Lesson 1: What happens when room temperature substances are mixed together?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

T	**This Lesson....What we are doing now:** This is the first lesson in the series. Students will observe a perplexing anchoring event: mixing together two different room temperature substances in a beaker results in it cooling, so much that the beaker freezes to a wooden block. Students develop models to try to explain this phenomena. You will help the class agree on aspects of the phenomena that need to be accounted for a representations to use for particles and temperature changes that they want to use in future explanations and models. And you will help them develop a driving question board.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L1: What happens when room temperature substances are mixed together? (3 periods) S *Building toward* ⬇ *<u>NGSS PEs:</u>* *HS-PS1-4,* *HS-PS3-5*	Primary: When ammonium chloride and barium hydroxide are added in a beaker, the beaker will freeze to a wood block. Secondary: Mixing baking soda, water, and pink lemonade also results in a drop in temperature.	**Ask questions** that arise from careful observation of unexpected results, to clarify and seek additional information *about how mixing room temperature substances together caused the temperature to drop.* **Develop a model** based on evidence to illustrate the relationships between components of a system *to begin to identify the parts of the system that we should represent in future models explaining why the temperature drops when room temperature substances are mixed.*	It's strange that adding room temperature ammonium chloride to room temperature barium hydroxide made the beaker get colder! It seems like a chemical reaction due to the presence of gas (evidence: the very bad smell) and because the mixture looked like it changed. We also think that temperature change is another indication of a chemical reaction. We try and think of parallel phenomena from our own lives but most of our example of temperature change involve combining things of differing temperature not combining things of the same temperature. We think that the temperature is changing in this case because this is a chemical reaction but we are now wondering, *do other chemical reactions result in a drop in temperature.* **We decide to look at another chemical reaction and see if the temperature drops in this reaction as well.** We mix baking soda, pink lemonade, and water. We think that this a chemical reaction due to the presence of gas (evidence: the bubbles). In this case, the temperature drops as well! At this point we think that these two chemical reactions are examples of the same GENERAL phenomena as all of our evidence points to the idea that chemical reactions result in a drop, or at the very least in a change, of temperature. *But we still have a lot of questions! Why is the temperature dropping? What is changing in these chemical reactions? Does it get cold because it is a chemical reaction? Do other processes result in a change in temperature? Do all chemical reactions result in a temperature change? Is there something special inside these chemicals? Does everything we mix together result in a drop in temperature?* **After making a record of our questions on our Driving Question Board, we decide to spend some time brainstorming HOW the temperature changes.** We decide that we want to model this phenomena and represent temperature changes and different stuff in the model to try to get at a possible cause. This is Model 1. Before modeling this phenomena on our own, we have a conversation about what a model is and why it is useful. We then work individually to come up with a potential GENERAL model that explains HOW and WHY the temperature changes for both phenomena.

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			As we compare models we notice some differences between them and decide we need to come to consensus on how we want to represent temperature differences and substance differences going forward. This raised some questions about modeling these phenomena including: ● *How do we show same vs. different substances?* ● *How do we show a change over time in our model?* ● *What scale should our model be at -- the macro or particle level?* ● *Wait! What is temperature, really? Are we describing the same thing when we use that word? How do we depict changes of temperature in our model?* We have a class discussion where we come to a consensus that we need same or different particles to represent same or different stuff (molecules vs. atoms). We also decide that our models will require stages (before, during, after) and that our model must include the particle level. But our discussion about temperature is a bit trickier. We know that the molecules of a cold substance move slower than the molecules of a warmer substance. So if you heat up a substance like water, but don't change it from a liquid to a gas, then we think all the water molecules are still there in the container (which we think is the case, and could test by massing the system if we needed to). So we decided we need to keep the number of water molecules stay the same but they begin to move faster as the water heats up. In other words, the more molecules move, the more kinetic energy they have and the hotter the substance is. We call the average kinetic energy of all the molecules in a substance the substance's thermal energy. Thermal energy can be measured by finding a substance's temperature. We come to a class consensus on how we will represent temperature and particles of matter in our models (e.g. dots as molecules, small arrows for slower speeds and large arrows for higher speeds). We decide that since temperature is a reflection of what is happening at the atomic level, all of our future models and explanations for this phenomenon must occur at the particle level. We draw out how we want to represent different temperatures of substance in our models (cold -> hot). We agreed that in all future models to include a representation of: ● Different types of substances (different particles) ● The amount of substance (amount of particles) ● The temperature of the substance (movement of particles) We return to our Driving Question Board to add any additional questions we have come up with and to help us organize our thoughts about the phenomenon. But we are mostly wondering if any of our ideas as to how or why the temperature dropped are correct. *Did it get cold because these are both chemical reactions? Do other processes cause their surroundings to get colder? We should try another example to see.* **Next Steps: After making a record of our questions on our Driving Question Board and organizing them broadly in categories, we identify some next steps to pursue. Because these two phenomena are both chemical reactions, we are curious if the temperature with drop if we mix two things and no chemical reaction occurs.**

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Getting Ready: Materials Preparation

Materials For Small Groups

- EXPERIMENT 1:
  - 100 or 250 mL beaker
  - Wooden block
  - Trays to measure chemicals out on (2)
  - Thermometer that reads at least -30℃
- EXPERIMENT 2:
  - Sandwich bag
  - Graduated cylinder that contains at least 10 mL
  - Thermometer

Preparation of Materials

- DAY 1:
  - Have all chemicals out ready to be massed out for both experiments
  - Have materials for the first experiment on students lab tables
  - Have materials for the second experiment grouped and ready
  - Every student should have safety goggles
  - Have an empty bulletin board prepared for the Driving Question Board
  - Have the video of the first experiment at this link loaded
- DAY 2:
  - Have blank papers and different color pens/markers ready for students to use
- DAY 3:
  - Have a way for students to present models from their packets to the entire class

Materials For Each Student

- Lesson 1: Student Activity Sheets (1)
- Safety goggles

Materials Shared Between Classes.

- Chemicals: barium hydroxide octahydrate (32 grams min per group), ammonium chloride (10 grams min per group), pink lemonade, baking soda, and distilled water
- Lab balance and scoopulas for each chemical
- Different color pens/markers and extra blank paper

Safety

- Barium hydroxide is CORROSIVE
- Ammonium chloride is HARMFUL

Materials For Each Class

- Blank poster papers to keep track of evidence collected and what the class is including in future models (4)

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Learning Plan: What happens when room temperature substances are mixed together? (135 min)

DAY 1 - 45 minutes

1. (15 min) Have students do Experiment 1 in small groups, following the procedure in their packets, shown below: A

- **Students will first measure out 32 grams of $Ba(OH)_2$ ● 8 H_2O and 10 grams of NH_4Cl out. Students should write down their observations about these two powders (without touching them!) and record initial temperatures.**
- **Increasing the amount of chemicals will make the reaction more dramatic, just make sure that you use three times more grams of barium hydroxide octahydrate than ammonium chloride to maintain the correct molar ratio.**
- **Then students should squirt a small amount of water onto a wooden block and place the beaker on top of the water.**
- **Next the students should combine the two powders in the beaker, mixing the powders together with the thermometer. Students should again record their observations and the final temperature of the combined substances.**
- **After the experiment is done, have students dispose of the chemicals appropriately as chemical waste.**

If students beakers did not freeze or if the chemicals are not available show the students the loaded video of the experiment.

Teacher Supports & Notes

Additional Guidance

A Things to remind students of as they do this experiment:

- They should wait until the temperature stops changing before recording the temperature. If you are not sure if the temperature is still changing or not, write down the temperature and wait a bit to see.
- Write down every single observation of the substances you are using and what happens when they are mixed together. The more observations the better. Even if you do not think an observation is important now, you may discover its importance later.
- You should not stick your nose into a beaker to see if it smells, instead waft the gas towards your nose using your hand.

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2. (10 min) Ask students to share from their class what they observed during the experiment.

Summarize the key observations with the class. Have students make sure that they have recorded all of these major observations. You can choose to write this on the board or on a poster so that the class can refer to it later.

Suggested Summary:

- The temperature dropped so dramatically that the beaker froze to the wooden block
- The two substances started off as powders with different textures, but when combined they turned into a milky, thick, liquidy substance
- There was a really bad smell

Students might begin to refer to this as a chemical reaction. Even if they do not, ask them questions about how we would know this is a chemical reaction or not. B

Suggested Prompts:

➔ What is a chemical reaction?
➔ How would we know if a chemical reaction is occurring?
➔ Is there evidence that mixing together barium hydroxide and ammonium chloride is a chemical reaction?

Make sure the class comes to consensus on this point:

- **Experiment 1 is a chemical reaction.**

Ask students to turn and talk to their partner about if they have ever experienced any similar phenomena to the one the class just saw.

Then have students share out their ideas to the class.

Possible *student responses*:

➔ *I put my water bottle in the freezer and it got so cold that it froze*
➔ *One time I licked a metal pole when it was cold outside and my tongue stuck to it!*
➔ *We have ice packs that are room temperature until you pop and shake them, then they get cold*

Supporting Students in Arguing From Evidence

B Students most likely will begin to refer to this as a chemical reaction without any prompting. Use this conversation as an opportunity to talk about the importance of (1) Supporting all claims with evidence and (2) Not using vocabulary that we cannot define.

Students should be able to define a chemical reaction as when substance combine to form a new and different substance AND YOU CANNOT GET BACK WHAT YOU STARTED WITH. Eventually this definition will be expanded to include the idea of breaking and making bonds, but that is not necessary to our definition at this point.

Additionally, from middle school students should be able to argue that evidence that a chemical reaction MAY have occurred includes: temperature change, color change, presence of a gas, etc. However, the only feature that can conclusively indicate that there has been a chemical reaction is if you cannot get back the products you started with.

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If students only mention phenomena that involve temperature gradients (i.e., things of different temperatures interacting), prompt students to think about phenomena that are chemical reactions that start at room temperature and then get colder. C

Suggested Prompts:

- ➔ Can you think of any examples where room temperature substances change temperature when they are mixed together?
- ➔ Are any of the ideas we have come up with chemical reactions?
- ➔ Can you think of any examples of other chemical reactions where the temperature drops?

Summarize some of the ideas the class came up with and emphasize that the majority of these examples do not involve substances that all start at room temperature.

Then ask students why they think the temperature went down when we mixed together room temperature barium hydroxide and ammonium chloride.

If students do not immediately attribute the drop to the chemical reaction press them on what they know is happening in this reaction.

Suggested Prompts:

- ➔ What happens when barium hydroxide and ammonium chloride are mixed together?
- ➔ Does our evidence indicate that mixing together barium hydroxide and ammonium chloride results in a chemical reaction?
- ➔ Is the temperature drop and the fact that this is a chemical reaction related? Or are they unrelated?
- ➔ Do you think the temperature drops in other chemical reactions? Do you have any examples?

At this point, students often feel that the fact that experiment 1 is a chemical reaction is related to the fact that there is a temperature drop. Use this instinct to motivate looking at other chemical reaction to see if this pattern holds!

Strategies for this Initial Ideas Discussion

C The point of this brainstorming activity is to have students realize that while they can think of many phenomena where the temperature changed, they cannot think of very many that involved room temperature substances changing temperature without being exposed to some sort of external energy source (e.g., air conditioning, refrigerators) or an item of a different temperature (e.g., ice, fire).

Examples of phenomena that do map are instant ice packs or hand/feet warmers.

That being said, at this point in the conversation try and encourage participation and work to elicit as many ideas as possible even if they do not map perfectly to this phenomenon. Celebrate students contributing to the conversation and remind them that this is not a "right" or "wrong" question, every answer is a good answer.

After a fair amount of students have shared their ideas, utilize the fact that this phenomena seems to be different as a way to emphasize how weird and mysterious this phenomena is. It may not be something we've ever experienced!

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Make sure the class comes to consensus on this next step:

- **Students should say that they want to see if the temperature drops in other chemical reactions.**

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3. (15 minutes) Before students do experiment 2 have them brainstorm what evidence they would need in order to see (1) if this experiment is a chemical reaction and (2) if mixing these substances together results in a temperature drop in order to design a data table.

Have students do Experiment 2, following the procedure in their packets. D

- **Students should put ~5 heaping scoops of pink lemonade in a plastic bag and record the temperature.**
- **They should then measure out ~5 heaping scoops of baking soda and record the temperature.**
- **Next, students should combine the two powders mixing them well and record the temperature.**
- **After that, students should measure out ~10mL of distilled water and record the temperature.**
- **Lastly, students should slowly add in the water, stirring the mixture with a thermometer and recording the final temperature of the mixture.**

Throughout this entire process students should record their observations.

Have students come up and record on the board what they measured the change in temperature to be, if they measured a change in temperature at all.

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4. (5 minutes) Have the students look at the classrooms' data. They should recognize the pattern that the temperature is dropping, though less dramatically than it did in the first reaction.

Additional Guidance

D Emphasize to students that their worksheets contain suggestions about what evidence they should collect, but that should collect as much evidence as they feel necessary to help them explain what is going on.

Also point out to students that they might have to take the final temperature multiple times until they are sure that it is no longer changing.

Strategies for this Consensus Building Discussion

E If students seem to be dancing around committing to a specific idea, latch on to any productive fragments they raise, "Wow that's an interesting thought and it seems like multiple students have been thinking about this too, what I think I hear you saying is, ".... " did I get that right?" Make sure to allow the students to respond on your rephrasing to give feedback or further clarify their thinking.

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Ask the students if they believe that this is a chemical reaction or not. Press them to provide evidence to support their claim.

Make sure the class comes to consensus on this point:

- **Experiment 2 is a chemical reaction.**

Ask the students how this experiment is similar and different from the first experiment. Possible *student responses*:

- ➔ *They are similar because they both involve mixing room temperature substances together and a resulting temperature drop*
- ➔ *They are different because experiment 1 has two powders and experiment 2 has two powder AND water*
- ➔ *They are similar because both result in the formation of a gas*

Make sure the class comes to consensus on this point:

- **These two experiments are parallel because they are both chemical reactions and they are both getting colder.** E

The students should be asking lots of questions now and beginning to wonder how and why the temperature is dropping.

DAY 2 - 45 minutes

1. (10 minutes) Recap what happened the previous day with this students.

Suggested Prompts:

- ➔ We did two experiments yesterday, what happened in them?
- ➔ What was similar between the two experiments? What was different?

Explain to the students that we are now going to create a Driving Question Board (DQB) of all the

Another good strategy to use here to make sure we are all on the same general page is to make sure we get a response from everybody by voting to answer the question, "Do we all agree on the ideas that student A raised? Do others agree or do you have something else you want to add?"

Strategies for this Sharing Initial Questions Discussion

F The goal though is to hear from everyone, even if the questions are redundant. It's important that we develop a joint mission statement. Encourage risk taking with sharing first draft questions we have. We want to create an environment where curiosity and confusion are celebrated as motivators for future experimentation.

Emphasize that the point of the DQB is to keep track of all our questions so that we can answer as many of them as possible. Students should feel like their questions are driving and influencing what they are learning in the classroom.

If some students raise additional questions later in the lesson or unit that they don't know the answer to, make sure to add those to the initial questions board to validate them and encourage sharing our

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questions students have related to this phenomena that they would like to understand. ANY question counts. Try and group questions into emergent categories if they are related to one another.

Pass out post it notes and give students a few minutes to write down any and all questions they have. Come together as a class and have students brainstorm and place as many questions inspired by these two phenomena as they possibly can on the DQB. F

When students ask how and why the temperature drops in a chemical reaction, highlight this question. We do not know the answer to how the temperature drops, though we maybe do have a theory as to why the temperature drops (that's what happens in chemical reactions).

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2. (5 minutes) Introduce the next activity as each student individually taking some time trying to come up with a general explanation as to what happens when room temperature substances are mixed together that results in a temperature drop.

Use this opportunity to have a quick conversation about what a model is in science. G

Have students spend 5 minutes modeling in their packets a general mechanism as to how the temperature drops when a chemical reaction occurs.

Emphasize that:

(1) These are just students' ideas about what is going on and that there are no wrong or right answers

(2) The goal is for this model to be general so that it can be used to explain BOTH phenomena

(3) The mechanism this model is trying to explain is how the temperature drops when a chemical reaction occurs between room temperature substances H

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thinking.

Supporting students in the science practice of modeling

G The purpose of scientific models models is one that is key both to this unit and to learning science. There are a few things that are key to students learning early on about models.

1) At this level, models are NOT pictures, they are diagrams that students can use to answer a question. In other words, they should be created so that what is drawn in the model is useful in answering the question asked.
2) Models correspond to the real world, but they do not replicate it. That means that they focus on some features while obscuring others. This means that EVERYTHING does not have to be included in a model, only the pertinent pieces to the model. As such, models make approximations and are limited.
3) Models are based on evidence, but it is possible that more than one model can be correct. Different models may afford us different things. We might not have enough evidence yet to discern which

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3. (20 minutes) Only have the selected students present their models to the class. Celebrate each potential explanation, regardless of how far-fetched it is.

Focus the conversation around choices that the student made in their model.

After each presentation, have students point out what is being represented in the model and how these factors are being represented.

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4. (10 minutes) Point out how different all of these models are and use this to motivate a consensus discussion about what the class thinks should be included in all future models.

Push the class to agree upon about what features should be included in future models and how they should be depicted in order to make it easier to understand and compare models.

Remind students that at this point we are not arguing about what explanation is best, rather what features will be the most productive to include as we continue to create a model that explains how the temperature is dropping.

Make sure the class comes to consensus on these points:

- **We need different symbols to represent different substances.**
- **Our model must have different stages (e.g., before, during, after).**
- **Our model must include the particle level.**
- **Our model must represent different temperatures (but depending on our prior knowledge we might not know how yet)**

There may be more features the class agrees upon (e.g., the presence of a key) which is great! But the three features above should definitely be agreed upon. If students do not bring up these issues, prompt them to think about them:

model is more productive. As long as models account for the evidence we currently have, they are considered plausible, even if models seem to be contradictory

4) Models are based on evidence. Therefore they are always being updated and revised as we gain new evidence that the current model connect explain. As a class, we will be refining our model through an iterative cycle where we see what is happening in the real world and then adjusting our models to gain insight into what mechanistically might be happening in this phenomenon

Additional Guidance

H As students work, walk around and pick out models that can be productively used as examples for the class to push on the following ideas:

1) Should models be at the macro level or at the particle level? Or both?
2) How should we represent different types of particles?
3) Does the amount of particles we draw matter?

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Suggested Prompts:

- ➔ What are some of the things you like about this model?
- ➔ Is there anything you would change about this model?
- ➔ How many substances are represented in this model? Can we tell them apart? Did we have more than one substance in our experiments?
- ➔ Was the temperature the same at all points during the reaction? How can we show this change over time in our models?
- ➔ When trying to explain how the temperature dropped, do you think it is important for that explanation to happen at the particle level? Why or why not?

You might want to keep track of the features the class will be including in future models and the agreed upon depiction on a poster for future reference.

NEXT STEPS: ***The students realize that they need to find a common way to depict different temperatures but modeling temperature is confusing and the class wants to talk about it further.***

DAY 3 - 45 minutes

1. (20 minutes) Recap what features the class had decided the day before were crucial to include in future models and how the class had agreed upon depicting those features.

Remind the students that the class had not yet decided how to depict temperature and found modeling temperature a little confusing.

If a model from the previous day was particularly productive, consider projecting it for the class to see again.

Have an extended conversation about temperature. This should be a review. If it is not a review,

4) How should represent temperature and temperature change?
5) Should we show the passage of time in our model? How would we do that?

Strategies for this Building Understandings Discussion

One of the most difficult aspects of chemistry is the idea that macro level phenomenon can be explained through sub-microscopic (i.e., particle) interactions. It is notoriously difficult for students to transition between the macro and micro levels. As such, it is VERY important to support students in level-thinking.

This is a fantastic opportunity to help support students in beginning to reason through for themselves why it is important to consider particles when attempting to explain macro-level phenomenon such as the drop in temperature.

Push students to see the need to include particle interactions in their models by reminding them of the relationship between temperature and particle interactions.

Throughout this entire unit, push students to map the conversations they are having at

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pause here until students have a basic understanding of temperature. This will be explored further in Lesson 3 if students are struggling here.

Suggested Prompts:

- What is temperature?
- What does it mean if a substance heats up or cools off? What changes in that substance? Does anything even change?
- Does the number of molecules change when the temperature change?
- Does the (average) speed of molecules change when the temperature change?

Students should be able to define the terms kinetic energy and thermal energy and should understand temperature as the average speed of particles.

Make sure the class comes to consensus on this point:

- **The faster particles are moving, the warmer the substance is (slower movement = colder)** J
- **KINETIC ENERGY is the energy that comes from the motion of particles**
- **THERMAL ENERGY is a measure of the average kinetic energy, so it is another term for temperature**

Make sure to add the terms KINETIC ENERGY and THERMAL ENERGY to a poster where we can keep track of important scientific terms we have defined. K

We also decide on a way to depict temperatures by indicating molecular movement at different speeds.

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2. (25 minutes) Return the DQB and add any new questions that students have.

Try and group all of the questions into broader categories. Remember we need everyone involved

the particle level to the macro level and vice versa!

Additional Guidance

J It will be useful at this point of the conversation to have a conversation as to whether using + or - signs will be useful in indicating temperature change. Have a quick discussion where you prompt students to think about this if they haven't yet, "Do you think the mathematical signs + or - would be useful in indicating a change in temperature? How so?"

Having a preliminary conversation here about the convention of how + can indicate the temperature increasing and - can indicate the temperature decreasing will be useful for later!

Additional Guidance

K We will be adding words to our "Important Scientific Terms" we have defined all unit as a way of keeping track of what we have learned. You can decide whether you would like to include brief

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because these questions are in essence the draft of what we will be exploring in class over the next few weeks!

At the end of this process we realize that we are mostly wondering if any of our ideas as to how or why the temperature dropped are correct. *Did it get cold because these are both chemical reactions? Do other processes cause their surroundings to get colder? We should try another example to see.*

Have the students brainstorm what would be a useful example of mixing things together that DO NOT react to pursue.

Possible *student responses*:

- ➔ *Sugar and salt. I don't think they react together!*
- ➔ *Hot chocolate in water. Wait do they react? Can I get my hot chocolate powder back after I have put it in the water?*
- ➔ *Salt in water. When I'm sick my mom makes me gargle salt water and even though the water looks different, I think the salt is still there because I can taste the salt. So I don't think that's a chemical reaction.*

As soon as students say something about dissolving, jump in and ask students if dissolving is a chemical reaction or not. From middle school, students should say they do not think it is a chemical reaction. If they say it is, or are unsure, recommend that we explore it further to see if it is a chemical change or not.

