SAM Teachers Guide
Newton’s Laws at the Atomic Scale

Overview
Students explore how Newton’s three laws apply to the world of atoms and molecules. Observations start with the originally contradictory observation of Brownian motion. Then, each law is addressed at the atomic level. Examples of the laws in real-world applications are given to help students make sense of how these laws are always at work.

Learning Objectives
Students will be able to:
• Describe how Newton’s laws are relevant and in action at the atomic level.
• Observe how Brownian motion seems to contradict Newton’s first law and deduce how interactions of individual atoms can approximate Brownian motion.
• Use models to experimentally derive Newton’s second law (F=ma) and determine why some atoms move faster than others when equal forces are applied.
• Explain how attraction between atoms (either neutral or oppositely charged) relates to Newton’s third law.
• Analyze a real-world example showing Newton’s third law.

Possible Student Pre/Misconceptions
• Only objects in motion exert forces (such as a person walking), but objects that are stationary do not (such as a table).
• Newton’s laws exist for forces that are visible, but not at the atomic level.
• According to Newton’s first law, an object in motion will stay in motion, but only if a continuous force is applied.
• An object cannot be in motion if the forces acting on it “cancel out.”

Models to Highlight and Possible Discussion Questions
After completion of Part 1 of the activity:
Models to Highlight:
• Page 1 – Riding an Atom
  o Have students share what they observed as they rode the single Argon atom (the first run) and how that was different than if they were on an atom in a larger molecule. What conclusions can they draw about the motion and interactions of atoms that make up our atmosphere?
Page 3 – Model of a Single Atom
  o Highlight the ways in which Newton’s laws are apparent in this model, particularly the first and third laws.

Possible Discussion Questions:
• Many times things we cannot see affect the world around us. This is true regarding the motion of atoms. Can you think of other examples (e.g., black holes)? What surprised you about the motion of atoms or the atomic world?
• Does a single atom’s motion obey Newton’s laws? Have students share their observations and contrast them to the discussion of Brownian motion on page 2.
• Have students start to hypothesize how both Brownian motion and Newton’s laws can be accurate.

After completion of Part 2 of the activity:
Models to Highlight:
• Page 5 – Newton’s Second Law and Mass Spectrometry Model
  o When the same force is exerted on atoms, the acceleration is dependent on the mass of the atom, according to Newton’s second law: \( F=ma \).
• Page 6 – Newton’s Third Law and Attraction Between Atoms
  o Discuss the forces observed for atoms of the same mass versus atoms of different masses.
  o Link to other SAM activities: Electrostatics. Use this opportunity to review the attraction and repulsion between atoms. In addition, emphasize the importance of distance between atoms in this model.
• Page 7 – Newton’s Third Law and the Balloon Model
  o Use the popping of the balloon to discuss Newton’s third law: for every force, there is an equal and opposite force.

Possible Discussion Questions:
• What are some other ways Newton’s laws are at work around us in ways we can and cannot see?
• Does the mass of the atoms colliding affect the force experienced? Or, are equal and opposite forces observed when atoms collide?
• When atoms collide, is their acceleration in opposite directions the same if their masses are different? Why or why not?
• Demonstration/Laboratory Ideas for Newton’s Third Law: Balloon races that tie into the model on page 7.
Connections to Other SAM Activities

The concepts presented in this activity are so fundamental that no lessons truly support this activity. The concepts covered here underlie the basic nature of atomic motion and support all SAM activities.

Many lessons are directly supported by the information presented in Newton’s Laws at the Atomic Level. First, Electrostatics can be better understood when exploring the attractive and repulsive forces caused by charged particles. In Atoms and Energy students learn about conversions between kinetic and potential energy when atoms collide and how the energy is transferred. Newton’s Laws also supports Gas Laws. The chaotic nature of gases is a result of the fact that gases are in constant motion in a straight line (Newton’s first law) until they are deflected. This helps to explain how gases behave and how pressure builds up in gases as molecules collide within their containers. Finally, Newton’s first law is also in action in Diffusion, Osmosis, and Active Transport. Diffusion, or the natural tendency of particles to spread out, is a result of molecules being in constant motion.
Activity Answer Guide

Page 1:

1. Give one example of how Newton's laws affect atoms and molecules, using your observations of the model above.

Newton’s first law states that an object in motion stays in motion unless acted on by outside forces. When riding an atom, it continues in one direction until it collides with another atom or the boundary of the container.

