Science Unit: *Space*

Lesson 10: *Rockets: Exploring the Solar System*

Summary:	In part one of this two-part lesson, students make and launch **Alka-seltzer rockets** and learn about the chemical reaction causing them to move. They also learn about the chemical reactions that fuel real rockets. In part two, students use steel balls, magnets and a ramp to model the "**gravity assist**" technique scientists use to direct rockets in space.
School Year:	2014/2015
Developed for:	Lord Strathcona Elementary School, Vancouver School District
Developed by:	Ingrid Sulston (scientist); Reid McInnes and Phyllis Daly (teachers)
Grade level:	Presented to grade 6/7; appropriate for grades 1 – 7 with age appropriate modifications
Duration of lesson:	1 hour and 20 minutes

Objectives

1. Manipulate molecule models to figure out the chemistry that underlies a film canister rocket propelled by Alka-Seltzer tablets.
2. Manipulate molecule models to figure out the chemistry that drives a real rocket into space.
3. Experiment with magnets and steel balls to model how "gravity assist" can direct spacecraft far across our solar system.

Background Information

Rockets, always popular with students, are an opportunity to visit Newton's Third Law of Motion: for every action there is an equal and opposite reaction. By setting off their own mini rockets, students can experience the power involved in combatting gravity on a small scale, as a segue to watching and hearing a video of a real rocket take off and escape Earth's gravity. By modeling the chemistry occurring within the respective combustion chambers, students understand the relatively simple chemistry and physics that underlies rocket propulsion.

Rocket fuels can only take us so far: much of the weight of a rocket is its fuel, and if fuel was needed to take a rocket across the Solar System, the weight of a rocket would be impractical for take off. So another method of travel called "gravity assist" (also called "gravitational slingshot" or "swing by") employs the gravitational pull of the sun and other planets to direct spacecraft (once released from the rockets that gave them escape velocity) across and beyond the solar system.

In this lesson, students model gravity assist with magnets and a steel ball. While there is a real risk that students become confused about whether gravity or magnetism is used in gravity assist, the model is an effective way to experiment with variables of the speed of a spacecraft and the size of planets it swings by.

Vocabulary

molecules and atoms:	Tiny particles that make up everything around us. Molecules and atoms are too small to see individually, but with enough of them together they make objects we can see. Two or more atoms are bonded together to make a molecule.
chemical reaction	A chemical reaction occurs when molecules break apart and their atoms rearrange to make new molecules. Sometimes the new molecules are a different state of matter.
gravity assist, gravitational slingshot, fly by	The use of the gravity of the sun and planets to speed up, slow down, and redirect the path of a spacecraft. The change in speed depends on whether the spacecraft flies with the movement of the planet or against it.

Materials for Activity (1) Alka-seltzer Rocket and Molecule Modeling
(Ideally one of the following for each student. If not, enough for each student pair.)

- film canister
- Alka-seltzer tablet
- water in a dispenser
- outdoor field to shoot off rockets
- molecule model pieces: 3 red oxygen atoms, 2 white hydrogen atoms, 1 black carbon atom, 6 bonds

Materials for Activity (2) Real Rocket Molecule Modeling

(One of the following for each student, or student pair)

- molecule model pieces: 2 red oxygen atoms, 4 white hydrogen atoms, 4 bonds

Materials for Activity (3) Gravity Assist Activity

(One of the following for each group of three students)

- tray
- Plexiglas sheet that fits in tray
- 4 blocks to support Plexiglas
- three button magnets
- masking tape, 10cm
- ramp cut from a piece of wide straw
- plasticine
- steel ball
- dry erase pen
- protractor

In the Classroom

Introductory Discussion

1. Understanding the planets beyond Earth requires using rockets to send spacecraft to explore them.
2. We will look at how rockets work and how we use other ways to explore the outer reaches of the solar system.