If students do not bring up dissolving themselves, try prompting students:

Suggested Prompts:

- ➔ What about adding a hot chocolate packet to hot water? Do you think that is chemical reaction?
- ➔ Have any of you every gargled salt water? Do you think the salt water is still there after it dissolves in water?

definitions on the poster or have it just be terms.

This will be a helpful guide for students to remember what we have figured out already. It will also familiarize students with a new vocabulary and is an easy tool to support students' incorporation of these new terms into their everyday science talk. Finally, this allows us to feel a sense of accomplishment in our learning progression so we do not get frustrated at the lack of answers.

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At this point decide that tomorrow you are going to look at dissolving salt in water, which the class does not THINK is a chemical reaction, to see if the temperature drops.

If you have time, record students predictions as to what they think will occur.

NEXT STEPS: ***We identify some next steps to pursue. Because these two phenomena are both chemical reactions, we are curious if the temperature with drop if we mix two things and no chemical reaction occurs. We decide to try dissolving salt in water.***

Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 2: Will the temperature still drop if we mix two things and no chemical reaction occurs?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been In the previous lesson students discovered that two different chemical reactions between room temperature substances result in a drop in the temperature.

This Lesson....What we are doing now: Students will observe that the temperature drops when room temperature potassium chloride, a salt, is dissolved in room temperature water. Students will confirm that this is not a chemical reaction and that the potassium chloride is merely breaking into smaller pieces as it dissolves.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L2: Will the temperature still drop if we mix two things and no chemical reaction occurs? (2 periods) *Building toward* ↓ *NGSS PEs:* *HS-PS1-4*	Dissolving potassium chloride in water results in a temperature drop.	**Plan and Carry Out Investigations** to produce data to serve as evidence *as to whether or not there is a pattern where the temperature only drops in chemical reactions* as part of supporting explanations for phenomena.	We think from middle school that dissolving is a physical change and not a chemical reaction and so we try dissolving solid KCl in water to see if it causes a temperature drop. It does! *Isn't KCl dissolving in water a physical change? Maybe it's really a chemical change? We're not sure.* If it is a physical change, that means that it's not just chemical reactions that make things get colder. **We should make sure that it is a physical change.** We think that when a salt dissolves the salt is still there, it has just been broken down to really small pieces. If dissolving is really a physical change we should be able to get the salt back if we evaporated off the water. If dissolving KCl in water is a chemical reaction, then we would get something new and we would not be able to get the KCl back. We check to see if we can get KCl back if we can evaporate off the water. We can, so we think that it is just a physical change rather than a chemical reaction. Therefore processes besides chemical reactions must also absorb thermal energy - it seems to just disappear. Other investigations provide evidence that: (1) the salt is still in the water even if we cannot see it and (2) the total amount of "stuff" is not changing. So the evidence we have that we need to make sure we include in all future explanations of these phenomena is: 1) Things can get colder when they mix in both chemical reactions and physical changes 2) When KCl is added to water, we no longer see it but it is definitely still there and nothing new seems to be formed *Where is the thermal energy in the water going?* **We need to think about this process and come up with an answer.** In some classes, we didn't all agree on whether water at room temperature has thermal energy, so we want to see if room-temperature water has energy. We know that hot water has thermal energy that transfers to its surroundings. If room-temperature water has energy, it should act the same way with cold water as hot water does with room-temperature water. And some of us were wondering, *"Why anything changes temperature (why do cool things like ice warm up and warm things like a cup of hot water, cool down)"* We think that the surrounding air interacts with it to cause this to happen. But this led to another question, *"How does air cool some things down and warm other things up?"*

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			Next steps: The main two reasons why we would investigate further: (1) If we aren't convinced that room temp water has any energy to do anything OR (2) we don't readily argue that typically, like for water, when something warms up something else cools down because of energy transfer.

Next Lesson….Where we're going Students will explore temperature to better understand generally what temperature is and how things change temperature. Students will study systems of changing temperature and come to a consensus that (1) everything has thermal energy; (2) a change in thermal energy can be explained through particle collisions; and (3) energy is always conserved in a system.

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Getting Ready: Materials Preparation

Materials For Small Groups

- 100 or 250 mL beaker (2)
- Thermometer sensitive enough to detect changes of a few degrees
- Tray to measure out chemicals in

Preparation of Materials

- DAY 1:
  - Have balance, potassium chloride and distilled water ready
  - Have materials for the first experiment on students lab tables
  - Have some potential useful materials for second experiment ready
  - Every student should have safety goggles
- DAY 2:
  - Have the video of the flame test at this link loaded
  - Potassium chloride, sodium chloride and flame test set-up ready

Materials For Each Student

- Lesson 2: Student Activity Sheets (1)
- Lesson 2: Home Learning Assignment (1)
- Safety goggles

Materials Shared Between Classes.

- Chemicals: potassium chloride, sodium chloride (table salt) and distilled water
- Lab balance and scoopulas for each chemical
- Multimeter (if necessary)
- Bunsen burner (or propane torch) and nichrome wire for flame test
- Set up to evaporate water from a 100 mL beaker
- Extra thermometers
- Lab balance, scoopula, and weighing trays

Safety

- Potassium chloride is HARMFUL

Materials For Each Class

- Posters to keep track of evidence or definitions if necessary
- 250 mL beaker to dissolve KCl in order to have saturated solution
- Wooden stirrer to place into saturated solution

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Learning Plan: Will the temperature still drop if we mix two things and no chemical reaction occurs? (90 min)

DAY 1 - 45 minutes

1. (10 min) Recap what happened the previous day with this students. Remind students that this investigation is motivated by our question: Did it get cold because it's a chemical reaction? Do other processes (not chemical reactions) cause their surroundings to get colder?

Suggested Prompts:

➔ What question did we decide to investigate today?
➔ How did we decide that we will proceed with this investigation?

So now we're looking at something we're pretty sure is not a chemical reaction -- dissolving salt. If you have not already, have the students predict what they believe will happen with the temperature before doing the experiment.

Have students do Experiment 3 in small groups, following the procedures in their packet.

- **Measure and record the temperature of ~50 mL of room-temperature water below.**
- **Measure ~3g of salt (potassium chloride, KCl) and record its temperature.**
- **Add the salt to the water and stir it in.**
- **Record the lowest temperature of the mixture. Graph the temperature change.**
-

While the students are doing this, dissolve ~35.2 g of KCl in ~100 mL of water in the front of the classroom and put a wooden applicator or coffee stirrer inside. This will later be used as a demo, but if students ask just say that you are doing the same thing as them but with larger amounts! You can take the temperature of your solution before and after and add your data to the class data if

Teacher Supports & Notes

Additional Guidance

A This should be a familiar pattern because in Experiment 2, with pink lemonade, baking soda, and water, the class data should also not be homogenous. Both of these are great opportunities to talk about different reasons students might have different data.

Perhaps there were differences in measurement. Did all students measure the temperature at the same point? Could the temperature have changed more after they wrote down their final temperature? Maybe even some students read the thermometer differently!

If students bring up the idea that they might not have used the same AMOUNT of stuff and that might have impacted their data, highlight that point. Have students think about why the amount of stuff used might be related to the temperature drop. This idea will be explored later in this unit, and perhaps even later in this class, so discussing it a little now is wonderful

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you make it clear that you used more water and much more KCl than the students used in their experiments.

Have students come up and record on the board how much salt they used, how much water they used, and what their change in temperature is.

---

2. (10 min) As a class, look for any patterns that exist in the data collected.

Suggested Prompts:
- ➔ Our question was do only chemical reactions get colder
- ➔ Is this pattern similar or different to the pattern we saw in our previous investigations?
- ➔ The change in temperature that each group found is not the same across groups. Should it be? Why or why not? A

The class will quickly notice that the temperature is dropping just like it did for the two chemical reactions we saw. Celebrate the fact that we have now collected new evidence that disproves our working theory that perhaps the temperature dropped because it was a chemical reaction -- this is so cool! This is science! B

Have students turn to the person next to them and talk together about what they believe is happening when potassium chloride dissolves.

Suggested Prompts:
- ➔ What do we think is happening when we put potassium chloride in water? Is it dissolving?
- ➔ What does dissolving even mean?
- ➔ Is this phenomenon similar to or different from the chemical reactions we have already seen?
- ➔ Is this a physical change or a chemical reaction? What evidence would we need to collect to be able to know if it was one or the other? C

After having students talk with their partner for ~1-2 minutes, return to a class discussion having

motivation.

Additional Guidance

B This is a really important moment because we want to be building a celebratory environment here (i.e., we just figured something out!) instead of a frustrated environment (i.e., that stinks, we were wrong).

In science, as we develop models and explanations for what is happening in the world around us, we are constantly adapting, revising, and changing our ideas as we gain new evidence. We had a theory, we tested that theory by collecting new evidence, and now we can reject that theory! That is so cool! We have accomplished something and so we should treat this as an accomplishment.

Additional Guidance

C The definition of what a chemical reaction is something that we will return to. Right now it is not essential that students have a perfect definition, but they should have an idea that in chemical reactions you get something new and in physical changes you still have the same substances, they

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students share what they spoke about with their partners and any new ideas they might have. If there are any new questions, add them to the Driving Question Board.
At this point the class is no longer confident if this is a physical change or not and so the class is motivated to better understand what exactly is happening when we dissolve potassium chloride in water.

Have a brainstorming session with the class to come up with potential investigations that could be done to discover what is happening when we dissolve potassium chloride in water.

Push students to think about how we would know if the KCl is still there throughout the entire dissolution process.

Suggested Prompts:

➔ How would we know that the potassium chloride is not changing into something new when it is dissolved in water? What evidence would we need to collect?

At least one group should be investigating to see if the KCl is still there if they evaporate off the water. If no students suggest this idea, you should present it to the class for their consideration. Another productive investigation to suggest is massing the solution before and after combining the KCl and water.

Make sure the class comes to consensus on this point:

- **If dissolving KCl in water is really a physical change, then we should be able to get KCl back if we evaporated off the water. If dissolving KCl in water is a chemical reaction, then we would get something new and we would not be able to get the KCl back.**

---

3. (20 minutes) Have students choose one of the investigations discussed in class, or design another investigation, to pursue in their small groups. Have them outline what the goal of their investigation is, make predictions, collect evidence, record their procedure and write down their

might just look different. In other words, chemical reactions are irreversible while physical changes are reversible.

It is okay if students give other evidence for what is considered a chemical reaction (e.g., temperature change) but push back and ask "If there is a _____, does that definitely mean that it is a chemical reaction? What evidence would we need to know for sure that a chemical reaction is occurring?"

Work through different examples of known chemical reactions to get at this reversible/irreversible, no new stuff/new stuff dichotomy if necessary.

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conclusions.

Make sure that the group (or groups) that do the evaporation investigation do not clean up their materials because you will need the evaporated KCl for the flame test demo the next day.

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4. (5 minutes) In the last few minutes of class, remind the students that potassium chloride is a chemical salt that is not safe for us to touch or ingest. Ask them if they can think of a parallel phenomenon to dissolving potassium chloride in water.

Suggested Prompts:

- Potassium chloride is a chemical salt that is not safe for us to touch or ingest. Is there another substance you know of that might act similarly to potassium when mixed with water?

Students might bring up that table salt (sodium chloride) dissolves in water and that is a safe chemical. If they do not, ask them if they think this is a good parallel to consider or not.

If students wonder if dissolving sodium chloride in water also results in a drop in temperature , quickly dissolve ~3-4 g of NaCl in 50 g of water (the more salt, the larger the temperature drop, however the solution will only drop ~1 degree celsius).

Do not worry about getting an exact temperature drop, just emphasize that it is dropping! If you spend too much time on this, room temperature will just cause the temperature of the water to rise again so do this demo quickly and have one student come up and attest to the drop in temperature.

If students ask why the drop is smaller than it was for KCl tell them that is a great question and we will return to it (in lesson 6). Instead focus on the class coming to consensus that these seem to be parallel processes.

nextgenstorylines.org

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HOME LEARNING ASSIGNMENT: Give students a home learning assignment that night. Have them go home and taste some salt. Then have them dissolve some in water and then drink (or at least taste) the water. Ask them to report tomorrow if they believe that the table salt was still in the water after it was dissolved in the water.

DAY 2 - 45 minutes

1. (10 minutes) Have the students report what they discovered in their home learning investigation. Come to a consensus that it seems like the table salt is still in the water after it has dissolved.

Next turn to your other investigations from the day before to see if they support that theory.

Have one student from each group summarize their group's findings from the day before to the class.

Emphasize that students should support their conclusion with evidence from their investigation. D

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2. (15 minutes) After presenting all the data, ask students what they believe this evidence indicates.

Suggested Prompts:

- ➔ Is dissolving potassium chloride in water a physical change or a chemical reaction?
- ➔ Our theory was that if KCl was a physical change, then we should be able to get the KCl back if we evaporated off the water. Did we? How do we know?

Students might be convinced at this point that this was a physical change, but push them to think about how we *know* that the leftover residue is definitely still potassium chloride. E

Additional Guidance

D This is a great opportunity to get students to engage with other students work. Instead of you restating a group's claim, ask a student from another group to restate the claim. Encourage students to ask questions about each other's claims. Perhaps you might have the students construct a chart in the front of the room that accurately captures their classmates claims and supporting evidence. You want to try and encourage an environment where the entire class is engaging in this discussion as opposed to merely you and the student representing his or her group.

Additional Guidance

D Emphasize to students that scientists work to support their claims with evidence gathered first hand, from data they collect investigations they conduct, or second hand using data from other people's investigations that they conducted.

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Keep the following conversation short, it is merely a motivation for the three flame tests you are about to do as a demo. If students seem very confused consider using LESSON 2b as an extension to this unit in order to have more time to explore this idea. Otherwise continue on with this lesson as planned.

Suggested Prompts:

- ➔ Is it possible that this is a different white powdery substance? Why or why not?
- ➔ What properties would the leftover substance need to have for us to know that it is definitely potassium chloride?
- ➔ Generally what are properties that we know that substances retain no matter what form they are in? F

Possible *student responses*:

- ➔ *I could taste the salt when it was a solid and when it was dissolved in water so taste!*
- ➔ *I think things can smell the same maybe if they are in different forms.*
- ➔ *What about color? When we dissolved the pink lemonade in water it stayed pink.*

Tell students that some substances have a property where when they burn they emit a specific color flame and that can be used to identify that substance. It turns out that potassium chloride is one of those substances!

At this point take (1) some solid KCl from the labeled jar; (2) the wooden stick that has been soaking in the saturated KCl solution; and (3) some solid KCl that was leftover after the water was evaporated off. Do a flame test on all three substances. All should produce a violet flame. G

To emphasize the violet flame effect, have students watch a 30 second video (found here) that demonstrates the different color flames that substances can produce to emphasize that violet flame can be used as an identifying factor.

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3. (15 minutes) Have students work in small groups for ~5 minutes to think about 1) if dissolving

Additional Guidance

F At this point, you may want to define what a property and post it on the wall is if you haven't done this before in previous units.

Additional Guidance

G You can find a more detailed flame test procedure with nichrome wire here and a more detailed flame test procedure with a wooden applicator in a saturated solution here.

Make sure to first clean the nichrome wire with hydrochloric acid before the flame test.

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KCl in water is a chemical reaction or a physical change and 2) what exactly happens as KCl (or anything) dissolves in water.

Then return to a full class discussion to ask students to share their ideas and come to a consensus as to whether or not dissolving KCl in water is a physical change and what our definition of dissolving is.

Suggested Prompts:

➔ Based on your investigations, do you think this process is a chemical reaction or a physical change? What evidence do you have to support this idea?
➔ Based on your investigations and what we know about dissolving, can we come up with a definition for dissolving?
➔ Now that we have a better understanding of what happens when KCl is added to water, is this phenomenon similar to or different from the chemical reactions we have already seen?
➔ Why does the temperature drop when KCl is dissolved in water?

It may be useful to add some of the evidence students have collected to a poster titled: Evidence We Must Account For. It may be useful to write down the class consensus of what dissolving means on a poster titled: Scientific Terms We Have Defined.

Make sure the class comes to consensus on these points:

- **KCl dissolving in water is NOT a chemical reaction because KCl is still there as evidenced by massing the solution, evaporating the water, and the flame tests.**
- **Dissolution can be understood as a substance splitting into smaller and smaller pieces until it can no longer be seen, but it is still there**
- **When KCl is dissolved in water, the temperature drops in a way that seems similar to what we saw with the two chemical reactions because in all cases these phenomena began with room temperature substances. But we'd like to know more…**
- **Depending on the class investigations, we may know that the more KCl that is dissolved in**

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water the larger the drop in temperature

NEXT STEPS: At this point the students should still be wondering WHY the temperature is dropping in all three of these phenomena. Encourage any and all questions about this to be added to the Driving Question Board.
Ask the students if they think they should focus on one of the three phenomena for simplicities sake, before ultimately returning to the other two phenomena.

Help motivate the students to choose to focus on the dissolution of potassium chloride as opposed to the two chemical reactions, because at least in the dissolution of KCl the class has some idea as to mechanistically what is happening.

Once the class has decided to focus on the dissolution of KCl as a phenomena, we should feel comfortable deciding that our next big question that we need to answer is WHY is the temperature dropping when KCl is dissolved in water.

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5. (5 minutes) Before moving on do a quick check in on what the students know about thermal energy and temperature transfer.

Suggested Prompts:
- ➔ Remind me, how did we define thermal energy? What about kinetic energy?
- ➔ Does everything have thermal energy? What about this table? What about the water sitting in that bottle?

If students are able to define kinetic energy as the energy that comes from the motion of particles and thermal energy as a measure of the average kinetic energy (how fast particles are moving) AND reason that everything has thermal energy because it can get hotter or colder then prompt students to begin to think about why the temperature is dropping when we dissolve KCl in water.

Suggested Prompts:
- ➔ Why is the thermal energy decreasing when KCl is dissolved in water?

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- ➔ What is happening to the thermal and kinetic energy?
- ➔ Why do you think that is happening?

If students do not have strong conceptions of these ideas start focusing the discussion on students questions about thermal energy. H

Possible *student responses*:

- ➔ *How could water at room temperature have thermal energy?*
- ➔ *How does something change temperature?*
- ➔ *Why does putting an ice cube out in the room make the ice cube melt, but putting a hot coffee in the room make the coffee cool down?*

Use these questions to motivate going to LESSON 2a where we will explore how air cools some things down and warm other things up.

If students seem to have mastered these ideas you can go to LESSON 3 where you will explore why the thermal energy is decreasing when you dissolve potassium chloride in water.

Additional Guidance

H If you can't tell for certain whether students have a strong model of thermal energy as a measure of the sum of all the particle level kinetic energy, then err on the side of caution and assume that students will need to develop this idea further in lesson 2a

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Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 2a: How does air cool some things down and warm other things up?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been: Students now know that in both chemical reactions AND in physical changes (i.e., dissolution) the temperature can drop despite starting with materials that are all the same temperature.

This Lesson....What we are doing now: Students will explore temperature to better understand generally what temperature is and how things change temperature. Students will study systems of changing temperature and come to a consensus that (1) everything has thermal energy; (2) a change in thermal energy can be explained through particle collisions; and (3) energy is always conserved in a system.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L2a (optional): How does air cool some things down and warm other things up? (2 periods) *Building toward* ⬇ *NGSS PEs: HS-PS1-4.*	**Ask questions** and evaluate them to determine if they are testable and relevant *in order to motivate taking extended time to explore thermal energy transfer between systems.* **Engage in Argumentation from Evidence** and respectfully provide and receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions *in order to come to a consensus understanding of what temperature is and how thermal energy is transferred between systems.*	**Planning and Carrying Out Investigations** "Select appropriate tools to collect, record, analyze, and evaluate data." "Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated." **Analyzing and Interpreting Data** "Evaluate the impact of new data on a working explanation and/or model of a pro	We place a hot water beaker in a room-temperature air closed box and we place a cold water beaker in a room-temperature air closed box. We measure the temperatures of the air and water over time. We model the system (Model 2a, building on Model 1) using what we know about particles and temperature and notice some new things we need to include in future models: We discover that: • We can transfer thermal energy between particles of stuff through particle collisions, even when we don't intermix the particles of the stuff together other • Energy doesn't disappear, it gets transferred to something else [e.g. to or from the surrounding matter (air)] • Everything has thermal energy We suspect that the amount of particles also influence the amount and rate of thermal energy transfer (based on prior experience and the past two lessons). We add any new depictions we have now decided to to our chart (from lesson 1) of ways we want to represent things. We agree that when modeling any kind cooling/heating phenomena (dissolving, chem reaction, or sitting in a beaker): • When particles at different speeds hit each other their kinetic energy changes: fast (hot) particles slow down and slow (cold) particles heat up • Particle energies are all relative • We need to always account to where the energy is going because energy is conserved (it doesn't disappear) *So why is the thermal energy decreasing when we dissolve potassium chloride in water considering that it cannot disappear but everything begins at the same temperature? Why are the particles slowing down? Can particle collisions account for this change in temperature?* **We decide to return to our example of salt dissolving in water to try and understand why thermal energy is decreasing when the salt, water, and air all begin at the same temperature.**

Next Lesson....Where we're going: Students come up with theories as to what is making the particles slowing down ultimately deciding that perhaps particles are slowing down because energy is being used to break apart the potassium chloride into smaller pieces so that it can dissolve.

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Getting Ready: Materials Preparation

Materials For Small Groups

- 250 mL beaker
- Thermometers (2)
- Coffee can with inserts for the thermometers in lid
- Ice and boiling water
- Timer

Preparation of Materials

- Poke two small holes in a box or container (e.g., large coffee cans with lids) so that students can simultaneously measure air temperature and water temperature
- Ice water and hot water available for students to fill their beakers with

Materials For Each Student

- Lesson 2a: Student Activity Sheets (1)

Materials Shared Between Classes.

- ~12 Marbles if necessary

Safety

- N/A

Materials For Each Class

- Posters (1 per small group)

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Learning Plan: How does air cool some things down and warm other things up? (90 min)

Teacher Supports & Notes

DAY 1 - 45 minutes

1. (5 min) Recap what happened the previous day with this students.

The class has seen that combining room temperature substances can result in a drop in temperature in both chemical reactions and physical changes like dissolving.

Remind students that this next investigation is motivated by our questions about temperature and an attempt to better understand other processes that involve changes in thermal energy such as stuff cooling down or warming up. The point of this next investigation is to try and understand how air cools some things down and warms other things up.

