*Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.*

## HS-PS1-6

Students who demonstrate understanding can:

**HS-PS1-6.** **Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*** [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [*Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

### Science and Engineering Practices

**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 ideas, principles, and theories.

- Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

### Disciplinary Core Ideas

**PS1.B: Chemical Reactions**

- 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.

**ETS1.C: Optimizing the Design Solution**

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary)*

### Crosscutting Concepts

**Stability and Change**

- Much of science deals with constructing explanations of how things change and how they remain stable.

| Observable features of the student performance by the end of the course: | | | |
|---|---|---|---|
| 1 | Using scientific knowledge to generate the design solution | | |
| | a | Students identify and describe* potential changes in a component of the given chemical reaction system that will increase the amounts of particular species at equilibrium. Students use evidence to describe* the relative quantities of a product before and after changes to a given chemical reaction system (e.g., concentration increases, decreases, or stays the same), and will explicitly use Le Chatelier's principle, including: | |
| | | i. | How, at a molecular level, a stress involving a change to one component of an equilibrium system affects other components; |
| | | ii. | That changing the concentration of one of the components of the equilibrium system will change the rate of the reaction (forward or backward) in which it is a reactant, until the forward and backward rates are again equal; and |
| | | iii. | A description* of a system at equilibrium that includes the idea that both the forward and backward reactions are occurring at the same rate, resulting in a system that appears stable at the macroscopic level. |
| 2 | Describing criteria and constraints, including quantification when appropriate | | |
| | a | Students describe* the prioritized criteria and constraints, and quantify each when appropriate. Examples of constraints to be considered are cost, energy required to produce a product, hazardous nature and chemical properties of reactants and products, and availability of resources. | |
| 3 | Evaluating potential solutions | | |
| | a | Students systematically evaluate the proposed refinements to the design of the given chemical | |

| | | |
|---|---|---|
| | | system. The potential refinements are evaluated by comparing the redesign to the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources). |
| 4 | Refining and/or optimizing the design solution | |
| | a | Students refine the given designed system by making tradeoffs that would optimize the designed system to increase the amount of product, and describe* the reasoning behind design decisions. |