



Level B Investigations

B-1 The Air Rocket

How does the air rocket work?

This introductory Investigation is designed to provide students with the skills they will need to complete the subsequent Investigations. As the students familiarize themselves with the air rocket, they will learn about the motion of the rocket and how to measure its speed. They will gain experience in using the timer, calculating speed, and converting angular distance to linear distance.

B-2 Motion of the Rocket

What is the motion of the rocket like after it is launched?

According to Newton's first law of motion, once launched, a rocket's motion could continue at constant speed forever if there were no other forces present. In the real world, the presence of 'other forces' changes the motion in interesting ways. By investigating the motion, we learn much about the forces that are acting. What is the air rocket's motion like between launch and the catcher? Students explore this question in the Investigation by mapping the speed of the air rocket during its orbit.

B-3 Pressure and Speed

How does pressure affect the speed of the air rocket?

In this Investigation, students will measure the speed of the air rocket as a function of initial rocket pressure. At the beginning of the Investigation, pressure is defined and discussed. Students discover how pressure affects the motion of the air rocket by designing their own experiment.

B-4 The Rocket and Newton's Laws of Motion

How does the mass of the air rocket affect its speed?

In this Investigation, students design an experiment that uses the air rocket to see how mass influences acceleration. In the process, students prove Newton's second law of motion that acceleration is equal to force divided by mass. Because the air rocket also demonstrates Newton's first and third laws of motion, the Investigation provides students with an excellent review of Newton's laws of motion.

B-5 The Acceleration of a Rocket

How quickly does a rocket accelerate?

The rocket has a very high acceleration for a very short distance. In this Investigation, students develop a technique for indirect measurement of the rocket's acceleration. Using what they know about speed and acceleration, students first derive an approximate equation for acceleration as a function of only time and distance. They then make experimental measurements of time and distance and use their equation to estimate the acceleration of the rocket.

Level C Investigations

C-1 The Air Rocket

How does the air rocket work?

This Investigation provides students with basic skills needed to complete subsequent Investigations. As the students familiarize themselves with the air rocket, they will learn about the motion of the rocket and how to measure its speed. They will gain experience in using the timer, calculating speed, and converting angular distance to linear distance. The assessment questions for this C-level version of the introductory Investigation are more challenging than those for the B-level version.

C-2 Motion of the Air Rocket

What is the motion of the air rocket like after it is launched?

According to Newton's first law of motion, once launched, the air rocket's motion could continue at constant speed forever. However, friction acts to slow it down, and the catcher stops it at 330 degrees! What is the air rocket's motion like between launch and the catcher? Students explore this question in the Investigation by mapping the speed of the air rocket during its orbit.

C-3 Acceleration and G-forces

What are the forces on the air rocket?

In this Investigation, students will derive an approximate equation that will allow them to determine the rocket's acceleration within a short distance from the launch tower. The Investigation provides students with experience in performing experiments. If students are practiced in using the air rocket, they will be able to work independently and, with trial and error, develop experiments that further their understanding of some very interesting physics, including high accelerations exceeding 500 m/sec^2 .

C-4 Energy and Power

How does pressure affect the speed of the rocket?

In this Investigation, students apply the concepts of energy, energy conservation, and power to the motion of the rocket. Pressure is shown to be equivalent to energy density, and the pressure times the volume of the bottle is the potential energy available for launching the rocket. The concept of efficiency is explored. Students use the measured efficiency of the rocket to predict the performance of the air rocket. Finally, students calculate and discuss the power of the rocket.

C-5 Conservation of Momentum

How fast is the air leaving the rocket?

In this Investigation, students apply the law of conservation of momentum to the rocket. A short discussion shows momentum conservation to be a direct consequence of Newton's third laws. Students use conservation of momentum to calculate the speed of the air jet that leaves the rocket. They predict the effect of adding mass by applying momentum arguments. If the experiment is done correctly, students find (and must explain) an apparent violation of the law of conservation of energy.

C-6 Rotational Motion

How do we account for the fact that the orbit is circular?

In this Investigation, students will address the differences between linear and rotational motion and use the equations for rotational motion to analyze the kinetic energy of the rocket. Students use the concept of conservation of energy to indirectly measure the moment of inertia of the rocket.



Question: How does the mass of the air rocket affect its speed?

