ASPECt

Assessing Students' Progress on the Energy Concept

Gas Simulations: AP49-4

High School – Thermal Energy

TASK OVERVIEW

Students are introduced to the idea that the molecules of a gas can be modeled as spheres that collide with one another. They are then told that scientists want to simulate the mixing of two samples of a gas at different temperatures using this model. They then use ideas about energy transfer and the distribution of the speed of the molecules to predict how the temperature of the gases and the speed distribution of the molecules will change when they are allowed to mix. Lastly, students select a graph that best represents the final speed distribution and write an explanation for why the average speed of both gases becomes the same.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- PS3.B-H.5: Uncontrolled systems always evolve toward more stable states--that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- PS3.A-M.5: Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

- PS3.A-M.1 Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.

Science & engineering practices

- SEP5-H.2: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
- SEP6-H.2: Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future

Crosscutting concepts

- CCC5-H.1: The total amount of energy and matter in closed systems is conserved

Related Performance Expectations

- HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects). [*Clarification Statement*: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]
- HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [*Clarification Statement*: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [*Assessment Boundary*: Assessment is limited to investigations based on materials and tools provided to students.]

TASK PERFORMANCE EXPECTATION

Predict how the temperature and the energy of the gases in two systems will change when the systems are allowed to be in thermal contact with each other. *Support your prediction by explaining how* changes in the temperature and molecular speed distributions are related to molecular collisions and energy transfer.

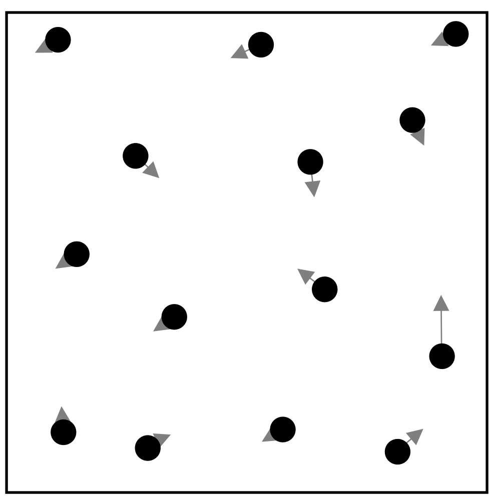
LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/611

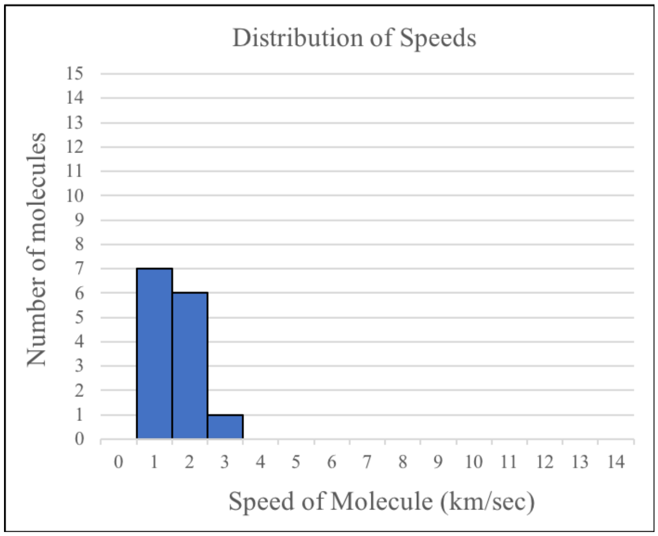
Task

One way that scientists model the behavior of gases is to represent the molecules that make up the gases as small spheres colliding with each other.

