**Lesson 10 – Expansion and Contraction in Liquids, Solids, and Gases**

**Storyline Summary:**

The prior set of activities about heating, cooling, and the kinetic energy of molecules prepares students to observe *actual* substances expanding and contracting when heated and cooled. Students explore and observe evidence of expansion and contraction in a liquid, a solid, and a gas in two activities and a demonstration.

At this point, the emphasis is on seeing evidence that heating causes particles to move further apart, and that cooling causes particles to move closer together. When applied to the Lava Lamp, students can conclude that the heated blob expands and becomes less dense and floats. They can also conclude that the cooled blob contracts, becomes more dense and sinks.

Students will wait until lesson 11 to revise their Lava Lamp models to reflect these concepts of thermal expansion and contraction causing floating and sinking.

**Note:** This lesson covers two different activities and a demonstration and will take more than one class period:

**What Student Do**

**Part 1:** Students explore how heating and cooling cause the expanding and contracting of the *liquid* in a thermometer.

**Part 2:** Students observe a teacher demonstration using a brass ball and ring to see and understand how heating and cooling cause a *solid* to expand and contract.

**Part 3:** Students use a detergent film on a disposable water bottle to show that heating and cooling cause a *gas* to expand and contract.

**What Students Learn**

* Heating causes molecules to move faster.
* Faster movement competes with attractions between molecules, causing molecules to move further apart.
* Cooling causes molecules to move more slowly.
* Slower moving molecules allow attractions to bring molecules closer together.
* Heating causes substances to expand, and cooling causes substances to contract whether or not a change in state occurs.

**Materials & Preparation**

**Part 1: Materials for Each Group**

* Student thermometer
* Magnifier
* Cold water
* Hot water (about 50 °C)

**Part 2: *Materials for the Demonstration***

* Ball and ring designed specifically for this demonstration
* Bunsen burner for heating the ball
* Room temperature water (to cool the ball)

***Notes about the materials***

The metal ball and ring are available from Flinn Scientific (AP9031) or other suppliers. <https://www.flinnsci.com/ball-and-ring-apparatus/ap9031/>

**Part 3:**

***Materials for Each Group***

* 2 clear plastic cups
* 8-oz plastic bottle
* Detergent solution in a cup
* Hot water (about 50 °C)
* Cold water

**Part 1 – Expanding and Contracting in Liquids**

Refer to the DQB and point out that students were curious about why blobs expanded and pulled apart. We know, on the molecular level, that the motion and arrangement of molecules changes when matter is heated and cooled. When a substance is heated, the motion of atoms and molecules increases causing them to move further apart. They also saw that cooling can cause molecules to slow down causing them to move closer together.

Now students will explore the effects of those changes on the macro level - what we can see with our eyes to further explain how the Lava Lamp works.

Explain to students that they will conduct three activities to see how heating and cooling a liquid, a solid, and a gas cause each substance to expand and contract.

**The Ups and Downs of Thermometers**

(From Middle School Chemistry - Chapter 1, Lesson 3)

***Key Concepts***

* The way a thermometer works is an example of heating and cooling a liquid.
* When heated, the molecules of the liquid in the thermometer move faster, causing them to get a little farther apart. This results in movement up the thermometer.
* When cooled, the molecules of the liquid in the thermometer move slower, causing them to get a little closer together. This results in movement down the thermometer.

***Summary***

Students will look closely at the parts of a thermometer. After placing a thermometer in hot and cold water, students will look at molecular model animations of the liquid in a thermometer. Students will then draw a model of the molecules of a thermometer after it has been placed in hot and then cold water.

***Objective***

Students will be able to describe, on the molecular level, why the liquid in a thermometer goes up when it is heated and down when it is cooled.

***Evaluate***

The activity sheet will serve as the “Evaluate” component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

***Safety***

* Be sure you and the students wear properly fitting goggles.
* Students should use care when handling hot tap water.
* When using isopropyl alcohol, read and follow all warnings on the label. Isopropyl alcohol is flammable. Keep it away from any flames or spark sources.