Before doing this investigation, ask students for their thoughts on the experiment:

Suggested Prompts:

- ➔ Why are we doing this investigation? What question is motivating this investigation?
- ➔ What are we trying to find out in this investigation?
- ➔ What data do you think we should collect? What should we be measuring the temperature of? Why?
- ➔ What are students predictions as to what will happen during this investigation?

---

2. (15 min) The students break into small groups and do one of two experiments:

- **Place a beaker filled with hot water in a room-temperature air closed box**
- **Place a beaker filled with ice in a room-temperature air closed box**

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Make sure that the students take the temperature of everything that may be experiencing changes in thermal energy multiple times over this experiment!

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3. (5 minutes) The students discuss their results and the class notices the pattern that as the temperature of the water/ice changes, so does the surrounding air!

Push students to unpack *why* this pattern may exist by getting students to articulate (1) how the water and air might interact and (2) that the temperature is changing, but not the substance.

Suggested Prompts:

- ➔ What happened to the temperature of the air? What happened to the temperature of the water?
- ➔ Why is both the temperature of the surrounding air AND the water changing?
- ➔ How does the temperature change of the air relate to the temperature change in water?
- ➔ Do the water and air interact in some way? Where? How?
- ➔ Are the water and air changing in any way? Is this a physical change? A chemical reaction? Neither?

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4. (5 minutes) Have students spend some time individually modeling the temperature changes they saw in the system that they studied.

Remind students that they should choose one scenario: water cooling down or water warming up and attempt to model that instead of attempting to model both simultaneously. However, remind students to keep in mind that it is highly possible that these phenomena are related so they should think about how their explanation might work for the other scenario.

---

5. (15 minutes) Have the students work in their small groups to draw out these models making sure that they are representing temperature the way the class decided to during lesson 1 by modeling at the particle level, accounting for changes in temperature with particle speed.

Additional Guidance

A This process can be complicated if students do not already have a particulate model of nature and view the world as mostly empty space with particles that move around in it. Ideally this unit should be more fully paused to spend time exploring this idea. However, if you are fully committed to this unit you can instead use this small group time to go around from table to table guiding the students towards an understanding of particles moving in space that have a potential to collide.

Push students to think about what would happen if a faster moving particle collided with a slower moving particle. Would they both remain the same speed? Would they

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Remind students to make sure that their model accounts for why the temperature of the air changes inversely from the temperature of the water. A

DAY 2 - 45 minutes

1. (5 minutes) Have a quick recap to remind the students what they were trying to capture in their models: what happens when water cools down or warms up and how that is related to the air changing temperature inversely.

Have students quickly go over what we saw in each scenario and what we know about temperature already (i.e., that particles moving faster are hotter and particles moving slower are colder). Use this conversation to transition into the model presentations.

2. (30 minutes) Before beginning the model presentations, encourage students to listen carefully and to ask question about both the content of the model and the representations chosen. More specifically, tell students to think about if the model presented:

1. **Accounts for all of the evidence we know based on what we saw in the investigation and what we know about temperature;**
2. **Utilizes the representations we came up with in the class previously**

Have each group present for ~2 minutes with ~2 minutes of questions. If the class discussion is productive, do not cut it off. Have the students who presented manage the discussion, calling on students or yourself to hear questions. B

Instead of summarizing the model yourself, call on someone and ask them to summarize what the group has presented. Prompt students to share their thoughts and concerns about the model being presented.

slow down? Speed up?

Have some marbles on hand for the students to play with in order to explore what would happen as they come up with their model for how air could warm up or cool down water?

If students are struggling with this idea then spend another day exploring this idea until students feel comfortable with the idea of heat transfer through particle collisions.

Additional Guidance

B A key part of developing a community of learners is to have the students take on the role of productively critiquing each other's ideas. The goal is for students to take authority during these conversations instead of the teacher. However, at this point you might need to model these types of interactions for the students to see what constructive criticism, clarifying questions, holding ideas accountable to evidence, and building on others' ideas looks like. You can do this by using Talk Moves, encouraging students to explain their reasoning further and pushing students to engage with others' ideas.

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Suggested Prompts:

- ➔ Are you convinced that this model accounts for why the water gets cooler, the air gets warmer and vice versa?
- ➔ How does this group depict the change in temperature in their model? Does this make sense with what we know about temperature?
- ➔ Does this group's argument about how the air and water interact make sense? Why or why not?
- ➔ Do you agree with this group's explanation? Why or why not?

---

3. (10 minutes) Have a class discussion about the different models we saw as class. Have the class work together to come up with a consensus model that explains the changes in thermal energy we saw.

Suggested Prompts:

- ➔ After these presentations, what is our consensus idea as to what is happening at the particle level when cold water warms up or hot water cools down?
- ➔ When hot water cools down, where is that thermal energy going? Is it going anywhere?
- ➔ How is thermal energy transferred?
- ➔ Do you think everything changes temperature due to this same mechanism? Why or why not?
- ➔ Does anything not have thermal energy? What would it mean for something to have NO thermal energy at all?
- ➔ What about the room temperature items we used in our previous investigations? Do they have thermal energy? For example, does room temperature water have thermal energy?

Make sure the class comes to consensus on these points:

- **Thermal energy can be transferred between particles of stuff via particle collisions, even if we aren't mixing anything**
- **Thermal energy (and all energy) does not disappear, it gets transferred to something else (e.g., to the surrounding air)**

Since this is likely the first time students are truly engaging in this way, focus your support at this point at creating a positive and productive discursive environment. Practically this means that you should use this opportunity to emphasize two things, (1) how students should talk to one another, and (2) the fact that there are no wrong answers :

(1) Students should be reminded that they are NOT criticizing each other, rather they are respectfully talking about the ideas on the table. As such:
  - (a) Feel free to raise their hand and say something positive about the model being presented -- something they like or agree with.
  - (b) Ask questions that try to uncover what the presenters intended before critiquing an idea. It is not productive to say, "That's a stupid idea". It is productive to say, "What did you mean by this? I found this confusing." And then follow up by saying, "I am not sure I agree with that idea because of ...".
  - (c) If a student is critiquing an idea they should try and provide evidence as to why they believe the presenters idea is flawed or

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- Everything has thermal energy, even room temperature water, because it has a temperature. Changing an item's temperature means changing its thermal energy C

We add any new depictions we have now decided to to our chart (from lesson 1) of ways we want to represent things since we now agree that when modeling any kind of cooling/heating phenomena (dissolving, chemical reaction, or sitting in a beaker):

- **When particles at different speeds hit each other, their kinetic energy changes: fast (hot) particles slow down and slow (cold) particles heat up**
- **Particle energies are all relative**
- **We need to always account for where the energy is going because energy is conserved (it does not disappear)**

Spend a few minutes at the end of class mapping the idea of energy transfer to the dissolution of potassium chloride in water.

Push on the following ideas:

- **In the situation of water cooling off/warming up the water and air are at different temperatures while in the case of potassium chloride in water the substances are at the same temperature.**
- **In the situation of water cooling off/warming up the water and air are not changing in any physical way, they are only changing temperature. In the situation of the potassium chloride dissolving in water, the potassium is physically changing as it is broken down into smaller and smaller pieces.**

Suggested Prompts:

➔ Is dissolving potassium chloride in water similar or different from water cooling off or warming up? Press students to verbalize why they came to this decision.

This leaves the class with many new questions!

incomplete in some way. In other words, students should be encouraged to say more than "I disagree (or agree)". They must say "I disagree (or agree) because...".

(2) Students may be reluctant to share their ideas because they are worried about having the correct answer. Emphasize to students that no idea is "wrong" as long as it accounts for all of the evidence we have collected as a class.
That being said, even ideas that only partially account for evidence should be shared because every idea is valuable in that it might inspire another idea. Therefore, students are rewarded for sharing any and all ideas. When building explanations as a class NO IDEA IS TREATED AS WRONG, all ideas are contributions to the collective knowledge building process.

Additional Guidance

C It is possible that this line of questioning will lead the class to talk about whether or not solids have thermal energy and how one would model that.

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Why is the thermal energy decreasing when we dissolve potassium chloride in water? Why are the particles slowing down if both substances begin at the same temperature? Can particle collisions account for this change in temperature? Where is the thermal energy going when we dissolve potassium chloride in water?

NEXT STEPS: ***We decide to return to our example of salt dissolving in water to try and understand why thermal energy is decreasing when the salt, water, and air all begin at the same temperature.***

What does it mean for the room temperature potassium chloride to have thermal energy?

This idea will be addressed more fully in lesson 8 so it is okay if the students do not address this now. But if the students naturally begin to discuss this do not cut this discussion short!

As a class, try and model what salt, water, and air would look like at the same temperature even if they are different phases. We already have a way of depicting movement of atoms in a gas and a liquid, but what about in a solid? Try different ways of depicting energy in a solid and eventually come to a class consensus that since the solid is barely moving, energy in a solid would be like vibrations.

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Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 3: Why is the thermal energy decreasing?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Lesson....Where we've been Students now know that in both chemical reactions AND in physical changes (i.e., dissolution) the temperature can drop despite starting with materials that are all the same temperature. They also know that this drop in temperature is due to the particles slowing down, but we do not yet know WHY the particles are slowing down considering that everything began at the same temperature.

This Lesson....What we are doing now: Students come up with theories as to what is making the particles slowing down ultimately deciding that perhaps particles are slowing down because energy is being used to break apart the potassium chloride into smaller pieces so that it can dissolve.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L3: Why is the thermal energy decreasing when potassium chloride dissolves in water? (2 periods)	Previous phenomenon from L2: Dissolving potassium chloride in water results in a temperature drop.	**Develop a model** based on evidence to illustrate the relationships between components of a system *to answer why the temperature is decreasing when KCl dissolves in water by tracking where the energy is going.*	We develop our own models (Model 3, building on 1 and 2) to try and explain why the thermal energy is decreasing when potassium chloride dissolves in water. After arguing and discussing our different ideas, we decide that: • All that is happening in dissolution (as far as we know) is atoms breaking away from each other (from a solid to go into the liquid) • Thermal energy appears to have gone missing, and we know we have to be able to track energy (it can't disappear) • The energy must be used to break the connection between atoms. This makes sense, as more connections are broken and more energy absorbed if we use more KCl • Thermal energy is just kinetic energy at the molecular level, so when that energy is used to break connections, overall thermal energy decreases and that is why the surroundings become colder *What should we call this process?* Since the energy is going into the system from the surroundings, the name "endothermic" makes sense (for thermal energy going in). *Wait, what IS this connection that we're breaking? Why do we need energy to break it? Why isn't the energy just transferring like it did when water was cooling off/heating up? And where is the energy going after it breaks the connection since it cannot disappear?* **We decide to investigate what is holding the potassium chloride together in the first place to try and understand why the thermal energy is decreasing when these connections are broken.**

Next Lesson....Where we're going Students want to understand what was holding together the potassium chloride together in the first place that requires energy to break.

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Getting Ready: Materials Preparation

Materials For Small Groups

- Poster board
- Markers and pens

Preparation of Materials

- Set up modeling supplies for students

Materials For Each Student

- Lesson 3: Student Activity Sheets (1)

Materials Shared Between Classes.

- Markers and pens

Safety

- N/A

Materials For Each Class

- Poster boards

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Learning Plan: Why is the thermal energy decreasing when KCl is dissolved in water? (90 min)

DAY 1 - 45 minutes

1. (5 min) Recap what happened the previous day with this students. Go over with students the evidence we have collected thus far and the ways we have decided to depict these phenomena in our models:

- **Evidence the class has collected:**
  - **Combining room temperature substances can result in a drop in temperature in both chemical reactions and physical changes like dissolving**
  - **Temperature is just a measure of thermal energy, or the average kinetic energy of the particles (i.e., how quickly particles are moving)**
  - **Everything has thermal energy and that energy is conserved**
  - **Substances of different temperatures can transfer thermal energy through particle collisions**
- **Ways the class is depicting things:**
  - **We have decided our models must include particle-level interactions**
  - **We have ways of depicting different types and different amounts of particles**
  - **We know that kinetic energy is the energy that comes from the motion of particles and thermal energy is a measure of the average kinetic energy, so we have a way to depict relative motion of particles in order to represent colder and hotter substances**
  - **Anything else the class has decided in addition to these (e.g., models must have a key; the model must have stages showing before, during, and after; etc.)**

Moving forward we want to make sure we think about these when modeling these phenomena.

Teacher Supports & Notes

Additional Guidance

A A key part of modeling, as mentioned in lesson 1, is that multiple models can be plausible as long as they account for the evidence we have collected as a class. Use this moment as an opportunity to remind students that we are NOT looking for one, correct answer. Rather we are looking for mechanistic explanations the students come up with that explain *why* the phenomena is occurring and account for all of the evidence we have collected.

Students may be worried about "guessing" since they do not know the "correct answer". Continue to emphasize the above point and the idea that while knowledge building there are no "wrong" or "right"

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2. (30 min) Before beginning the modeling activity, remind students why modeling is so important in our science class: this is our way of sharing ideas and working towards a consensus model that explains our driving question of "Why do room temperature substances get colder when mixed together?" A

Emphasize that not only does no one know the "right answer" at this point, we are not looking for a "right answer". We are looking for ideas that account for the evidence we have collected in order to collaboratively work together to build the best answer we can. We should be prepared that our answer might change dramatically as we collect more evidence we need to account for.

Have students spend a few moments thinking by themselves before working together in small groups to come up with a model that explains why the thermal energy is decreasing when potassium chloride dissolves in water.

Emphasize that our model should account for room temperature substances decreasing in temperature after the potassium chloride dissolves.

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3. (10 minutes) Have groups of students come up and present their model to the class.

Remind students of the classroom norms that we started to build the day before where we made sure to listen, then question/clarify to make sure the presenters intentions are understood, and then productively hold students ideas accountable to the evidence we have collected.

Have each group present for ~2 minutes with ~3 minutes of questions. If the class discussion is productive, do not cut it off.

Have the students who presented manage the discussion, calling on students or yourself to hear questions.

Encourage students to interact during these presentations by having them B:

- **Asking clarifying questions about things they don't understand**

answers. Every answer is productive.

You can also use this opportunity to remind students about aspects of modeling that you were noticing they were not incorporating into their models the previous few days.

Additional Guidance

B The previous lesson, the class worked on developing positive classroom norms and encouraging students to contribute because there are no wrong answers.

In this lesson, work to reinforce these classroom norms while also focusing more specifically prompting students to ask productive questions. These prompts will demonstrate to students the types of questions and comments they should be asking during model presentations.

In addition, encourage students to disagree with the model being presented if it contradicts or does not account for some of the evidence we have collected as a class. When students become passionate about their opinions, they are more likely to engage in genuine discussion about their peers' models.

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- **Providing additional evidence in support of or constructively against the model being presented**
- **Stating their position vis-a-vis the model being presented. Do they agree? Disagree? Why?**
- **Summarizing what someone else's explanation is**
- **Explaining how your model is similar or different to the model presented previously**

Remind students to take notes during others' presentations to help them with this.

DAY 2 - 45 minutes

4. (5 minutes) Before continuing with the presentations, have the students recap the models that were presented from the day before.

If possible, have students recap presentations from small groups other than their own.

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5. (30 minutes) Have groups of students come up and present their model to the class. Remind students of the classroom norms that we started to build the day before where we made sure to listen, then question/clarify to make sure the presenters intentions are understood, and then productively hold students ideas accountable to the evidence we have collected.

Have each group present for ~2 minutes with ~4 minutes of questions. If the class discussion is productive, do not cut it off. Have the students who presented manage the discussion, calling on students or yourself to hear questions.

See the previous day for more specific guidelines as to how to support students be active listeners engaged in the knowledge building process.

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6. (10 minutes) Spend some time having a consensus building conversation to figure out where the class stands after these presentations. C

Additional Guidance

C Building consensus is difficult if the entire class is silent. If students are hesitant to provide their opinion, encourage students to vote. Remind students that saying "I don't know" or abstaining will not move the class forward.

Emphasize that we are just trying to get a feeling of what the majority of class is thinking and make sure we are on the same page. We are not making any definite decisions now, we are just trying to come up with a working theory. We expect this theory to change as we collect more evidence!

Additional Guidance

D If students seem convinced that stirring is an important part of dissolving, ask students "Do you think something would dissolve if it wasn't stirred? Do you think stirring something in water always dissolves it?" Ask students to come up with some experiments to test these ideas.

For example, you can have students

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Suggested Prompts:

- After hearing all of the presentations, what do you feel is the most compelling answer to why the thermal energy is decreasing when KCl is dissolved in water? Why?
- Who disagrees with this idea? Why?
- What questions do we still have?

Make sure the class comes to consensus on these points: D

- **When salt dissolves it is breaking into smaller pieces**
- **We know that energy is conserved and thermal energy has decreased, but we are still not really sure where it went**
- **We think that the thermal energy was used to break the salt into smaller pieces. We think this makes sense because we saw the temperature drop more when we dissolve more salt, so it takes more energy to break down more stuff**
- **Since thermal energy is just kinetic energy at the particle level, and we think that energy is being used in order to break down the salt into smaller pieces, the overall thermal energy or temperature is decreasing and that's why it's getting colder**

We decide that we are going to officially define DISSOLVING as a physical change where something breaks into smaller pieces in a liquid.

We decide that we are going to call this process ENDOTHERMIC which means absorbing thermal energy since the energy is going from the surroundings into the system (the system is absorbing the thermal energy to do something with it). E

Add the words DISSOLVING and ENDOTHERMIC to our poster tracking scientific words that we have defined.

But we still have questions!

What is actually breaking when we break down potassium chloride? Why do we need energy to break it? Where is the energy even going after it breaks the connection if it can't disappear?

attempt to dissolve sand in water and see that no matter how hard they stir the sand will not dissolve.

If students seem convinced that the energy is leaving into the air, as many of them do, ask students "If energy was going off into the air what would that mean for the air?" Ask students to come up with ideas that would test whether or not energy is being released and so the temperature drops.

For example, you can return to the setup in 2a and measure the surrounding air as the salt dissolves and see that energy is seemingly NOT conserved in this situation. Before the temperature of the air changed inversely from the temperature of the water. Now the air temperature is unchanging (or even potentially getting colder, though the temperature change is so slight that is unlikely)!

Additional Guidance

E It is important to introduce this term, "endothermic" now so that students become comfortable with it and learn to use it appropriately. If it does not seem like a student is using the term correctly,

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NEXT STEPS: ***We decide to investigate what holds the potassium chloride together that is being broken down when potassium chloride dissolves.***

ask the class what the class thinks rather than correcting the student. Make sure not to make the student feel as if they are wrong. Instead say, “Interesting! You are using the term endothermic differently than I had thought to use it. Could you say that again? What does the class think about the use of the term endothermic in this way?” Make sure to be genuinely interested so students think of this as a part of learning and not as a place where they have done something wrong.

This is also a useful place to demonstrate to students that what they are learning is aligned with what scientists have discovered. This will help students feel productive despite being early on in their investigations.

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Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 4: What is connection between particles?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students know that in both chemical reactions AND in physical changes (i.e., dissolution) the temperature can drop despite starting with materials that are all the same temperature. The students have come up with a working theory that, in the case of dissolving KCl in water, the particles are slowing down because energy is being used to break apart the potassium chloride into smaller pieces.

This Lesson....What we are doing now: The students try and find a physical model for what might be holding the potassium chloride together in the first place. Ultimately, they decide based on the little they know about atomic structure, that magnets are the most productive model for the connection between particles.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L4: What is the connection between particles that is breaking when salt is dissolved? (1 period)	Previous phenomenon from L2: Dissolving potassium chloride in water results in a temperature drop. Different connection toys "stick" to each other with different structures. Some metallic ones are attracted or repelled from one another at a distance.	**Develop a Model** and evaluate the merits and limitations of different models of the same proposed mechanism or in order to select model that best fits the evidence *as to how particles are structurally connected to one another.*	We brainstorm different types of connections and decide to choose one that we think will be a good model for how particles are connected. Playing with a variety of connection toys leads us to decide that we don't want something that physically attaches. We want something that has an attractive "at-a-distance pull" between the atoms. Magnets or magnets and steel spheres are like that. So these magnets are a decent physical stand-in for the "structure" of the connection between atoms because they have positive and negative components that attract and repel, behaving similarly to the positive and negative parts of atoms. We think that connections are formed by the positive charges from one atom pulling on the negative charges from another atom. The forces of the charged parts of the atoms pull the atoms together. What is similar is that to separate the charges or magnets from each other: • We have to pull the parts apart against the direction of an at-a-distance force - we need to apply force to overcome a force field--it takes energy to move against the direction of a force • We don't have to apply a force for them to come back together, that force to pull them back together is already in the system of two parts. • Some parts of the magnets pull together and some push apart • They pull together and push apart when put in certain configurations/orientations • They pull together and push apart when close enough together (distance matters) *What should we call this connection?* Some of us say we've heard people talk about bonds, which sounds like a good name. *What does this look like? It's hard to visualize, especially since magnets seem to have some problems as a model.* Our tentative picture is called Model 4. *But now we are left wondering can we truly attribute the loss in thermal energy to the fact that bonds are being broken? What exactly is happening when bonds break and how does that lead to a decrease in thermal energy?* **We decide to play with magnets as a model or representation of bonds in order to better understand the loss of thermal energy that is occurring when potassium chloride dissolves in water.**

Next Lesson....Where we're going Students want to understand how breaking these connection results in a decrease in thermal energy, mapping this idea onto the phenomena of KCl dissolving in water.

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Getting Ready: Materials Preparation

Materials For Each Student	*Materials Shared Between Classes.*
• Lesson 5: Student Activity Sheets (1)	• Magnets • Legos • Tape • Staples • String • Velcro • Any other connections that you feel will be productive

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Learning Plan: What is the connection between particles? (45 min)

Teacher Supports & Notes

1. (5 min) Recap what happened the previous day with this students. Remind student of our consensus working theory, that the thermal energy is decreasing because it is somehow being used to break down the potassium chloride into smaller pieces (i.e., dissolving it).

Have students articulate the motivation behind today's investigation: that we are trying to figure out more about what the connection is that is breaking when we dissolve potassium chloride in water.

In order to better understand the connection between particles, let's first think about different types of connections that we know about. Have a brainstorming discussion about different ways we know that two things can be connected (e.g., tape, rubber bands, staples, magnets, glue, velcro).

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2. (15 min) Have students work in small groups and manipulate and play with as many of their brainstormed connections as possible.

Remind students that we are looking for a connection that can be *used as a physical representation of how particles are connected* and so we don't expect any of these to be perfect. We are just looking for the best option given what we know.
You can either give each table a pile of options or have students rotate through tables to see as many different types of connections as possible.

Help them think about how these connections might be similar or different to how particles are connected.

Suggested Prompts:

➔ What do you know about the pieces of atoms? Do any of these connections model these properties?