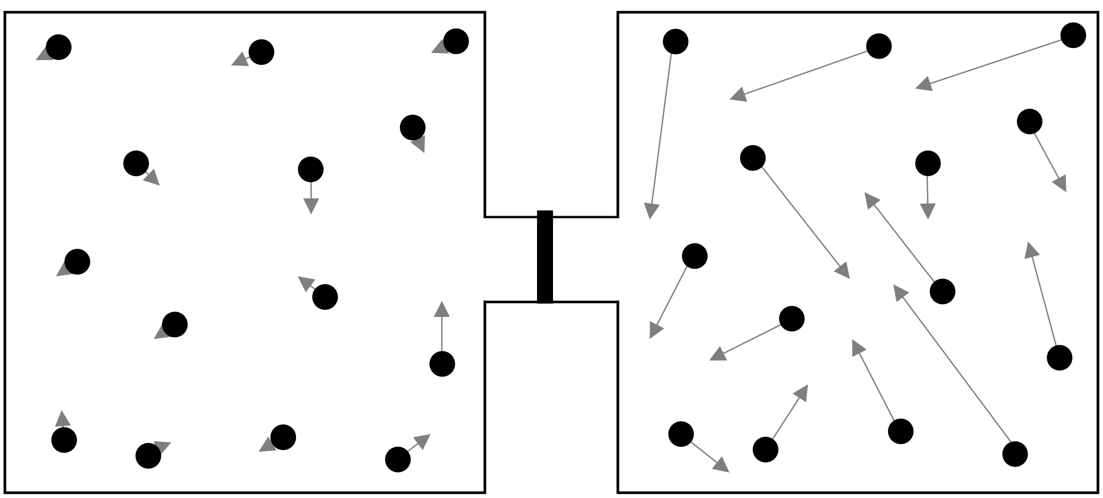
Below is a diagram representing a model of a gas in a box (the model is not to scale). Each molecule of the gas is represented as a black circle. The direction that a molecule is moving is represented by an arrow. The length of the arrow represents how fast the molecule is moving, with longer arrows representing faster molecules.

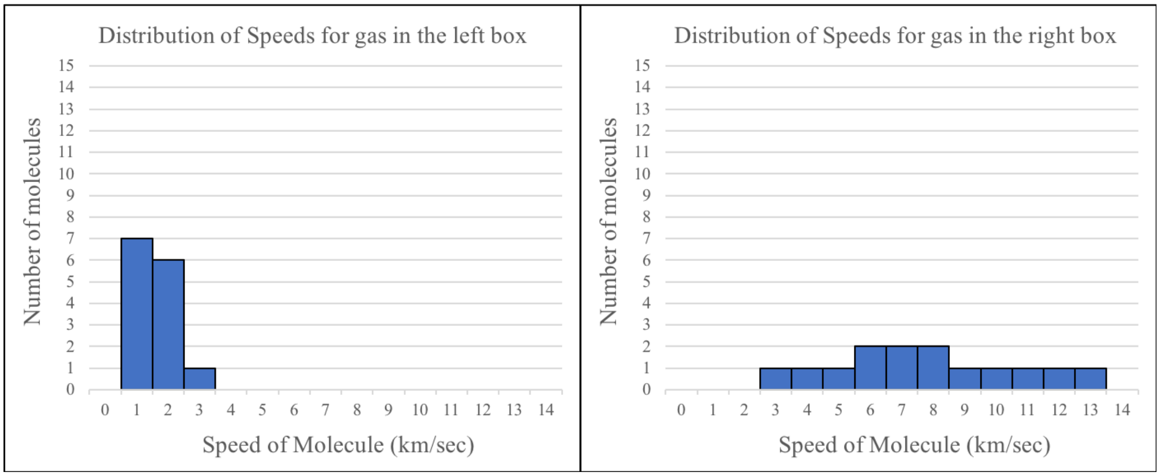


Notice that the molecules are moving at different speeds with most of them moving quite slowly. Below is a plot of the distribution of speeds for the diagram above.



A scientist wants to simulate how the speeds of the molecules in two samples of a gas change when the samples mix. He uses two boxes, each containing molecules with different average speeds. The boxes are connected by a tube containing an insulated wall that prevents the transfer of matter and energy between the samples. Below is a diagram showing the scientist's simulation and the distributions of speeds for the molecules in each box before they are allowed to mix.





Answer the following questions about the gases before they mix.

