2024 MCAS Sample Student Work and Scoring Guide

High School Introductory Physics
Question 21: Constructed-Response

Reporting Category: Motion, Forces, and Interactions
Practice Category: Investigations and Questioning
Standard: HS.PHY.2.3 - Apply scientific principles of motion and momentum to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
Item Description: Calculate the change in momentum of a ball during a collision and the net force applied to the ball, explain how to reduce the average net force on the ball, and analyze an investigation to determine which factors change and which factors must be kept constant.

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Scoring Guide

Select a score point in the table below to view the sample student response.

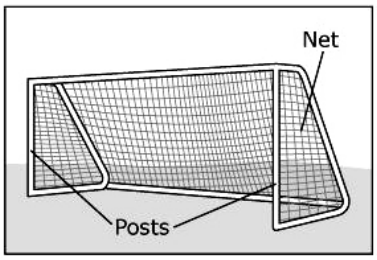
Score*	Description
4A	The response demonstrates a thorough understanding of motion and momentum during a collision. The response correctly calculates both the change in momentum of the soccer ball and the average net force applied to the soccer ball. The response correctly identifies one way to reduce the average net force applied to the soccer ball and clearly explains the reasoning. The response also correctly identifies factors that will change during the investigation, those that must be kept constant, and those that do not affect the outcome.
4B	
3	The response demonstrates a general understanding of motion and momentum during a collision.
2	The response demonstrates a limited understanding of motion and momentum during a collision.
1	The response demonstrates a minimal understanding of motion and momentum during a collision.
0	The response is incorrect or contains some correct work that is irrelevant to the skill or concept being measured.

*Letters are used to distinguish between sample student responses that earned the same score (e.g., 4A and 4B).

Score Point 4A

This question has four parts.

During a soccer game, players kick a ball into a goal to score a point. The goal is made of posts and a net, as shown.



A player kicked a 0.42 kg soccer ball into a goal. The ball was traveling 22 m/s when it collided with the net. The net stopped the ball.

Part A

Calculate the change in momentum of the ball during the collision with the net. Show your calculations and include units in your answer.

$$p = mv$$

$$p = 0.42 \times 22$$

$$p = 9.42\,\text{kg} \times \frac{m}{s}$$

$$p = mv$$

$$p = 0.42 \times 0$$

$$p = 0\,\text{kg} \times \frac{m}{s}$$

$$\Delta p = p\ \text{final} - p\ \text{initial}$$

$$\Delta p = 0 - 9.24$$

$$\Delta p = -9.24\,\text{kg} \times \frac{m}{s}$$

Part B

The collision between the ball and the soccer net lasted 0.25 s.

Calculate the average net force that the soccer net applied to the ball. Show your calculations and include units in your answer.

$$a = \frac{v}{t}$$

$$a = \frac{22}{0.25}$$

$$a = 88 \cdot \frac{m}{s^2}$$

$$F = 0.42 \times 88$$

$$F = 36.96N$$

Part C

The ball is kicked into the soccer net again.

Identify one way to reduce the average net force on the ball as it is stopped by the soccer net. Explain your reasoning.

If the ball has less mass the force would be smaller. Net force is made up of mass times the acceleration, and force is directly proportional to mass so decreasing mass would also decrease the force.

Part D

A group of students investigate how the magnitude of the force applied to a soccer ball as it is kicked affects the ball's velocity after it is kicked. The students will conduct their investigation on an indoor soccer field.

Drag and drop two factors into each box to identify whether the factor will change during the investigation, must be kept constant (controlled), or will not affect the outcome of the investigation.

Factors That Will Change	Factors That Must Be Kept Constant (Controlled)	Factors That Do Not Affect the Outcome
how hard the ball is kicked	the ball's mass	the amount of light on the field
the ball's velocity after being kicked	how inflated the ball is	the time of day the data are collected

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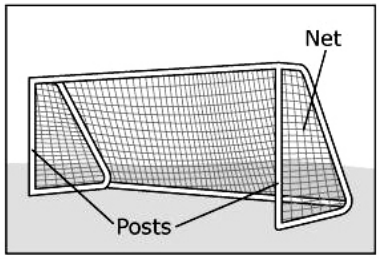
Score Point 4B

This question has four parts.

During a soccer game, players kick a ball into a goal to score a point. The goal is made of posts and a net, as shown.



A player kicked a 0.42 kg soccer ball into a goal. The ball was traveling 22 m/s when it collided with the net. The net stopped the ball.