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- How do you think that particles connect? Do you think that they must touch in order to connect? Could they sense other particles at a distance? Do any of these connections model these properties? [A]

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3. (10 minutes) Have students share out what they, as a small group, felt was the best physical representation of how particles are connected. Encourage them to share the pros and cons of their choice.

Suggested Prompts:

- What connection do you think is the best model of the connection between particles?
- Why do you think this model is the best representation of the connection between particles?
- What weaknesses, if any, does this model still have?
- What aspects of this connection between particles do we want to make sure to incorporate into our future models where we try to explain why the temperature drops when we dissolve potassium chloride in water?

Possible *student responses*:

- *We think magnets are a good model because they have positive and negative components that attract and repel which is similar to the positive and negative parts of atoms.*
- *We think that magnets are a good model because they can form connections with other magnets at a distance and we think that*
- *We realized that it takes energy to pull magnets (or any other connection) apart and we think that makes sense because it requires energy to break their connection*
- *We think that magnets are not a very good model because they can only be connected in one way and we think particles form more complex connections than that*
- *We think that legos are a good model because atoms are the building blocks of the world and legos can be used to build anything*

Additional Guidance

A This is a very difficult exercise because the students know next to nothing about atomic structure. That is okay! You can focus student thinking around what they might have heard about atomic structure (i.e., atoms have positive and negative pieces) and see if that leads students towards magnets.

However, the most compelling reason to choose magnets as a model over any other connection is the fact that magnetic forces can result in interactions and connections from a distance. Push on this as much as you can. As students if they think that particles must physically touch to connect and then ask them to identify any of the connections they are working with to see if any can model that behavior.

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Remind students that there is no correct or perfect answer, every model will have its pros and cons. Work with the class to come up with the class consensus on the most productive connection to use as a model for now.

Make sure the class comes to consensus on this point:

- **The most productive model for how particles connect is magnets** B

Once the class has chosen the connection they will be using, ask the class to name the connection between particles?

Suggested Prompts:

- ➔ What should we call this connection between particles?
- ➔ Do you think that this connection only exists between the potassium chloride particles? Or do you think it is a more general term?

Make sure the class comes to consensus on these points:

- **The connection will be called a BOND because that is a scientific word that we have heard before that we think makes sense in this context**
- **Bonds have the potential to exist between all particles, not just between potassium chloride particles**

Add the word BOND to the poster where we keep track of scientific words we have defined.

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4. (10 minutes) As a class, try and draw how a bond might work between particles.

Invite students up to the front of the class to try and draw their ideas on the board and work collaboratively to come up with a general model for a bond. C

Additional Guidance

B Importantly, any of these connections could be used as models for a bond. Continually emphasize to the class that any of these could work, but they all have have strengths and weaknesses. As a class we are just trying to choose the model that we believe will be the most productive for reasoning about the connection between particles. That does not make it any more or less correct than other options.

In fact, this is something that is true about science! All of our understanding of the world is a model that takes into account the evidence we have collected. Sometimes we have multiple models, even conflicting models, to explain the same phenomena because they have different affordances.

It is of course possible that the students will not choose magnets as a model for the connection between particles. If this happens, honor the students instincts and proceed with the following lessons utilizing whatever model they chose. If it is no longer productive than have them go and choose another model.

That being said, if you push on the idea that

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Suggested Prompts:

➔ How should we represent the positive and negative pieces of the atom?
➔ How should we represent the particles being able to attract or repel at a distance?

Make sure the class comes to consensus on these points:

- **Our models should include positive and negative pieces inside a particle generally, without quantifying the amount or pieces**
- **Our models should indicate that attraction (and maybe even repulsion) is possible from a distance**

The class may decide that they should have a way to indicate a gradient of attraction (i.e., that the attraction is stronger when the particles are closer together and the attraction is weaker when the particles are farther apart). This is great! But not necessary.

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5. (5 minutes) Summarize what we have determined--that magnets may be a productive way of conceptualizing the connection between particles.

But we still have questions: *Why is thermal energy lost when bonds are broken? What exactly is losing thermal energy and why is it lost and not transferred?*

NEXT STEPS: We decide to play with magnets as a model or representation of bonds in order to better understand the loss of thermal energy that is occurring when potassium chloride dissolves in water.

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magnets can act at a distance and have positive and negative pieces the students should decide that magnets are the most productive.

Additional Guidance

C Focus the students on the idea that we are trying to draw a *general* model for the interaction between particles since we still know so little.

We do not know that much about atomic structure so we do not want to be too specific about what atoms look like. Instead we want to focus on the how particles connect and a general representation of what about atoms facilitates this connection.

Encourage students to think beyond quantifying the amount of positive and negative charges and focus on the fact that particles contain both and they form connections due to those pieces, even from a distance.

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Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 5: How can magnets help us figure out why the temperature of substances drops when the bonds between the particles that make them up are broken?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been The students have decided that magnets are the most productive model for the connection between particles and that these connections are breaking when the potassium chloride dissolved.

This Lesson....What we are doing now: Students play with magnets to see if they can investigate what is happening when the connections between the potassium chloride are breaking and why there is a subsequent loss of thermal energy. Ultimately, the students decide that when a water particle collides with the KCl at a fast enough speed it can break the bond but it then decreases in speed, resulting in a decrease in temperature.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L5: How can magnets help us figure out why the temperature of substances drops when the bonds between the particles that make them up are broken? (2 periods) *Building toward*	Previous phenomenon from L2: Dissolving potassium chloride in water results in a temperature drop.	**Develop and Use a Complex Model** that allows for manipulation and testing of a proposed system *to better understand what happens to the system when chemical bonds are formed.* **Engage in Argumentation from Evidence** and respectfully provide and/ receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining	We design a setup of marbles and magnets that simulates the breaking of bonds. We then try and simulate what we think would happen if a water molecule and the potassium chloride collide and the bonds in the potassium chloride break! But are we absolutely certain that this model explains that KE is being *used* to break the bond, instead of just being transferred? Well if KE was being used what would that mean? That there would be less KE after the collision. Is there actually less KE in the marble after it collides with the magnets? Yes! The marble actually moves slower after the collision which explains the temperature drop. We know this because we look at the speed of the marble going down the ramp when it collides with the magnets and when there are no magnets for it to collide with and there is a significant drop in speed. We learn from this setup that: • When the magnetic marble is bonded, a light push of the non-magnetic marble will not succeed in breaking the bond. Instead the magnetic will just come back to it's bonded position. • When the magnetic marble is not bonded, a light push of the non-magnetic marble will succeed in pushing the magnetic marble down the track. We decide this is what happens when we are transferring energy. • If we want the magnetic marble to break its bond, we need need to push the non-magnetic marble hard enough so that the magnetic marble is not just pulled back into the bonded position. We find the minimum amount of energy needed to break the bond. We decide to call this the **bond energy**. We realize that KCl is simply breaking apart when it dissolves, but it can't break apart without the necessary energy to overcome the connection between the atoms. That energy comes from the kinetic energy of the surrounding particles. We know this because the surrounding particles are losing kinetic energy (aka getting colder) as the KCl dissolves. This makes sense because we now know that it takes energy to break bonds.

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⬇ *NGSS PEs:* *HS-PS1-4, HS-PS3-5*		additional information required to resolve contradictions *as the class works to come up with a consensus explanation as to how the energy of the system changes as atomic bonds are broken.*	We decide to update our models (utilizing what we know from model 3 and 4) and create Model 5 which mechanistically explains why the temperature is dropping when the potassium chloride dissolves: the water particles collide with the KCl, breaking the bonds between the KCl particles, and slowing down due to these collisions resulting in a drop in temperature. We come to consensus on this idea. This reminds of us of something we saw when first dissolving the potassium chloride - the more KCl we dissolved, the more the temperature dropped. *Why did the temperature drop more when we put more KCl in?* We hypothesize that this is because more thermal energy from the environment was needed to break the additional bonds, but we are now curious. *What about other chemicals? Do we always need more energy to dissolve more? Are all bonds the same? Is dissolving always the same?* **We decide to investigate the dissolution of other substances to see if we can find some answers to our questions.**

Next Lesson....Where we're going The students investigate to see if all substances' bonds require the same amount of energy or not to break and if it requires more energy to break more bonds..

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Getting Ready: Materials Preparation

Materials For Small Groups

- 1 or 2 glass marbles
- 1 metallic marble
- 2 to 3 rulers with varying strength magnets attached to them
- Textbooks or a ladder to prop up the rulers

Preparation of Materials

- Attach magnets to the rulers in advance providing enough time for the adhesive to dry.
  - Make sure to be consistent with which color ruler is associated with different strength magnets (i.e., blue = weak, yellow = medium, red = strong). You can attach multiple magnets to a ruler in order to increase strength if you would like.

Materials For Each Student

- Lesson 5: Student Activity Sheets (1)

Materials Shared Between Classes.

- Rulers with magnets attached
- Glass and metallic marbles

Safety

- N/A

Materials For Each Class

- Optional: Coffee or hot chocolate, hot water, cold water, two 100 mL beakers

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Learning Plan: How can magnets help us figure out why the temperature of substances drops when the bonds between the particles that makes them up are broken? (90 min)

DAY 1 - 45 minutes

1. (5 min) Recap what happened the previous day with this students. Summarize again what we have determined: that magnets may be a productive way of conceptualizing the connection between particles because they have positive and negative pieces that can attract and repel at a distance. Remind students that we have called this connection a bond.

Suggested Prompts:

- ➔ What did we decide to call the connection between particles?
- ➔ Did we decide that all particles have the potential to form bonds or is this term specific to the connections between potassium chloride particles?
- ➔ What physical connection did we decide would be most productive to use as a model for bonds?
- ➔ Why did we decide on this physical connection as a model for bonds? What aspects of bonds did we feel that magnets accounted for that made them productive?

Have students articulate the motivation behind today's lesson: to find out what exactly happens when a bond breaks and why, if at all, it results in the loss of thermal energy. A

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2. (5 min) Give the students some time to brainstorm how they might physically model a bond breaking. Show students the materials you are providing them with. Explain that there are rulers with magnets glued underneath them, metallic marbles that are attracted to magnets, and glass/wood/plastic marbles that are not attracted to magnets.

Teacher Supports & Notes

Additional Guidance

A This is a great moment to remind students that our working theory right now is that energy is used to break the bonds in the potassium chloride but we are not positive that is the case. There is just as much of a chance that we could disprove this theory as we could prove it true. Much of science is collecting evidence and revising or updating our theories and models appropriately.

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Make sure to go around to each small group to make sure they are having a productive conversation as students might need some guidance.

Suggested Prompts:

- If magnets are our model of a bond, then how would we model particles of KCl that are bonded?
- What else is present when KCl is dissolved in addition to KCl? Do you think we should represent that in our model? How would we represent it?
- Do you think the water should be represented by a metallic or non-metallic marble? Why?
- If water has kinetic energy, then what does that mean for our model? B
- How would you represent a broken bond?
- What in this system could cause the bond to break?
- If the temperature is decreasing, what is happening to the thermal energy? What is happening to the kinetic energy?
- How would you be able to collect evidence that kinetic energy is decreasing when a bond is broken in your setup?

Students will continue to explore these questions in their investigation, this time is used so you can go around and provide guidance to students so that they can use their investigation time effectively.

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3. (15 minutes) Have students experiment and play around with their setup of marbles and magnets to model what exactly is happening when a bond breaks and whether or not the breaking of bonds is truly the reason why the thermal energy of the system is decreasing. C

Students should be pressed to notice two patterns that will be discussed further in the class discussion:

1) **Not all collisions will break a bond--the marble has to be moving fast enough**
2) **The glass marble moves slower when it hits a bonded metallic marble than it does when it**

Additional Guidance

B If students bring up that the potassium chloride has kinetic energy as well that is fantastic! Prompt students to think about how the relative differences in kinetic energy between the water and KCl might look when we model this system. This should get students to think about the fact that the solid moves much more slowly than the liquid and so it might look like it's not moving in comparison.

If students do not get here, that is fine. Students will discuss this further in lesson 7.

Additional Guidance

C Students can just use books to help the rulers lie flat. However, if you want to utilize this opportunity as a chance for students to collect some quantitative data you can use a ladder to help students quantify the height increases necessary to break the "bond" even further.

Additionally, you can have students build tables and graphs as part of this activity (either in small groups or as a class) as a

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collides with an un-bonded glass marble

Make sure students discuss the following questions, which are also in their packets, and develop their own tentative model before reconvening for class discussion. It is crucial that students spend some time modeling on their own in order to ensure that the class discussion is productive.

Suggested Prompts:

- Do you think this same thing happens when we dissolve potassium chloride in water? Why or why not?
- Do you think this happens when we dissolve anything in water? Why or why not?
- If this is a model for what happens when KCl dissolves, where does the energy come from to break the bonds in the KCl?
- Does the temperature of the water impact this process at all? Why or why not?

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4. (20 minutes) Have students share what they discovered in their investigations with the class. This is an in depth conversation where the class will first discuss what happened in their investigation, and then map what they have discovered to the phenomenon of KCl dissolving in water.

Suggested Prompts about the Investigation:

- How did you represent the salt particles that were bonded together?
- Was there anything else represented in your investigation?
- What happens when a bond breaks?
- Does every collision result in the breaking of a bond?
- Does breaking a bond result in a decrease in thermal energy? What is your evidence?
- Where is the energy coming from to break the bonds?

Make sure the class comes to consensus on these points:

way to visualize the data they have collected quantitatively. This will be a crude graph (what heights did you try and did the "bond" break or not) but it will still be productive!

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- **If the metallic marble is bonded, a light push of the non-metallic marble will not succeed in breaking the bond, the metallic marble will just return to it's bonded position.**
- **If the metallic marble is not bonded, a light push of the non-metallic marble will succeed in pushing the metallic marble down the track**
  - **We decide this is an example of energy transfer**
- **In order to break the connection of a bonded metallic marble, the non-metallic marble must hit it with enough force so that the metallic marble is not just pulled back into the bonded position.**
  - **This collision results in a decrease in speed in comparison with energy transfer**
- **The energy to break the magnetic bond comes from the glass marble that collides with the bonded particles**

Suggested Prompts Mapping the Investigation to the Phenomenon:

➔ Do you think this same thing happens when we dissolve potassium chloride in water? Why or why not?
➔ Do you think this happens when we dissolve anything in water? Why or why not?
➔ If this is a model for what happens when KCl dissolves, where does the energy come from to break the bonds in the KCl?
➔ Does the temperature of the water impact this process at all? Why or why not?
➔ Scientists have a term for the minimum about of energy needed to break a bond. What do you think that term should be called?

These four prompts are the same prompts that students discussed in their small groups.

Make sure the class comes to consensus on these points:

- **This model implies that when potassium chloride is dissolved in water, water particles collide with the KCl with enough energy to break apart the KCl, using up some of their energy to break the bonds and therefore moving more slowly**
- **We hypothesize this mechanism holds for all cases of dissolving substances in water**
- **This model also implies that if the water is not hot enough, the KCl will not be dissolved** D

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- The hotter the water, the faster the water particles, the more easily the substance is dissolved
- The colder the water, the slower the water particles, the less easily the substance is dissolved

- We call the minimum amount of energy needed to break a bond the BOND ENERGY

Add the term BOND ENERGY to the poster where we keep track of scientific words we have defined.

DAY 2 - 45 minutes

1. (5 minutes) Spend a few moments recapping all of the ideas we came to consensus on the day before.

- **KCl particles are held together by something similar to a magnetic connection**
- **A bond will only break when the bonded particles collide with another particle that is moving fast enough**
- **We call the minimum amount of energy necessary to break a bond the BOND ENERGY**
- **In our model, the energy to break the bond came from the marble representing water. Therefore, we think that when dissolving KCl in water, the water particles are colliding with the KCl particles, breaking their bonds and decreasing in kinetic energy**

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2. (10 minutes) Ask the students to work in small groups and try and model "Why does the temperature drop when a substance is dissolved in water?" Their goal should be to use their current knowledge to update and combine Models 3 and 4. E

Make sure that students' models account for how bonds break in addition to explaining the decrease in temperature.

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3. (20 minutes) Have groups of students come up and present their model to the class.

Additional Guidance

D If students question this idea, this is a very easy mini-investigation to do for the class. You can use coffee or hot chocolate powder in a clear mug and show that it is much harder to dissolve all of the powder in the cold water than it is in the hot water. These powder are preferable to potassium chloride because they are easier to see.

Additional Guidance

E This exercise should ensure that students are modeling at the atomic level (possibly in addition to the macro level). If students aren't showing molecular interactions in their models at this point, have a conversation probing at why so that the class remembers that this is important for them to include in their models. Remind them that models are not merely pictures, they are explanatory tools.

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Remind students of the classroom norms that we have built. We must make sure to listen, then question/clarify to make sure the presenters intentions are understood, and then productively hold others' ideas accountable to the evidence we have collected.

Have each group present for ~2 minutes with ~2 minutes of questions. If the class discussion is productive, do not cut it off.

Have students share their explanations as to what happens when a bond breaks and whether or not that could result in a drop in thermal energy. F

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4. (10 minutes) Have students spend some time building consensus to ensure that the majority of the class is on the same page still.

Probe student thinking to discover:

- **Whether the students are confident that energy is actually being used to break the bond or if it is possible that energy is merely being transferred to heat something up and cool something down (like we saw in lesson 2a and model 2a)**
- **Whether the students are confident that the decrease in thermal energy can be attributed to the bonds breaking since when water particles collide with the KCl, bonds break and the water particles slow down (it has used some of its KE to break the bond)**

Do not move on until the class understands these two ideas!

Check in to see if students still believe that magnets are a productive model for the connection between particles.

<u>Suggested Prompts Mapping the Investigation to the Phenomenon:</u>

- Do we still think that magnets are a productive model for the bonds between particles? Why or why not?

Additional Guidance

F This is a good opportunity for formative assessments. All students' models should be fairly similar at this point because of all the consensus building work we have done up to this point.

Listen carefully to student presentations, and probe for students beliefs about bonds, bond energy, and how and why the breaking of bonds might explain why the temperature drops when room temperature KCl is dissolved in room temperature water?

If students' models are not similar or they are still struggling greatly with these ideas, spend time building consensus around these ideas until students are confident about these ideas. Continue to push students to support their ideas with evidence.

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- Does this conception of bonds make sense with the evidence we have collected thus far?

This conversation may remind us of something we saw when we were first dissolving potassium chloride, the more KCl we dissolved, the more the temperature dropped.
Why did the temperature drop more when we put more KCl in? **We hypothesize that this is because more thermal energy from the environment was needed to break the additional bonds, but we are now curious.** ***What about other substances? Do we always need more energy to dissolve more? Are all substances' bonds the same? Is dissolving always the same?***

NEXT STEPS: We decide to investigate the dissolution of other substances to see if we can find some answers to our questions.

Alignment With Standards

Building Toward Target NGSS PE

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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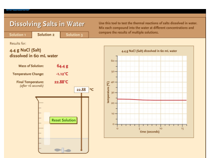
Lesson 6: Are all bonds the same?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students decided that when a water particle collides with the potassium chloride at a fast enough speed it can break the bond but it then decreases in speed, resulting in a decrease in temperature. This is what happens when KCl is dissolved in water.

This Lesson....What we are doing now: Students discover that dissolving more of the same substance results in a larger temperature drop and that dissolving different substances results in different temperature drops. Students attribute this phenomena to bond strength arguing that stronger bonds require more energy to break just as more bonds require more energy to break. The class calls stronger bonds stable and weaker bonds unstable.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L6: Are all bonds the same? (1 period) *Building toward* ⬇ *NGSS PEs:* *HS-PS1-4,* *HS-PS3-5*	A simulation provides results for changing the amount or type of substance dissolved in water and the subsequent temperature change. http://bit.ly/290EJUs 	**Use a model** (including mathematical and computational) to generate data *and identify patterns within that data* that support explanations *about how quantity and type of bonds breaking impact the system differently.*	We do a virtual lab experiment where we dissolve different substances in water and look at the resulting drops in temperature. We notice a pattern that it takes different amounts of force and energy to break different bonds, as we see from some salts causing a greater temperature drop when dissolved than others. Some atoms must pull harder than other atoms. The greater this force, the stronger the bond. An atom with stronger bonds is more stable (unlikely to change when disturbances from external forces in the surroundings are applied to the system, like a collision) than an atom with weaker bonds. We can model different bond strengths using different strength magnets. We work groups to design a way to try this and we find evidence for our hypothesis. We realize that some magnets require more energy to be pulled apart than others. This makes sense because our first phenomena got WAY colder than our other phenomena! Since we think that the positive and negative pull in atoms comes from the protons and electrons, we think that the bigger the atom the stronger the pull. But we're not sure about this. We have other theories too about maybe there's something else about the atoms that make bonds stronger or weaker. We want to find out more about this. We're not going to get to this completely, *but what is it about the structure of the atom that causes it to have a stronger bond?* Since it's related to the strength (energy required to break the bond), let's call it bond strength. We call strong bonds stable because they are unlikely to change compared to weaker bonds because they require WAY higher temperature collisions to come apart. Through our discovery of bond energy, we see that: ● **"one must provide at least [a certain amount of] energy in order to take the molecule apart." (PS1.A)** ● That amount of energy is different from bond to bond (*we're not sure why, maybe different atoms have different strengths just like different magnets do?*) *What does this mean for our initial phenomenon? We didn't add water, so if bonds were breaking, where did the energy come from to break those bonds?* **We decide to check if our model now explains the temperature drops in the chemical reactions we saw at the beginning.**

Next Lesson....Where we're going Students look more closely at the chemical reaction between barium hydroxide and ammonium chloride more carefully to see if their current explanation can extend to include that chemical reaction.

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Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 6: Student Activity Sheets (1)

Preparation of Materials

- Have the virtual lab found here loaded on a projector or on personal computers:
- http://illinois.pbslearningmedia.org/resource/lsps07.sci.phys.matter.dissolvesalt/dissolving-salts-in-water/

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Learning Plan: Are all bonds the same? (45 min)

1. (5 min) Recap what happened the previous day with this students. Summarize again what we have determined:

- **It requires a minimum amount of energy to break a bond, also called bond energy**
- **Our working theory is that when dissolving KCl in water, that energy used to break KCl's bonds comes from the surrounding water**
- **When the water particles collide with the KCl, it loses kinetic energy as some of that energy is used to break the bonds in KCl, thus explaining the drop in temperature**

Have students articulate the motivation behind today's lesson: to find out if all bonds are the same.

