most common elements to under go fission. This is the source of the energy produced in nuclear reactors. Example:  ${}_{92}^{235}\text{U} + {}_0^1\text{n} \rightarrow {}_{54}^{144}\text{Xe} + {}_{38}^{90}\text{Sr} + 2{}_0^1\text{n} + \text{energy}$
- Nuclear reactions release large amounts of energy due to the conversion of some mass into energy according to Einstein's equation,  $E = mc^2$ .
- Alpha radiation, being the largest particle, has the weakest penetrating power.
- Gamma radiation, being massless and neutral, has the greatest penetrating power.

## Set 1 — Symbols Used in Nuclear Chemistry

1. Which particle has the *least* mass?  
 (1)  ${}^4_2\text{He}$       (3)  ${}^1_0\text{n}$   
 (2)  ${}^1_1\text{H}$       (4)  ${}^0_{-1}\text{e}$       1 \_\_\_\_\_
  
2. In the reaction  ${}^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} + X$ ,  
 what does  $X$  represent?  
 (1) a neutron  
 (2) a proton  
 (3) an alpha particle  
 (4) a beta particle      2 \_\_\_\_\_
  
3. Positrons are spontaneously emitted from  
 the nuclei of  
 (1) potassium-37  
 (2) radium-226  
 (3) nitrogen-16  
 (4) thorium-232      3 \_\_\_\_\_
  
4. Given the nuclear equation:  
 ${}^{19}_{10}\text{Ne} \rightarrow X + {}^{19}_9\text{F}$   
 Which particle is represented by  $X$ ?  
 (1) alpha      (3) neutron  
 (2) beta      (4) positron      4 \_\_\_\_\_
  
5. Which list of radioisotopes contains  
 an alpha emitter, a beta emitter, and  
 a positron emitter?  
 (1) C-14, N-16, P-32  
 (2) Cs-137, Fr-220, Tc-99  
 (3) Kr-85, Ne-19, Rn-222  
 (4) Pu-239, Th-232, U-238      5 \_\_\_\_\_
  
6. Which product of nuclear decay  
 has mass but no charge?  
 (1) alpha particles  
 (2) neutrons  
 (3) gamma rays  
 (4) beta positrons      6 \_\_\_\_\_
  
7. Which type of radioactive emission  
 has a positive charge and weak  
 penetrating power?  
 (1) alpha particle    (3) gamma ray  
 (2) beta particle    (4) neutron      7 \_\_\_\_\_
  
8. Which of these types of radiation has  
 the greatest penetrating power?  
 (1) alpha      (3) gamma  
 (2) beta      (4) positron      8 \_\_\_\_\_
  
9. Which reaction is an example of  
 natural transmutation?  
 (1)  ${}^{239}_{94}\text{Pu} \rightarrow {}^{235}_{92}\text{U} + {}^4_2\text{He}$   
 (2)  ${}^{27}_{13}\text{Al} + {}^4_2\text{He} \rightarrow {}^{30}_{15}\text{P} + {}^1_0\text{n}$   
 (3)  ${}^{238}_{92}\text{U} + {}^1_0\text{n} \rightarrow {}^{239}_{94}\text{Pu} + 2 {}^0_{-1}\text{e}$   
 (4)  ${}^{239}_{94}\text{Pu} + {}^1_0\text{n} \rightarrow {}^{147}_{56}\text{Ba} + {}^{90}_{38}\text{Sr} + 3 {}^1_0\text{n}$       9 \_\_\_\_\_
  
10. Given the balanced equation representing  
 a nuclear reaction:  
 ${}^{235}_{92}\text{U} + {}^1_0\text{n} \rightarrow {}^{142}_{56}\text{Ba} + {}^{91}_{36}\text{Kr} + 3X + \text{energy}$   
 Which particle is represented by  $X$ ?  
 (1)  ${}^0_{-1}\text{e}$       (3)  ${}^4_2\text{He}$   
 (2)  ${}^1_1\text{H}$       (4)  ${}^1_0\text{n}$       10 \_\_\_\_\_