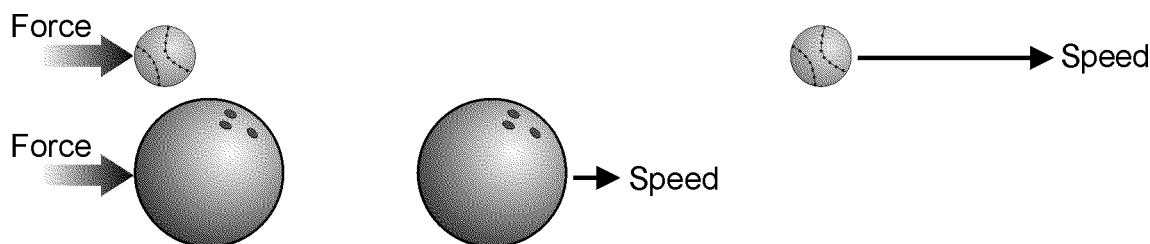
In this Investigation, you will:

1. Test whether the mass of the air rocket affects its speed.
2. Learn how Newton's three laws of motion apply to a rocket.

Applying a force makes an object move. Since Aristotle's time, people have struggled to understand how and why objects move. The rocket provides a tool for seeing how mass resists acceleration, a property often called **inertia**. Sir Isaac Newton was the first to put all the pieces together in the *Principia* where the three laws of motion were published for the first time. All three laws are important for understanding rocket motion, as you will see in this Investigation.

1

Making a hypothesis



Imagine throwing a baseball and then throwing a bowling ball. The bowling ball has a much greater mass than the baseball. If you apply the same force to each, how will their speeds compare? The real experiment would be difficult to do because there are variables that are hard to control. For example, it would be difficult for you to apply exactly the same force the same way to each ball. The rocket is a better experiment to test the relationship between mass and speed because you can precisely control the applied force by varying the pressure.

Newton's first law states that the rocket should stay at rest or continue at constant speed unless acted on by a net force.

The second law says that the acceleration of the rocket should be equal to the ratio of the force acting on the rocket divided by the mass of the rocket.

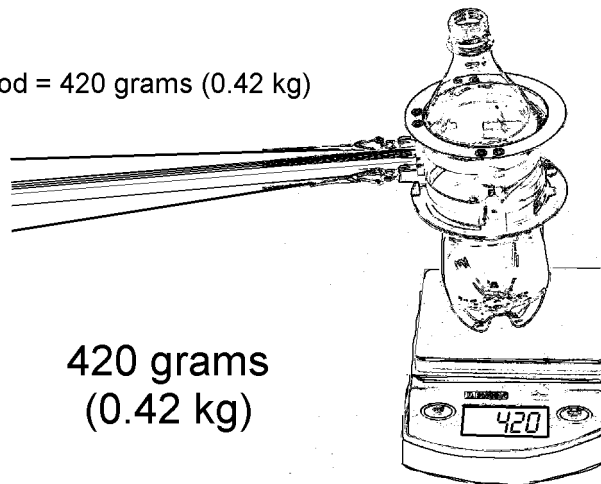
Force causes acceleration, which results in the increase in speed of the rocket. The speed of the rocket increases from zero (when it starts) to the speed you measure as the rocket goes through a photogate.

$$\begin{array}{ccccc}
 \text{Force} & \longrightarrow & \text{Acceleration} & \longrightarrow & \text{Speed} \\
 F & & a = \frac{F}{m} & & v = ?
 \end{array}$$

The third law states that for every force acting on the rocket there will be an equal and opposite reaction force acting on something else.

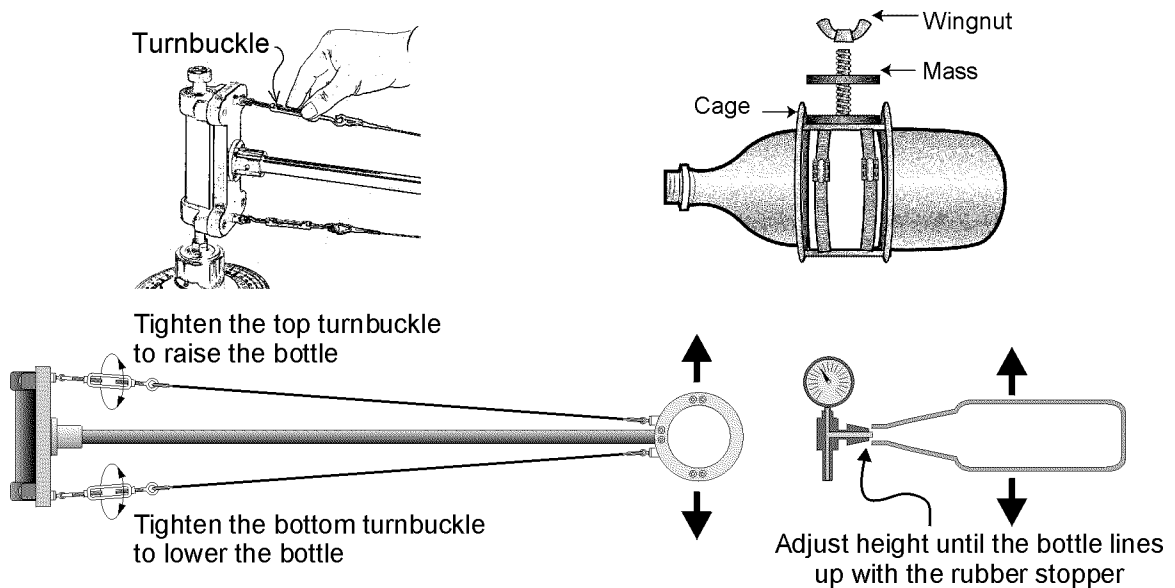
Write a hypothesis that answers the question at the start of the Investigation. Your answer should include at least one reason why you think your hypothesis may be the correct one.