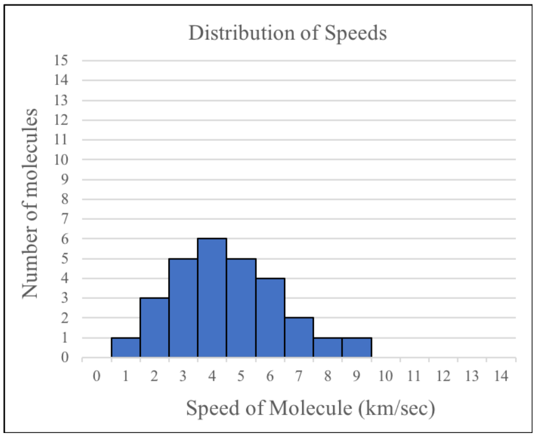
1. On average, which gas has faster moving molecules before they mix?
   A. The molecules of the gas in the left box are moving faster than the molecules of the gas in the right box.
   B. The molecules of the gas in the right box are moving faster than the molecules of the gas in the left box.
   C. The molecules of both gases are moving at the same average speed.

2. Which gas has more energy before they mix?
   A. The gas in the left box has more energy than the gas in the right box.
   B. The gas in the right box has more energy than the gas in the left box.
   C. Both gases have the same amount of energy.

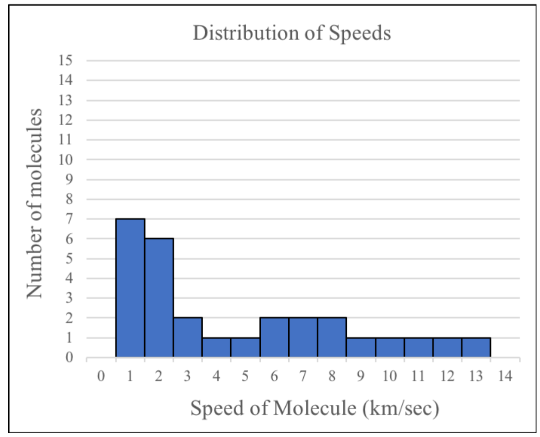
3. How do the temperatures of the gases compare before they mix?
   A. The gas in the left box has a higher temperature than the gas in the right box.
   B. The gas in the left box has a lower temperature than the gas in the right box.
   C. Both gases have the same temperature.

4. If you were to combine the speed data for the molecules in the two boxes before the gases were mixed, which of the following would best represent the overall distribution of speeds before the molecules have started to mix?

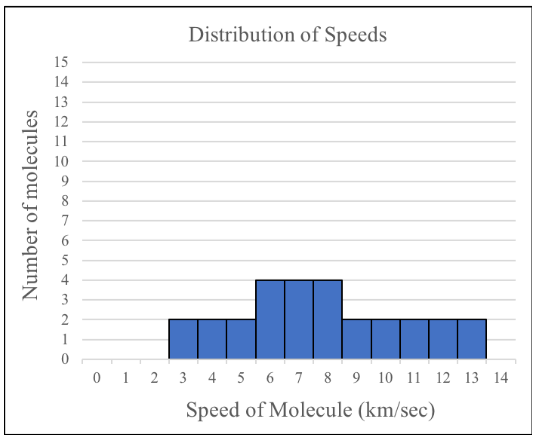
A.



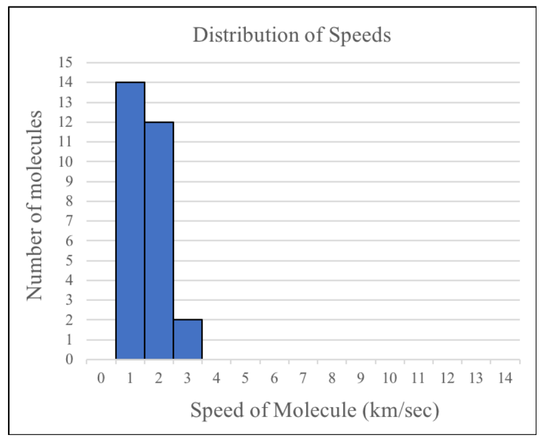
B.



C.



D.