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2. (15 minutes) The following virtual lab investigation is outlined as an activity for entire class but it can also be done with small groups or partners if there are enough computers. A

The virtual lab can be found here. For the purpose of this lab, *only* investigate potassium chloride, ammonium nitrate, sodium chloride (aka table salt), sodium nitrate, and ammonium chloride.

Before starting the investigation, ask students for their predictions.

Suggested Prompts:

- ➔ Do you think there will be a difference in what we see when we dissolve a different substance in water? Why?
- ➔ Do you think changing the amount of substance dissolved in water will impact the results? Why?

Do not ask students to quantify their predictions, merely to predict whether the temperature change will be larger, smaller, or the same.
Have students choose one volume of water and keep that constant throughout the experiment. B

Teacher Supports & Notes

Additional Guidance

A This lab can also be done with real chemicals, but the temperature changes are so small they can be hard to detect in a laboratory setting.

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It is useful to start this investigation with potassium chloride to show that this virtual lab confirms what we have already seen in lab. Have students choose two amounts of KCl: one relatively larger than the other. Make sure you have students predict what will happen each trial and explain why they made this prediction.

After doing this experiment with KCl, go through the other salts systematically only changing the type of salt and not the two selected amounts of salt.

Suggested Prompts:

- ➔ When we choose a new substance, should we also change the amount of water and substance used for the two trials? Why or why not?
- ➔ What does keeping other variables constant afford us?

We notice a pattern that there are different temperature drops for different salts. We think this makes sense, but we want to go back to our magnets to make sure our model accounts for this difference in bonds.

We might also notice a pattern that the more salt we dissolve, the larger the temperature drop. We think this makes sense because breaking more bonds would require more energy. If students bring up this point, emphasize that they can reason out the answer to this pattern themselves!

Suggested Prompts:

- ➔ What patterns are you noticing?
- ➔ Does something change when we change the substance we are dissolving?
- ➔ Does something change when we change how much of a substance we are dissolving? Is that change consistent across salts?
- ➔ Do you think these findings are generalizable across the dissolution of all chemicals? Why or why not?
- ➔ Do these findings make sense with our pre-existing theories and our model of chemical bonds as a

Additional Guidance

B This is a great opportunity to talk about the importance of keeping a variable constant when experimenting if the class has not talked explicitly about this yet. Have a short conversation where you ask students if they think it's important to have a constant variable and ask them to explain their reasoning.

Ultimately, we want students to buy into the idea that holding variables constant allows us to compare different trials and make conclusions about the patterns that emerge.

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magnetic connection?

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3. (10 minutes) Have the students work in their small groups to see if similar patterns exist with magnets and find that they do. There are weaker and stronger magnetic connections that are respectively easier and harder to break.

Suggested Prompts:
- ➔ Can you use magnets to explain the pattern(s) you saw when different salts were dissolved in water?
- ➔ Does it require the same amount of energy to pull all magnets apart? Why or why not?

Still in small groups, the students should discuss how this maps onto atoms. The students may have many ideas as to why some atoms form stronger bonds than others, but the main takeaway of this discussion should be that there likely is a parallel between magnets and bonds in that some atoms form stronger bonds than others.

Suggested Prompts:
- ➔ Why do you think that the temperature change was different for different salts?
- ➔ Thinking about what we know about atoms, do you think it's possible that some atoms form stronger bonds than others? Why or why not? C

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4. (10 minutes) Have students spend some time building consensus to ensure that the majority of the class is on the same page.

As part of this conversation introduce two terms BOND STRENGTH and BOND STABILITY. Add these terms to the poster where we keep track of scientific words we have defined.

Suggested Prompts:
- ➔ Are all bonds the same? Why or why not? What evidence do we have?
- ➔ Do we have any evidence from other investigations that supports this claim? If so, what?

Additional Guidance

C This unit does not expect students to have any prior knowledge about atomic structure so do not worry about students being able to explain structurally why different atoms form different strengths.

Instead, build on students instincts from

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- ➔ How should we refer to these bonds of relatively different strengths? What term do you think scientists use?
- ➔ What term do you think scientists use to describe substances with lots of very strong bonds?
- ➔ Why do you think scientists call these substances this?
- ➔ What is the class consensus as to why dissolving different salts results in different changes in temperature?
- ➔ Why do we think that different bonds have different strengths?
- ➔ Do we know the answer to why the temperature drops when room temperature potassium chloride, or any other room temperature substance, is mixed with room temperature water? What is it? Is this a physical change or a chemical reaction?

Make sure the class comes to consensus on these points:

- **We decide that bonds have different strengths (i.e., BOND STRENGTH) as evidenced by different substances requiring different amounts of energy to dissolve the same amount of salt**
  - **This makes sense because our first investigation, with barium hydroxide and ammonium chloride, got MUCH colder than our other investigations.**
- **Stronger bonds are more stable because they are less likely to break due to external forces (i.e., BOND STABILITY). Therefore particles with many strong bonds are more stable than particles with many weak bonds since more energy is needed to break them.**
- **We map this back to our phenomenon and we decide that the temperature drop in the water is relative to the amount of energy needed to break a bond (i.e., BOND ENERGY). If the bond is stronger, there will be a larger temperature drop.**
  - **Similarly, if more bonds are broken, there will also be a larger temperature drop.**

At this point we feel confident in our explanation as to why the temperature drops when room temperature potassium chloride, or any other room temperature substance, is mixed with room temperature water. D

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their use of magnets and help students build an intuition that atoms probably have different strengths, just like magnets do, and that there might be a structural reason for this. We will table wondering about atomic structure for now--but we will come back to it at a different point in the year!

If students do have prior knowledge about atomic structure, feel free to draw on this to help students reason that different atomic configurations might lead to greater or smaller pulls.

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5. (5 minutes) Now that we have reached a consensus and have an explanation for the phenomena of dissolving KCl, or any other substance, in water, prompt the students to think about the chemical reactions we saw in Lesson 1.

Suggested Prompts:

- ➔ Does this explanation for a physical change map onto the chemical reactions we saw at the beginning of this unit? Why or why not?
- ➔ Why do you think that the temperature dropped when room temperature water was mixed with room temperature pink lemonade and baking soda?
- ➔ Do we think that this is similar or different from why salt dissolving in water makes the temperature colder?
- ➔ Why do you think that the temperature dropped when two room temperature powders, barium hydroxide and ammonium chloride, were mixed together? (Remember, we did not add water into the beaker in this reaction!)
- ➔ Do we think that this is similar or different from why salt dissolving in water makes the temperature colder?

After some discussion we that what is happening in the lemonade/baking soda/water reaction seems similar to the dissolution of a substance in water as students argue both involve water molecules breaking bonds with their kinetic energy. *But what about the first reaction we saw between barium hydroxide and ammonium chloride? There is no water in that reaction so where did the energy come from to break the bonds and result in a drop in temperature? We didn't add water, so if bonds were breaking, where did the energy come from to break those bonds?*

NEXT STEPS: We decide to look at the chemical reaction between barium hydroxide and ammonium chloride more carefully to see if our explanation can extend to include that chemical reaction.

Additional Guidance

D When moments like this happen, where we figure out something big, take a moment to marvel and celebrate! This is just as much a part of building classroom culture as facilitating safe, constructive discourse is. Students can get frustrated feeling like they are not learning anything because of this new format of learning when they are in reality learning so much! So take some time to admire how much the students have accomplished even at this point in the unit!

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Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 7: Why does the temperature drop when room temperature barium hydroxide and ammonium chloride are mixed together?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students decided that water can collide with substances, breaking their bonds, and then subsequently slowing down resulting in a decrease in temperature. When there are more bonds to break (i.e., more stuff) or the bonds are harder to break (i.e., more stable) then the temperature drop is greater.

This Lesson....What we are doing now: Students are now wondering how their explanation for the temperature drop in a physical change extends to explain a temperature drop in chemical reactions. The students examine and then model the reaction between barium hydroxide and ammonium chloride more carefully and find that bonds are also broken in this chemical reaction, helping the students realize the two explanations are parallel.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L7: Why does the temperature drop when room temperature barium hydroxide and ammonium chloride are mixed together? (2 periods) *Building toward* *NGSS PEs: HS-PS1-4, HS-PS3-5*	Previous phenomenon from L1: When ammonium chloride and barium hydroxide are added in a beaker, the beaker will freeze to a wood block.	**Revise a Model** based on evidence to illustrate the relationship between bonds *breaking and changes in kinetic energy when explaining what causes the temperature to drop.* **Argue from evidence** and make and defend a claim based on evidence about the natural world that reflects scientific knowledge and student-generated evidence *when presenting your model explaining how the temperature drop is caused by bonds breaking.*	We bring what we know back to our original phenomenon reminding ourselves of everything we want to account for: • There was a large temperature drop (energy absorption) • A gas formed (bubbles) • We smelled a new odor (different substance produced than was there before) We argued that in this case we aren't just breaking bonds, we're also making something (we smelled a gas!). We're going to have to take that into account (a chemical reaction is happening - new products are being made from old atoms, that came from old products). We want to look up the exact chemical reaction that is occurring here, so we can describe specifically what is occurring. Then we are going to use Model 5 to help us create Model 7. First model the chemical reaction, using manipulatives for atoms and bonds, and try and keep track of the bonds that are breaking. From using this model we note that bonds are both being broken *and being made* in these reactions. Though we know that energy causes these bonds to break, we do not know if the making of bonds would have cause any temperature effects. We try and draw Model 7 and we can see there are two stages to the reaction that we need to account for and we may need to show "before and after" for each stage: a. Before we break the bonds b. Breaking the bonds (During or right after the breaking of the bonds) c. Making the bonds (During or right after the forming of the bonds) -- ?? d. After forming the new bonds We realize that going from a to d is the mechanism of the reaction we are trying to figure out (the arrow that is the black box of these chemical reaction we took for granted up until now).

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			At this point one of our unresolved question is, *Where does the energy come from in order to break bonds now that there are no water molecules to break things apart?* We develop some initial explanations that include these ideas: a. Even though solids do not have that much energy, they still have some thermal energy (they are room temperature) so maybe they could have enough vibrational energy (like in lesson 5) to break bonds right at surface of the solid b. Maybe us stirring the solids together not only speeds up the solid pieces so that they have more energy but also brings all the solid pieces close enough together so that the vibrating pieces are close enough to break a bond. And another unresolved question is, *What happens when you make a bond? How are bonds made??* We brainstorm some possibilities. We argue from evidence that (major take aways): 1. You can get the energy to break bonds from more places than just water (from anything in the surrounding environment or any molecules that collide with it). 2. We have no idea what happens when bonds are made and we have no idea how that impacts things. *What happens when bonds are made? Does making bonds have any effect on the energy of a reaction? What happens in other reactions, now that we've figured out this one?* **Next Steps: We decide should try another reaction and see if provides additional evidence that might help us figure that out.**

Next Lesson....Where we're going Students want to know if all complex chemical reactions result in a decrease in temperature.

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Getting Ready: Materials Preparation

Materials For Small Groups

- Poster boards for modeling
- Colored pens and markers
- Cut out atoms that can be rearranged into chemical formula (Lesson 7: Atom Rearrangement sheet)
- Scotch tape (optional)

Preparation of Materials

- Print out one Lesson 7: Atom Rearrangement sheet for each small group and cut the sheet up into "atomic squares"

Materials For Each Student

- Lesson 7: Student Activity Sheets (1)

Materials Shared Between Classes.

- Barium hydroxide and ammonium chloride for demo

Safety

- N/A

Materials For Each Class

-

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Learning Plan: Why does the temperature drop when room temperature barium hydroxide and ammonium chloride are mixed together? (90 min)

DAY 1 - 45 minutes

1. (5 minutes) Recap what happened the previous day with this students. Summarize again what we have determined:

- **The class has a working model that it requires energy to break bonds when dissolving something and that the energy used to break those bonds comes from the kinetic energy of the water.**
- **We think this theory holds up when talking about the pink lemonade/baking soda/water reaction because this also involved water and that water may have dissolved the pink lemonade therefore breaking bonds.**

Have students articulate the motivation behind today's lesson: to figure out how our working model extends, or does not extend, to include the reaction between the two room temperature powders, considering that there is no water that can use its kinetic energy to break bonds.

Suggested Prompts:

- ➔ What is the class' current model about why the temperature drops when a substance is dissolved in water?
- ➔ Do we think that this model can explain why the temperature drops when room temperature pink lemonade, baking soda, and water are mixed together? Why or why not? A
- ➔ Do we think this model can explain why the temperature drops when room temperature barium hydroxide and ammonium chloride are mixed together? Why or why not?
- ➔ Do you think bonds are breaking in one, neither, or both of the chemical reactions we saw? Why or why not?

Teacher Supports & Notes

Strategies for this Building Understandings Discussion

A This is a question that you are simply looking for confirmation that this model seems like it could work for this reaction. Students will be pretty confident of this.

Plan to spend more time discussing the barium hydroxide and ammonium chloride reaction which had no water added to it. Because two starting substances are solids, unlike what the students observe in the other two phenomena, they will argue about whether the same model can apply to solids. Part of this argument is likely to center on whether the particles within a solid are moving or not (or how they are moving if they are).

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2. (5 minutes) At this point, the class should feel pretty confidant that their working model explains the temperature drop in the pink lemonade reaction but be unsure if it explains the barium hydroxide/ammonium chloride reaction. The class should want to know more about the chemical reaction that happened in this second reaction.

You should write the chemical formulas of the two powders on the board: $Ba(OH)_2$ + NH_4Cl and then prompt the students to brainstorm what the products might be? Have the class recap all of the observations they had when they did this reaction to prompt them to help them think of the products. Remind them they can take out their very first packet to help them with this.

Possible *student responses*:

- ➔ *Maybe water or a liquid is a product because the powders turned slushy*
- ➔ *There was a gas product because it smelled really bad when we did that reaction*
- ➔ *The gas smelled like ammonia, like when my mom cleans the house or when my cat pees!* [B]

Once students have brainstormed for 2 minutes give them the products: NH_3 (g), $BaCl_2$ (s), and H_2O (l). [C]

3. (10 minutes) Have students work in their small groups trying to identify which specific bonds need to break in order to form these products by cutting up pieces of paper you provide for them and having them rearrange those letters, first forming the products, using tape to represent bonds) and then the reactants. [D]

Support students in reflecting about what it actually means when you rearrange those atoms and help them connect that rearrangement to breaking and forming bonds.

In this small group discussion have students really think about where the energy is coming from break bonds in this reaction.

Additional Guidance

B If a student claim that the gas is ammonia based on their observations or identify the name of the chemical (ammonium chloride), then work with that claim, and ask students to elaborate further why it might be ammonia.

Strategies for this Building Understandings Discussion

C **Do not** worry about balancing reactions right now. If students ask questions about whether we need to do this, them that we may not have the proportions exactly right, and they can think about that further for home-learning, but for now our goal is to identify possible substances that could be created with any proportion of reactants used.
Do not worry about aqueous solutions and the solubility rules with barium chloride. But do explain what the notations g (gas), s (solid), and l (liquid) mean.

Additional Guidance

D If you have magnetic ions this could

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4. (10 minutes) Share our ideas from our small group discussions to the class. After establishing that in this chemical reaction bonds are being both broken and formed, work towards defining chemical reactions and physical changes, so the class is no longer ambiguously using those terms.

Suggested Prompts:

- Now that we have talked a little bit about physical changes and chemical reactions, do we think we have a better idea of what the difference between them are?
- What did we learn when we rearranged the atoms in our exercise? Do we think that is what happens in a physical change?

Add the terms PHYSICAL CHANGE and CHEMICAL REACTION to the poster where we keep track of scientific words we have defined.

Then push students to think about where the kinetic energy might have come from to break the bonds in this chemical reaction. E

Possible *student responses*:

- *The kinetic energy came from stirring the mixture*
- *Maybe the solid particles are vibrating in place and so when the solids are touching they can vibrate with enough energy to break a bond*.

Suggested Prompts:

- Are bonds being broken in this chemical reaction? Are new bonds being formed?
- How does this compare to dissolving which is a physical change not a chemical reaction? When something dissolves are bonds broken? Are new bonds formed?
- I feel like sometimes we do not exactly know what we mean when we say chemical change or physical reaction. Do we know enough to be able to define these terms? What would their definitions be?

be useful for students, otherwise, if students are struggling, you could have them cut out pieces of colored pieces of paper and tape them together (taping representing bonds) and detach/reattach them to really be able to focus on which bonds are breaking. Legos are another possible manipulative to use for this activity.

Remember--students don't have to worry about balancing the reaction for the question we are trying to answer at this point.

Do not worry about students forming the appropriate atomic structure and connecting the "right" atoms together. The point is merely for students to see that bonds are breaking and then reforming differently.

Strategies for this Building Understandings Discussion

E Have students really think about where the energy is coming from to break bonds in this reaction. Push on the idea that the particles in solids are maybe vibrating because if they weren't moving at all they wouldn't have any temperature and solids can be warmed up and cooled down

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- ➔ If bonds are being broken in this chemical reaction, where is the energy coming from to break the bonds?
- ➔ Is there any kinetic energy present in the room temperature powders? What evidence do you have to support your answer?
- ➔ Do all solids have kinetic energy? What evidence do you have to support your answer?
- ➔ How could we represent solids having kinetic energy in our model?

Make sure the class comes to consensus on these points:

- **PHYSICAL CHANGES are defined as reversible changes where bonds are broken but no new bonds are formed as nothing new is formed.**
- **CHEMICAL REACTIONS are defined as irreversible changes where old bonds are broken and new bonds are formed and something new is formed.**
- **We think that maybe the kinetic energy to break the bond comes in part from the kinetic energy within the solids.**
  - **We know that solids have inherent kinetic energy because they have and can change temperature.**
  - **We have a way to depict the movement of solids in our models.**
  - **It is likely that stirring also provides kinetic energy in order for the necessary bonds to be broken.**

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5. (5 minutes) Have students spend a few minutes on their own drawing a model that explain why the temperature dropped when the two room temperature powders barium hydroxide and ammonium chloride were mixed together.

Remind students to include all the features of models that we've already discussed including stages (before, middle, after), temperature changes, zoomed in versions of the molecular interactions, a key, etc.

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and still be solids. Make sure to come up with a way to depict this type of particle motion in the class models.

It is okay if students insist that the initial energy comes from mixing the solid, but still push on the idea that even if it's not enough energy to start a reaction, there is particle level kinetic energy (thermal energy) in solids.

A way to demonstrate that the reaction still happens without stirring, it to simply layer the reactants in a beaker very gently (in the 3:1 ratio specified in the procedure). And even if you don't stir it, students will see and smell evidence of the reaction occurring, just much more slowly. Conducting the extra demo may help provide evidence that the particles within the solid reactants are still hitting into each other at the surfaces where they are touching one another.

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6. (15 minutes) Have students work together in small groups to create consensus posters that explain why the temperature dropped when the two room temperature powders barium hydroxide and ammonium chloride were mixed together.

Remind students that they will have to present these!

DAY 2 - 45 minutes

1. (30 minutes) Have groups of students come up and present their model to the class. F **Have each group present for ~2 minutes with ~3 minutes of questions. If the class discussion is productive, do not cut it off.**

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2. (10 minutes) Spend some time having a consensus conversation.

Suggested Prompts:

- ➔ What is our consensus model on why the temperature dropped when the two room temperature powders barium hydroxide and ammonium chloride were mixed together?
- ➔ Are there any pieces we still do not understand? Any questions we still have?
- ➔ Does this idea make sense with our model for why the temperature drops when room temperature potassium chloride is dissolved in water?
- ➔ Can we come up with a general explanation as to why the temperature drops when room temperature substances are mixed together that accounts for both physical changes and chemical reactions?

Make sure the class comes to consensus on these points:

- **In this reaction, we are pretty confident that energy to break bonds is actually coming from the solids since they have thermal energy (they are room temperature!) so maybe they**

Strategies for this Consensus Building Discussion

F Emphasize the importance and growth the class has made in the classroom norms that we have built before students going public. You may want to ask students to identify some of these and why they are important to our learning community:

- We must make sure to listen, then question/clarify to make sure the presenters intentions are understood
- We need to ask questions in order productively hold others' ideas accountable to the evidence we have collected.

Remind students that when they are presenting, they are managing the discussion and calling on people and you, the teacher, become like any other student. Go over some of the specific productive ways students can interact with the presenters:

- Asking clarifying questions about things they don't understand
- Providing additional evidence in support of or constructively against the model being presented
- Stating their position vis-a-vis the model being presented. Do they agree? Disagree? Why?

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have enough vibrational energy to break bonds when they come close enough together.
  - **Maybe us stirring the solids together not only speeds up the solid pieces so that they have more energy but also brings all the solid pieces close enough together so that the vibrating pieces are close enough to break a bond.**
- **In chemical reactions there are 4 stages we need to account for: before we break the bonds, breaking bonds, making bonds, and after forming new bonds.**
  - **We think we have the first, second, and fourth stage figured out but *what is happening when bonds are formed??? How does that impact things??* We might brainstorm about this a little but we really have no idea.**
- **Generally we feel like we understand why the temperature drops when room temperature substances are mixed!**
  - **Our model currently is: The temperature drops when room temperature substances are mixed when that combination results in bonds are being broken--EITHER through a chemical reaction or physical change. The energy needed to break the bonds comes from the kinetic energy of the room temperature substances resulting in a decrease in the KE of the substances and therefore a drop in temperature.**

Write your general consensus explanation as to why the temperature drops when room temperature substances are mixed together that accounts for both physical changes and chemical reactions on a poster board. G

NEXT STEPS: We are still left with some questions. *What happens when bonds are made? Does making bonds have any effect on the energy of a reaction? What happens in other reactions, now that we've figured out this one? Are all complex chemical reactions alike?* We decide to try a few more chemical reactions to see if we can answer some of these questions.

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4. (5 minutes) Before moving on we quickly return to the driving question board to see how we have progressed in answering our questions.

- Summarizing what someone else's explanation is
- Explaining how your model is similar or different to the model presented previously

You may want to remind students to take notes during others' presentations to help them with this.

The goal of this discussion for students to take ownership of the goals and outcomes of these conversations instead of the teacher. But if this is early in the year, at this point you might still need to model these types of interactions for the students to see what constructive criticism, clarifying questions, and building on others' ideas looks like.

Strategies for this Consensus Building Discussion

G This is an excellent time to celebrate the accomplishments of the learning community. Do not move onto the next lesson until the class feel good about what they accomplished and recognizes all of what that entails. You may want to say something like, "You should feel very proud about all that you have figured out. We only got to this point, by taking risks asking questions and volunteering first draft ideas,

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This can also be done at the beginning of the next class depending on timing.

and by working together, building off each others ideas over time. Even if we have other questions we want to answer, we have gotten really far."

Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 8: Do all complex reactions absorb energy and make their environment colder?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students came up with a consensus explanation as to how room temperature substances can drop in temperature when mixed, regardless if it was a chemical reaction or a physical change, arguing that when bonds are broken the temperature drops because kinetic energy must be used to break the bonds resulting in a decrease in kinetic energy and therefore a decrease in temperature.

This Lesson....What we are doing now: In the exploration of chemical reactions we were able to explain how breaking bonds impact the energy of the system, but we do not really know much about the formation of bonds. The students investigate other chemical reactions but realize that this chemical reaction gets hotter instead of colder! Students investigate more about these chemical reactions in an attempt to better understand what is happening and name them exothermic reactions.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L8: Do all complex reactions absorb energy and make their environment colder? (1 period) S *Building toward* *NGSS PEs: HS-PS1-4, HS-PS3-5*	Alkali metals have hot, explosive reactions with water. Video, if uncomfortable doing more violent reactions: http://bit.ly/1znUkyR	**Ask Questions** to clarify and refine our explanation *that chemical reactions result in a decrease in kinetic energy in the system.* **Analyze and Interpret Data** to evaluate the impact of new data on a working model *of how chemical reactions impact the energy of a system.*	We add alkali metal to water see some interesting patterns in the phenomena: • Flames and light are emitted from where the reaction is occurring in many cases and the temperature increases • Smoke or gas is produced • The metal piece moves around in the water, getting smaller over time, and sometimes stuff flies out of the container • Different types of substances seem to react more vigorously than others • More of the substance releases more energy We are a little confused because in these chemical reactions the temperature is going up instead of down. *Are these definitely chemical reactions?* We think so because it looks like something new (gas) is being produced and we are not very confident that we could get the metal back. *But we thought chemical reactions required bonds to break and that breaking bonds resulted in a decrease in temperature? Maybe bonds are not breaking in this chemical reaction?* We decide to investigate further and see what is happening in these chemical reactions. We identify the reactants and products that are in the reaction and confirm that molecules (reactants) are being broken apart and atoms are rearranged into new molecules (products). This means that bonds are being broken (and formed), probably from the kinetic energy of the water, but the temperature is NOT dropping! We decide that this seems to be a new class of chemical reactions that release heat into the surroundings instead of absorbing it, so we decide to call these chemical reactions Exothermic. *But where does the thermal energy come from? Does it have anything to do with the formation of bonds?* **We think that maybe something that has to do with the formation of bonds is affecting these reactions, since that is the part of chemical reactions we know the least about. We decide to return to our physical representation of bonds (i.e., magnets) and we can figure anything out.**

Next Lesson....Where we're going Students decide to use magnets to explore what happens when bonds are formed and to see if that might explain the increase in temperature.

nextgenstorylines.org

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Getting Ready: Materials Preparation

Materials For Small Groups

- Cut out atoms that can be rearranged into chemical formula (Lesson 7: Atom Rearrangement sheet)
- Scotch tape (optional)

Preparation of Materials

- Print out one Lesson 8: Atom Rearrangement sheet for each small group and cut the sheet up into "atomic squares"
- Pull out alkali metals, distilled water OR load the video found here

Materials For Each Student

- Lesson 8: Student Activity Sheets (1)
- Safety Goggles

Materials For Each Class

- ***Small*** pieces of alkali metals: lithium, sodium, and potassium (optional)
- Three 100 mL beakers filled with distilled water (optional)

Safety

- **Lithium:** Dangerous; water-reactive; explosion risk; flammable solid. Use a Class D fire extinguisher or have a generous supply of dry sand to use as a fire extinguisher. Corrosive to skin, eyes and respiratory tract. Possible reproductive/fertility hazard.
- **Sodium:** A flammable, corrosive solid; dangerous when exposed to heat or flame; dangerous by reaction with moist air, water or any oxidizer. Spontaneously flammable when heated in air; reacts violently with water, producing very dangerous hydrogen gas and a solution of corrosive sodium hydroxide.
- **Potassium:** Extremely dangerous in contact with moisture and water; releases hydrogen with sufficient heat to cause ignition or explosion; may ignite spontaneously in air or oxygen; can cause severe skin or eye burns. Shipped under dry oil (no water) and that is the way it must be stored. Keep away from water and handle with dry utensils. SPECIAL HAZARD ALERT: Peroxide coatings are well known to develop on the exterior surface of potassium metal. The peroxide coating consists of potassium superoxide (KO2) and potassium peroxide (K2O2). Potassium superoxide is yellow and reacts explosively with the light oil in which the product is stored when the metal is cut into small pieces. Do not us any potassium that is old or yellow! If you have a choice as to which alkali metal you use, sodium metal is a better choice since, upon aging, it does not develop peroxides.

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Learning Plan: Do all complex reactions absorb energy and make their environment colder? (45 min)

1. (5 min) If you have not yet, revisit the driving question board to see if we've answered some of our questions and to add in any new questions we might have.

Have students re-articulate the current state of the classroom model:

- **The temperature drops when room temperature substances are mixed when that combination results in bonds are being broken--either through a chemical reaction or physical change. The energy needed to break the bonds comes from the kinetic energy of the room temperature substances resulting in a decrease in the KE of the substances and therefore a drop in temperature.**

Have students articulate the motivation behind today's lesson: To look at more chemical reactions to see if all complex chemical reactions are the same.

---

2. (10 min) Do the following class investigation as a demonstration. A

Before starting the demonstration, ask students to predict what will happen.

Suggested Prompts:

➔ Do you think this will be similar to the two chemical reactions we have seen already? Why or why not?

For this demonstration, drop chunks of Lithium, Sodium, and Potassium (in that order) into water. You can do this outdoors or indoors in a large beaker of water (use glass so students can see more easily). If you do this indoors, make sure you adjust the amount of metal appropriately.

Teacher Supports & Notes

Additional Guidance

A If you do not have access to the materials for this lab, you can use this video starting at 20 seconds. Note that the "large volume" of cesium demonstration toward the end of the video was actually accomplished with the use of explosive charges for effect, so it should be avoided in a classroom setting, along with the concluding simulation of francium in water.

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In between each alkali metal, again ask students to predict what will happen.

For each experiment have one student volunteer take the temperature of the water before and after the reaction. You can also have another student volunteer touch the side of the beaker.

Have the students write down their observations as they observe this phenomenon.

---

3. (10 minutes) Have a class discussion reflecting on the investigation.

Suggested Prompts:

- ➔ What patterns do we see in our data?
- ➔ Are these patterns similar or different to what we saw in the previous chemical reactions we investigated? How so?
- ➔ Are we certain that these are really chemical reactions? Do we have any evidence from our investigation to support that claim?
- ➔ Is it possible that bonds are not breaking in this process?

Make sure the class comes to consensus on these points:

- **The temperature is going up instead of down**
- **We may notice that different size chunks of the same metals make different changes in temperature and that different metals make different changes in temperature and draw the parallel to dissolving different salts**
- **This is a chemical reaction but we're not sure what's going on**
  - **There were bubbles which would mean a gas (and therefore something new) was produced**
  - **Evidence includes that the metal got smaller and it didn't look like we could get it back**

Once students feel confident that there is evidence that this is a chemical reaction, have them work in small groups to figure out what exactly is happening in these reactions. *Are bonds even breaking?*

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4. (5 min) Provide students with the chemical equations for each of the three chemical reactions they saw.

Li (s) + H_2O (l) → H_2 (g) + LiOH (aq)
Na (s) + H_2O (l) → H_2 (g) + NaOH (aq)
K (s) + H_2O (l) → H_2 (g) + KOH (aq) B

Have students work in their small groups rearranging paper print outs of "atoms", first forming the products and then the reactants, to see if bonds are breaking or forming.

5. (10 minutes) Have a class discussion going over what we saw in our small group work.

Suggested Prompts:

- Are bonds being broken and/or formed in these chemical reactions? Does this make sense with our definition of chemical reactions?
- Where do you think the energy is coming from to break the bonds?
- If bonds are breaking, and energy is being used to break the bonds, why is the temperature increasing?

Make sure the class comes to consensus on these points:

- **Bonds are definitely being broken, probably from the kinetic energy of the water**
- **The temperature is going up instead of down and that is confusing, this seems to be a different type of chemical reaction than endothermic ones, so we're going to name this chemical reaction something else -- EXOTHERMIC**
    - **Exothermic means releasing thermal energy which seems to be what is happening here**
- ***Maybe something else is going on in these reactions, maybe something that has to do with the formation of bonds?*** C

Additional Guidance

B Again, **do not** worry about balancing reactions right now. If students ask questions about whether we need to do this, them that we may not have the proportions exactly right, and they can think about that further for home-learning, but for now our goal is to identify possible substances that could be created with any proportion of reactants used.

Go over again what the notations g (gas), s (solid), and l (liquid) mean. You can choose whether or not you want to define aq (aqueous) depending on what the students have already learned or not. If you choose to not define aq, just write s (solid).

Additional Guidance

C Push students to articulate that maybe the formation of bonds has something to do with this themselves. Have them look back at their previous models and see if there is anything that we have not yet accounted for that might explain this change in thermal energy. Since most students will have black boxed this in their models, this should be a natural jump.

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Add the word EXOTHERMIC to our poster tracking scientific words that we have defined.

Once the class is on board that maybe the formation of bonds has something to do with this push them to think about how they could investigate these questions. The students should suggest that we return to magnets!

Suggested Prompts:

- ➔ How could we investigate how the formation of bonds impacts temperature?
- ➔ What did we use when modeling the breaking of bonds? Would that be helpful in this scenario? Why or why not?

NEXT STEPS: The class should decide to use magnets to investigate the formation of bonds and how that may, or may not, have to do with the increase of temperature in these chemical reactions. D

Additional Guidance

D Try and see if you can get a student to come up with the idea to explore the formation of bonds using magnets instead of suggesting it yourself. This should not be too difficult, but it is important to have students see how their ideas drive the learning that happens in the classroom.

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Alignment With Standards

Building Toward Target NGSS PE

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 9: Why do some reactions warm things up?

Teacher Guide

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students experienced chemical reactions that involved bonds breaking but got hotter instead of colder! These reactions were named exothermic. Students are now curious as to how bond formation works and whether or not it contributes to this phenomena.

This Lesson....What we are doing now: Students return to their marble/magnet setup to explore what happens when a bond forms and to see if it is connected to the gain in thermal energy. Students discover that thermal energy is released when bonds are formed. They then decide to examine this phenomena a little more closely utilizing a computer model to track energy when magnetic bonds are formed or broken.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L9: Why do some reactions warm things up? (3.5 periods) *Building toward* ⬇ *NGSS PEs: HS-PS1-4, HS-PS3-5*	Previous phenomenon from L8: Alkali metals have hot, explosive reactions with water	**Use a model** (including mathematical and computational) to generate data *as to what happens to the energy of the system when chemical bonds form.*	We want to better understand what really happens when a bond forms and see if it is potentially connected to the increase in thermal energy. We return to our old equipment - tracks, marble, magnet, and bearing - that we used in lesson 5. We set up a ruler on books so that it is stable and not moving. Then we place a metallic ball on the track an inch or so from the magnet, being careful not to push it in any direction, and watch the metallic ball get pulled in by the magnet! Kinetic energy appearing from what seems like nowhere! We try different distances and find the farthest the metallic ball can be from the magnet and still be pulled in. We also try placing a glass marble in the path of the metallic marble and when the two collide the marble goes flying away in the other direction! This seems to be the opposite of when we were breaking bonds and the KE decreased, in this case the KE is increasing! *Where does that KE come from??* We also try changing the strength of the magnet and replacing the metallic ball with a metallic coated marble, and we realize that two strong magnets forming a bond release MORE energy than two weak magnets forming a bond. We realize that the formation of every single bond is not equal! This makes sense because we already figured out that breaking different bonds requires different amounts of energy. We think that maybe magnet have some of potential to make something happen that is a form of energy that we call potential energy, and that might be where the KE comes from. But we are still a little confused about this. We decide that it might be practical to build a computer simulation of this model so we can collect data more effectively. We use a virtual model to more effectively explore how breaking bonds affect the speed of particles entering and exiting the system. Our virtual investigation confirms what we knew but gave us a slightly more nuanced understanding of why kinetic energy changes when bonds are broken or formed, especially because it allows us to visualize the magnetic field. We realize that potential energy exists within that magnetic field and the amount of potential energy something experiences changes depending on where it is within that magnetic field. This makes sense with what we have seen in all of our investigations with magnets so far. Major Takeaways:

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			• Potential energy in this system is visualized through the magnetic field which indicates what a particle will experience depending on where it is in the magnetic field • The KE of the system increases when bonds are formed due to the potential energy of the magnetic field causing entering particles to speed up • Forming stronger bonds releases more energy than forming weaker bonds • The KE of the system decreases when bonds are broken due to the potential energy of the magnetic field cause exiting particles to slow down • Breaking stronger bonds requires more energy than breaking weaker bonds But we still have lots of questions about chemical reactions! *If chemical reactions always involve both breaking and forming bonds, then why does the temperature sometimes increase and other times decrease? Why is it different for different chemical reactions? In other words, why do some chemical reactions get hot and others get cold?* **We decide to return to our model and see if we can try model breaking and forming bonds at the same time in order to better answer this question!**

Next Lesson....Where we're going Students want to put this all together and model a chemical reaction where bonds are both broken and formed.

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Getting Ready: Materials Preparation

Preparation of Materials (30 min)

- Day 1: Have magnets, marbles, rulers out and ready. Have a ball (or another object) that can be used to demonstrate gravitational potential energy when dropped from different heights.
- Day 2 and 3: Have the NetLogo model loaded on the projector and on every computer ready to go.
  - The Netlogo model can be downloaded from http://goo.gl/hCyfW9

The directions for running the model using a web browser are available on the Bonds and Chemical Energy ScreenCast available here: https://goo.gl/LsFKy6

Materials For Each Student

- Lesson 9: Student Activity Sheets (1)

Alternate Preparation of Material (1 week ahead of time - 60 min)

- NetLogo runs faster when the application is installed on the computer ahead of time. This is only possible on computers that have hard drive space and administration access to support that installation. If you have this access, coordinate with your IT department, about getting NetLogo software installed on all the computers in a computer lab.
- Using this method, students will still download the Bonds and Chemical Energy.nlogo file from http://goo.gl/hCyfW9
- But the next step will be to simply double click on the Bonds and Chemical Energy.nlogo model file that they downloaded to the desktop or downloads folder to launch it.

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Learning Plan: Why Do Some Reactions Warm Things Up?

3.5 periods: (3 x 60 min each + 30 min wrap up)

Teacher Supports & Notes

DAY 1 - 60 minutes

1. (5 min) Recap what happened the previous day with this students. Have students restate what they saw in the demonstration the day before and what they discovered in the subsequent investigation.

Students should remember:

- **We saw chemical reactions that got hot**
- **We called these chemical reactions exothermic**
- **We know bonds are broken in these reactions, even though the temperature doesn't drop**
- **We also know bonds are being formed**

Have students articulate the motivation behind today's lesson: To use our physical model of magnets to better understand what happens when bonds are formed and see if that has any impact on the thermal energy of the system.

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2. (5 min) Have students brainstorm ideas for how they could test their ideas using the same materials and equipment that you used in Lesson 5 with the glass marbles, metal marbles, magnets, and ruler (or other equipment). Have students work on questions Q1 through Q4. Make sure to give time for all students to at least completed Q1 and Q2. You can revisit Q3 and Q4 with

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small groups in the next step, if all students don't get to these questions during this individual brainstorming time.

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3. (5 min) Have students work in their small groups to plan what their investigation into what happens when bonds are formed might look like. Push students' thinking as you walk around the room.

Suggested Prompts:

- ➔ How would you represent a bond being formed in your model using magnets?
- ➔ What evidence would you need to see to convince yourself that kinetic energy is being released when a magnetic bond is formed?

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3. (10 minutes) Have students experiment and play around with their setup of marbles and magnets to model what exactly is happening when a bond forms and whether or not the forming of bonds is related to the thermal energy of the system increasing.

Students should be pressed to experiment and find:

- **The maximum distance away from a magnet that a metallic ball can be and still form a connection**
- **How introducing a non-magnetic marble into the system affects things**
- **How swapping out the metallic ball for a metal paint coated marble impacts the system**
- **How changing the strength of the magnet under the ruler impacts the system**

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4. (10 minutes) Pull students together in a scientist's circle, to have students share what they discovered in their investigations with the class.

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Suggested Prompts:

- ➔ How did you represent the two particles that were bonding together?
- ➔ Was there anything else represented in your investigation aside from the bonding particles?
- ➔ What happens when a bond forms?
- ➔ Do you think this is a good model for how bonds are formed between particles?
- ➔ Does forming a bond result in an increase in thermal energy? If so, what is your evidence?
- ➔ Does changing the strength of the magnets change anything?
- ➔ Did introducing a non-bonding marble into the system reveal anything?
- ➔ What are the similarities and differences between how bonds are formed and how bonds are broken?

Make sure the class comes to consensus on these points:

- **Bonds can form without any outside force acting on them, the metallic ball will start moving and forming a bond on its own**
- **If there is something non-magnetic in the path of the metallic ball forming a bond, that marble will shoot off**
- **These two facts are the evidence that forming bonds releases thermal energy**
- **Making either the marble or the magnet underneath the ruler stronger, will make the thermal energy released stronger (and vice versa)**
  - **Therefore, the formation of stronger bonds will release more energy than the formation of weaker bonds**

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5. (10 min) Use the last half of class to introduce a way of measuring kinetic energy, and an analogy between bonds formed from gravity vs. bonds formed from magnetism. A

The goal of this conversation is to:

(1) help students to start drawing a parallel between the steel marble and magnet which has "magnetic potential energy" when released from a distance to a ball above the ground which has

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Additional Guidance

A This activity can also be done by alternating between small groups and large group discussion. Do this by having students first work through chunks of their worksheet and then come together for group discussion.

Depending on the background knowledge the students have, this might be a heavy lift so be prepared for this conversation to be a long one.

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"gravitational potential energy" and (2) help students begin to think about the idea that potential energy can be converted into kinetic energy, and vice versa.

First, push on the idea of what it means for something to be bonded.

Suggested Prompts:

➔ What about the magnet and the magnetic ball makes them be considered bonded?
➔ Is anything touching considered bonded?

Place a ball on the floor and ask students if the ball and ask the students if this is a phenomenon that is parallel to the "bonded" metallic ball and magnet.

Suggested Prompts:

➔ When I try to separate the ball and the ground, how is that similar and/or different from separating the "bonded" metallic ball and magnet?
➔ In what ways could we consider that this ball is "bonded to the Earth"?
➔ What do we have have to do to pull the ball apart from magnet and pull apart the ball from the Earth?
➔ What happens to the ball that we pulled away from the Earth when we released it? How is that similar to what happens to the metal ball when we pull it away from the magnet?
➔ We know that the magnetic pull is strongest near the surface of the magnet, is that also true for the gravitational pull of the Earth? Is it strongest near the surface and weaker the further away you get?
➔ What are some ways that gravity and magnetism are similar? Different?

Anticipated *student responses*:

➔ *The ball and the ground aren't bonded exactly the same way as the metal ball and magnet, but there are some similarities.*
➔ *Both balls are attracted toward toward another object*
➔ *In both cases we have to pull or lift the ball away from the Earth or Magnet to get it to seperate from it.*

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- ➔ *In both cases when we release it (if it is close enough) the ball goes back to the thing that we pulled it away from.*
- ➔ *In both cases, there is an at-a-distance-force that is pulling on the ball.*
- ➔ *We think that gravity gets weaker the further away you get, and you can get far enough away from the Earth that it feel like their is no gravity (or nearly no gravity). That is similar to the magnets.*
- ➔ *Gravity and magnetism is different too, because only certain kinds of objects exert magnetic forces and they only attract other kinds of objects (certain metals), but the Earth attracts all kinds of objects. And magnets are small, but the Earth is big. (e.g. certain kinds of metals)*

Emphasize the following idea:

- **It may be useful to think of the ball on the surface of the Earth as being bonded to it, since it shares many similar characteristics as a magnetic marble bonded to a magnet, including:**
  - **There is an at-a-distance force that pulls it toward that other object**
  - **If you lift/pull it away and it is still close enough, we can see the ball go back to the thing we pulled it away from.**
  - **The further away you pull the objects apart, the weaker the attractive force between them.**

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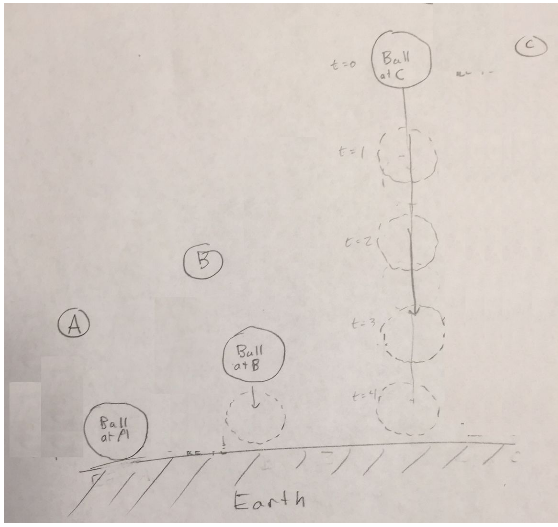
5. (15 min) Ask students to start thinking about how energy might be a useful way to describe changes in the motion of the objects in both systems. Show the ball on the ground and draw a picture of this on the board. Label this as "position A". Then lift the ball one a foot above the ground and show students how high you have the ball now. Draw a picture of this on the board and ball this as position B. Lift the ball 5 feet above the ground and show students how high you



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have the ball now. Draw a picture of this on the board and label this as position C.

Suggested Prompts:

- ➔ When I held the ball at each of these positions it wasn't moving. Since it wasn't moving, what can we say about its kinetic energy at position A, B, and C?

Anticipated *student responses*:

- ➔ *The kinetic energy of the ball at A, B, and C are all zero.*

Ask students to predict what would happen to the ball if you released it in B vs. C. And again to compare that to A.

Suggested Prompts:

- ➔ If I release the ball in B and C, what will happen to its speed?
- ➔ Why would B and C speed up, but A would not?
- ➔ Will it speed up as much from dropping it from B as from C?
- ➔ Will they have the same amount of kinetic energy (energy of motion) just before they reach the ground or will one have more kinetic energy than the other?
- ➔ How could we test this?