**ENGAGE**

1. **Find out what students know about thermometers.**

Hold up an alcohol thermometer and ask students:

* + **Why do you think the liquid in a thermometer moves up and down when it is heated and cooled?**

Students should realize that the movement of the liquid in a thermometer is related to the motion of the molecules of the liquid when they are heated and cooled. Remind students that molecules move faster and a little further apart when they are heated. Molecules also move slower and a little closer together when they are cooled.

Tell students that they will apply their understanding of what happens when liquids are heated and cooled to explain how a thermometer works.

**Give each student an Activity Sheet for Part 1.**

Students will record their observations and answer questions about the activity on the activity sheet. The *Explain It with Atoms & Molecules* and *Take It Further* sections of the activity sheet will either be completed as a class, in groups, or individually depending on your instructions. Look at the teacher version of the activity sheet to find the questions and answers.

**EXPLORE**

1. **Do an activity to investigate what makes the liquid in a thermometer go up and down.**

**Question to investigate**

What makes the liquid in a thermometer go up and down?

**Materials for each group**

* + Student thermometer
	+ Magnifier
	+ Cold water
	+ Hot water (about 50 °C)

**Procedure**

1. ***Look closely at the parts of a thermometer.***
	1. Look closely at your thermometer. The liquid inside is probably a type of alcohol that’s been dyed red.
	2. Practice reading the temperature in °C by having your eye at the same level as the top of the red

liquid. What is the temperature?

* 1. Use a magnifier to look closely at the thermometer from the front and from the side. Look at the bulb and the thin tube that contains the red liquid.
	2. ****Put your thumb or finger on the bulb and see if the red liquid moves in the thin tube.
1. ***Observe the red liquid in the thermometer when it is heated and cooled.***
2. ****Place the thermometer in hot water and watch the red liquid. Keep it in the hot water until the liquid stops moving. Record the temperature in °C.
3. Now put the thermometer in cold water. Keep it in the cold water until the liquid stops moving. Record the temperature in °C.

**Expected results**

The red liquid goes up in hot water and down in cold water. Students will have an opportunity to relate these observations to an explanation, on the molecular level, of why the liquid moves the way it does.

If you have time, you can have students pick a temperature somewhere

between the temperature of cold water and hot water and then attempt to

combine an amount of hot and cold water to achieve that temperature in one

try. They can see how close they can get.

1. **Record and discuss student observations.**

Give students time after the activity to record their observations by answering the following questions on their activity sheet. Once they have answered the questions, discuss their observations as a whole group.

1. Based on what you know about the way molecules move in hot liquids, explain why the liquid in the thermometer goes up when heated.
2. Based on what you know about the way molecules move in cold liquids, explain why the liquid in the thermometer goes down when cooled.
3. Why do you think the tube that contains the red liquid is so thin?
4. What do you think is the purpose of the larger outer tube?

When heated, the molecules of the red liquid inside the thermometer move faster. This movement competes with the attractions the molecules have for each other and causes the molecules to spread a little further apart. They have nowhere to go other than up the tube. When the thermometer is placed in cold water, the molecules slow down, and their attractions bring them a little closer together bringing them down the tube. The red liquid is contained in a very thin tube so that a small difference in the volume of the liquid will be noticeable. The large outer tube has two purposes—to protect the fragile inner tube and act as a magnifier to help you better see the red liquid.

**EXPLAIN**

1. **Show an animation of the molecules of liquid in a thermometer as they are heated and cooled.**

***Note:*** *Alcohol molecules are composed of different atoms, but in the model shown in the animation the molecules are represented as simple red spheres.*

**Show the molecular model animation *Heating and Cooling a Thermometer*.** [www.acs.org/middleschoolchemistry/simulations/chapter1/lesson3.html](http://www.acs.org/middleschoolchemistry/simulations/chapter1/lesson3.html)

Point out that when the thermometer is heated, the molecules move faster, get slightly further apart, and move up the tube. When the thermometer is cooled, the molecules move more slowly, get closer together, and move down the tube. Help students realize that the attractions the molecules in the thermometer have for each other remain the same whether the thermometer is heated or cooled. The difference is that when heated, the molecules are moving so fast that the movement competes with the attractions, causing the molecules to move further apart and up the tube. When cooled, the movement of the molecules is slower and does not compete as much with the attractions the molecules have for one another. This is why the molecules in the thermometer move closer together and down the tube.