At the start of the simulation, the scientist removes the wall that prevents the transfer of matter and energy between the two boxes. As the molecules mix, they only interact with each other through collisions and no chemical reactions occur. The scientist runs the simulation until the molecules are thoroughly mixed and the average speed of the molecules in each box is the same.

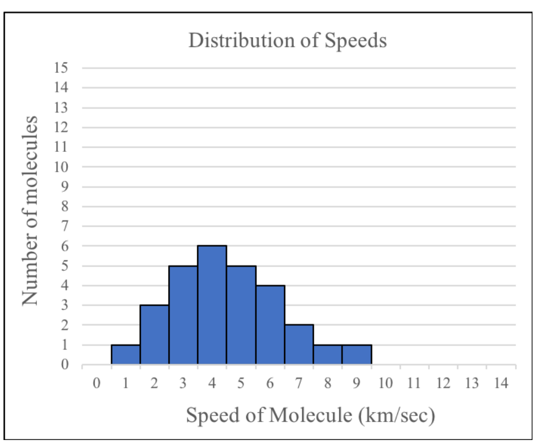
Answer the following questions about the gases at the end of the simulation after they have thoroughly mixed.

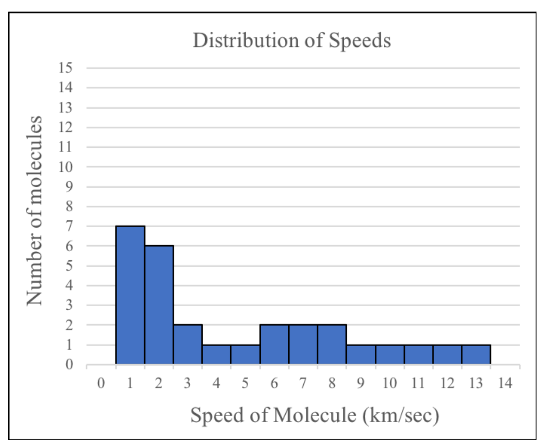
5. How will the molecules be distributed in the two boxes at the end of the simulation?
    - A. There will be the same number of molecules in each box at the end of the simulation.
    - B. The box on the left will have more molecules than the box on the right at the end of the simulation.
    - C. The box on the left will have fewer molecules than the box on the right at the end of the simulation.

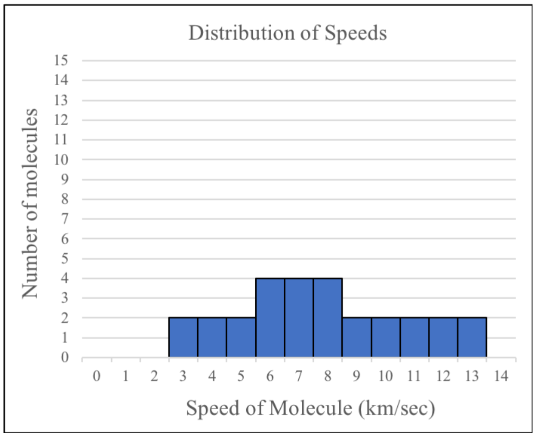
6. How will energy be distributed in the two boxes at the end of the simulation?
    A. On average, the molecules in the box on the left will have less energy than the molecules in the box on the right.
    B. On average, the molecules in the box on the left will have more energy than the molecules in the box on the right.
    C. On average, the molecules in the box on the left will have the same amount of energy as the molecules in the box on the right.

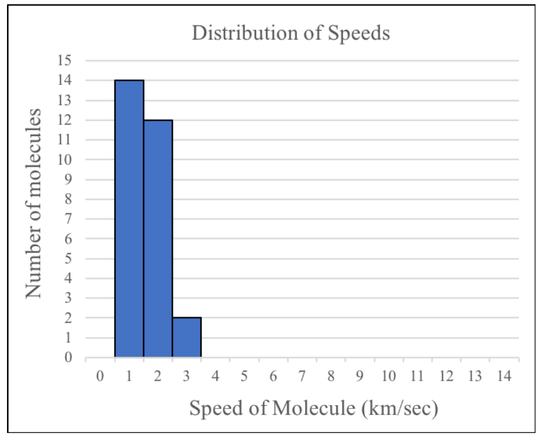
7. How will the temperature of the gases in the two boxes change as the gases mix?
    A. The temperature of the gas in the box on the left will increase and the temperature of the gas in the box on the right will increase.
    B. The temperature of the gas in the box on the left will increase and the temperature of the gas in the box on the right will decrease.
    C. The temperature of the gas in the box on the left will decrease and the temperature of the gas in the box on the right will decrease.
    D. The temperature of the gas in the box on the left will decrease and the temperature of the gas in the box on the right will increase.

