Hypersonics STEM Curriculum

Launch Chemistry

Grade	Time	Subject Area	Key Concepts
High School	50 min	Physical Science	Chemical reactions

Lesson Overview

In this lesson, students will use chemical reactions that were part of the history of the study of rocket fuel to practice balancing equations and calculating molar mass. Students will also be asked to compare and contrast the different chemical equations and the total mass on both sides of the chemical equations.

NGSS Standards

HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

Learning Objectives

By the end of this lesson, students will be able to:

- Balance nine chemical equations used in the development of rocket fuel.
- Calculate the molar mass of different compounds used in rocket fuel research.
- Compare and contrast the chemical equations of nine different rocket fuels.
- Explain how the law of conservation of mass applies to the balanced equations.

Essential/Overarching Question

What are the chemical reactions needed to launch a rocket?

Key Vocabulary

Speed – the rate at which an object is moving. Speed is calculated by dividing the distance travelled by the time it took to travel that distance.

Speed of Sound – the rate at which sound moves through a medium. The speed of sound depends on both the density and the temperature of the medium. The speed of sound through air at 20° C (68° F) at sea level is 343 m/s (767 mph).

Mach – the ratio of the speed of an object to the speed of sound or how many times the speed of sound an object is moving. It is often followed by a number indicating the ratio; for example: Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, Mach 5 is five times the speed of sound.

Sonic – speeds equal to the speed of sound (Mach 1).

Subsonic – speeds smaller than the speed of sound (less than Mach 1).

Transonic – speeds near (Mach 0.8-1.2) the speed of sound where drag is highest (e.g. sound barrier).

Supersonic – speeds greater than the speed of sound (Mach 1 and greater).

Hypersonic – speeds greater than five times the speed of sound (Mach 5 and greater).

Fluid – a substance with no fixed shape; a liquid, gas, or plasma. A substance that flows when an external force is applied to it.

Flow – the motion of a fluid (liquid, gas, or plasma) when it experiences unbalanced forces.

Atom – the smallest unit of matter. A particle that consists of a nucleus of protons and neutrons that is surrounded by electrons.

Element – a substance that cannot be broken down into simpler substances by a chemical reaction.

Molecule – a particle made up of two or more substances that are chemically bonded together.

Compound – substances made up of two or more elements that are chemically bound together in a fixed ratio.

Atomic Number – the number of protons in the nucleus of each atom of that element. In an electronically neutral atom, it is the number of protons and electrons in the atom.

Atomic Mass – the mass of an atom of a chemical element measured in atomic mass units (amu). It is approximately equal to the number of protons and neutrons in the nucleus.

Molar Mass – the ratio between the mass of the substance (measured in kilograms or grams) and the amount of substance (measured in moles). The mass of one mole of a substance or the mass of 6.022×10^{23} units of a substance.

Law of Conservation of Mass – mass is neither created nor destroyed; it can be rearranged and changed in form. The total mass of the system must remain the same and is simply transferred from one object or type of energy to another.

Science Concepts Overview

There is a rich history of the research scientists performed in order to develop rocket fuel. This research started even before the Wright brothers had taken their first flight. The first step into the ability to develop rocket fuel occurred when scientists were able to liquefy gasses such as nitrogen, oxygen, and hydrogen, which occurred towards the end of the 1800's. Starting in the early 1900's scientists studied a wide variety of chemicals in an attempt to create a rocket propellant that would be safe enough for human travel into space.

The variety of different chemical reactions that were used in rocket fuel research offer a set of contextual examples for students to practice balancing equations. Due to the law of conservation of mass, the same number and type of atoms must be on both sides of a chemical reaction.

An important tool in studying chemical reactions is the molar mass. The molar mass is the ratio between the mass of the substance (measured in kilograms or grams) and the amount of substance (measured in moles). The molar mass is also the mass of one mole of a substance or the mass of 6.022×10^{23} units of a substance. The molar mass is calculating by adding the atomic mass of each atom in the molecule.

Materials List

- ☐ Launch Chemistry handout (one per student)
- ☐ Periodic Table of the Elements (one per student)
- ☐ Baking Soda Rocket (one kit or homemade rocket for demonstrations)
- ☐ Baking soda (for demonstrations)
- ☐ Vinegar (for demonstrations)

Lesson Preparation

Prior to the lesson, the instructor should make copies of the Material Engineering for Hypersonic Speeds handout and ensure that students have access to a copy of the periodic table. There are a couple of online, interactive periodic tables noted in the References & Resources section.

If the instructor plans to do the baking soda rocket demonstration, a large space such as a gymnasium, cafeteria, or outside space might be best for the lesson. If the demonstration is done indoors, it is encouraged that the liquid leaving the rocket is taken into account when choosing a location.

Safety

Due to the nature of this lesson, it is recommended that the class take the following safety precautions:

- Participants in the demonstration should wear eye protection.
- The flight path of the baking soda rocket should be cleared.
- Depending on the scale of the rocket being used, the launch may need to occur over a bucket or sink to catch the liquid leaving the rocket.
- Students not participating in the demonstration should be given clear instructions of where the demonstration will be taking place.

Procedure

Engage (15 minutes)

1. As a class, watch the short video of a NASA rocket booster test.
   https://www.youtube.com/shorts/6F0e3UHcQkg
2. Pose the following questions to the students:
   - What are your observations from the video?
   - What evidence do you see in the video of a chemical reaction?
   - What can you tell about the chemical reaction based on your observations?
3. As a class, watch the video of chemist Andrea Sella explains the history of rocket fuel and does a demonstration.
   https://www.youtube.com/watch?v=IcjYdEW_HLQ
4. As a class, or individually, read the Introduction to the Launch Chemistry handout.