Processes of science that the students will focus on: accurate measuring, collecting data, classifying and comparing data, graphing data, interpreting graphs, designing experiments, inferring, concluding.

Safety guidelines: The Alka-Seltzer rockets take off with some force. Students need to stay well back after they are set to explode.

Science Activities

(1) Activity: Rocket Powered by Alka-Seltzer

Purpose of Activity: To observe action and reaction in a mini-rocket, and to see that it is powered by a chemical reaction.

Methods and Instructions:
Set-up prior to experiment: none

Students will work individually, or in pairs if materials limit.

1. Instruct students on how to set off rocket: First, fill the film canister with water, hold an Alka-Seltzer tablet in the lid, and find a space to set it off away from others. Then in quick succession, tip the Alka-Seltzer tablet into the water, snap the lid on tight, set the canister lid down in an open area, and stand back.
2. Some of the canisters will be projected up quickly, some will take a full minute, and some may disappointingly fizzle with no take off. Make sure that every student sees a take off. Half-used tablets from spent rockets can be combined to set off another.
3. Ask students what is making the film canister rockets take off. With their ideas, lead a discussion on how a chemical reaction is happening inside the canister.
   - The fizzling remains of an Alka-Seltzer tablet can be seen in exploded canisters. This chemical reaction makes a gas, whose pressure builds up inside the canister.
   - Eventually the pressure blows the cap off and the gas shoots out of the bottom of the inverted canister.
   - The downwards action of this gas causes an equal and opposite upwards reaction on the canister, which propels the canister upwards. (Newton's Third Law of Motion: for every action there is an equal and opposite reaction).

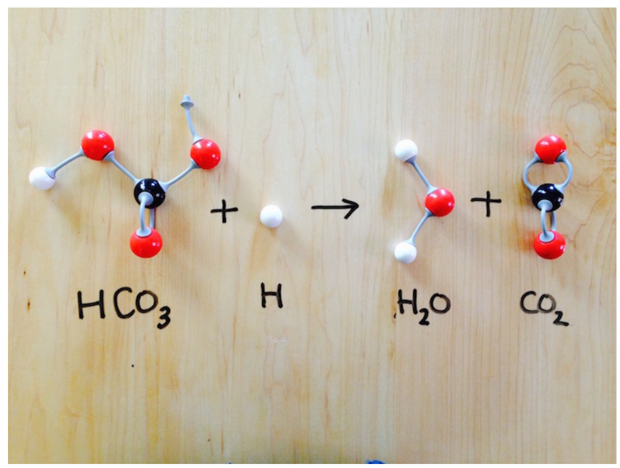
(2) Activity: Chemistry of the Alka-Seltzer Rocket

Purpose of Activity: To figure out the chemical reaction that drives the Alka-seltzer rocket

Methods and Instructions:
Set-up prior to experiment: assemble the Alka-Seltzer molecule, HCO_3 (called bicarbonate, though students do not need to know the name of this molecule).

Students will work individually, or in pairs if materials limit

1. Give each student an HCO_3 molecule and an H atom (made up of the molecule model parts listed).
2. Tell the students that these are the two molecules in Alka-Seltzer tablets that give rise to the chemical reaction that powers the rocket. When they added the water, these two molecules are able to mix and chemically react. The chemical reaction rearranges the atoms into two new molecules.
3. Ask students to figure out what the two new molecules are. Give them the hint that one of them is water, H_2O. (They might already know the chemical formula for water.) Tell them that they will use up all their atoms and bonds and fill all the holes in the atoms.
4. Students will first make an H_2O molecule, then from the remaining pieces, gradually arrive at making a CO_2 molecule, with two double bonds. They may need reminding to fill all the holes.
5. Ask what CO_2 is (a gas). Ask what happens when a lot of gas is made in the enclosed space of the film canister (pressure builds up), so the gas eventually shoots out of the bottom and propels the rocket upwards.



