Brominator: Instructor Guide

Title:

The Brominator

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Discipline:

Chemistry and Biochemistry

Target Audience

Introductory, science majors

Keywords

Experiment design, graph interpretation, ionic formulas, limiting reagent, stoichiometry

Length of Time/Staging

2-3 50-minute classes; staged by sequential questions

Abstract

In this problem, students: learn to predict formulas for the products of "metal + nonmetal" reactions using the periodic table as a guide; encounter the idea of limiting reagents through a graphical presentation of data; predict limiting reagents based on stoichiometric conversions; and review the relationship between formula and mass composition.

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Format of Delivery

Students work in groups of four with assigned roles; during the whole-class discussion, each group is expected to describe their response to at least one of the questions in the problem. A written summary of each group's findings is collected at the end of the problem.

Student Learning Objectives

1. To recognize elements as metals or nonmetals from their position in the periodic table
2. To recognize the reaction between a metal and a nonmetal as an electron transfer process, and to be able to explain why such occurs, in the context of element positions in the periodic table.
3. To learn the ionic charges associated with elements in Groups 1, 2, 3, 15, 16, and 17, and to understand why those charges are observed.
4. To be able to predict the formula for an ionic compound using the periodic table and the idea of electroneutrality.
5. To gain experience in interpreting data presented graphically
6. To understand the role of a limiting reagent in determining product yield
7. To identify the limiting reagent in a system and predict the yield of product based on that choice

Student Resources

Primary resource: a general chemistry textbook

Author's Teaching Notes

At the University of Delaware this problem has been used to introduce the ideas of predicting formulas for ionic compounds and of limiting reagents in a first-semester Honors general chemistry course for life sciences and engineering majors. Prior to the problem, students have encountered the following ideas/concepts: empirical mass laws and the postulates of atomic theory; atomic structure (isotopes, mass spectrometry); relative atomic mass scales and the mole; and the experimental determination of formula (mass composition, combustion analysis). General features of the periodic table (e.g., the classification of elements into metals and nonmetals) have not yet been mentioned, nor have the concepts of ionic compounds or limiting reagents yet arisen.

The first question of the problem asks students to predict the formulas for the product of the reaction between one of three metals and bromine. (Bromine is deliberately referred to as Br_2, to bypass the common error of assuming it to be "Br"; this point is brought out during the discussion later.) To do this requires that the student recognize that the metal, as such, has a tendency to lose electrons, and that the bromine, from the far right side of the periodic table, will tend to gain electrons. The relative "distance" of each element from the noble gas family can be used to predict the number of electrons that each element will gain or lose in the reaction. From those expected ionic charges, the formula for the bromides may be constructed.

The ideas involved here are likely to have been dealt with in the high school chemistry course, so this segment of the problem generally serves primarily as a memory prod, to get the students to recall something they saw a few years ago, but may not remember very precisely. Depending on the background of the students, this discussion may be expanded or truncated as seems appropriate. The follow-up exercises in question 1 are designed to give some immediate practice in applying the general ideas just discussed, and to be sure that students aren't simply writing formulas from memory, without having discussed how they may be constructed via these principles.

The second question invites the students to think for themselves about the situation posed, and to brainstorm together about what kind of information might be useful and about how they would obtain that information experimentally. In order to devise an experiment, student must first come up with a clear statement of the problem, and of the issue they're trying to resolve - tasks which are often unfamiliar and therefore challenging. In addition, since students often have little experience in planning experiments on their own, this discussion provides an opportunity to deal with some practical lab-related issues as well as theoretical concerns.

Question 3 could be easily answered through a simple subtraction of the mass of the metal from the mass of the metal bromide, if the values on the x-axis scale had been shown. Without that information, students are forced to use mole ratios from the balanced equation to determine the amount of bromine used from the mass of metal bromide produced. (This generally leads to some concern on their part as to whether one should talk about moles of Br_2 or moles of Br in this conversion, and provides a good opportunity to discuss how while atoms and mass are conserved, moles often are not.) Students also must recognize that the appropriate mass of metal bromide to use in this conversion is the maximum amount that was produced; using a point from the rising part of the curve will give the mass of bromine used in that experiment, but it will not be the "fixed mass" added to the reaction mixture. Students sometimes pick the correct mass without really knowing why, so this point should be probed.

In Question 4 students must explain why the amount of metal bromide produced stops increasing after a given amount of metal is employed. While some students quickly recognize this as an indication that no more bromine is available for reaction past that point, others don't see the connection as readily. This is an area where the students who do get the concept are often very good at explaining it to those who have more difficulty with it.

For both questions 3 and 4, some students seem to have a hard time simply with interpreting the data presented in the graph, and it takes them a while to see why the break point in the plot is different for each metal. For this reason, in the whole-class discussion students are asked what they would have to do to get identical breakpoints for each metal, leading to the idea of plotting moles instead of masses, and reinforcing how the use of moles can reveal similarities hidden by mass differences. Question 5 gives the students a chance to apply the ideas they have just discussed, and points out how there are several different way to combine the essential stoichiometric relationships involved here to get to an answer. Groups with different approaches are given the chance to present their work and reasoning to the class.

Question 6 is a straightforward application of using percent composition to find a formula, a topic dealt with earlier in the course.

Question 7, sometimes listed as a bonus question, leads into some descriptive chemistry, and brings the discussion back to the initial idea of the electron-transfer nature of these reactions. Students often have no idea about how to find this, but the chapter on halogens in most general chemistry textbooks usually includes some discussion of how bromine is isolated from sea water either by reaction with Cl_2 or via electrolysis, and a few general hints about exploring the book usually gets this rolling. This question gives the students a chance to encounter some descriptive chemistry, and at UD is used as an excuse for demonstrations of both techniques for regenerating Br_2. The difference in reactivity between Cl_2 and Br_2 provides the chance to preview some of the differences among elements in the same family, to contrast with the similarities seen through Question 1.

Assessment Strategies

How well the students understood the two main concepts developed here--predicting ionic formulas using the periodic table, and limiting reagents--were assessed on an hourly exam through questions such as the following:

Formula

An element Q has two isotopes: ${}^{x}Q$ (57.3%) and ${}^{(x+2)}Q$ (42.7%). An atom of ${}^{x}Q$ is 10.0753 times as heavy as an atom of ${}^{12}C$; an atom of ${}^{(x+2)}Q$ is 10.2420 times as heavy as an atom of ${}^{12}C$.

a. What is the average atomic mass and most likely identity of Q?
b. Based on your answer to (a), predict formulas for the products of the reaction of Q with (i) K and (ii) Ca.

Limiting reagent

Potassium chromate, K_2CrO_4, is produced from the reaction of chromite ore ($FeCr_2O_4$) with potassium carbonate and dioxygen at high temperatures:
$FeCr_2O_4(s) + K_2CO_3(s) + O_2(g) \text{ ----> } K_2CrO_4(s) + Fe_2O_3(s) + CO_2(g)$

[Mol. Wts. (g/mol): $FeCr_2O_4$, 223.84; K_2CO_3, 138.21; K_2CrO_4, 194.19; Fe_2O_3, 59.69]

In one experiment 169 g of chromite ore, 298 g of potassium carbonate, and 75.5 g of O_2 were sealed in a reaction vessel and heated, producing 194 g of K_2CrO_4.

a. Balance the equation describing this reaction.
b. Calculate the percent yield of potassium chromate.