Part A

Calculate the change in momentum of the ball during the collision with the net. Show your calculations and include units in your answer.

before

p = 0.42kg * 22m/s

p = 9.24 $\frac{\text{kg}\times m}{s}$

after

p = 0 $\frac{\text{kg}\times m}{s}$

the momentum of the ball decreased by 9.24 $\frac{\text{kg}\times m}{s}$

Part B

The collision between the ball and the soccer net lasted 0.25 s.

Calculate the average net force that the soccer net applied to the ball. Show your calculations and include units in your answer.

$F * \Delta t = \Delta p$

$F * 0.25s = 9.24 \ \frac{kg \times m}{s}$

$F = 4 \times 9.24 \ \frac{kg \times m}{s^2}$

$F = 36.96 \ N$

Part C

The ball is kicked into the soccer net again.

Identify one way to reduce the average net force on the ball as it is stopped by the soccer net. Explain your reasoning.

You can decrease the net force by decreasing the speed at which the ball is kicked, since this will decrease the momentum, and a decrease in momentum results in a decrease in force.

Part D

A group of students investigate how the magnitude of the force applied to a soccer ball as it is kicked affects the ball's velocity after it is kicked. The students will conduct their investigation on an indoor soccer field.

Drag and drop two factors into each box to identify whether the factor will change during the investigation, must be kept constant (controlled), or will not affect the outcome of the investigation.

Factors That Will Change	Factors That Must Be Kept Constant (Controlled)	Factors That Do Not Affect the Outcome
how hard the ball is kicked	the ball's mass	the amount of light on the field
the ball's velocity after being kicked	how inflated the ball is	the time of day the data are collected

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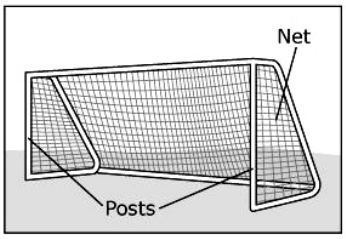
Score Point 3

This question has four parts.

During a soccer game, players kick a ball into a goal to score a point. The goal is made of posts and a net, as shown.



A player kicked a 0.42 kg soccer ball into a goal. The ball was traveling 22 m/s when it collided with the net. The net stopped the ball.

Part A

Calculate the change in momentum of the ball during the collision with the net. Show your calculations and include units in your answer.

$p = mv$

$p = 0.42 \times 22$

$p = 9.24 \text{ kg} \times \frac{m}{s}$

Part B

The collision between the ball and the soccer net lasted 0.25 s.

Calculate the average net force that the soccer net applied to the ball. Show your calculations and include units in your answer.

$f = ma$

$m = 0.42$

$a = ?$

To find the the average net force, you need to find the acceleration.

$a = \frac{v}{t}$

$a = \frac{22}{0.25}$

$a = 88 \left(\frac{m}{s^{\square}}\right)^2$

$F = 0.42 \times 88$

$f = 36.96$ N

Part C

The ball is kicked into the soccer net again.

Identify one way to reduce the average net force on the ball as it is stopped by the soccer net. Explain your reasoning.

If you make the strings tighter, the ball will fall into the net causing the time it took to fall to the ground quicker. This means that everything will be reduced because it is a smaller time than the orgininal.

Part D

A group of students investigate how the magnitude of the force applied to a soccer ball as it is kicked affects the ball's velocity after it is kicked. The students will conduct their investigation on an indoor soccer field.

Drag and drop two factors into each box to identify whether the factor will change during the investigation, must be kept constant (controlled), or will not affect the outcome of the investigation.

Factors That Will Change	Factors That Must Be Kept Constant (Controlled)	Factors That Do Not Affect the Outcome
how hard the ball is kicked	the ball's mass	the time of day the data are collected
the ball's velocity after being kicked	how inflated the ball is	the amount of light on the field

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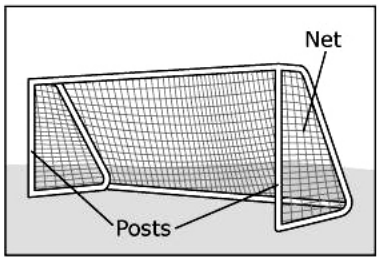
Score Point 2

This question has four parts.

During a soccer game, players kick a ball into a goal to score a point. The goal is made of posts and a net, as shown.



A player kicked a 0.42 kg soccer ball into a goal. The ball was traveling 22 m/s when it collided with the net. The net stopped the ball.

Part A

Calculate the change in momentum of the ball during the collision with the net. Show your calculations and include units in your answer.

$0.42 \times 22 = 9.24$ N

Part B

The collision between the ball and the soccer net lasted 0.25 s.