8. Which of the following would best represent the overall distribution of speeds for the molecules on both sides after the simulation has run for a long time and after the gases have thoroughly mixed?

A.


B.


C. 

D. 

9. Using what you know about energy transfer, explain why the average speed of the molecules in each box eventually becomes the same.

Alignment to Targeted DCIs, SEPs, and CCCs and Scoring Rubrics

QUESTION 1

On average, which gas has faster moving molecules before they mix?

A. The molecules of the gas in the left box are moving faster than the molecules of the gas in the right box.

B. The molecules of the gas in the right box are moving faster than the molecules of the gas in the left box.

C. The molecules of both gases are moving at the same average speed.

LEARNING GOAL

Learning Performance

- Compare the averages of two plotted distributions.

Targeted DCIs, SEP, and CCC

- SEP5-H.2: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	B. The molecules of the gas in the right box are moving faster than the molecules of the gas in the left box.

QUESTION 2

Which gas has more energy before they mix?

A. The gas in the left box has more energy than the gas in the right box.

B. The gas in the right box has more energy than the gas in the left box.

C. Both gases have the same amount of energy.

LEARNING GOAL

Learning Performance

- Compare the total energy of two gases given the distributions of speeds of the molecules making up each gas.

Targeted DCIs, SEP, and CCC

- PS3.A-M.1: Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- SEP5-H.2: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	B. The gas in the right box has more energy than the gas in the left box.

QUESTION 3

How do the temperatures of the gases compare before they mix?

A. The gas in the left box has a higher temperature than the gas in the right box.

B. The gas in the left box has a lower temperature than the gas in the right box.

C. Both gases have the same temperature

LEARNING GOAL

Learning Performance

- Compare the temperatures of two gases given the average speed of the molecules making up each gas.

Targeted DCIs, SEP, and CCC

- PS3.A-M.5: Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- PS3.A-M.1: Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- SEP5-H.2: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

SCORING RUBRIC

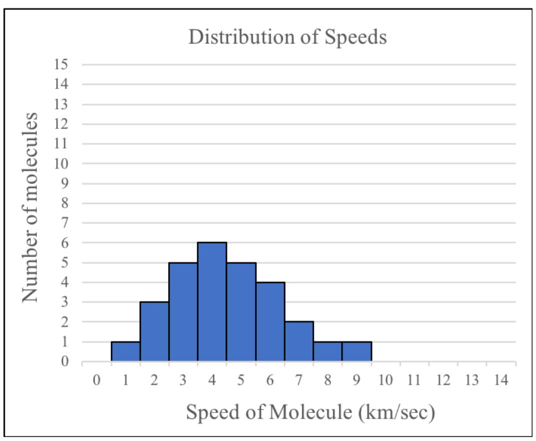
Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	B. The gas in the right box has a higher temperature than the gas in the left box.

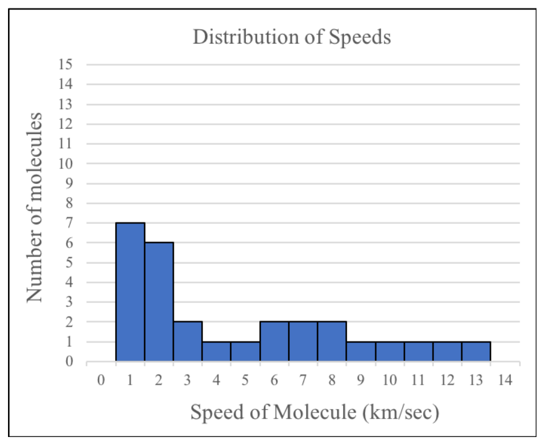
QUESTION 4

If you were to combine the speed data for the molecules in the two boxes before the gases were mixed, which of the following would best represent the overall distribution of speeds before the molecules have started to mix?