Ask students:

* + **The animation shows that the molecules spread out slightly when heated. Do you think the thermometer would work as well if the tube of red liquid were wider?**

The molecules spread out in all directions when heated. If the tube were wide, the molecules would be free to spread out sideways as well as up. In the thin tube, the molecules can’t move very far sideways, so they go up. This causes a greater difference in the height of the liquid, which is easier to see.

1. **Have students draw a molecular model to represent the molecules of the liquid in a thermometer.**

**Project the image *Molecules in a Thermometer*.**

[www.acs.org/middleschoolchemistry/simulations/chapter1/lesson3.html](http://www.acs.org/middleschoolchemistry/simulations/chapter1/lesson3.html)

In the drawing, lines have been added to indicate the level of the liquid in each tube. In reality, there is no line. The “line” is made up of molecules. Students should draw circles representing molecules all the way up to the line drawn in each tube.

Have students use the projected illustration as a guide as they draw a model of the molecules in a hot and cold thermometer on their activity sheet.

The *Hot Thermometer* illustration should show random circles with more motion lines. The circles should be a little further apart than in the cold thermometer.

The *Cold Thermometer* should show random circles with fewer motion lines. The circles should be a little closer together than the circles in the hot thermometer.

**EXTEND**

1. **Discuss with students why thermometers with different liquids in them rise to different heights even at the same temperature.**

**Project the image *Different Thermometers Same Temperature*.** [www.acs.org/middleschoolchemistry/simulations/chapter1/lesson3.html](http://www.acs.org/middleschoolchemistry/simulations/chapter1/lesson3.html)

Tell students that this picture shows two thermometers that are identical in every way, except one has alcohol and the other has mercury inside. Point out that both thermometers are placed in hot water that is 100 °C. The levels of the alcohol and mercury are shown.

Ask students:

* + **How can the liquids in the thermometers be at different levels even though they are in water that is the same temperature?**

**Hint: Alcohol and mercury are both liquids but are made of different atoms and molecules. Use what you know about the motion and attractions the particles in a liquid have for one another to explain why the levels of alcohol and mercury in the thermometers are different.**

The main reason why the level of liquid in each thermometer is different is that they are different substances with different properties. The molecules that make up the alcohol have different attractions for each other than the atoms that make up the mercury. Therefore, heating and cooling them are going to make them move different distances up or down the tube.

After the class discussion, have students write their own response to the question about the two different thermometers on the activity sheet.

**Part 2 – Expanding and Contracting Solids**

(From Middle School Chemistry, Chapter 1, Lesson 4)

***Key Concepts***

* In a solid, the atoms are very attracted to one another. The atoms vibrate but stay in fixed positions because of their strong attractions for one another.
* Heating a solid increases the motion of the atoms.
* An increase in the motion of the atoms competes with the attraction between atoms and causes them to move a little further apart.
* Cooling a solid decreases the motion of the atoms.
* A decrease in the motion of the atoms allows the attractions between atoms to bring them a little close together.

***Summary***

Students will see a demonstration with a metal ball and ring showing that heat causes atoms to spread a little further apart. They will also see that cooling a solid causes the atoms to get a little closer together. The same rules they discovered about liquids also apply to solids.

***Objective***

Based on their observations students will describe, on the molecular level, how heating and cooling affect the motion of atoms in a solid.

***Evaluation***

The activity sheet will serve as the “Evaluate” component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

***Safety***

Be sure you and the students wear properly fitting goggles.

***Materials for the Demonstration***

* Ball and ring designed specifically for this demonstration
* Bunsen burner for heating the ball
* Room temperature water (to cool the ball)

***Notes about the materials***

The metal ball and ring are available from Flinn Scientific (AP9031) or other suppliers. <https://www.flinnsci.com/ball-and-ring-apparatus/ap9031/>

**Note:** The solid explored in this lesson is a metal. Metal is composed of individual atoms instead of molecules like in the water and alcohol students have already seen in previous lessons. Although atoms and molecules are different, for the purpose of these models of heating and cooling different substances, they will be represented as simple spheres. This representation will help students focus on the motion and position of the particles when they are heated and cooled.

