HS.PS-CR Chemical Reactions

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Students who demonstrate understanding can:

- **a. Analyze and interpret data to support claims that energy of molecular collisions and the concentration of the reacting particles affect the rate at which a reaction occurs.** [Assessment Boundary: Limited to simple (zero or first order in each reactant) reactions. The exact relationship between rate and temperature is not required.]
- **b. Develop and use models to explain that atoms (and therefore mass) are conserved during a chemical reaction.** [Clarification Statement: Models can include computer models, ball and stick models, and drawings.] [Assessment Boundary: Stoichiometric calculations are not required.]
- **c. Analyze and interpret data to make claims that reaction conditions can be used to optimize the output of a chemical process.** [Assessment Boundary: Limited to simple reactions. Reaction conditions are limited to temperature, pressure, and concentrations of all substances in the system.]
- **d. Construct mathematical models to explain how energy changes in chemical reactions are caused by changes in binding energy as the reactants form products and in which changes in the kinetic energy of the system can be detected as change in temperature.** [Assessment Boundary: Limited to calculating the change in binding energy and resulting change in thermal energy for simple chemical reactions, (i.e., reactions of simple hydrocarbons with oxygen).]
- **e. Construct and communicate explanations using the structure of atoms, trends in the periodic table and knowledge of the patterns of chemical properties to predict the outcome of simple chemical reactions.** [Assessment Boundary: Only those chemical reactions readily predictable from the element's position on the periodic table and combustion reactions are intended.]
- **f. Construct and communicate explanations that show how chemical processes and/or properties of materials are central to biological and geophysical systems.** [Clarification Statement: Chemical processes can include oxidation of hydrocarbons, and the reaction of CO_2 and H_20 to give hydrocarbons. Properties of materials can include water expanding when freezing.] [Assessment Boundary: Restricted to overall chemical processes (for example, oxidation of carbon compounds), or construction of carbon compounds (photosynthesis); details of biochemical pathways are not required (for example, Krebs Cycle).]
- **g. Use system models (computer or drawings) to construct molecular-level explanations to predict the behavior of systems where a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.** [Assessment Boundary: Limited to simple reactions, adding or removing one reactant or product at a time.]
- **h. Construct explanations using data from system models or simulations to support the claim that systems with many molecules have predictable behavior, but that the behavior of individual molecules is unpredictable.**

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and constructing models to predict and explain relationships between systems and their components in the natural and designed world.

- Use multiple types of models to represent and explain phenomena and move flexibly between model types based on merits and limitations. (b)
- Construct, revise, and use models to predict and explain relationships between systems and their components. (b),(g)
- Use models (including mathematical and computational) to generate data to explain and predict phenomena, analyze systems, and solve problems. (d)

Analyzing and Interpreting Data

Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (a),(c)
- Consider limitations (e.g., measurement error, sample selection) when analyzing and interpreting data. (a),(c)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories.

- Make quantitative claims regarding the relationship between dependent and independent variables. (h)
- Apply scientific reasoning, theory, and models to link evidence to claims and show why the data are adequate for the explanation or conclusion. (h)
- Construct and revise explanations and arguments based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories) and peer review. (e),(f)

Disciplinary Core Ideas

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 total binding energy (i.e., the sum of all bond energies in the set of molecules) that are matched by changes in kinetic energy. (a),(d)
- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (c),(g)
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (b),(e)
- Chemical processes and properties of materials underlie many important biological and geophysical phenomena. (f)

PS2.C: Stability and Instability in Physical Systems

- When a system has a great number of component pieces, one may not be able to predict much about its precise future. For such systems (e.g., with very many colliding molecules), one can often predict average but not detailed properties and behaviors (e.g., average temperature, motion, and rates of chemical change but not the trajectories or other changes of particular molecules). (h)

PS3.A: Definitions of Energy

- "Chemical energy" generally is used to mean the energy that can be released or stored in chemical processes, and "electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. Historically, different units and names were used for the energy present in these different phenomena, and it took some time before the relationships between them were recognized. (d)

Crosscutting Concepts

Patterns

Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. Mathematical representations are needed to identify some patterns. (e),(f)

Cause and Effect

Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. 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. Systems can be designed to cause a desired effect. Changes in systems may have various causes that may not have equal effects. (a),(b),(c),(d),(h)

Energy and Matter

The total amount of energy and matter in closed systems is conserved. 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. Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (g)

- [Clarification Statement for g: Dynamic and condition-dependent balances are dependent on matter and energy flows.]

HS.PS-CR Chemical Reactions *(continued)*	
Connections to other DCIs in this grade-level: **HS.ETS-ED, HS.LS-SFIP, HS.LS-MEOE, HS.ESS-ES**	
Articulation to DCIs across grade-levels: **MS.PS-CR**	
Common Core State Standards Connections: [Note: these connections will be made more explicit and complete in future draft releases]	
ELA –	
W.8.8	Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation.
RST.9-10.9	Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
Mathematics –	
MP.2	Reason abstractly and quantitatively.
MP.4	Model with Mathematics
8.SP	Investigate patterns of association in biivariate data.
S.ID	Summarize, represent, and interpret data on a single count or measurement variable
A-CED.1	Create equations that describe numbers or relationships