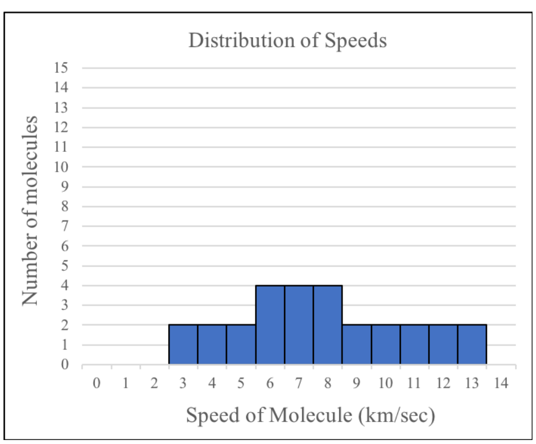
A.



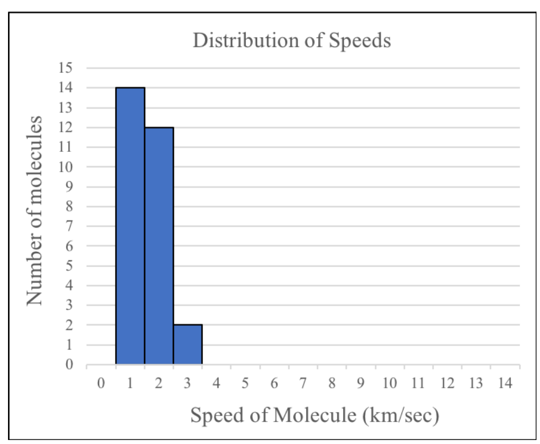
B.



C.



D.



LEARNING GOAL

Learning Performance

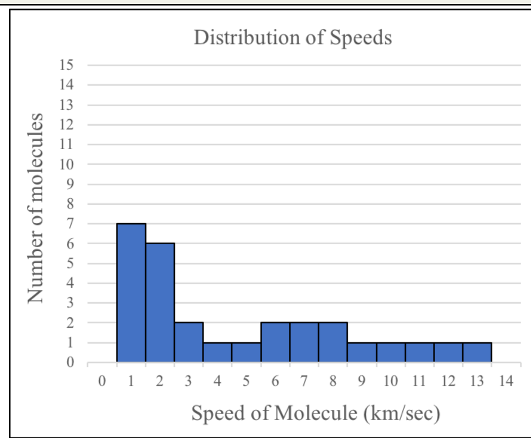
- Identify a graph representing the combination of two distributions of data.

Targeted DCIs, SEP, and CCC

- SEP5-H.2: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	B. 

QUESTION 5

How will the molecules be distributed in the two boxes at the end of the simulation?

A. There will be the same number of molecules will be in each box at the end of the simulation.
B. The box on the left will have more molecules than the box on the right at the end of the simulation.
C. The box on the left will have fewer molecules than the box on the right at the end of the simulation.

LEARNING GOAL

Learning Performance

- Predict how gas molecules will distribute themselves after two systems are allowed to interact.

Targeted DCIs, SEP, and CCC

- PS3.B-H.5: Uncontrolled systems always evolve toward more stable states--that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. The molecules will distribute themselves in each box so that the same number of molecules will be in each box.

QUESTION 6

How will energy be distributed in the two boxes at the end of the simulation?

A. On average, the molecules in the box on the left will have less energy than the molecules in the box on the right.

B. On average, the molecules in the box on the left will have more energy than the molecules in the box on the right.

C. On average, the molecules in the box on the left will have the same amount of energy as the molecules in the box on the right.

LEARNING GOAL

Learning Performance

- Predict how energy will be distributed between two interacting systems at equilibrium.

Targeted DCIs, SEP, and CCC

- PS3.B-H.5: Uncontrolled systems always evolve toward more stable states--that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	C. On average, the molecules in the box on the left will have the same amount of energy as the molecules in the box on the right.