Page 2:

1. Describe the motion of the particles you see above.

The motion of the pollen particles is slow and random. There is no good way to predict where the pollen grains will move next.

2. Why does the observed motion not seem to be following Newton's first law?

Newton's first law states that objects in motion will maintain their velocity unless acted upon by an outside force. When first observing this motion, the particles seem to be changing the direction of their motion randomly, even when no visible force is applied.

Page 3:

1. Does a single atom obey Newton's laws? Describe your observations and how you affected the model by applying forces in support of your answer.

When looking at a single atom, it does obey Newton’s first law. When no force is applied, the speed and direction (velocity) of the atom is maintained. It is only by applying forces that it is possible to slow the atom down, speed it up, stop it, or cause it to change its direction.

2. If you don’t apply any force to the atom, what is true of its velocity? (c)

Page 4:

1. Why could Brown come back to his particles over and over again, and always observe that they were moving in the same way? (b)

2. Explain how Brown's particles, which were surrounded by water molecules, appear to be moving "randomly" yet also follow Newton's first law at the same time.

The water molecules that surround the pollen grains are constantly colliding with the pollen. The pollen grain moves in response to the collisions, in a straight line until they collide with another water molecule. The constant collisions make the particle move in unpredictable random motion.

Page 5:

1. The force on each atom is represented by the green vector, and the acceleration is represented by the yellow vector. What is true of the force on each atom? (a)

2. Explain why some atoms move faster than other atoms if the same force is applied to all of them. Be sure to talk about the relevance of F=ma in your answer.

Newton's second law states that F=ma. The acceleration is then equal to force/mass. If all of the atoms are experiencing the same force, then as the atoms get heavier, the acceleration of the atoms (how much they speed up in this case) will be lower.

Page 6:

1. Take a snapshot of two atoms with the same mass colliding, and then place that snapshot here.
Yes. Atoms of differing masses repel one another with the same force after a collision. The action of the collision is followed by the equal and opposite reaction of the atoms moving apart from one another.

Page 7:

1. Take a snapshot of a sealed balloon, and then place that snapshot here. Make sure to draw arrows indicating where the gas exerts force on the balloon.

Sample snapshot: Gas particles inside the balloon push outward in all directions. Forces inside and outside the balloon are equal and opposite.

2. Take a snapshot of a popped balloon, and then place that snapshot here. Make sure to draw arrows indicating where the gas exerts force on the balloon.

Sample snapshot: Gas particles in the balloon push outward and the balloon moves in the direction opposite that of the puncture.

3. When is there a significant force between atoms? (d)

4. Do the snapshots you took illustrate Newton’s third law or not? Explain your reasoning.
4. Explain on an atomic level why the balloon moves the way it does when you provide an opening for the air, and connect this to Newton’s third law.

Newton’s third law states that for every force, there is an equal and opposite force. The compressed gas inside the balloon pushes outward in all directions. Popping the balloon releases the air through the opening (action) and causes the balloon to motor or be propelled in the opposite direction (reaction).

Page 8:

1. How does atom mass affect the vibrational frequency of the bonded atoms? (c)

2. How does the strength of the bond affect the vibrational frequency of the bonded atoms? (a)

3. How does Newton’s second law help explain the relationship between:
   a) bond strength and vibrational frequency?
   b) atom mass and vibrational frequency?

Newton’s second law states that \( F = ma \). a) The greater the bond strength (or force present between the atoms), the more vibration of the atoms will be present. b) The greater an atom’s mass, the lower the frequency of vibration due to the force between the two atoms.

4. How do Newton’s first and third laws help explain why the molecule as a whole is not moving around within the model container, and just vibrates in place?

Newton’s first law states that an object will continue to do what it is doing (in this case, staying still) unless acted upon by an outside force. Although the atom is vibrating internally, there is not an unbalanced force present to cause it to move up, down, left or right. Newton’s third law describes the equal and opposite forces experienced because of the covalent bond present.

5. When doing infrared spectroscopy an infrared light is shined on a substance to determine the vibrational frequency of the various bonds in a molecule. Because each molecule has a unique set of vibrations you can identify the molecule using this procedure, which is often used in forensics.

If you knew that part of a molecule had a high vibrational frequency, what could you say about the atoms and how they were bonded together in that part of the molecule?