11. The change that is undergone by an atom of an element made radioactive by bombardment with high-energy protons is called
- (1) natural transmutation
  - (2) artificial transmutation
  - (3) natural decay
  - (4) radioactive decay
- 11 \_\_\_\_\_

12. One benefit of nuclear fission reactions is
- (1) nuclear reactor meltdowns
  - (2) storage of waste materials
  - (3) biological exposure
  - (4) production of energy
- 12 \_\_\_\_\_

13. In a nuclear fusion reaction, the mass of the products is
- (1) less than the mass of the reactants because some of the mass has been converted to energy
  - (2) less than the mass of the reactants because some of the energy has been converted to mass
  - (3) more than the mass of the reactants because some of the mass has been converted to energy
  - (4) more than the mass of the reactants because some of the energy has been converted to mass
- 13 \_\_\_\_\_

---

14. Given the nuclear equation:  ${}_{92}^{235}\text{U} + {}_0^1\text{n} \rightarrow {}_{56}^{142}\text{Ba} + {}_{36}^{91}\text{Kr} + 3{}_0^1\text{n} + \text{energy}$

- a) State the type of nuclear reaction represented by the equation. \_\_\_\_\_
- b) The sum of the masses of the products is slightly less than the sum of the masses of the reactants. Explain this loss of mass.

- \_\_\_\_\_
- \_\_\_\_\_
- c) This process releases greater energy than an ordinary chemical reaction does. Name another type of nuclear reaction that releases greater energy than an ordinary chemical reaction.

15. Using Reference Table N, complete the equation below for the nuclear decay of  ${}_{88}^{226}\text{Ra}$ . Include both atomic number and mass number for each particle.



## Set 2 — Symbols Used in Nuclear Chemistry

16. A beta particle may be spontaneously emitted from
- (1) a ground-state electron
  - (2) a stable nucleus
  - (3) an excited electron
  - (4) an unstable nucleus
- 16 \_\_\_\_\_

17. Given the nuclear equation:
- $${}^{14}_7\text{N} + X \rightarrow {}^{16}_8\text{O} + {}^2_1\text{H}$$
- What is particle  $X$ ?
- (1) an alpha particle
  - (2) a beta particle
  - (3) a deuteron
  - (4) a triton
- 17 \_\_\_\_\_

18. In the reaction  ${}^9_4\text{Be} + X \rightarrow {}^6_3\text{Li} + {}^4_2\text{He}$ , the  $X$  represents
- (1)  ${}^0_{+1}\text{e}$
  - (2)  ${}^1_1\text{H}$
  - (3)  ${}^0_{-1}\text{e}$
  - (4)  ${}^1_0\text{n}$
- 18 \_\_\_\_\_

19. Given the nuclear reaction:
- $${}^{32}_{16}\text{S} + {}^1_0\text{n} \rightarrow {}^1_1\text{H} + X$$
- What does  $X$  represent in this reaction?
- (1)  ${}^{31}_{15}\text{P}$
  - (2)  ${}^{32}_{15}\text{P}$
  - (3)  ${}^{31}_{16}\text{S}$
  - (4)  ${}^{32}_{16}\text{S}$
- 19 \_\_\_\_\_

20. Given the nuclear equation:
- $${}^{253}_{99}\text{Es} + X \rightarrow {}^1_0\text{n} + {}^{256}_{101}\text{Md}$$
- Which particle is represented by  $X$ ?
- (1)  ${}^4_2\text{He}$
  - (2)  ${}^0_{-1}\text{e}$
  - (3)  ${}^1_0\text{n}$
  - (4)  ${}^0_{+1}\text{e}$
- 20 \_\_\_\_\_

21. Given the equation:  ${}^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} + X$
- When the equation is balanced correctly, which particle is represented by  $X$ ?
- (1)  ${}^0_{-1}\text{e}$
  - (2)  ${}^1_1\text{H}$
  - (3)  ${}^2_1\text{H}$
  - (4)  ${}^1_0\text{n}$
- 21 \_\_\_\_\_