QUESTION 7

How will the temperature of the gases in the two boxes change as the gases mix?

A. The temperature of the gas in the box on the left will increase and the temperature of the gas in the box on the right will increase.

B. The temperature of the gas in the box on the left will increase and the temperature of the gas in the box on the right will decrease.

C. The temperature of the gas in the box on the left will decrease and the temperature of the gas in the box on the right will decrease.

D. The temperature of the gas in the box on the left will decrease and the temperature of the gas in the box on the right will increase.

LEARNING GOAL

Learning Performance

- Predict how the temperatures of two systems will change after they are allowed to interact and reach equilibrium.

Targeted DCIs, SEP, and CCC

- PS3.B-H.5: Uncontrolled systems always evolve toward more stable states--that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- PS3.A-M.5: Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

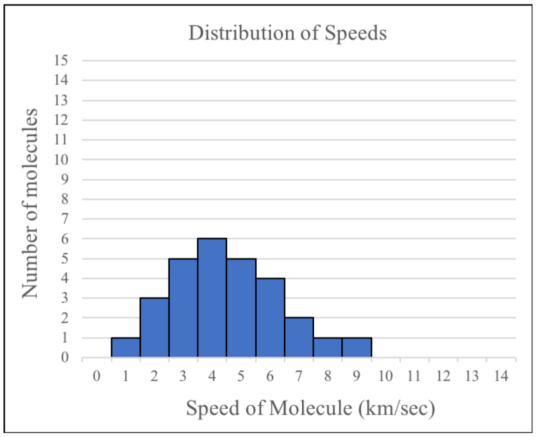
SCORING RUBRIC

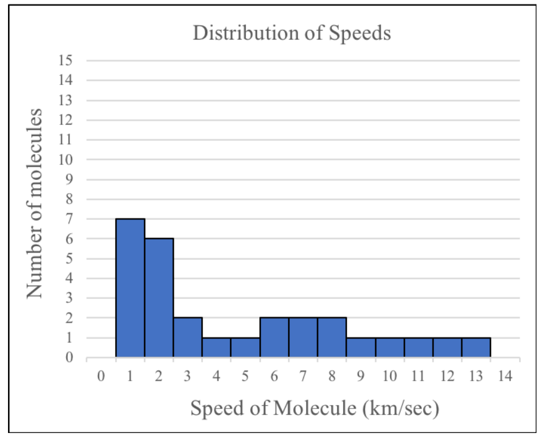
Elements of a Correct Response

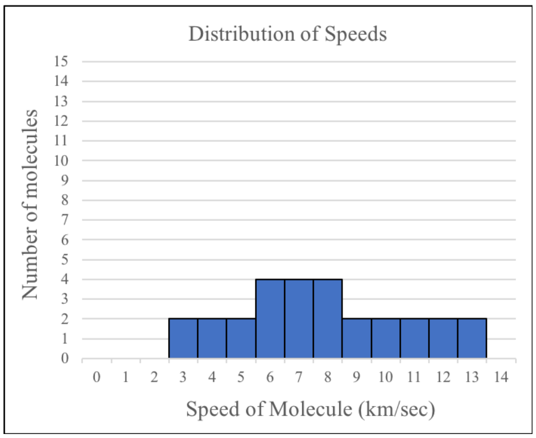
Categories	Elements
Student selects the correct multiple-choice answer	B. The temperature of the gas in the box on the left will increase and the temperature of the gas in the box on the right will decrease.

QUESTION 8

Which of the following would best represent the overall distribution of speeds for the molecules on both sides after the simulation has run for a long time and after the gases have thoroughly mixed?

A.


B.


C.