(3) Activity: Chemistry of Real Rockets

Purpose of Activity: To figure out a chemical reaction that drives real rockets.

Methods and Instructions:

Set-up prior to experiment (or ask students to do this from the atoms and bonds they already have plus two more H atoms that you give them): from the molecule pieces, assemble two H_2 molecules and one O_2 molecule.

Students will work individually, or in pairs if materials limit

1. Show students a video of real rocket, to highlight the intensity and power of a real rocket. Tell students that as the fuel is burned, the rocket gets lighter and acceleration increases further.
2. Tell students that real rockets work in essentially the same way as their Alka-Seltzer rocket: in the combustion chamber, a lot of gas is made by a chemical reaction, which is forced out of a nozzle at the bottom of the rocket. This action produces an equal and opposite reaction that projects the rocket upwards. (Newton's Third Law of Motion.)

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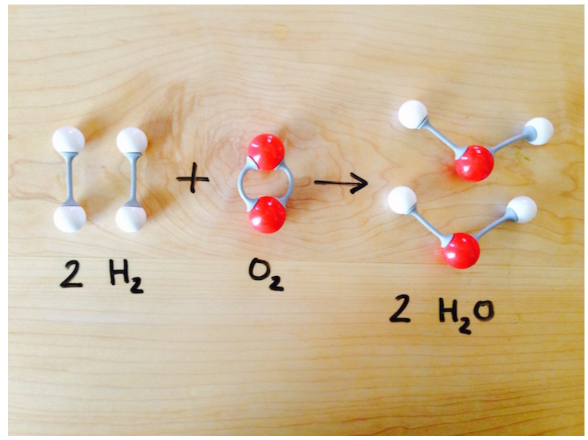
3. Real rockets use various propellants. The most efficient mixture is liquid oxygen combined with liquid hydrogen (called LOX/LH2), which chemically react in the combustion chamber to make a gas.
4. Students are asked to identify their their model oxygen molecule (O_2) and two hydrogen molecules (H_2). In this room, these molecules are gas, but in rockets they are kept at very low temperatures so they are liquids.
5. Ask students to recombine the atoms in their molecules to find out what gas is made in the combustion chamber of rockets. Tell them that when they make the new gas molecules they will be using up all the atoms, all the bonds and filing all the holes. Give them a hint that they will make two new identical molecules.



6. Students should gradually figure out that the new molecules are two H_2O molecules, which once you say the chemical formula, they may realize is water.
7. It is so hot in the combustion chamber that water is a gas. The ejection of H_2O gas through the nozzles in the bottom of the rocket propels the rocket upwards.

(4) Experiment: Gravity Assist Model

Purpose of Experiment: To model how spacecraft are directed by employing the gravity of planets.

Methods and Instructions:

(This activity is adapted from Refs. 1 and 2)

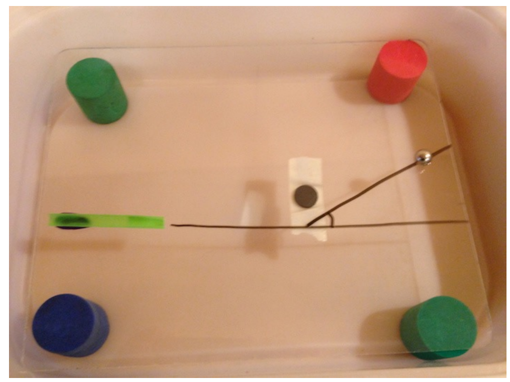
Set-up prior to experiment: Collect sets of materials in each tray. Younger students may need the activity set up for them (see point 3 below).

Students will work in groups of two or three.