Bottle + 1/2 rod = 420 grams (0.42 kg)



420 grams
(0.42 kg)

1. The mass of the rocket, including 1/2 the rod is about 420 grams. Part of the rod needs to be included because it moves with the rocket. You should NOT disassemble the rocket and try to make the measurement yourself.
2. Set a single photogate to measure the speed of the rocket where it has reached the end of its acceleration (after the end of the boost phase).
3. Use a balance to measure the mass of one steel weight.



ALWAYS tighten one side and loosen the other to maintain balanced tension in the cables.

4. You can add mass to the air rocket by adding steel weights to the top of the rocket. When adding weights, you need to adjust the turnbuckles on top and bottom so the rocket nozzle is centered on the rubber cork on the launcher. **ALWAYS** tighten and loosen the turnbuckles together. If you tighten the top one (to raise the rocket) loosen the bottom one a corresponding amount.
5. Calculate the rocket mass by adding the mass of the added weights to the starting mass of the rocket without any added weights (from step 1).




3 Design your experiment

 **It is important that the weights be firmly attached to the rocket!**

By answering the questions below, you will come up with the design of your experiment.

- a. Fill in the blanks of this statement: In the experiment, I am trying to see how the air rocket's _____ changes as _____ changes. The variable, _____, will be changed while other variables are kept constant.
- b. What is the independent variable in your experiment? What is the dependent variable?
- c. Use Table 1 to record the name and value of important variables that will remain constant throughout the experiment.
- d. Based on your work in parts 1 and 2 and your answer to questions 4(a) - (c), write a paragraph that describes the experiment you will perform to answer the Investigation question. You may want to perform more than one trial for each set of conditions.

 **Be very careful and pay attention when working near the air rocket! Make sure everyone is out of the way before triggering the air rocket!**

4 Collecting your data

Table 1: Variables kept constant

Variable	Value (units)

Table 2: Air rocket speed vs. mass data

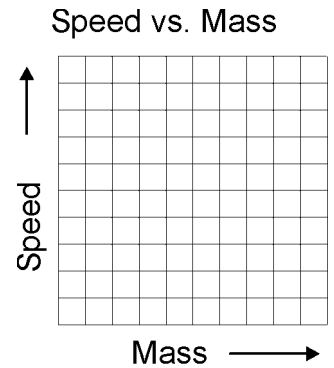
Pressure (psi)	Mass (kg)	Time Through Photogate A (t_A , sec)	Speed at A (v_A , m/sec)



5

Graphing and analyzing the results

- Make a graph showing the relationship between speed and mass. The independent variable, mass, is on the x -axis, and the dependent variable, speed, is on the y -axis. When you have plotted your data, answer the questions below.
- Since the air rocket does not have a motor, what keeps it going around in its orbit?
- Describe the shape of the plot of your data. Are the data points linear, an upward curve, or a downward curve?
- Write a few sentences that describe the relationship between the mass of the air rocket and its speed. Include answers to these questions: Does your data suggest that the speed of the rocket is independent of the mass? Does the speed decrease or increase with added mass?
- If the mass of the rocket were doubled, what would happen to the speed? Your answer should say numerically how much you expect the speed to change, based on your experimental observations. For example, you might say that doubling the mass reduces the speed by $1/4$. It is not enough to just say you expect the speed to go down as the mass increases.
- Write a short paragraph that explains whether or not the results of the experiment provide evidence of Newton's second law of motion.





Question: How does the mass of the air rocket affect its speed?

1 Make a hypothesis

- a. Write a hypothesis that answers the question at the start of the investigation. Your answer should include at least one reason why you think your hypothesis may be the correct one.

2 Setting up the experiment

- 1. Mass of rocket with no weights (kg). _____
- 2. Mass of one steel weight (kg). _____

3 Design your experiment



It is important that the weights be firmly attached to the rocket!

By answering the questions below, you will come up with the design of your experiment.