If I knew that part of a molecule had high vibrational frequency, I could infer that the bond strength was high in that part of the atom. The atoms themselves in that part of the molecule probably had low masses.

Page 9:

1. The image above shows two atoms colliding. Which of Newton’s laws are demonstrated by this image? (c)

2. Use Newton’s second law to predict how the motion of these two atoms will change after colliding. (Note: the bigger atom has a larger mass.)

The force that repels them is the same strength, just opposite in direction (as shown by the equal and opposite green arrows). Therefore, after their collision, the atom on the right (with the smaller mass) accelerates more in the rightward direction than the heavier atom on the left. This is because \( a = F/m \).

3. You release two perfumes at opposite ends of a room, but one perfume is made from heavy molecules and one from light molecules. Which one would reach your nose first if you were standing in the center of the room? Explain your reasoning.

I would expect the perfume made of lighter molecules to reach my nose first. This follows the same logic as above. If the force releasing the two perfumes is the same, then the perfume with the smaller mass will accelerate more as it moves through the air towards my nose.
4. Give one example of an object that you can observe with your eyes that comes close to having the same characteristics of motion as an atom. Explain why.

Answers will vary. Make sure students include a reference to Newton’s laws in the explanation.

One example is a pool ball in a game of billiards. The balls move when a force is applied with a certain velocity that is changed when an outside force (such as colliding with the table) is met. Colliding balls create equal and opposite forces. When hit with the same amount of force, balls of equal masses will accelerate at the same rate. This is true neglecting friction with the table, etc.

5. Another way to apply a force to a charged atom is to pass it through a magnetic field. If the field is oriented properly you will apply a force that is perpendicular to the motion of the atom, causing the atom to deflect from its previously straight line path. The amount of force depends on the charge of the atom and strength of the magnetic field. If you had two atoms moving at the same speed with the same charge, but one atom had more mass than another, what would you expect to happen when they both enter the magnetic field? (b)
SAM HOMEWORK QUESTIONS
Newton’s Laws at the Atomic Scale

Directions: After completing the unit, answer the following questions to review.

1. How did you determine that Newton’s first law is true given what you learned about random, Brownian motion?

2. Write the equation that states Newton’s second law.

3. An equal force is applied to a series of atoms. Yet some atoms accelerate faster than others as a result. How can this be explained given Newton’s second law?

4. Below are two snapshots from the balloon model you studied in this unit. Use the before and after pictures from the model to explain Newton’s third law in action.

5. **Career Connection:** One of the most important applications of Newton’s Law is in the use of computer models to calculate the amount of force to use in what direction to apply that force to send rockets and special instruments into space. Report on at least one recent or upcoming mission that NASA is working on or has completed. In a few sentences give a brief overview of the name and purpose of the mission.
SAM HOMEWORK QUESTIONS
Newton’s Laws at the Atomic Scale – With Suggested Answers for Teachers

Directions: After completing the unit, answer the following questions to review.

1. How did you determine that Newton’s first law is true given what you learned about random, Brownian motion?

Brown observed random motion. Newton's first law states that a moving object will continue to move in a straight line and a motionless object will remain at rest unless the object is acted upon by some external force. In order to explain Brownian motion, we looked at the motion of many atoms and their collisions. When there were constant collisions the atoms movement looks random much like the particles Brown observed.

2. Write the equation that states Newton’s second law.

Force = mass x acceleration

3. An equal force is applied to a series of atoms. Yet some atoms accelerate faster than others as a result. How can this be explained given Newton’s second law?

Newton’s second law states that F=ma. If the force applied is equal, atoms will have a greater acceleration if they have a smaller mass. Those with a larger mass will accelerate less.

4. Below are two snapshots from the balloon model you studied in this unit. Use the before and after pictures from the model to explain Newton’s third law in action.

Newton’s third law states that for every force, there is an equal and opposite force. With the sealed balloon, the force of the gas inside pushes out against the wall of the balloon. When the balloon is popped, the force of the gas emerging from the balloon causes it to move in the opposite direction.

5. Career Connection: Report on at least one recent or upcoming mission that NASA is working on or has completed. In a few sentences give a brief overview of the name and purpose of the mission.

This will change over the years, so use some internet search engine to find many possible examples. Other sites to view are: [http://www.nasa.gov](http://www.nasa.gov) and [http://www.jpl.nasa.gov](http://www.jpl.nasa.gov)