Anticipated *student responses*:

- ➔ *Both B and C are pulled down by gravity. That causes them to speed up, but A can't be pulled down anymore, so it can't speed up.*
- ➔ *Some students will claim that B will speed up as much as C, others will claim that C will speed up more than B.*
- ➔ *We could test this by rolling them down a ramp from different heights (1 foot vs. 2 meters) and timing how far they go in 1 sec.*
- ➔ *We could test this by making slow motion video of releasing each on an iphone camera, and then play it back to see how far it moves between two frames just before it reaches the ground.*
- ➔ *We could test th is by seeing which one keeps bouncing up and down longer than the other.*

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Tell students that it sounds like we agree that in both B and C, the ball gains Kinetic energy when we release it and it travels downward toward the earth from gravity, but we are wondering if it is gaining more kinetic energy in one case than another, so we want to test that to find out. Work with the class to come up with a way to test the amount of KE released from a ball held at different heights. B

DAY 2 - 55 minutes

6. (15 minutes) Review the ideas that students for the tests they suggested last time to see which ball has more energy before it reaches the ground (position B or C). Conduct one of the tests that students suggest. B

In addition to one of the tests that students come up with show also show the two slow motion videos of the release of ball from different heights. You can use these as an alternate if students don't suggest making their own videos or suggest another test to conduct.

Project the video on the board and mark the position of ball every 10 frames in both cases. Students show see that the distance between every 10 frames is increasing in both, but that it increases further in the ball dropped from 5 feet.

Suggested Prompts:
- ➔ What can we now claim about the kinetic energy of the ball dropped from C vs. B, right before it hits the ground?
- ➔ Why does ball C gain more kinetic energy than B?
- ➔ If we dropped the ball from a height twice as high as C, how would its kinetic energy compare to C right before both hit the ground?
- ➔ Why is increasing the height of the ball causing the ball to gain more KE on its way down.

Anticipated *student responses*:
- ➔ *Ball C falls farther than B.*

Additional Guidance

B There are many ways to test this.

The most important this is for students to realize that the ball gains different amounts of KE when dropped at different heights. DO NOT try and quantify this difference too intensely. The slow motion videos will provide qualitative data to help the class build a model.

Remember that this is just an activity to help us ultimately think about where the KE is coming from in our marble/magnet set up and in our understanding about the formation of bonds.

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- ➔ *Doubling the height you drop it from should increase its KE even further (right before it hits the ground)*
- ➔ *The increased kinetic energy comes from gravity. The farther away anything is from the ground the faster it will hit when it strikes the ground.*
- ➔ *Gravity is pulling on it. The longer it pulls it down for, the faster the ball moves before it hits.*

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7. (20 minutes) Tell students that, We agree that the greater the height, the greater distance the ball has to fall, which gives it a greater potential to speed up due to the gravity pulling on. This idea that greater distances lead to a greater potential for the object to gain more Kinetic Energy when the object falls back toward the thing pulling is an important one. One way to refer to this greater potential, is to describe it as a greater amount of potential energy that the object has at different heights. Potential energy is the energy that the system has, based on the position of the objects in it. It is always due to at-a-distance forces. C

Tell students that it can be useful to describe both the kinetic energy and the potential energy that an object has to help us visualize the relationship between the two, and that doing this for our ball falling to earth due to gravity might also be helpful for describing what is happening when the ball falls toward the magnet. Start by drawing the ball at for the 3 starting positions.

Then add a dotted line representation to show it falling over time. Point out that the dotted line ball right above the floor represents the moment right before it hits the floor.

Suggested Prompts:

- ➔ How does the KE of ball C compare to ball B right before it hits the floor?
- ➔ How much KE does ball A have?

Expected *student responses*:

- ➔ *Ball C has more KE than B. Ball A has zero KE.*

Update the model to add a bar graph representation

Additional Guidance

C Throughout this conversation, you may want to sinder using the term “potentially energy” instead of “potential energy”. You could also choose to be more specific saying “gravititaional potential energy” or “magnetic potential energy”

The point of using different terms to emphasize the conceptual understanding of what we are trying to describe, rather a specific vocabulary word of phrase. At point the focus of the conversation is differentiating between this type of energy and kinetic energy.

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of KE for ball at its position right above the floor (for B and C) and right on the floor for A. Then ask students about why the ball at all of these positions would have no additional potential to gain any kinetic energy from falling.

Suggested Prompts:

- ➔ Why would the ball at all of these positions would have no additional potential to gain any kinetic energy from falling?
- ➔ When the ball has a height of zero from the ground, why would it make sense that it has zero potential energy from gravity?

Anticipated *student responses*:

- ➔ *There is no height left to fall.*
- ➔ *Gravity can't speed it up anymore because there is no more space for it to keep pulling it down.*

Now motivate adding different Potential energy to the initial potential energies to the ball at B and C just before they are dropped.

Suggested Prompts:

- ➔ Why would ball B have a greater potential for gaining speed than ball C would just before we release it?
- ➔ Which ball would have more gravitational potential energy just before its released?

Anticipated *student responses*:

- ➔ *Ball C has more potential than B to gain more speed, because it has more height to fall.*
- ➔ *Ball C would have more gravitational potential energy than B.*

Tell students that scientists use potential energy representations as a way to keep track of where the energy in the system is. Point out that at position C, we

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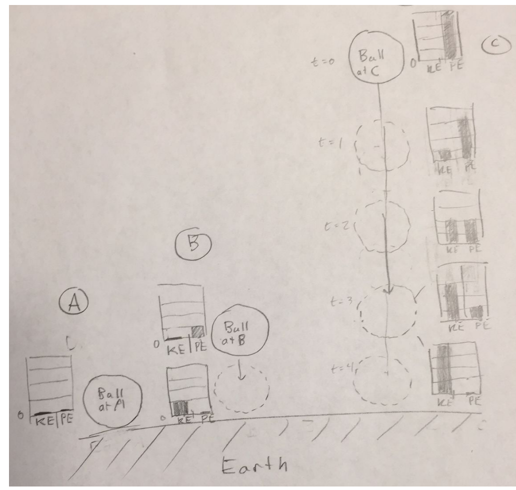
want to show that not only does ball C have more potential energy than ball B before it is dropped, we want to show that all that potential energy converts into kinetic energy by the time it reaches the ground, therefore we want to make the bar for PE at positions B and C, represent this. (Update the model as shown to the right)

Suggested Prompts:

- ➔ What is happening to the speed of C as it falls?
- ➔ So what should happen to the KE?
- ➔ What is happening the remaining potential energy?



Anticipated *student responses*:

- ➔ *Ball C is speeding up as it falls, so it's KE should be going up.*
- ➔ *Ball C's remaining height is decreasing as it falls, so its PE should be decreasing.*

Update the model to show this (see updated model to the right).

Make sure the class comes to consensus on these points:

- **The higher the ball is held, the more KE the ball has when it hits the ground.**
- **The KE is coming from a force acting on the object. That force is called gravity and it works from a distance. The greater the distance, the more it can pull, and the more the object it is pulling on speeds up.**
- **Even though a ball being held in the air does not have KE, it has another type of energy that is like the "potential" for something to happen.**
  - **That "potential" energy can convert into kinetic energy and we can track that conversion of energy!**
  -

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- **POTENTIAL ENERGY is a type of energy that measure the potential of something to happen to the objects in the system due to attractive (or repulsive) forces between them**
  - **Potential energy can be converted to Kinetic energy when objects in the system move together (from attractive forces)**

Add the word POTENTIAL ENERGY to our poster tracking scientific words that we have defined.

---

8. (10 min) Have students complete Q15. Then ask students how might a similar model help us explain where the energy is coming from when an alkali metal reacts with water?

Suggested Prompts:

- ➔ Is there also a form of potential energy with magnets?
- ➔ Does distance impact the amount of kinetic energy released? How could we test that?
- ➔ If you moved a metal ball 1 cm from a weak magnet would it have the same magnetic potential energy from that magnetic interaction as it would if you moved it 1 cm away from a weak magnet?
- ➔ If you lifted a hammer 5 feet above the Earth would it have the same gravitational potential energy from its interaction with the Earth as it would with with moon if you moved it 5 feet above the surface of the moon? Why?

Anticipated *student responses*:

- ➔ *There is a form potential energy with magnets*
- ➔ *Distance would affect the amount of KE released. We could test this by releasing the metal ball a short distance from a glass marble above magnet and seeing how far/fast a glass marble leaves the system. We could compare that to when we release the metal ball a little further away.*
- ➔ *There would be more magnetic potential energy from a stronger magnet than a weaker magnet.*
- ➔ *There would be more gravitational potential energy from the Earth when it is 5 feet above the Earth than there would be from the moon when it is 5 feet above the moon. This is because the Earth's gravity is stronger.*

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9. (10 min). Emphasize that the classes model of bonds seems to have some parallels with gravity, particularly related to thinking about the relationship between forces at-a-distance, "potential" energy, distance, and where the kinetic energy is coming from when a bond is formed.

Have the class imagine that you have hired a computer programer to design a computer simulation to include all the important parts of the system that would help us visualize all of these things that might going on in the marble track system. Build a list with the class of what that simulation would need to include in Q16.

Suggested Prompts:

- ➔ In order to help us simulate and visualize these mechanisms and outcomes more clearly, what physical objects would the simulation need to have represented?
- ➔ What kind of interactions would you want to be able to amplify or remove?
- ➔ What would you want to be able to visualize?
- ➔ What measurement tools would you want to be able to use in the system?

Have students share out their ideas and keep track of all of them on a poster called "Specifications for our Virtual Model"

Make sure the class comes to consensus on these points:

- **Our virtual model needs to include:**
  - **A metallic marble and a magnet to represent a bond**
  - **A glass marble that can roll into the system or be pushed out**
  - **A way to change the strength of the magnets**
  - **A way to track particle speed/temperature**
  - **A way to see the at-a-distance forces**
  - **A way to visualize the potential energy in the system.**

Keep a record of this criteria to refer to next time. Tell students that it appears we will need to find

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a computer simulation to use the next time they meet, that will meet the criteria they came up with.

DAY 3 - 50 minutes

10. (5 min) Direct students attention to the criteria list that they generated last time in Q16. Remind students that this was their criteria for a computer simulation. Tell students that you found a computer simulation, that may meet none, some, or all of the criteria they came up with, and they will need to evaluate it to determine which criteria, if any, it meets. Have students keep track of which criteria it meets by looking back at their table on Q16, putting a checkmark next to each each thing that appears to be a part of this simulation that was on the list.

To demonstrate the model you can use the ScreenCast found here: https://goo.gl/LsFKy6

If you want to demonstrate how to use the model yourself, start by showing how to move the sliders to change the initial position of the two magnets and the two particles. Point out that particle A is off screen but you can change its incoming speed in a slider. Make sure you tell students that particle B is a metallic marble while particles A and C are glass marbles.

Demonstrate how to change the strength of, or turn off, the two magnets. Also demonstrate the different ways of visualizing how far the magnet can reach (i.e., the magnetic field). While doing this, go over how one should press Setup before pressing Go every time sliders are adjusted.

Suggested Prompts:

- ➔ What, if anything, appears to be missing from this simulation that was on your list?
- ➔ How did the person who built this virtual model choose to visualize forces? Does visualizing the force field help us get a sense of the magnetic potential energy? Let's take a moment to evaluate this representation. Does it capture most of what we were talking about with magnetic potential energy? Are we okay using it moving forward?[D]

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Turn off all magnets and run the model once with A at some initial speed and show students how the different sensors track the speed of the particles both in numerical and graphical form.

Have a quick check in with students about what they just saw by answering questions Q17 and Q18. Have this conversation lead into whether or not we should have friction in our model or not. E

Suggested Prompts:

- ➔ How does the speed of the particle entering the system compare to the speed of the particle leaving the system when there are no magnets under the track?
- ➔ Why would this only happen when track-friction-energy-loss is set to 0%?
- ➔ Is having 0% track friction a useful representation for what is happening in collisions between individual particles at a microscopic level? Or should there be some friction included?

Make sure the class comes to consensus on this point:

- **We should keep the slider at 0% track friction because that is probably closest to what is happening at atomic interactions where there is no physical track, merely empty space**

---

11. (10 min) Have the students do investigation 1 with their partners. Students should be discussing and recording their responses to the investigation 1 questions during this time.

---

12. (15 min) Have a class discussion to make sure that everyone is on the same page.

First ask students some general questions about the virtual model:

Suggested Prompts:

- ➔ Does this virtual model indicate potential energy?
- ➔ How did the magnetic field impact the metallic ball?

Additional Guidance

D This virtual model, like all scientific models, foregrounds certain interactions, and simplifies others. No model is exact. No model is perfect. In real life there are no non-moving particles and attraction between particles is much more complicated. If students bring this up, acknowledge this!! This is very insightful and indicates that they are really thinking hard!

Ask students if even though our current virtual model is imperfect, is it productive enough for now? We can also make notes in how we would update our virtual model if we were to come back to it! If you have lots of extra time you can also play with the feature of giving marbles a metallic coating, that will add nuance into the model and potentially assuage some of the students concerns.

Additional Guidance

E Unless the students are really invested in friction as a factor, there is no need to spend too much time on this point. Just get the students to a place where they

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Then, focus on the last few questions from the student sheets.

Suggested Prompts:

- ➔ What causes particle B to speed up in certain parts of the system?
- ➔ What causes particle B to slow down in other parts of the system?
- ➔ What was the repeating motion of particle B in this virtual model?
- ➔ When you used an actual metal ball and released it at a distance from a real magnet, did it also exhibit this oscillating (wobbling back and forth) behavior for a bit?

After students summarize their findings from the investigation, push students to think about where KE comes from when the particle speeds up and where the KE goes when the particle slows down.

Suggested Prompts:

- ➔ What is happening to the KE over time? Does the KE ever disappear? Does the KE ever seem to appear from nowhere?
- ➔ Can we track the KE over time? Is there anything else that might be useful to track?
- ➔ Is there anything from our investigation with the ball and gravity that we could use to help us think about what is happening to the KE in our virtual magnetic model?
- ➔ In our investigation with the ball and gravity, we saw that when the ball was closer to the ground less KE was released because there was less potential for something to change. Would that be the same for magnetic potential energy?

At some point in this conversation, try changing the initial position of particle B and see if that impacts the maximum amount of KE released. Help students see the relationship between this and the ball and gravity investigation!

Make sure the class comes to consensus on these points:

are okay with keeping the slider at 0% friction by pushing on the idea that, “If atoms are moving in empty space, not on a ruler, is there even friction?”

You need students on board with this point because the NetLogo model should be run at 0% track-friction-energy-loss.

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- **Particle B, the metallic ball, is changing speed because of the forces of attraction between them across the space in between them. These invisible attractive forces across that space are referred to as a magnetic field.**
  - **As the metallic ball gets closer to the magnet, the strength of the magnetic field increases so the metallic ball speeds up**
  - **As the metallic ball gets farther from the magnet, the strength of the magnetic field is pulling the metallic marble back so it slows down**

---

13. (20 min) Have the students do investigations 2 and 3 with their partners. Make sure students complete the questions for each of their investigations before the next class

---

DAY 4 - 20 to 30 minutes

14. (20-30 min) Have a consensus building conversation with the class where the class shares what they found in their investigations. Have students begin to shift their language from metallic balls to particles supporting them in mapping the physical and virtual models back to the phenomena

Suggested Prompts:

- ➔ What did you learn about what happens when a bond is formed? What is your evidence?
- ➔ When bonds are formed, do they always release the same amount of energy? F What is your evidence? Think back to the phenomena we have seen and see if you can think of a real life example that supports this idea.
- ➔ What did you learn about what happens when a bond is broken?
- ➔ When bonds are broken, do they always release the same amount of energy? What is your evidence? Think back to the phenomena we have seen and see if you can think of a real life example that supports this idea.

Additional Guidance

F If students bring up the idea that equivalent bonds will require the same amount of energy to break as they release when they are formed themselves -- great!! Otherwise it will be discussed in more detail in Lesson 10.

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- ➔ Wait once we use up KE to break a bond can we ever get that KE back? Or does it disappear forever?
- ➔ Where is the KE coming from when a bond is made?
- ➔ Was what happened in the virtual model similar or different from what we saw in our physical models? How so?
- ➔ Does energy ever come from nowhere? Does energy every disappear?

Make sure the class comes to consensus on these points:

- **Potential energy in this system is visualized through the magnetic field which indicates what a particle will experience depending on where it is in the magnetic field**
  - **We decide to add to our definition of POTENTIAL ENERGY that position matters**
- **The KE of the system increases when bonds are formed due to the potential energy of the magnetic field causing entering particles to speed up**
- **Forming stronger bonds releases more energy than forming weaker bonds**
  - **This is because stronger magnets have higher potential energy (aka stronger magnetic fields) and so a particle within that magnetic field will experience a larger increase in kinetic energy when moving towards the magnet**
  - **This makes sense with what we saw when different metals released different amounts of energy when reacting with water**
- **The KE of the system decreases when bonds are broken due to the potential energy of the magnetic field cause exiting particles to slow down**
- **Breaking stronger bonds requires more energy than breaking weaker bonds**
  - **This is because stronger magnets have higher potential energy (aka stronger magnetic fields) and so a particle within that magnetic field will experience a larger decrease in kinetic energy when moving away from the magnet**
  - **This makes sense with what we saw when dissolving different salts required different amounts of energy** F
- **Energy never disappears nor comes from nowhere it is CONSERVED. It is converted back and forth from potential energy to kinetic energy and we can track it the entire time!** G

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Once these ideas have been established, bring the conversation back to the chemical reactions we saw that involve breaking AND forming bonds. *If chemical reactions always involve both breaking and forming bonds, then why does the temperature sometimes increase and other times decrease? Why is it different for different chemical reactions? In other words, why do some chemical reactions get hot and other get cold?*

Foreground the next lesson by asking, How might we revise or use our computer model to investigate this question further?

You may want students to answer questions Q33 and Q34 before starting the next lesson to build coherence from the end of this lesson to the start of that one.

Additional Guidance

G If this is the first time students have ever hear the idea of CONSERVATION OF ENERGY do not rush through that aspect of this conversation. Spend some time on the idea that PE and KE are interrelated and because they are constantly converting back and forth energy is in its essence conserved. Not only that but we can effectively track energy as it moves between PE and KE!

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Alignment With Standards

Building Toward Target NGSS PEs

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 10 : Why do some chemical reactions get cold and others get hot?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students investigations indicate that kinetic energy is released when bonds are formed! Further investigation with a virtual model helps us visualize that this kinetic energy comes from the potential energy that exists in the magnetic field of a particle.

This Lesson....What we are doing now: Students return to the virtual model to explore why some chemical reactions get cold and others get hot by modeling bonds breaking and forming together. Students come up with a final consensus understanding of exothermic and endothermic reactions, ensuring that their final model explains all of the chemical reactions we have seen in this unit.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L10: Why do some chemical reactions get cold and others get hot? (2 periods) *Building toward* ⬇ *NGSS PEs: HS-PS1-4, HS-PS3-5*	Previous phenomena from L1 and L8 (ammonium chloride/ barium hydroxide and alkali metals in water).	**Construct an Explanation** where you link evidence to the claims to assess the extent to which the reasoning and data support the explanation *by seeing whether your model tracking energy changes within a system due to chemical reactions can extend to include the original phenomena* **Communicate scientific information** and ideas (e.g., about phenomena) in multiple formats (i.e., orally, graphically, textually) *while presenting models explaining how changes in kinetic energy are caused by bonds of different strengths breaking and forming*.	We're still having a hard time conceptualizing what happens when bonds break and form as part of a chemical reaction so we return to our virtual model to explore the question *Why do some chemical reactions get cold and others get hot?* We play with these features systematically in order to find patterns as to how changing the strength of the magnets changes things. We realize that depending on the relative strengths of the bonding magnets/atoms, the "magnetic chain reaction" could either release more KE than you put into it (if the first magnet is weaker than the second magnet) or absorb more KE than you put into it (if the first magnet is stronger than the second magnet). • If the bond formed is stronger than the bond broken, it will take less energy to break the first bond than is converted (from PE) with the forming the second bond - resulting in more energy being released than absorbed (speed up the marble going out vs. coming in.) • If the bond formed is weaker than the bond broken, it will take more energy to break the first bond than is converted (from PE) when forming the second bond - resulting in more energy being absorbed than released (slowed down up marble going out vs. coming in.) We summarize everything we know about chemical reactions: • Bonds are both destroyed and formed in chemical reactions, so energy is both absorbed and released in all reactions through bond breaking and formation (aka ALL chemical reactions are either endothermic or exothermic) • Exothermic and endothermic reactions are determined by the net energy (scale, proportion, and quantity) that is absorbed/released into the surroundings determines whether the reaction is exothermic or endothermic. • Every bond has a specific bond energy, the minimum energy required to break that bond, but that same amount of energy is released into the surrounding when that bond is formed! We try and extend our model to explain all of the chemical reactions that we have seen in this unit, and it works! We also try and come up with a general model that explains what happens generally in exothermic and endothermic chemical reactions. *Our model seems to work, but is it really right? How do scientists model these processes? Is our explanation anywhere close to how scientists talk about this?*

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			We decide to look at the models scientists use to explain endothermic and exothermic reactions and see if we can make sense of them.

Next Lesson....Where we're going Students investigate how scientists model and think of these phenomena

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Getting Ready: Materials Preparation

Preparation of Materials

- Have the NetLogo model loaded on the projector and on every computer ready to go.
    - The Netlogo model can be downloaded from http://goo.gl/hCyfW9
- The directions for running the model using a web browser are available on the Bonds and Chemical Energy ScreenCast available here:

Alternate Preparation of Material

- NetLogo runs faster when the application is installed on the computer ahead of time. This is only possible on computers that have hard drive space and administration access to support that installation. If you have this access, coordinate with your IT department, about getting NetLogo software installed on all the computers in a computer lab.
- Using this method, students will still download the Bonds and Chemical Energy.nlogo file from http://goo.gl/hCyfW9
- But the next step will be to simply double click on the Bonds and Chemical Energy.nlogo model file that they downloaded to the desktop or downloads folder to launch it.

Materials For Each Student

- Lesson 10: Student Activity Sheets (1)

Materials For Each Small Group

- Poster boards and markers.

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Learning Plan: Does breaking the bond between particles really require energy? (90 min)

DAY 1 - 45 minutes

1. (5 minutes) Recap what happened the previous day with this students. Have students restate what they discovered in their physical and virtual investigations.

Suggested Prompts:

➔ How and why does forming bonds affect the speed of particles entering and exiting the system?
➔ How and why does breaking bonds affect the speed of particles entering and exiting the system?

Students should remember that:

- **Forming bonds releases kinetic energy into the system**
- **Breaking bonds uses kinetic energy from the system**

Have students articulate the motivation behind today's lesson: Chemical reactions involve breaking AND forming bonds, so, keeping what we know about bonds in mind, why does the temperature sometimes increase and other times decrease?