1. Introduce gravity assist and the activity:
    - We have used rockets to send probes to many parts of the solar system, and beyond (Show image of current position of probes (Ref. 3).
    - Once a spacecraft has escaped Earth's gravity (by the rocket it is carried on), the gravitational pull of the sun and other planets can be used to direct the spacecraft through the solar system, with minimal further fuel usage.
    - As the spacecraft flies by planets, their gravitational pull, as well as the gravity of the sun, can be used to change the speed and direction of a spacecraft.
    - This is called "gravity assist", "gravitational slingshot", or "swing-by", and has been used to send probes to the outer reaches of, and beyond, the solar system.

2. Show students the set up for the gravity assist model: They will roll a steel ball (a "spacecraft") down a ramp onto a Plexiglas sheet, which has a magnet (the "gravity" of a planet) in its path.

3. Assist older students in setting up their own model of gravity assist:
    - Tape the magnet about two thirds of the way across the Plexiglas sheet.
    - Turn the Plexiglas over so the magnet is underneath, and place the Plexiglas on the four supporting blocks inside the tray.
    - Use the modeling clay to secure the ramp to the edge of the top side of the Plexiglas sheet, so that ball rolled from the top of the ramp is directed towards the magnet.
    - Adjust the positioning of the ramp, so that when the ball is released from the top of the ramp, it is reproducibly deflected a small amount around the far side of the magnet.



4. Show students how to measure the angle of deflection:
    - Using the dry erase pen, draw a straight line on the Plexiglas sheet following the initial path of the ball, from the ramp and continuing on in a straight line off the edge of the Plexiglas.
    - Roll the ball from the top of the ramp, watch its path as it is deflected by the magnet, then mark where it falls off the edge of the Plexiglas.
    - Draw a straight line from this mark, back to where the ball's path changes direction at the magnet.
    - Measure the angle between the straight path, and the angled path.
5. Show students the worksheet (following this lesson), and where they will record the angle of deflection.
6. Explain that as the angle varies a little each time, we need to take several readings to make sure that the data we get is a true representation of the results.
7. Tell students that once they have collected data with the ball released from the top of the ramp (the "control"), then they will change one variable at a time, as listed below, to see how it affects the angle of deflection. In each case they will take several readings, as indicated on the worksheet.

8. Experimental Treatments: The speed of the spacecraft and the gravity of the planet will be varied.

Control treatment	"Spacecraft" released from the top of the ramp. "Gravity" of planet from one magnet.
Test treatment 1	"Spacecraft" released from middle of the ramp: SPACECRAFT SPEED REDUCED. "Gravity" of planet from one magnet, as in control.
Test treatment 2	"Spacecraft" released from the top of the ramp, as in control. "Gravity" of planet from several magnets (stacked underneath the first magnet): PLANET'S GRAVITY INCREASED.

9. Class data should be collected and graphed. Each group can either submit all their data, or an average of each treatment. Although there will be much variability in the data for this activity, decreasing the speed of the spacecraft, by releasing at a lower position on the ramp, should on average produce greater angles of deflection. Increasing the gravity of the planet, by adding more magnets, will on average produce greater angles of deflection.
10. Free experimentation: Once students have collected some data by changing one variable at a time, students will enjoy taping magnets at several positions on the Plexiglas sheet to try and redirect the ball more than once. Real spacecraft often use more than one planet's gravity to alter its path.

Closure Discussion

Show students trajectories of real spacecraft that have used gravity assist:

1. *Ref. 4:* Voyager 1 used gravitational assist from Jupiter and Saturn and in August 2014 entered interstellar space. Voyager 2 swung by Jupiter and Saturn and then also Uranus and Neptune and is currently in the outermost layer of the heliosphere, soon to enter interstellar space.
2. *Ref. 5*: Cassini is orbiting Saturn and sending back some amazing images, having arrived there with gravity assist from Venus, Earth and Jupiter.

References

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2. <https://www.teachengineering.org/view_activity.php?url=collection/cub_/activities/cub_solar/cub_solar_lesson07_activity1.xml> Gravity assist activity. TeachEngineering, a database for teachers funded by NSF. Accessed May 14, 2015.
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