**ENGAGE**

* 1. **Review what students have discovered about molecules in a liquid and discuss whether these same ideas might apply to solids, too.**

Ask students:

* + **What do you know about the molecules in a liquid?**

Be sure students understand that the molecules in a liquid are attracted to each other but are able to move past each other.

* + **How does heating or cooling affect the speed of the molecules and the distance between them?**

Heating speeds up the motion of molecules and cooling slows them down. We’ve also seen that speeding the molecules up makes them move a little further apart and slowing them down allows them to move a little closer together.

Ask students if these statements also apply to solids:

* + **Do you think the atoms in a solid are attracted to each other?**

Students will probably realize that the atoms of a solid are attracted to each other. Explain that this is how a solid stays together.

* + **Do you think heating or cooling a solid might affect the motion of the atoms?** Students should realize that if you heat a solid, the atoms or molecules move faster and move further apart. If you cool a solid, the molecules move more slowly and move a little closer together.
1. **Give each student an Activity Sheet for Part 1, and show an animation as review to help students compare the particles in solids and liquids.**

Explain that the little balls represent the particles of a solid, in this case the atoms in a metal. Although atoms and molecules are different, this same simple model of balls is used for both. Let students know that for now, they will use circles or spheres to represent atoms and molecules, but eventually they will use a more detailed model. Tell students that they should focus on the motion of the molecules, how they interact, and their distance from one another.

**Show the molecular model animation *Particles of a Solid*.**

[www.acs.org/middleschoolchemistry/simulations/chapter1/lesson4.html](http://www.acs.org/middleschoolchemistry/simulations/chapter1/lesson4.html)

Remind students the following characteristics of solids:

* + The particles (atoms or molecules) are attracted to each other.
	+ The particles (atoms or molecules) vibrate but do not move past one another.
	+ The solid retains its shape.

**EXPLORE**

**3. Do a demonstration to show that solid metal expands when it is heated and contracts when cooled.**

It is harder to show that the particles of a solid move faster and get further apart when heated than it is to show the same thing with a liquid. But you can do it if you have a special ball and ring apparatus that shows the expansion of a metal when heated.

This inexpensive device, available through science education equipment companies, consists of a rod with a metal ball on the end and another rod with a metal ring. At room temperature, the ball just barely fits through the ring. But when the ball is heated sufficiently, it will not pass through the ring. If you do not

have this equipment, you can show students a video of this demonstration titled ***Heating and Cooling a Metal Ball***.

[www.acs.org/middleschoolchemistry/simulations/chapter1/lesson4.html](http://www.acs.org/middleschoolchemistry/simulations/chapter1/lesson4.html)

**Question to investigate**

How do heating and cooling affect a solid?

**Materials for the teacher**

* + Ball and ring designed specifically for this demonstration
	+ Bunsen burner for heating the ball
	+ Room temperature water (to cool the ball)

**Procedure**

*A.* ***Heating the metal ball***

* 1. Hold the ball in one hand and the ring in the other. Show students how the ball fits through the ring.
	2. Place the metal ball in the flame of a Bunsen burner for about 1–2 minutes.
	3. Try to push the ball through the metal ring again.

**Expected results**

The ball will not fit through the ring.

Ask students:

* + - **Why won’t the ball fit through the ring?**

Students should infer that the speed of the atoms in the metal ball has increased. This increased motion competes with the attractions the atoms have for each other, causing the atoms to move slightly further apart. This is why the heated ball is too big to fit through the ring.

When students see that the ball expands, they may wonder if the atoms themselves expanded. Tell students that the atoms do not expand. Instead, the atoms in a solid follow the same rules as the molecules in a liquid. Heating increases molecular motion, causing the atoms to spread a little further apart.

1. ***Cooling the metal ball***

Ask students:

* **What could we do to the metal ball to make it fit through the ring again?**

Students should suggest cooling the ball.

 3. Dip the ball in room temperature water.

 4. Push the ball through the metal ring.****

**Expected results**

The ball will fit through the ring.

Ask students:

* + **Why does the ball fit through the ring now?**

Students should infer that the atoms slow down enough so that their attractions pull them closer together, making the ball smaller so that it can fit through the ring.