22. Which of these particles has the greatest mass?
- (1) alpha
  - (2) beta
  - (3) neutron
  - (4) positron
- 22 \_\_\_\_\_

23. Types of nuclear reactions include fission, fusion, and
- (1) single replacement
  - (2) neutralization
  - (3) oxidation-reduction
  - (4) transmutation
- 23 \_\_\_\_\_

24. Nuclear fusion differs from nuclear fission because nuclear fusion reactions
- (1) form heavier isotopes from lighter isotopes
  - (2) form lighter isotopes from heavier isotopes
  - (3) convert mass to energy
  - (4) convert energy to mass
- 24 \_\_\_\_\_

25. Energy is released during the fission of Pu-239 atoms as a result of the
- (1) formation of covalent bonds
  - (2) formation of ionic bonds
  - (3) conversion of matter to energy
  - (4) conversion of energy to matter
- 25 \_\_\_\_\_

26. Which equation is an example of artificial transmutation?

- (1)  ${}^9_4\text{Be} + {}^4_2\text{He} \rightarrow {}^{12}_6\text{C} + {}^1_0\text{n}$   
(2)  $\text{U} + 3 \text{F}_2 \rightarrow \text{UF}_6$   
(3)  $\text{Mg}(\text{OH})_2 + 2 \text{HCl} \rightarrow 2 \text{H}_2\text{O} + \text{MgCl}_2$   
(4)  $\text{Ca} + 2 \text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{H}_2$

26 \_\_\_\_\_

27. Which equation represents a fusion reaction?

- (1)  ${}^2_1\text{H} + {}^2_1\text{H} \rightarrow {}^4_2\text{He}$   
(2)  ${}^{14}_6\text{C} \rightarrow {}^0_{-1}\text{e} + {}^{14}_7\text{N}$   
(3)  ${}^{238}_{92}\text{U} + {}^4_2\text{He} \rightarrow {}^{241}_{94}\text{Pu} + {}^1_0\text{n}$   
(4)  ${}^1_0\text{n} + {}^{27}_{13}\text{Al} \rightarrow {}^{24}_{11}\text{Na} + {}^4_2\text{He}$

27 \_\_\_\_\_

28. Which list of nuclear emissions is arranged in order from the least penetrating power to the greatest penetrating power?

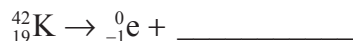
- (1) alpha particle, beta particle, gamma ray    (3) gamma ray, beta particle, alpha particle  
(2) alpha particle, gamma ray, beta particle    (4) beta particle, alpha particle, gamma ray

28 \_\_\_\_\_

29. Complete the equation below for the radioactive decay of  ${}^{137}_{55}\text{Cs}$ . Include both atomic number and mass number for each particle.



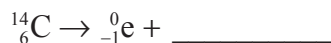
30. Complete the nuclear equation below for the decay of K-42. Your response must include the atomic number, the mass number, and the symbol of the missing particle.



31. Identify particle  $X$  in the equation  ${}^2_1\text{H} + {}^3_1\text{H} \rightarrow {}^4_2\text{He} + X + \text{energy}$ . Your response must include the symbol, the atomic number, and mass number of the particle.

\_\_\_\_\_

32. Complete the nuclear equation below for the decay of C-14. Your response must include the atomic number, the mass number, and the symbol of the missing particle.



33. Nuclear equation:  ${}^{235}_{92}\text{U} + {}^1_0\text{n} \rightarrow {}^{92}_{38}\text{Sr} + \text{_____} + 2{}^1_0\text{n} + \text{energy}$

Write an isotopic notation for the missing product in the nuclear equation.