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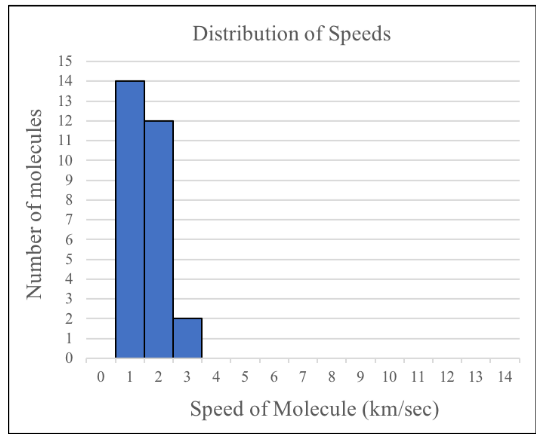


LEARNING GOAL

Learning Performance

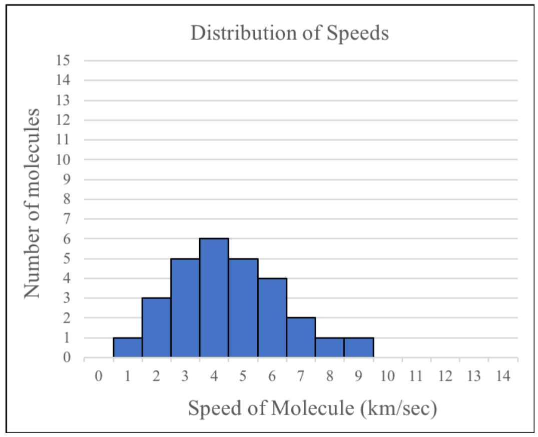
- Identify a graph representing the overall distribution of speeds of molecules in two interacting systems at equilibrium.

Targeted DCIs, SEP, and CCC

- PS3.B-H.5: Uncontrolled systems always evolve toward more stable states--that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- PS3.A-M.1: Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- SEP5-H.2: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. 

QUESTION 9

Using what you know about energy transfer, explain why the average speed of the molecules in each box eventually becomes the same.

LEARNING GOAL

Learning Performance

- Explain why the average speed of the molecules in the two systems will become the same when the systems interact using ideas about energy transfer and how systems move towards more uniform energy distributions.

Targeted DCIs, SEP, and CCC

- PS3.B-H.5: Uncontrolled systems always evolve toward more stable states--that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- PS3.A-M.1: Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.

- PS3.C-M.1: When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.
- PS3.A-M.5: Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- SEP6-H.2: Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
- CCC5-H.1: The total amount of energy and matter in closed systems is conserved

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SCORING RUBRIC

Ideal Response

When the gases are mixed, energy will be transferred from the faster moving gas molecules to the slower moving gas molecules as they collide. Over time this will cause the slowest moving molecules to increase in speed, the fastest moving molecules to decrease in speed, and the overall distribution of speeds to become more uniform. The new average speed of the gases will be somewhere between the average speed of the two initial gases.

Elements of a Correct Response

Categories	Elements
Student states or uses a general science idea	• Temperature is a measure of the average kinetic energy or speed of particles of matter (i.e. Molecules making up the higher temperature gas have more average kinetic energy or speed than the molecules up the lower temperature gas). [links temperature and molecular kinetic energy/speed] • When two objects interact, each one exerts a force on the other that can cause energy to be transferred (i.e., When molecules collide, they transfer energy to one another changing their speeds). [links collisions and energy transfer]

	• Uncontrolled systems always evolve toward more stable states (i.e., overtime the energy will become evenly distributed between the gases). [uniform energy distribution]
Students use reasoning based on valid science ideas to support the observation	• The transfer of energy from (or collisions of) faster moving molecules to slower moving molecules will cause the new average speed of the combined gas to be somewhere between the average speed of the two gases before they were allowed to mix.

Sample Student Responses

Student response	Scoring description
"because their is the same amount of molecules just spread out"	Score = 0 The response does not provide an explanation for why the average speed in each box becomes the same.
"If two things have two different energy they will balance out in the long run to get even and stay the same, just like if one thing is hot and one thing is cold they both will become the same temperature."	Score = 1 The response uses the science idea about uniform energy distribution but does not use reasoning at the atomic/molecular level.
"The gases will collide and transfer energy between each other. This will decrease the speed of the faster molecules and increase the speed of the slower molecules. This continues until equilibrium is reached."	Score = 2 The response includes both elements in the rubric.

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