**EXPLAIN**

1. **Show an animation and explain what happened to the atoms in the metal ball as it was heated and cooled.**

**Show the molecular model animation *Heating and Cooling a Solid*.** [www.acs.org/middleschoolchemistry/simulations/chapter1/lesson4.html](http://www.acs.org/middleschoolchemistry/simulations/chapter1/lesson4.html)

Point out that when metal is heated, the atoms move faster and move slightly further apart. This makes the heated ball expand, which prevents it from passing through the ring.

Point out that when the metal is cooled, the atoms move slower and move slightly closer together. This makes the cooled metal ball get slightly smaller so that it fits through the ring again.

Give students time to complete the questions and drawings on the activity sheet about heating and cooling the metal ball.

**Project the image *Molecules in a Room Temperature and Hot Metal Ball*.**

Help students draw circles to represent the atoms in the ball at room temperature and after it is heated. Have students write captions describing the speed and distance of the atoms in each picture.

**EXTEND**

1. **Have students apply what they have learned about heating and cooling solids to explain why bridges have flexible connections.**

Show students the picture of the flexible connection in the road on a bridge. Explain that the surface of the bridge gets colder in winter and hotter in summer than the road on either end of the bridge. This is because the bridge is completely surrounded by cold air in the winter and by hot air in the summer. It is not insulated by the ground beneath it.



Ask students:

* + **Knowing what you do about how solids act when they are heated and cooled, why do you think they put flexible connections in the surface of a bridge?**

Students should realize that if the bridge is hotter than the land around it, it should be able to expand a bit without breaking. If it is colder than the land around it, it should be able to contract a bit without breaking.

After the class discussion, have students write their own response to the question about flexible bridge connections on the activity sheet.

**Part 3 – Expanding and Contracting Gases**

(From Middle School Chemistry, Chapter 1, Lesson 5)

**Note:** Since molecules of a gas have very little attraction for each other, a gas must be cooled to extremely low temperatures for the attractions between molecules to bring them closer together.

This is not what is happening when cooling the bubble on the bottle. In the case of the bubble on the bottle, cooling the gas makes the molecules move slower allowing the outside air pressure to push the gas molecules closer together.

***Key Concepts***

* In a gas, the particles (atoms and molecules) have weak attractions for one another. They are able to move freely past each other with little interaction between them.
* The particles of a gas are much more spread out and move more independently compared to the particles of liquids and solids.
* Whether a substance is a solid, liquid, or gas at a certain temperature depends on the balance between the motion of the particles at that temperature and how strong their attractions are for one another.
* Heating a gas increases the speed of its atoms or molecules.
* Cooling a gas decreases the speed of its atoms or molecules.

***Summary***

Students consider how heating and cooling affect molecular motion in gases. They dip the mouth of a bottle in detergent solution and observe a bubble growing and shrinking when the bottle is warmed and cooled. Students will learn that the attractions between the particles of gases are weak compared to the attractions between the particles of liquids or solids.

***Objective***

Students be able to describe, on the molecular level, the effect of heating and cooling on the motion of molecules of a gas.

***Evaluation***

The activity sheet will serve as the “Evaluate” component of each 5-E lesson plan. The activity sheets are formative assessments of student progress and understanding. A more formal summative assessment is included at the end of each chapter.

***Safety***

* Be sure you and the students wear properly fitting goggles.
* Students should use care when handling hot tap water.

***Materials for Each Group***

* 2 clear plastic cups
* 8-oz plastic bottle
* Detergent solution in a cup
* Hot water (about 50 °C)
* Cold water

**EXPLORE**

1. **Give each student an Activity Sheet for Part 3, and have students do an activity to find out how heating and cooling affect gases.**

**Question to investigate**

How does heating and cooling affect a gas?

**Materials for each group**

* + 2 clear plastic cups
	+ 8-oz plastic bottle
	+ Detergent solution in a cup
	+ Hot water (about 50 °C)
	+ Cold water

**Teacher preparation**

Make the detergent solution for the entire class by adding 4 teaspoons of dishwashing liquid and 4 teaspoons of sugar to ½ cup of water. Gently stir until the detergent and sugar are dissolved. Place about 1 tablespoon of detergent solution in a wide clear plastic cup for each group.