- a. Fill in the blanks of this statement: In the experiment, I am trying to see how the air rocket's _____ changes as _____ changes. The variable, _____, will be changed while other variables are kept constant.
- b. What is the independent variable in your experiment? What is the dependent variable?

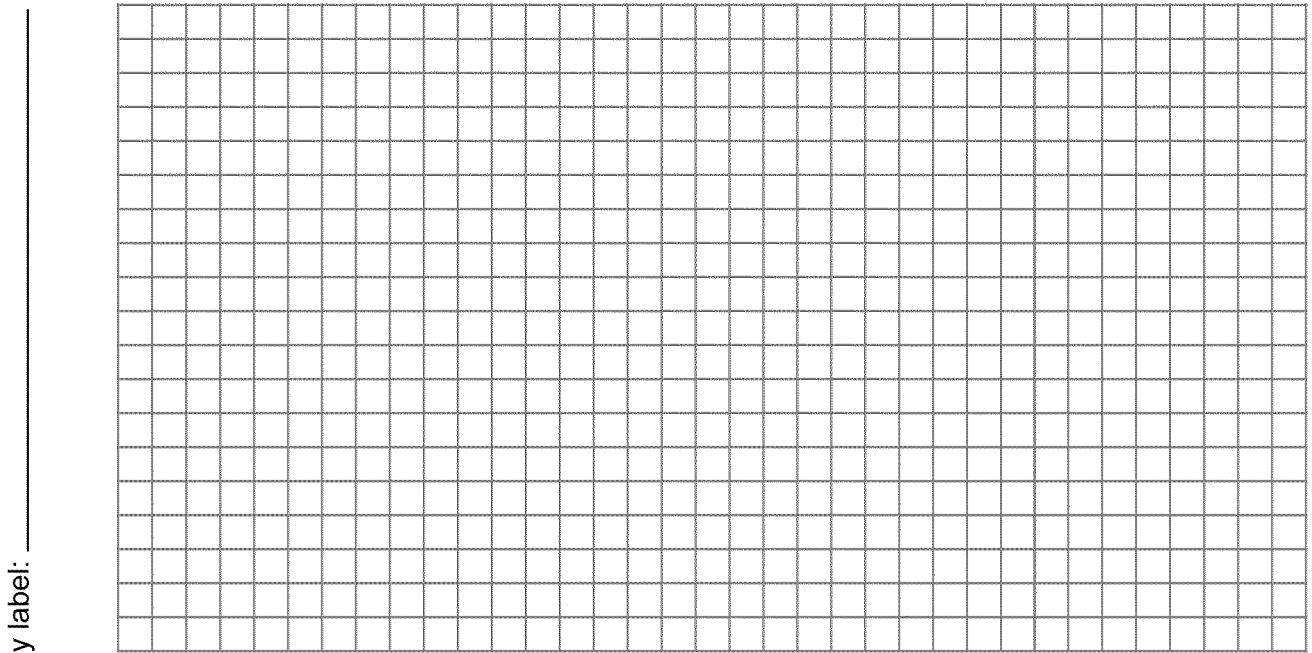
- c. Use table 1 to record the name and value of important variables that will remain constant throughout the experiment.
- d. Based on your work in parts 3 and 4 and your answer to questions 4(a) - (e), write a paragraph that describes the experiment you will perform to answer the Investigation question.



5 Graphing and analyzing the results

- a. Make a graph showing the relationship between speed and mass. The independent variable, mass, is on the horizontal axis, and the dependent variable, speed, is on the vertical axis. When you have plotted your data, answer the questions below.

Title: _____



- b. Since the air rocket does not have a motor, what keeps it going around in its orbit?

- c. Describe the shape of the graph of your data. Are the data points linear, an upward curve, or a downward curve?

- d. Write a few sentences that describe the relationship between the mass of the air rocket and its speed. Include answers to these questions: Does your data suggest that the speed of the rocket is independent of the mass? Does the speed decrease or increase with added mass?

Questions

1. Write an explanation for why changing the mass of an object affects the speed of an object.

2. In your own words, explain Newton's second law of motion..

3. How can you change the force applied to the air rocket.

4. A clever mechanic puts the engine from a large, massive car in a small, light car. Use one of Newton's laws to explain how you would expect the speed and acceleration of the small car to compare to the larger car with the same engine.

5. Suppose you could fill the rocket with Argon, a heavier gas than air. Given the same initial pressure and volume, which rocket would go faster, the rocket filled with argon or the one filled with lighter air? Give at least one physical reason to justify your choice. This is a difficult question to answer completely. Pick one physical property and think about how a heavier gas affects that property and therefore the motion of the rocket.



Extra space for notes:

Curriculum Resource Guide: Air Rocket

Credits

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