Explore (20 minutes)

5. On their Launch Chemistry handout, students will be given a series of nine chemical equations used in the development of rocket fuel or used in model rockets. For each equation, students will be asked to (a) fill in the blanks to balance the equation, (b) calculate the molar mass for each compound in the equation, and (c) calculate the total mass on each side of the chemical reaction.
   - $4HNO_3 \rightarrow 2N_2O_4 + 2H_2O + O_2$
   - $ClF_3 + 3HNF_2 \rightarrow 3HF + Cl(NF_2)_3$
   - $ClF_5 + N_2F_4 \rightarrow ClF_3 + 2NF_3$
   - $2B_5H_9 + 5N_2H_4 \rightarrow 10BN + 19H_2$
   - $2HBr + 2HNO_3 \rightarrow 2NO_2 + 2H_2O + Br_2$
   - $2C_{12}H_{26} + 37O_2 \rightarrow 24CO_2 + 26H_2O$
   - $K_2B_{10}H_{10} + 2[BH_2(NH_3)_2]Cl \rightarrow [BH_2(NH_3)_2]_2B_{10}H_{10} + 2KCl$
   - $2KNO_3 + S + 3C \rightarrow K_2S + N_2 + 3CO_2$
   - $NaHCO_3 + CH_3COOH \rightarrow CO_2 + H_2O + CH_3COONa$
6. While students are working with the chemical reactions, instructors can bring groups of students up to show a demonstration of the baking soda and vinegar reaction (#9) using a baking soda rocket. Instructors could either use a baking soda rocket kit such as the Liquifly Fizzrocket and the Kidzlabs Cosmic Rocket or they can make a homemade one (examples in the References & Resources section).

Explain & Elaborate (5 minutes)

7. Students will be asked to compare and contrast the chemical reactions by answering the following questions on the Launch Chemistry handout:
   - What are similarities you see across the different chemical reactions?
   - What are differences you see across the different chemical reactions?
   - What do you notice about the total mass on the two sides of the chemical equations? What concept or law supports your claim?
   - Current research into fuels for hypersonic vehicles is looking at solid fuels. What may be the benefits and drawbacks of using solids rather than liquids?

Evaluate (10 minutes)

8. Divide the class into nine groups and assign each group one chemical reaction. Each group should share their answers and explain their reasoning.

STEM Career Connections

- Hypersonics engineer
- Aerospace engineer
- Chemical engineer
- Testing engineer
- Materials engineer
- Chemist
- Astronaut
- Pilot
- Atmospheric scientist

Extensions

Students tend to be familiar with videos of the explosive reaction caused by dropping Mentos and into Coke. Students could use resources on the internet to *explore* and *explain* the difference in the chemistry behind the Mentos and Coke reaction and the vinegar and baking soda reaction (number 9 on the Launch Chemistry handout).

References & Resources

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Launch Chemistry

✈ Introduction

Before the Wright brothers had first taken flight, scientists were working to send rockets to space. The ability to liquefy gasses such as nitrogen, oxygen, and hydrogen towards the end of the 1800's was the tipping point for the development of rocket fuels. Starting in the early 1900's, scientists studied a wide variety of chemicals in an attempt to create a rocket propellant that would be safe, powerful, and light enough for human travel into space. To launch into space, rockets had to reach ***supersonic*** (faster than the speed of sound) and ***hypersonic*** (five times faster than the speed of sound) speeds. The quest for rocket propellant to push us higher and faster was a decade's long endeavor.

✈ Analysis

Below are chemical reactions that were studied at some point in the history of rocket fuel science, some more successfully than others. For each equation, (a) fill in the blanks to balance the equation, (b) calculate the molar mass for each compound in the equation, and (c) calculate the total mass on each side of the chemical reaction.

1. _____HNO_3 → _____N_2O_4 + _____H_2O + _____O_2

2. _____ClF_3 + ____HNF_2 → _____HF + _____$Cl(NF_2)_3$

3. _____ClF_5 + _____N_2F_4 → _____ClF_3 + _____NF_3

4. _____B_5H_9 + _____N_2H_4 → _____BN + _____H_2

5. _____HBr + _____HNO_3 → _____NO_2 + _____H_2O + _____Br_2

Clark, J. D. (2022). *Ignition! An informal history of liquid rocket propellants*. Rutgers University Press Classics

6. ______$C_{12}H_{26}$ + ______O_2 → ______ CO_2 + ______ H_2O

7. ______$K_2B_{10}H_{10}$ + ______$[BH_2(NH_3)_2]Cl$ → ______$[BH_2(NH_3)_2]_2B_{10}H_{10}$ + ______KCl

Similar chemical reactions occur in model rockets at a smaller, safer scale as shown below. For each equation, (a) fill in the blanks to balance the equation, (b) calculate the molar mass for each compound in the equation, and (c) calculate the total mass on each side of the chemical reaction.

8. ______KNO_3 + ______S + ______C → ______K_2S + ______N_2 + ______CO_2

9. ______$NaHCO_3$ + ______CH_3COOH → ______CO_2 + ______H_2O + ______CH_3COONa

What are similarities you see across the different chemical reactions?

What are differences you see across the different chemical reactions?

What do you notice about the total mass on the two sides of the chemical equations? What concept or law supports your claim?

Current research into fuels for hypersonic vehicles is looking at solid fuels. What may be the benefits and drawbacks of using solids rather than liquids?

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