Why do some things get colder (or hotter) when they react?

[1.0 pilot release - Jan. 2017]

Synopsis: *In this unit, students start by observing a perplexing phenomena. When two solids are mixed together in a beaker, the beaker drops in temperature so much, that it freezes to a wooden block it is sitting on! This leads students to start wondering about whether temperature changes occur when other things are mixed together. As students investigate other phenomena, they develop models to answer to the question, "Why do some things get colder (or hotter) when they react?*

What students figure out: *By the end of the unit, students develop ideas about the structure and properties of matter, chemical reactions, and the relationship between energy and forces. These ideas include:*

- *A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.*
- *When two objects interacting through a field change relative position, the energy stored in the field is changed.*
- *Whether or not energy is stored or released in a chemical process, it can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.*

NGSS PERFORMANCE EXPECTATIONS BUNDLE

HS Chemical Reactions		
HS-PS1-2	HS-PS1-4	HS-PS1-5
HS-PS1-6	HS-PS1-7	
HS Energy		
HS-PS3-1	HS-PS3-2	HS-PS3-3
HS-PS3-4	HS-PS3-5	

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Targeted NGSS Performance Expectation(s):
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.

Targeted Scientific Practice(s)	Targeted Disciplinary Core Idea(s)	Targeted Cross-Cutting Concepts
Developing and Using Models Modeling in 9-12 builds on K-8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural designed worlds. ● Develop a model based on evidence to illustrate the relationship between systems or between components of a system.	**PS1.A: Structure and Properties of Matter** ● A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. **PS1.B: Chemical Reactions** ● Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. **PS3.C: Relationship Between Energy and Forces** ● When two objects interacting through a field change relative position, the energy stored in the field is changed.	**Energy and Matter** ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. **Cause and Effect** ● Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

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Development History:

- Design team starts work on Alpha version of storyline in Spring of 2015.
- Alpha version of storyline piloted by Joshua Rappuhn in Fall 2015.
- Design team expanded.
- Beta version of storyline developed in Summer 2016.
- Beta version of storyline piloted by Joshua Rappuhn in Fall 2016.
- 1.0 field trials MI planned for spring of 2017.

Key to storyline columns:			
Lesson Question (time) *Building toward* ⬇ *NGSS PEs:*	**Phenomena**	**Lesson Performance Expectation(s):** • **Blue bold font: Science and Engineering Practice** • Regular font: Quoted from Appendix F Practices Matrix • *Italicized font: Specific storyline context (phenomena / question)* • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs)	**What We Figure Out** (CCCs & DCIs), *New Questions* and **Next Steps** • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs) • *Purple italicized font: New questions that we now have* • **Purple bold font: Our ideas for the next (or future) steps to pursue.**

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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* ⬇ *NGSS PEs:* *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 ammonium chloride to 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 so we want to see if other chemical reactions result in a drop in temperature. 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. 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?*

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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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This Lesson....What we are doing now: ...... Students explore a physical change, the dissolution of salt in water, and discover that it also results in a drop in temperature. As a class we try to understand what exactly is happening when salt is dissolved in water and we convince ourselves that this phenomena is indeed a physical change and not a chemical reaction.

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?"* **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.**

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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.*	If a beaker of water of one temperature changes temperature when placed in a closed box surrounded with room temperature air, the temperatures of both the even out over time- one gets colder, one gets warmer.	**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.*	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 3, 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?* **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.**

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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) S *Building toward* ↓ *NGSS PEs:* *HS-PS1-4.*	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?* **Next Steps: 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.**

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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) S *Building toward* ⬇ *NGSS PEs:* *HS-PS1-4,* *HS-PS3-5*	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?* **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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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 salt 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 are broken? (2 periods) *Building toward* ⬇ *NGSS PEs:* *HS-PS1-4, HS-PS3-5*	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 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 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 salt molecule collide and the bond breaks! 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. Our investigation provides evidence to argue 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 apply the discoveries from the investigation to argue that 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 salt dissolves. This makes sense because we now know that it takes energy to break bonds. 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 salt, breaking the bonds between the salt, 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 salts - the more salt 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 salts? Do we always need more energy to dissolve more? Are all salts' bonds the same?* **Next steps: We decide to investigate the dissolution of other chemical salts to see if we can find some answers to our questions.**

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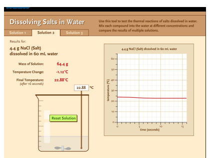
Why do some things get colder (or hotter) when they react?

[1.0 pilot release - Jan. 2017]

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?* **Next Steps: We decide to check if our model now explains the temperature drops in the chemical reactions we saw at the beginning.**

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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 we 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. Next 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 use this model to argue 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). 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.

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			And another unresolved question is, *What happens when you make a bond? How are bonds made??* We brainstorm some possibilities, but aren't sure. 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. **Next Steps:** Because we are still wondering: *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?* **We decided that we should try another reaction and see if provides additional evidence that might help us figure that out.**

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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) *Building toward* *NGSS PEs:* *HS-PS1-4, HS-PS3-5*	Alkali metals (lithium, sodium, and potassium) 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?* **Next steps: 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.**

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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? (2 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 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: • 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

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			• 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?* **Next Steps: 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!**

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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?* **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.**

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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) S *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)	**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 validates our thinking to know that other people (scientists) who investigated these sort of phenomena have come to the same general understandings of the phenomena as we did. 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?* **Next Steps: We decide to see if we can develop a (mathematical) model that would help us predict if a reaction was going to be endothermic or exothermic, based on the strength of all the bonds being broken and formed in a reaction.**

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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) S *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 helps 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. *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. What is it about the atoms that is causing them to have different strengths of "pulls" on other atoms? (build a periodic table!)***

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