Calculate the average net force that the soccer net applied to the ball. Show your calculations and include units in your answer.

$0.42 \times 22\,(0.25) = 2.31$

Part C

The ball is kicked into the soccer net again.

Identify one way to reduce the average net force on the ball as it is stopped by the soccer net. Explain your reasoning.

One way to reduce the average net force on the ball is to kick from a closer distance to the goal, so the force being put onto the ball doesn't have to be as high.

Part D

A group of students investigate how the magnitude of the force applied to a soccer ball as it is kicked affects the ball's velocity after it is kicked. The students will conduct their investigation on an indoor soccer field.

Drag and drop two factors into each box to identify whether the factor will change during the investigation, must be kept constant (controlled), or will not affect the outcome of the investigation.

Factors That Will Change	Factors That Must Be Kept Constant (Controlled)	Factors That Do Not Affect the Outcome
how hard the ball is kicked	the ball's mass	the time of day the data are collected
the ball's velocity after being kicked	how inflated the ball is	the amount of light on the field

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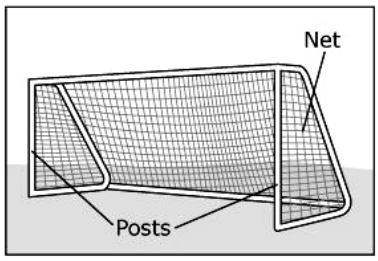
Score Point 1

This question has four parts.

During a soccer game, players kick a ball into a goal to score a point. The goal is made of posts and a net, as shown.



A player kicked a 0.42 kg soccer ball into a goal. The ball was traveling 22 m/s when it collided with the net. The net stopped the ball.

Part A

Calculate the change in momentum of the ball during the collision with the net. Show your calculations and include units in your answer.

$0.4\,\text{kg} \times 22m\,/\,s = 9.24$

Part B

The collision between the ball and the soccer net lasted 0.25 s.

Calculate the average net force that the soccer net applied to the ball. Show your calculations and include units in your answer.

$0.25 + 0.42 = 0.67s$

Part C

The ball is kicked into the soccer net again.

Identify one way to reduce the average net force on the ball as it is stopped by the soccer net. Explain your reasoning.

To reduce the net force you increase the speed of the soccer ball and see where it gets stopped in the net.

Part D

A group of students investigate how the magnitude of the force applied to a soccer ball as it is kicked affects the ball's velocity after it is kicked. The students will conduct their investigation on an indoor soccer field.

Drag and drop two factors into each box to identify whether the factor will change during the investigation, must be kept constant (controlled), or will not affect the outcome of the investigation.

Factors That Will Change	Factors That Must Be Kept Constant (Controlled)	Factors That Do Not Affect the Outcome
the amount of light on the field	how hard the ball is kicked	the time of day the data are collected
how inflated the ball is	the ball's mass	the ball's velocity after being kicked

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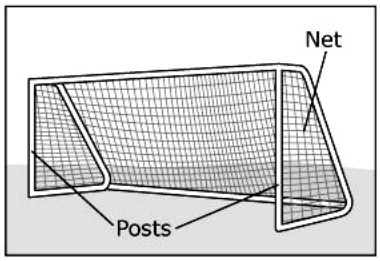
Score Point 0

This question has four parts.

During a soccer game, players kick a ball into a goal to score a point. The goal is made of posts and a net, as shown.



A player kicked a 0.42 kg soccer ball into a goal. The ball was traveling 22 m/s when it collided with the net. The net stopped the ball.

Part A

Calculate the change in momentum of the ball during the collision with the net. Show your calculations and include units in your answer.

$0.42 \div 22 = 52.3m$

Part B

The collision between the ball and the soccer net lasted 0.25 s.

Calculate the average net force that the soccer net applied to the ball. Show your calculations and include units in your answer.

$0.25 \times 0.42 = 0.105m$

Part C

The ball is kicked into the soccer net again.

Identify one way to reduce the average net force on the ball as it is stopped by the soccer net. Explain your reasoning.

Stop it with your hands

Part D

A group of students investigate how the magnitude of the force applied to a soccer ball as it is kicked affects the ball's velocity after it is kicked. The students will conduct their investigation on an indoor soccer field.

Drag and drop two factors into each box to identify whether the factor will change during the investigation, must be kept constant (controlled), or will not affect the outcome of the investigation.

Factors That Will Change	Factors That Must Be Kept Constant (Controlled)	Factors That Do Not Affect the Outcome
the time of day the data are collected	how inflated the ball is	how hard the ball is kicked
the amount of light on the field	the ball's mass	the ball's velocity after being kicked

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