**Procedure**

1. ***Warming the air inside the bottle***
	1. Pour hot water into an empty cup until it is about ½-full.
	2. Turn the bottle over and dip the opening of the bottle into the detergent to get a film of detergent covering the rim.
	3. While holding the bottle, slowly push the bottom of the bottle down into the hot water.

Ask students:

* + - **What can you do to make the bubble go down?**

If students have trouble thinking of an answer, remind them that heating the gas increased the speed of the molecules, which made the bubble grow. Students should suggest that they should cool the gas in the bottle. This can be done by putting the base of the bottle into cold water.

1. ***Cooling the air inside the bottle***
2. Pour cold water into another cup until it is about ½-full.
3. If there is still a bubble on the bottle, slowly push the bottom of the bottle down into the cold water.
4. If a bubble is not still on the bottle, make another bubble by dipping the opening into detergent and then pushing the bottom of the bottle into hot water again.
5. While holding the bottle, slowly push the bottom of the bottle down into the cold water.

**Expected results**

When the bottle is placed in hot water, a bubble forms at the top of the bottle. When the bottle is placed in cold water, the bubble gets smaller. It may actually be pushed down into the bottle.

1. **Record and discuss student observations.**

Give students time after the activity to record their observations by answering the following questions on their activity sheet. Once they have answered the questions, discuss their observations as a whole group.

* + **What happened to the film of detergent solution when you placed the bottle in hot water?**

It formed a bubble.

* + **What happened to the bubble when you placed the bottle in cold water?**

It shrunk and went into the bottle.

Tell students that you will show them an animation to help explain what caused the bubble to grow and shrink when the air in the bottle was heated and cooled.

**EXPLAIN**

**Show the animation *Heating and Cooling Gas in a Bottle*.** [www.acs.org/middleschoolchemistry/simulations/chapter1/lesson5.html](http://www.acs.org/middleschoolchemistry/simulations/chapter1/lesson5.html)

Tell students that the red arrows in the animation represent the outside air pushing down on the bubble film. Explain that heating the air inside the bottle makes the molecules move faster. These faster-moving molecules hit the inside of the bottle and the bubble film harder and more frequently. These molecules push against the inside of the bubble film harder than the surrounding air pushes from the outside. This pushes the bubble film up and out, forming a bubble.

Cooling the gas makes the molecules move more slowly. These slower-moving molecules hit the inside of the bottle and the bubble film less often and with less force. The molecules in the surrounding air are moving faster and push against the bubble from the outside. Since these outside molecules are pushing harder, the bubble gets pushed down and gets smaller.

1. **Have students answer the questions about the growing and shrinking bubble on the activity sheet.**

Give students time to complete the following questions. They should refer to the drawings included on the activity sheet.

Once they have answered the questions, discuss their explanations as a whole group.

* + **What caused the bubble to form when you placed the bottle in hot water? Be sure to write about the speed of the molecules inside the bottle and the pressure from the outside air.**

Point out that the molecules of air inside the bottle move faster when they are heated and push harder against the outside air. This makes the bubble form.

* + **Why did the bubble get smaller when you placed the bottle in cold water? Be sure to write about the speed of the molecules inside the bottle and the pressure from the outside air.**

When the air inside the bottle is cooled, the molecules move slower and do not push as hard against the outside air. The outside air pushes against the bubble, making it go down.

**4. Based on student observations, molecular animations, and reasoning, ask students if their observations confirm that substances expand when heated and contract when cooled.**

The overwhelming answer should be “Yes”.

**5. Have a class discussion about how the blob material changes when heated and cooled.**

Ask students:

* **If molecules are moving further apart and closer together when matter is heated and cooled, is the mass or volume changing?**

Volume

* **If the volume of an object changes, but the mass stays the same, what must also be changing?**

Density

Students now know that the blobs’ heating and cooling, expanding and contracting, and changes in density cause the blobs to rise and fall.

**EXTEND**

Let students know that the next lesson will explore examples of how heating and expanding, and cooling and contracting affect floating and sinking.