---

2. (10 minutes) Have the students do investigation 4 with their partners

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3. (15 minutes) Have students share what they discovered in their investigations with the class. Students should leave this conversation with a clear understanding of:

- **How the relative strength of bonds being broken or formed determines whether a chemical reaction is endothermic and exothermic**
- **That bond energy is not only the amount of energy needed to break that bond but also the**

Teacher Supports & Notes

Additional Guidance

A This conversation is the heart of the unit. As such, really work hard to let the students do all of the heavy lifting. This class period should be the ah ha moment where everything students have learned will come together. They have all the pieces, so really let them put it together. Encourage student driven conversation and have students convince their peers of their ideas not you.

Once students have put it all together, make

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amount of energy released when a bond is formed (i.e., bond energy is a property of a bond) A

Suggested Prompts:

- What were the three scenarios we investigated? What were our findings from each of these investigations?
- What did our graphs that tracked particle speed over time look like for each scenario? B
- Why do breaking and forming bonds sometimes result in particles exiting the system faster than they entered it?
- Why do breaking and forming bonds sometimes result in particles exiting the system slower than they entered?
- Why do breaking and forming bonds sometimes result in particles exiting the system at the same speed as they entered it?
    - In this scenario, could the bond being broken be the same bond that's being formed?
    - Do we have any way of predicting how much energy will be released when a bond is formed?
    - What do you think bond energy could tell us about how much energy will be released when that bond is formed?
- Does it always take the same amount of energy to break a certain strength bond? When a bond of a certain strength is formed is the same amount of energy always released into the surroundings?
- Is it random whether the temperature increases or decreases in a chemical reaction or is there an explanation that can help you predict what will happen?
- Could there be a chemical reaction where there is no temperature change? Why?

Make sure the class comes to consensus on these points:

- **Bonds are both destroyed and formed in chemical reactions, so energy is both absorbed and released in all reactions through bond breaking and formation (aka ALL chemical reactions are either endothermic or exothermic and if they aren't it is because bond strengths are equivalent)**

sure you celebrate what they have figured out! We might still have a few loose ends, but this feels like a huge accomplishment!

Additional Guidance

B Make sure to ask this question from multiple groups and marvel at the fact that even though students might have used different strength bonds, their pictures always look generally the same as long as the relative strengths of the bonds are the same.

In other words, breaking strong bonds and forming weak bonds always forms the same general image. Similarly, breaking weak bonds and forming strong bonds always forms the same general image. Marvel at this! Familiarizing students with this graphical representation will be important for later in this lesson as while as in lesson 11.

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- **Exothermic and endothermic reactions are determined by the net energy that is absorbed/released into the surroundings**
- **Every bond has a specific bond energy, the minimum energy required to break that bond, but that same amount of energy is released into the surroundings when that bond is formed!**

---

4. (15 minutes) But now we want to see if our model can actually explain all of the chemical reactions that we saw this unit! Does our model really work?

Have each small group pick one of the three *chemical reactions* that we have looked at this unit: 1) barium hydroxide and ammonium chloride; 2) pink lemonade, water, and baking soda; 3) lithium/sodium/potassium and water. Make sure that each chemical reaction is picked at least once.

Have each small group make a final consensus model that answers the question: Why is there a change in temperature in these chemical reactions between room temperature substances?

Remind students that they may want to think about how their vocabulary words might help them in their explanation including: kinetic energy, thermal energy, bond energy, bond strength, bond stability, etc.

DAY 2 - 45 minutes

1. (5 minutes) Give students 5 minutes to finish up their posters if they aren't finished yet.

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2. (30 minutes) Have groups of students come up and present their model to the class. Have each group present for ~2 minutes with ~3 minutes of questions. If the class discussion is productive, do not cut it off.

Additional Guidance

C These presentations are an opportunity for formative assessment. See which students are able to easily answer your questions or prompts and who is struggling. If a large majority of the class is struggling, stop and reassess. Address their

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Encourage students to ask each other questions, but also make sure to ask questions yourself in order to assess if students have really understood everything we have learned. C

Suggested Prompts:

- ➔ Where does the energy come from to break the bonds?
- ➔ Where does the kinetic energy that is released when bonds are formed come from?
- ➔ How did you depict kinetic energy in your poster? If you did not depict it, why didn't you?
- ➔ How did you depict thermal energy in your poster? If you did not depict it, why didn't you?
- ➔ When you say bond strength, what do you mean by that?
- ➔ What does bond energy have to do with your explanation? What even is bond energy again?
- ➔ Is your reaction exothermic or endothermic? What does that even mean?
- ➔ Are the bonds that are being broken more or less stable than the bonds that are being formed? How do you know? What does bond stability even mean?

This is exciting because our model actually explains all of the phenomena that we have seen in this unit!!

---

3. (10 minutes) As a class, try to come up with a general model that could be used to depict generally what happens in exothermic and endothermic reactions D

Suggested Prompts:

- ➔ Do you think we should have one general model? Or one for exothermic reactions and one for endothermic reactions?
- ➔ What do we want to make sure we are representing in this model?
- ➔ What changes in endothermic and exothermic reactions?
- ➔ Are there any graphical representations that you may have seen in your previous investigations that might be useful for us to think about right now?

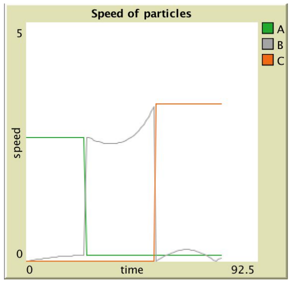
The class' final model can be anything as long as it makes sense and is useful in some way in generally representing exothermic and endothermic reactions!

issues immediately. If students seem hesitant, or unsure, ask them why they are uncertain. Hopefully most students will find this a very easy and rewarding presentation and be very confident in their answer!

Additional Guidance

D Ideally what you want students to use are a version of the graphs from the NetLogo model that track speed over time. If students feel strongly about pursuing another path, that is totally fine! But if after a few minutes students are not coming up with any productive ideas, encourage them to think about other graphical representations they may have seen in their investigations that may prove useful at this point.

Exothermic



Endothermic

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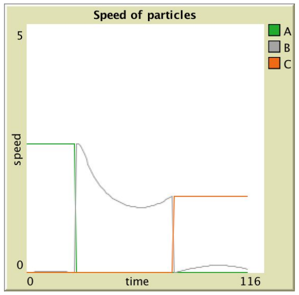
This seems to work, but is it really right? How do scientists model these processes? Is our explanation anywhere close to how scientists talk about this?

NEXT STEPS: We decide to look at the models scientists use to explain endothermic and exothermic reactions and see if we can make sense of them.



Alignment With Standards

Building Toward Target NGSS PE

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 11: How do scientists model endothermic and exothermic reactions?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students came up with a final consensus understanding of exothermic and endothermic reactions, ensuring that their final model explains all of the chemical reactions we have seen in this unit.

This Lesson....What we are doing now: Students make sense of scientists models, mapping their own understanding to scientists models of exothermic and endothermic reactions.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L11: How do scientists model endothermic and exothermic reactions? (1 period) *Building toward* ⬇ *NGSS PEs: HS-PS1-4, HS-PS3-5*	Previous phenomena from L1 and L8 (ammonium chloride/ barium hydroxide and alkali metals in water)	**Engage in Argumentation from Evidence** and evaluate the claims and reasoning behind currently accepted explanations to determine the merits of *scientists' models tracking energy changes over time in endothermic and exothermic reactions.*	We want to know how closely our models match to what scientists have come up with. We look at scientists' models, called reaction coordinates, and spend time first in small groups and then as a class trying to make sense of them. Through discussion we realize that the scientists' model is really just the inverse of ours. Scientists are merely tracking potential energy while we were tracking kinetic energy. We discover a few more ideas conveyed in the scientists' model: • **The y-axis is energy which is capturing the relative stability of the reactants or products.** In other words, if the reactants have stronger bonds than the products, then the reactants are more stable and so are lower in energy. If the reactants have weaker bonds than the products, then the products are less stable and so are higher in energy. Some of us might point out this makes sense, because a ball on the floor is more stable and has less energy than a ball being held in the air. • **The x-axis is time which provides us a way to track where the energy goes over time. We make the x-axis time.** In other words, if bonds are being broken our line would go up because we're using energy, and if bonds are being formed our line would go down because we're releasing energy. The stronger the bonds being broken, the more energy used, the higher our line goes up. The stronger the bonds being formed, the more energy released, the lower our line goes down. We define a few more terms in relation to scientists' model, enthalpy of reaction (the total change in energy due to a chemical reaction) and activation energy (the energy required to get the reaction started and break the bonds). Importantly, we realize that because the two graphical models are inverses of one another, if we added them together we would get 0. This helps us understand that even though the temperature is changing in the chemical reaction, energy is being conserved! We're not sure whether we like the scientists model better than ours, but it feels good to know that scientists have the same understanding of the phenomena as we do. We return to our Driving Question Board and feel accomplished by all that we have figured out! *But, what if we wanted to predict which reactions are endothermic and which are exothermic? Could we even do that?*

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			We decide to see if there is a mathematical model that we could come up with that would help us predict if a reaction was going to be endothermic or exothermic.

Next Lesson....Where we're going Students form a general mathematical model for exothermic and endothermic reactions that depends on the relative bond energies of the bonds being broken and formed in a chemical reaction.

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Getting Ready: Materials Preparation

Materials For Small Groups

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Preparation of Materials

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Materials For Each Student

- Lesson 4: Student Activity Sheets (1)

Materials Shared Between Classes.

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Safety

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Materials For Each Class

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Learning Plan: How do scientists model exothermic and endothermic reactions? (45 min)

Teacher Supports & Notes

DAY 1 - 45 minutes

1. (5 minutes) Recap what we discovered the day before.

Suggested Prompts:

- ➔ What do we call chemical reactions where there is a loss of energy from the surroundings?
- ➔ Why is there a loss of energy from the surrounding in these types of reactions?
- ➔ What happens to the temperature of chemical reactions when there is a loss of energy from the surroundings?
- ➔ What do we call chemical reactions where surroundings gain energy?
- ➔ Why do the surroundings gain energy in these types of reactions?
- ➔ What happens to the temperature of chemical reactions when surroundings gain energy?

Have students articulate the motivation behind today's lesson: To look at how scientists model exothermic and endothermic reactions and see if it is similar at all to what we came up with.

---

2. (5 minutes) Tell students that scientists do have a model for exothermic and endothermic reactions that they call reaction coordinate diagrams.

Have the students work on their worksheet in their small groups comparing scientists' models to our models. At this point, we are only trying to see the relationship between our representations and scientists'.

If students' used a variation of the NetLogo representation when modeling the day before,

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graphing energy against time, then students should be able to jump into this activity and recognize the two images as sort of being inverses of one another. If they didn't, remind them where the NetLogo representation comes from.

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3. (10 minutes) Have a whole class discussion where we talk about the similarities and differences visually between our model and scientists model.

Work with students to deduct what the labels might be on the scientists' model. You might have to ask some leading questions to help students see the relationship between the two images.

The goal of this conversation is for students to understand that scientists are graphing the change in potential energy over time, that stability can be inferred from these graphs, and the concepts of activation energy and enthalpy of reaction. [A]

Suggested Prompts:

- ➔ What do you notice about the two images if you turn your worksheet upside down?
- ➔ In our graph, we were measuring particle speed. What type of energy is that?
- ➔ Considering that the scientists' model is ours but upside down, what type of energy do you think they are tracking over time?
- ➔ Why do you think scientists' have the labels reactants and products where they do? Where would we put those labels on our graphs?
- ➔ In endothermic reactions, what substances are more stable, the products or the reactants? In exothermic reactions, what substances are more stable, the products or the reactants? By looking at the scientists' model, can we interpret the relative stability of the products or reactants? How?
- ➔ If I was to draw a line from the reactants to the bottom of the curve on our graph what would that represent? How would I draw that same line on the scientists graph? Scientists have a name for this: activation energy
- ➔ If I was to draw a line from the reactants to the products on our graph, what would that

Additional Guidance

A This can be a very confusing conversation with students. They will remember that scientists are opposite from us but they will confuse what we say and what scientists say. Make sure every time students talk about changes in energy due to a chemical reaction from now on that they specify whether they are tracking kinetic energy or potential energy.

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represents? How would I draw that same line on the scientists' graph? Scientists have a name for this: enthalpy of reaction.

Make sure the class comes to consensus on these points:

- **Scientists' model and ours are inverse images**
- **We are modeling the changes in kinetic energy over time and scientists are modeling the change in potential energy over time**
- **In scientists' models, when the reactants are lower than the products then they are more stable (less likely to change) since they have stronger bonds (and vice versa)**
    - **In our models, when the reactants are lower than the products they are less stable (more likely to change) since they have weaker bonds (and vice versa)**
- **ACTIVATION ENERGY is defined as the energy needed to start the reaction and break the bonds**
- **ENTHALPY OF REACTION is defined as the total change in energy in a chemical reaction**

Add the words ACTIVATION ENERGY and ENTHALPY OF REACTION to our poster tracking scientific words that we have defined.

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4. (15 minutes) Have the students return to their small groups to finish up their worksheet

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5. (10 minutes) Have a class conversation going over the end of the worksheet.

The goal of this conversation is for students to understand that energy is conserved so tracking the potential energy is literally just the opposite of tracking the kinetic energy!

Make sure the class comes to consensus on these points:

- **Energy is conserved -- tracking the potential energy is just the opposite of tracking the kinetic energy!**
- **Therefore, the value of the enthalpy of reaction (or the total change in energy) is always the same! What changes is the sign.**

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- **In our model: exothermic reactions have a positive change in energy since the kinetic energy is increasing while endothermic reactions have a negative change in energy since the kinetic energy is decreasing**
- **In scientists' model: exothermic reactions have a negative change in energy since the potential energy is decreasing (more stable products are formed) while endothermic reactions have a positive change in energy since the potential energy is increasing (less stable products are formed)**

We are still wondering, though, what this knowledge affords us? What if we wanted to predict which reactions are endothermic and which are exothermic? Could we even do that?

Suggested Prompts:

→ What could we calculate that would tell us whether or not a reaction was endothermic or exothermic?
→ What information would we need to calculate that?

NEXT STEPS: We decide to come up with a mathematical model that can be hopefully used to predict whether or not a reaction is endothermic or exothermic.

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Alignment With Standards

Building Toward Target NGSS PE

- **HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.**
- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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Lesson 12: Can we predict whether a chemical reaction will be exothermic or endothermic?

High School Chemical Energy Unit: Why Do Things Get Colder (or Hotter) When They React?

Previous Lesson....Where we've been Students made sense of scientists models, mapping their own understanding to scientists models of exothermic and endothermic reactions.

This Lesson....What we are doing now: Students form a general mathematical model for exothermic and endothermic reactions that depends on the relative bond energies of the bonds being broken and formed in a chemical reaction.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L12: Can we predict whether a chemical reaction will be exothermic or endothermic? (1 period) *Building toward* *NGSS PEs: HS-PS1-4, HS-PS3-5*	Previous phenomena from L1 and L9 (ammonium chloride/ barium hydroxide and alkali metals in water)	**Use a Mathematical** and algorithmic representation of phenomena to support claims and explanations *by coming up with a general mathematical expression that supports the idea that changes in kinetic energy are caused by changes in the sum of all bond energies*.	We try to write a mathematical representation of these ideas. Ultimately as a class we come up with: ● (The net energy gained or lost from the surroundings) = (The bond energy required to pull the atoms in the reactants apart) - (The energy released when the atoms are pulled together into new bonds in the products) ● If the difference is negative, more energy is released from the formation of bonds than is used in the breaking of bonds and so the reaction is *exothermic*. ● If the difference is positive, more energy is used in the breaking of bonds than is released from the formation of bonds and so the reaction is *endothermic*. By the end of this conversation we realize that we really have finally come to a complete consensus at this point that **"consequent changes in the sum of all bond energies in the set of molecules...are matched by changes in kinetic energy." (PS1.B)** The teacher tells us that bond energies have been calculated for many different types of bonds, which can help us predict whether a reaction is exothermic or endothermic. We look at a bond dissociation energy table. Knowing which bond energy is higher, help us visualize which magnet is stronger. The differences in the bond energies could help us predict relative differences in energy transferred to the surroundings or absorbed from the surroundings - which helps us answer the question - which reaction makes the surrounding warmer, which makes the colder? Which would change the temperature of the surroundings the most? And we realize that we can explain the WHY for comparing **any** two reactions that our numbers predict, because these numbers give us a way to picture how strong the bonds are between different combinations of atoms. Therefore we can use the individual bond energies and net bond energies to construct a mechanistic explanation for why some reactions release energy and other reactions absorb energy.

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			Summary: After this unit we understand what endothermic and exothermic reactions are and why there is a temperature change. We also understand: how thermal energy and kinetic energy relate to temperature; the difference between particle movement in solids/liquids/and gases that are the same temperature; bond strength; bond energy; what it means to have a stable or unstable compounds; what reaction coordinates/diagrams are and what they represent; and that PE can be converted to KE (and vice versa). ***Next steps: After this unit we can go on to learn about lots of things including ions and why different atoms form bonds of different strengths (build a periodic table!).***

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Getting Ready: Materials Preparation

Materials For Small Groups

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Preparation of Materials

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Materials For Each Student

- Lesson 12: Student Activity Sheets (1)

Materials Shared Between Classes.

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Safety

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Materials For Each Class

-

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Learning Plan: Can we predict whether a chemical reaction will be exothermic or endothermic? (45 min)

1. (5 minutes) Recap what we discovered the day before.

Make sure students are on the same page that:

- **Our models are just the inverse of scientists' models because we tracked kinetic energy and they tracked potential energy**

If our conversation at the end of class the day before about what we could calculate that would tell us whether or not a reaction was endothermic or exothermic and what information we would need to calculate that was productive go over it now. Otherwise, ask students these questions now.

Have students articulate the motivation behind today's lesson: To come up with a mathematical model that will allow us to predict whether a chemical reaction will be exothermic or endothermic.

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2. (3 minutes) Have students work in their small groups and try and come up with a generalized mathematical expression/model that captures how to determine whether a chemical reaction is endo- or exothermic. A

Tell students to think of this mathematical expression as a summary of our definition of the difference between the circumstances that result in an exothermic reaction as opposed to endothermic reaction.

If students get stuck, tell them to think about enthalpy of reaction and how that might help them.

Teacher Supports & Notes

Additional Guidance

A It might take a little while for students to understand what they are being asked to do by building a generalized mathematical expression that is a summary of our definitions of endothermic and exothermic reactions.

Definitely let the students struggle with this a little, but don't let them spend too much time if they are just staring at the page blankly.

Without giving the students the answer, push them to think about the enthalpy of reaction. How are we mathematically thinking of that idea? Would that help us?

Additional Guidance

B It may be helpful to have an explicit conversation about signs when deciding what to put first, the energy required to

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5. (10 minutes) A representative from each group comes up and writes their equations on the board. We come up with a general equation, but we get a little bit hung up on the order of the equation and therefore the signs. B

Suggested Prompts:

- ➔ What is the enthalpy of reaction again?
- ➔ Would the enthalpy of reaction for an exothermic reaction be designated positive or negative? Why or why not?
- ➔ Would the enthalpy of reaction for an endothermic reaction be designated positive or negative? Why or why not?
- ➔ If we didn't have a graph, how could we come up with the enthalpy of reaction mathematically? What would we need to have measurements of?
- ➔ What did we call the amount of energy needed to break a bond again?
- ➔ Do we have any way of knowing the amount of energy released when a bond is formed?
- ➔ Could bond energies be useful here?
- ➔ How is any of this related to temperature change or kinetic energy again?

Make sure the class comes to consensus on these points:

- **We should set up this equation to give us the enthalpy of reaction with the sign that scientists use because, even if it's counterintuitive, it will probably be more useful**
- **(The enthalpy of reaction or the net energy gained or lost from the surroundings) = (The bond energy required to pull the atoms in the reactants apart) - (The energy released when the atoms are pulled together into new bonds in the products)**
- **If the difference is negative, more energy is released from the formation of bonds than is used in the breaking of bonds and so the reaction is *exothermic*.**
- **If the difference is positive, more energy is used in the breaking of bonds than is released from the formation of bonds and so the reaction is *endothermic*.**
- **Therefore, consequent changes in the sum of all bond energies in the set of molecules are matched by changes in kinetic energy*****

break bonds or energy released when bonds are formed.
It's okay if students decide to order this so that their enthalpy of reaction comes out opposite from the traditional signs (i.e., they decide that exothermic is positive and endothermic is negative). Just make sure that they can
1) articulate what type of energy they are tracking (i.e., kinetic energy instead of potential energy)
and
2) that they understand when they look up scientists' pre-calculated values of enthalpy of reaction it will be opposite for them so they will always have to switch back and forth.

If this convinces them to track potential energy instead and use scientists numbers then fine! The important thing is for them to understand the relationship between their numbers and scientists numbers and for them to understand what energy they are tracking with their mathematical expression.

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2. (10 minutes) It turns out that scientists have calculated all the bond energies that we would need to use this equation for most chemical reactions!

Have students work in small groups on their worksheets calculating the enthalpy of reaction (ΔH_{rxn}) and designating each reaction exothermic or endothermic appropriately.

3. (5 minutes) Have each group share their answer to one question so that everyone can check their answers. Work through any questions as a class that students got incorrect as a class.

This is also a great opportunity to ask students some questions to make sure that all students really understand what is going on.

5. (7 minutes) Spend the remainder of the class at the Driving Question Board. Did we answer all of our questions? Do we have any questions left? C

We are done with the unit! At this point students should feel like they have answered most of their original questions -- though we might have some new ones now!

Why do bonds have different strengths? Is there something different in the particles? We were always given chemical reactions, is there a way we can figure those out for ourselves? Why do some things react when they are mixed together but not other things?

These are questions for future units! Have a class celebration -- we figured out a lot!!!

Additional Guidance

C This is a critical moment in the lesson. We have worked all unit to make sure we were honoring students ideas and that students felt as if their thoughts were motivating the next lesson and if they wanted to try something else (within reason) we pursued their idea.

But we also tracked students ideas on the Driving Question Board so we want to see how we did! Did we really answer all of our questions? Are there some that we missed that we can answer right now? Do we have new questions?

If you don't do this today make sure you do it the next day! This is a really important part of establishing our classroom culture, helping students see how they impact what we learn, and show students that we will and do learn stuff in this class! Their questions will always eventually get answered, it just might take a while!

If there are questions leftover or new questions, take a few minutes to talk

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about how we could investigate those questions if we had the time.

Alignment With Standards

Building Toward Target NGSS PE

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- **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.**

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