\_\_\_\_\_

34. Which nuclear emission has no mass and no charge? \_\_\_\_\_

## Table O – Symbols Used in Nuclear Chemistry

### Answers

#### Set 1

1. 4 Choice 4 is a negative beta particle which is an ordinary electron. The mass of an electron is negligible compared to a proton or a neutron.
2. 4 In a nuclear reaction, the sum of the atomic numbers on each side must be equal and the sum of the mass numbers on each side must be equal. Particle  $X$  therefore must have a charge number of  $-1$  and a mass number of  $0$ . From Table O, this must be a beta particle. Np, element 93, is a man-made radioactive element that decays to Pu, element 94, by releasing a beta particle.
3. 1 Table O shows that a positron, also known as a positive beta particle, has the symbol  $\beta^+$ . Open to Table N and locate K-37. Under Decay Mode, it shows that this element undergoes positron emission. During positron emission, the atomic number decreases by 1 and the mass number remains the same.
4. 4 To balance the nuclear equation, particle  $X$  must have a  $+1$  charge and zero mass. Using the notation column in Table O, a positron has a  $+1$  charge and  $0$  mass. During positron emission, the atomic number decreases by 1 and the mass number remains the same.
5. 3 Table O gives the particles and their notations referred to in this question. Using Table N, find the radioisotopes given in choice 3. The Decay Mode shows that choice 3 contains an alpha emitter, a beta emitter and a positron emitter.
6. 2 Looking at Table O, the neutron has the symbol  ${}_0^1\text{n}$ , indicating it has an atomic mass of 1 and carries no charge.
7. 1 The first particle shown in Table O is the alpha particle. This particle is a helium nucleus, consisting of 2 protons and 2 neutrons. This makes this particle positive in charge. The alpha particle is the largest particle that is emitted in radioactive decay. Being the largest particle, it would have the weakest penetrating power, giving up more energy with each particle it collides with.
8. 3 In the notation column of Table O, it shows that gamma radiation has no charge or mass. A massless, neutral entity can easily pass through matter without interacting with it. This makes the gamma radiation the most penetrating of the given choices.
9. 1 In natural radioactivity, also called natural transmutation, a radioactive element will undergo a spontaneous decay process involving the nucleus. An example of this decay is radioactive Pu-239 changing to U-235 by alpha emission. Choices 2 and 3 show artificial transmutation (see explanation for answer no. 11). Choice 4 shows the fission of a Pu-239 nucleus.

10. 4 In a nuclear reaction, the sum of the atomic numbers and the sum of the mass numbers on each side must be equal. Particle  $3X$  must have a charge number of 0 and a mass number of 1 (making a total mass number of  $3(1) = 3$ ). From Table O this particle is a neutron.
11. 2 In artificial transmutation, the nucleus of a non-radioactive element is bombarded with high energy particles, such as alpha particles, protons or neutrons. The end product of artificial transmutation is the formation of new radioactive elements.
12. 4 When nuclear fission occurs, a very large amount of energy is released. Under controlled conditions, this energy can safely be harnessed, changed to electrical energy and distributed to benefit mankind.
13. 1 In any nuclear reaction, the mass of the products is less than the mass of the reactants. This difference in mass is converted into a large amount of energy according to Einstein's equation,  $E = mc^2$ .

14. a) Answer: nuclear fission

Explanation: A neutron is captured by the nucleus of a uranium atom. This causes uranium to undergo nuclear fission, producing two lighter elements, while giving off subatomic particles and energy.

b) Answer: Mass has been converted into energy.

Explanation: In any nuclear reaction, the mass of the products is less than the mass of the reactants. This difference in mass is converted into a large amount of energy according to Einstein's equation,  $E = mc^2$ .

c) Answer: Nuclear fusion *or* natural transmutation *or* radioactive decay *or* nuclear decay

Explanation: In a nuclear fusion reaction, lighter nuclei combine or unite to form a heavier nucleus. As in any nuclear reaction, the mass of the products is less than the mass of the reactants. This difference in mass has been converted into energy.

15. Answer:  ${}_{88}^{226}\text{Ra} \rightarrow {}_2^4\text{He} + {}_{86}^{222}\text{Rn}$  *or*  ${}_{88}^{226}\text{Ra} \rightarrow {}_{86}^{222}\text{Rn} + {}_2^4\alpha$

Explanation: Locate Ra-226 in Table N. It shows that this element undergoes alpha emission. Table O shows the notation of an alpha particle. The above equations show that the total atomic numbers and mass numbers are conserved.